II. INTERNATIONAL FUTURE ENGINEERING CONFERENCE

APRIL 28-29, 2025 / BAKU, AZERBAIJAN

Baku Engineering University

PROCEEDINGS BOOK

EDITORS

Prof. Dr. Agasi MELIKOV
Assoc. Prof. Dr. Mahmut DİRİK
Prof. Dr. Hemzağa ORUCOV
Assoc. Prof. Dr. Asaf Tolga ÜLGEN

ISBN: 979-8-89695-073-8

IFEC2O25

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CONFERENCE ID

CONFERENCE TITLE

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II. INTERNATIONAL FUTURE ENGINEERING CONFERENCE

DATE AND PLACE

APRIL 28-29, 2025 / BAKU, AZERBAIJAN

ORGANIZATION

BAKU ENGINEERING UNIVERSITY

ŞIRNAK UNIVERSITY

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ŞIRNAK UNIVERSITY TECHNOLOGY TRANSFER OFFICE

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Prof. Dr. Hemzağa ORUCOV

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Total Accepted Article: 86

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Accepted Articles (Türkiye): 40

Accepted Articles (Other Countries): 46

ISBN: 979-8-89695-073-8

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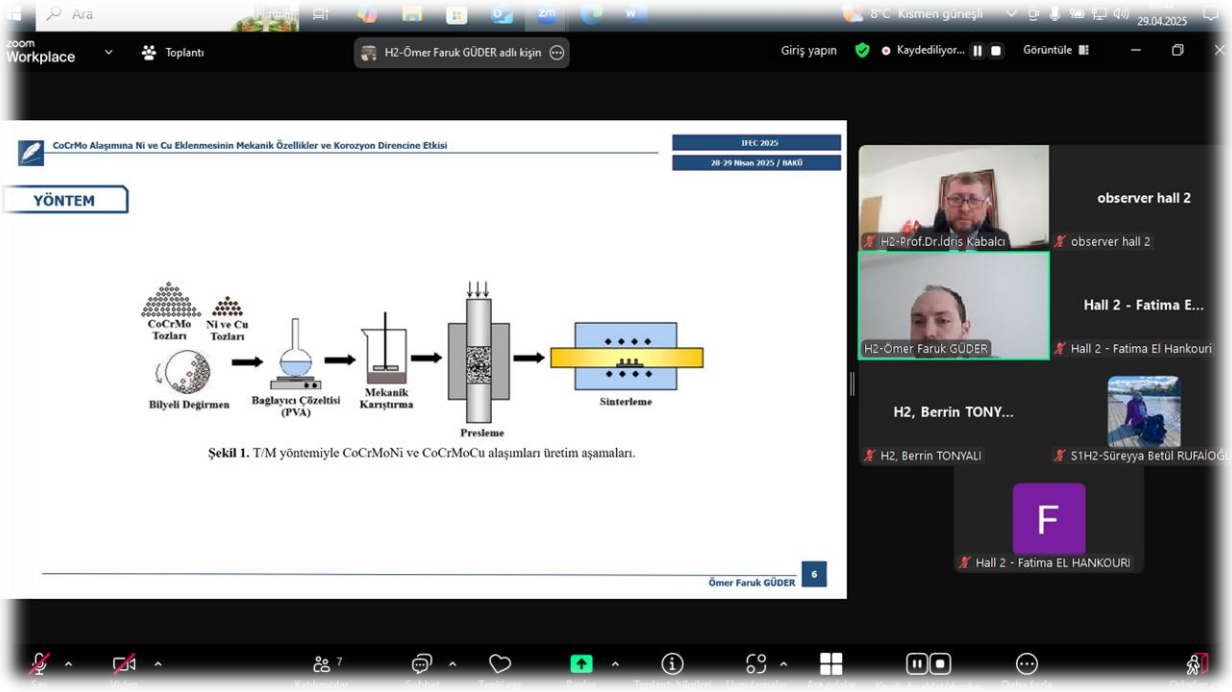

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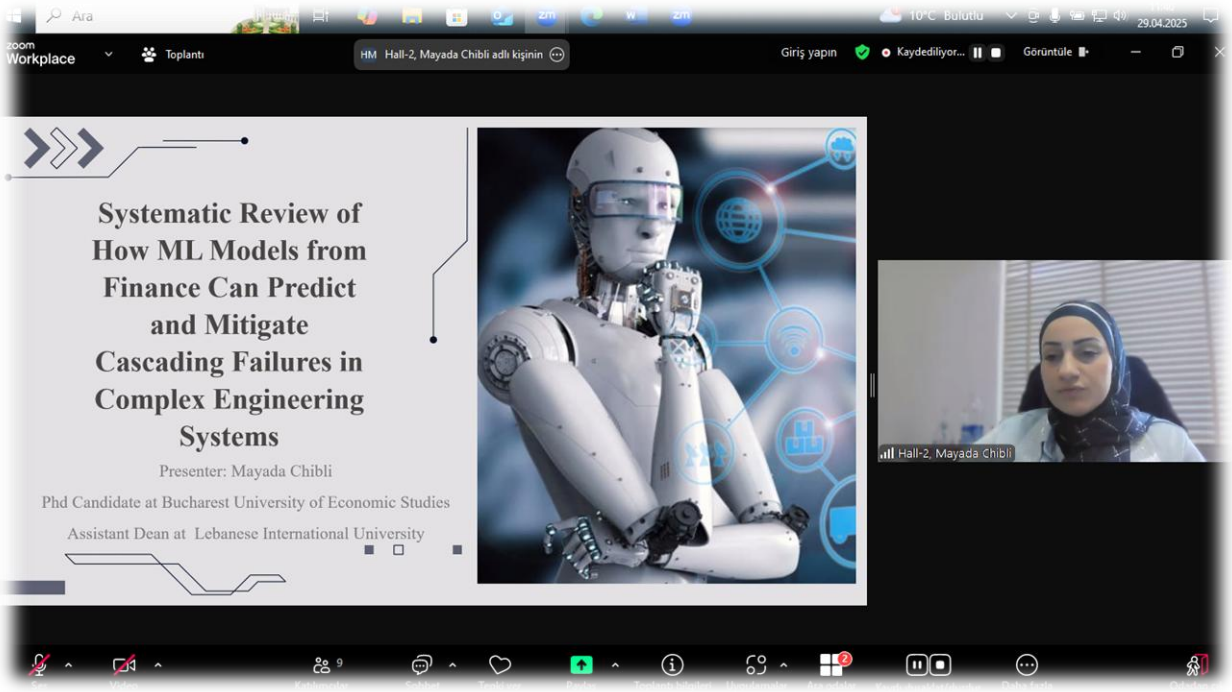

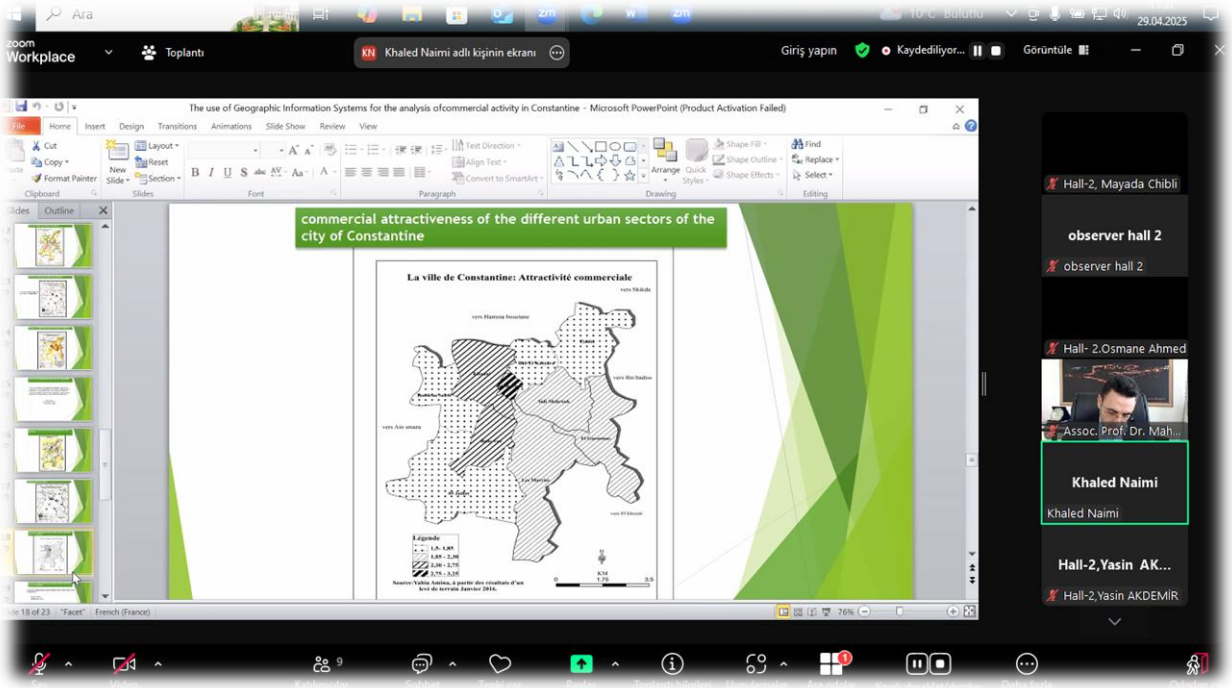

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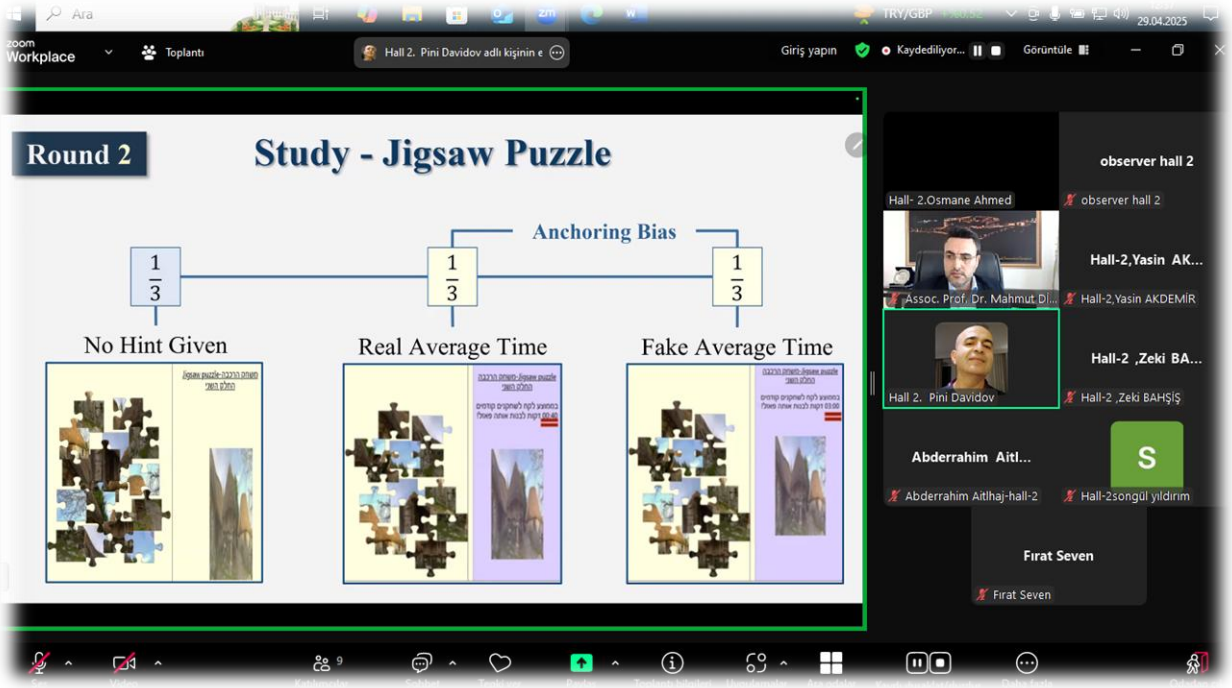

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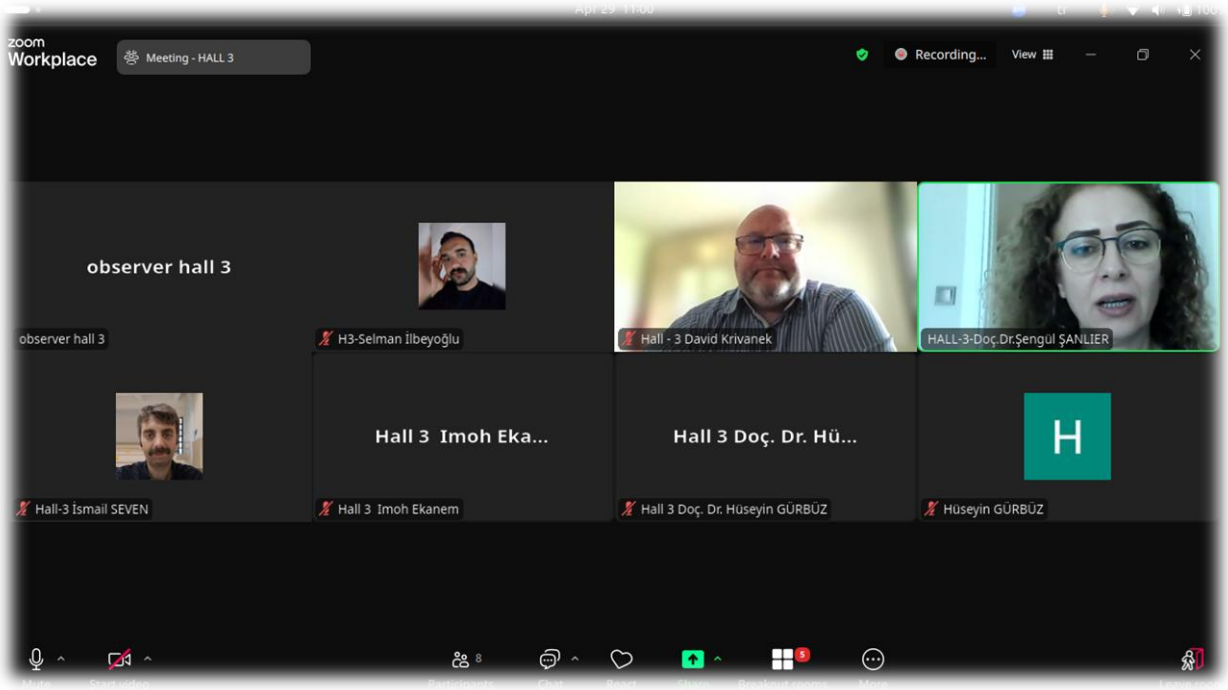

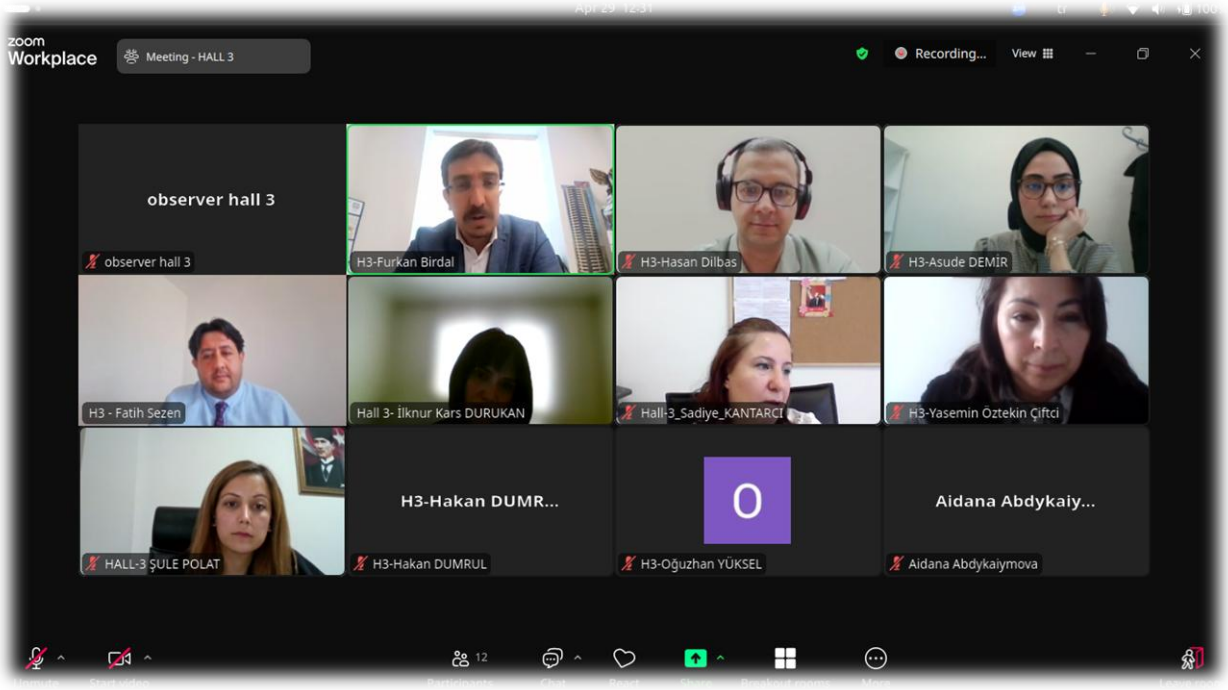

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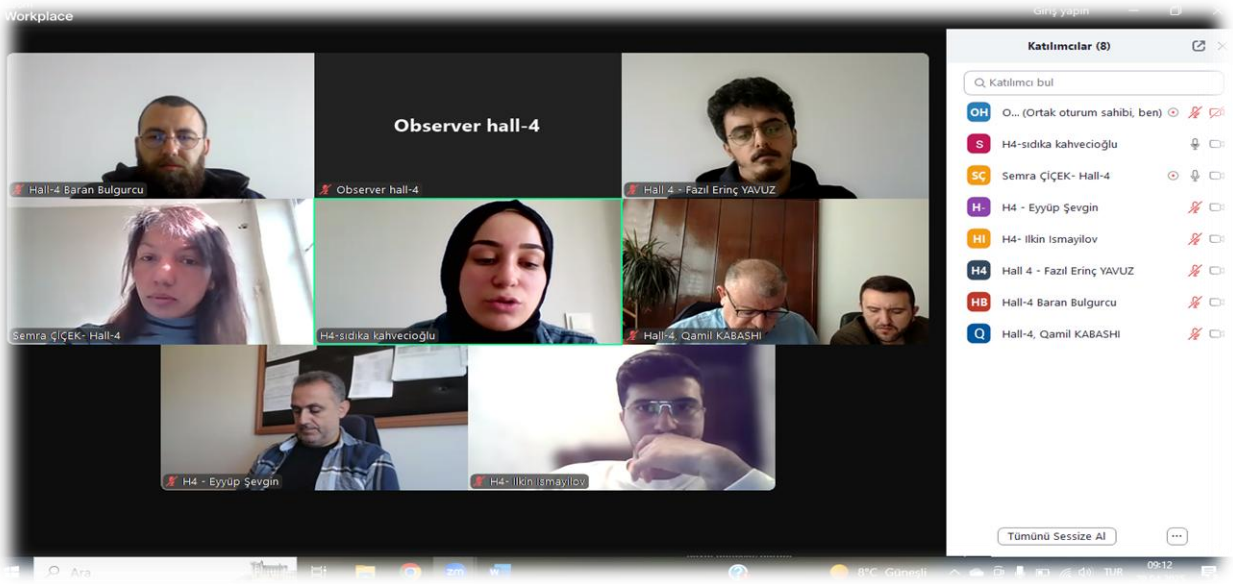

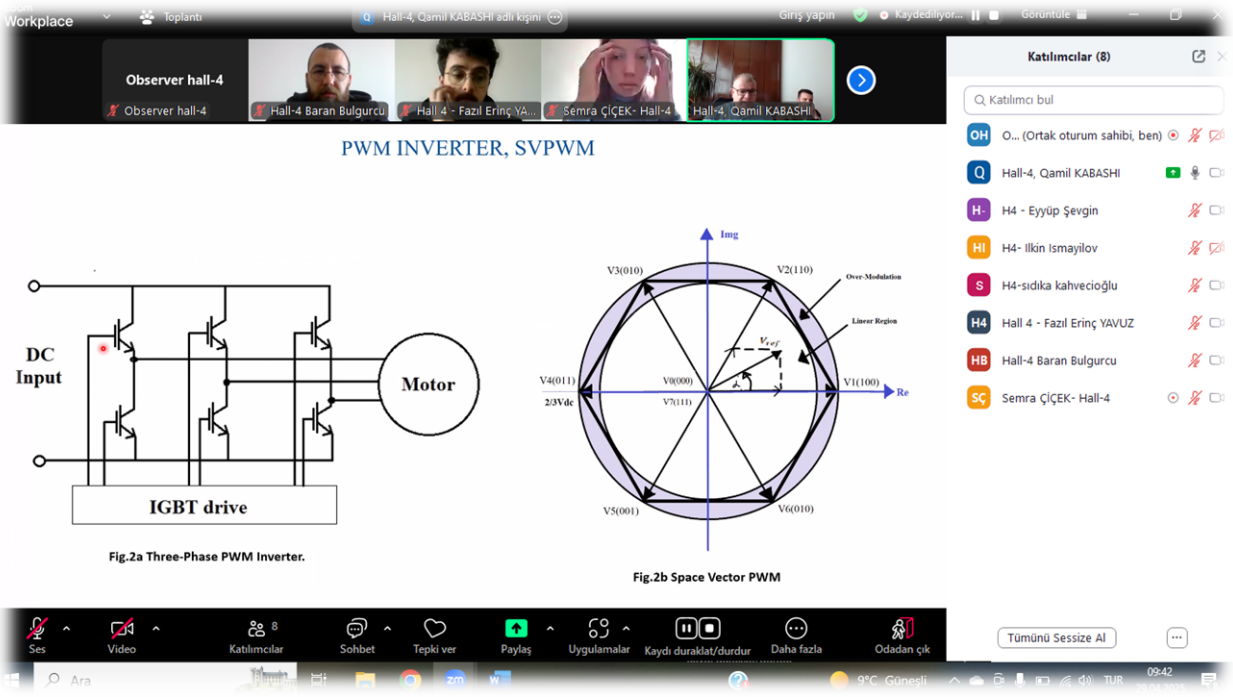

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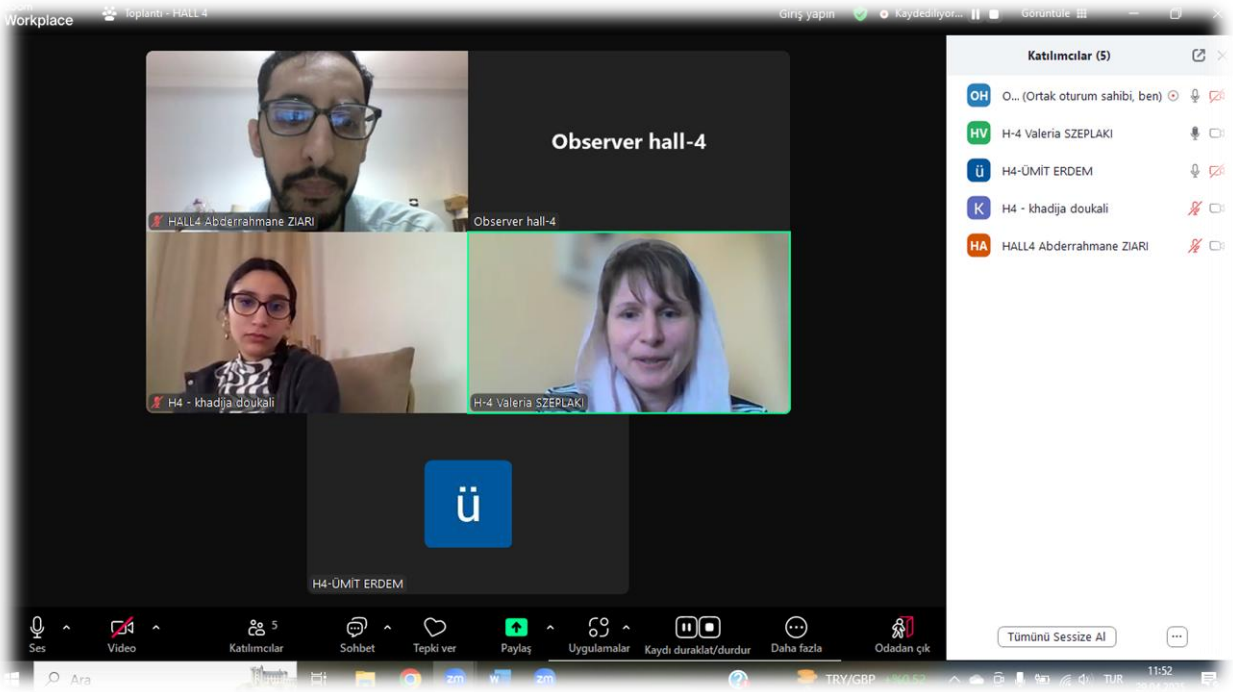

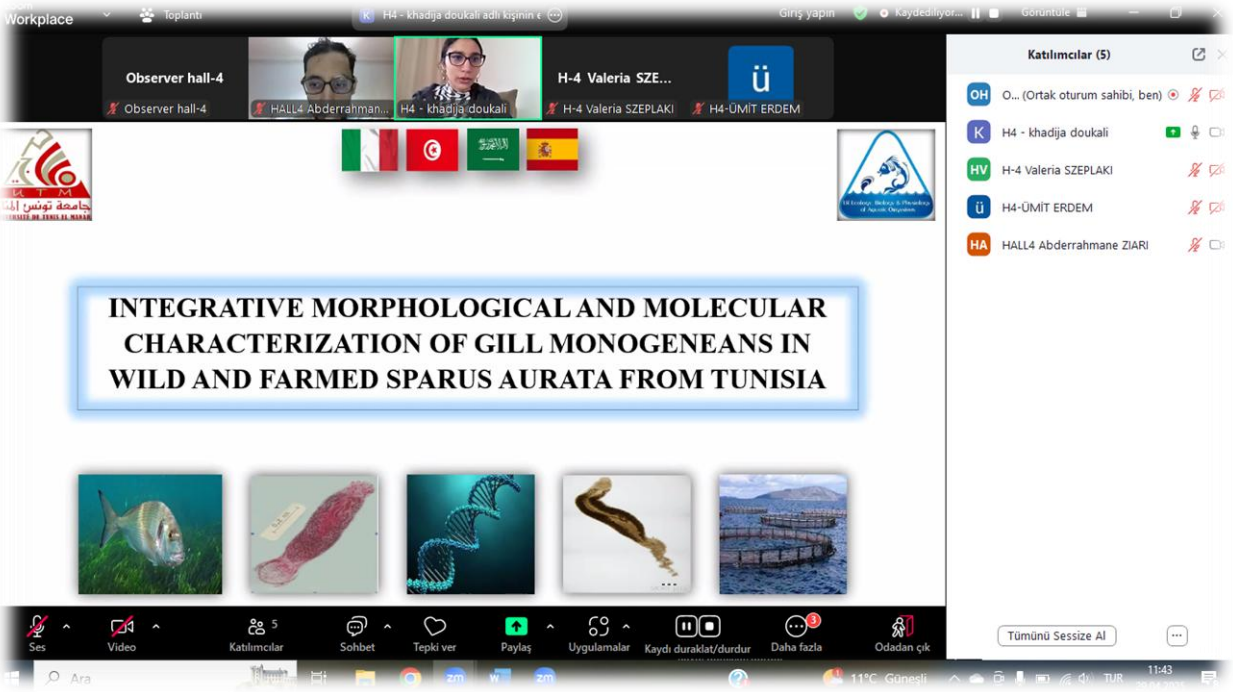

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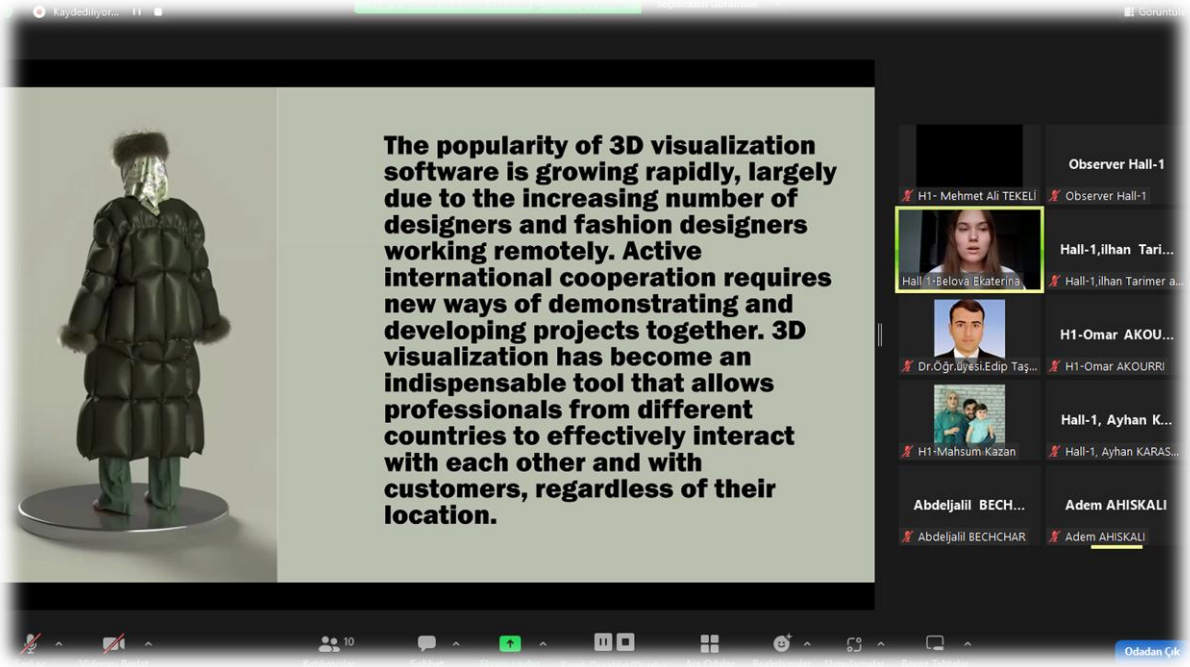

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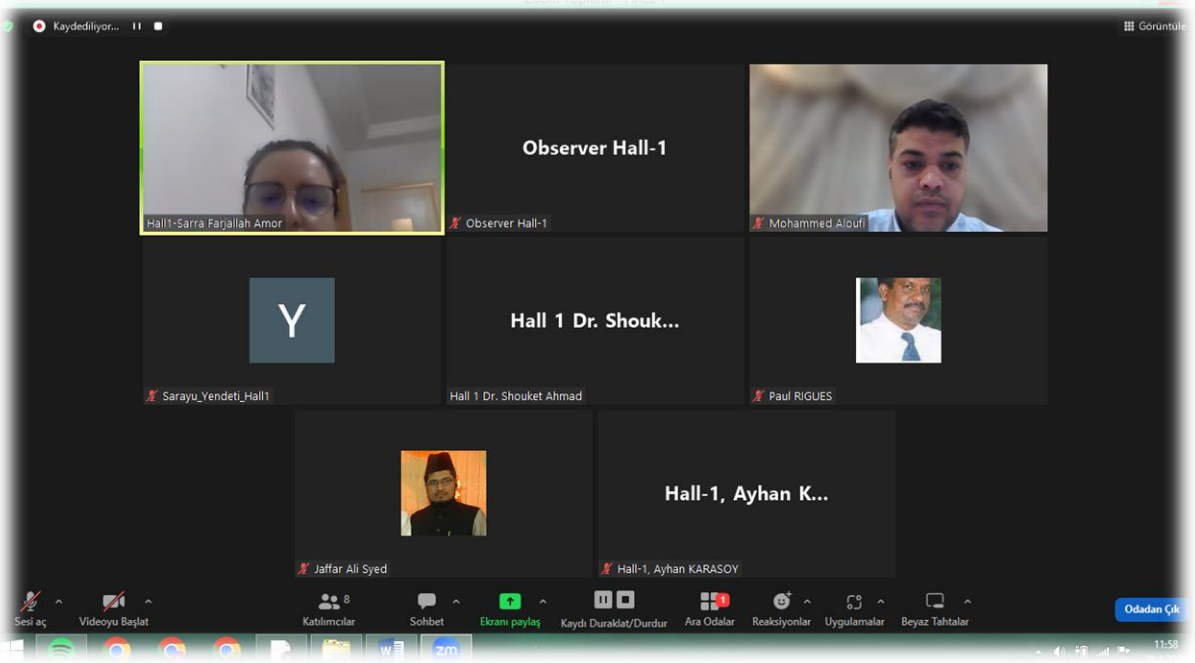

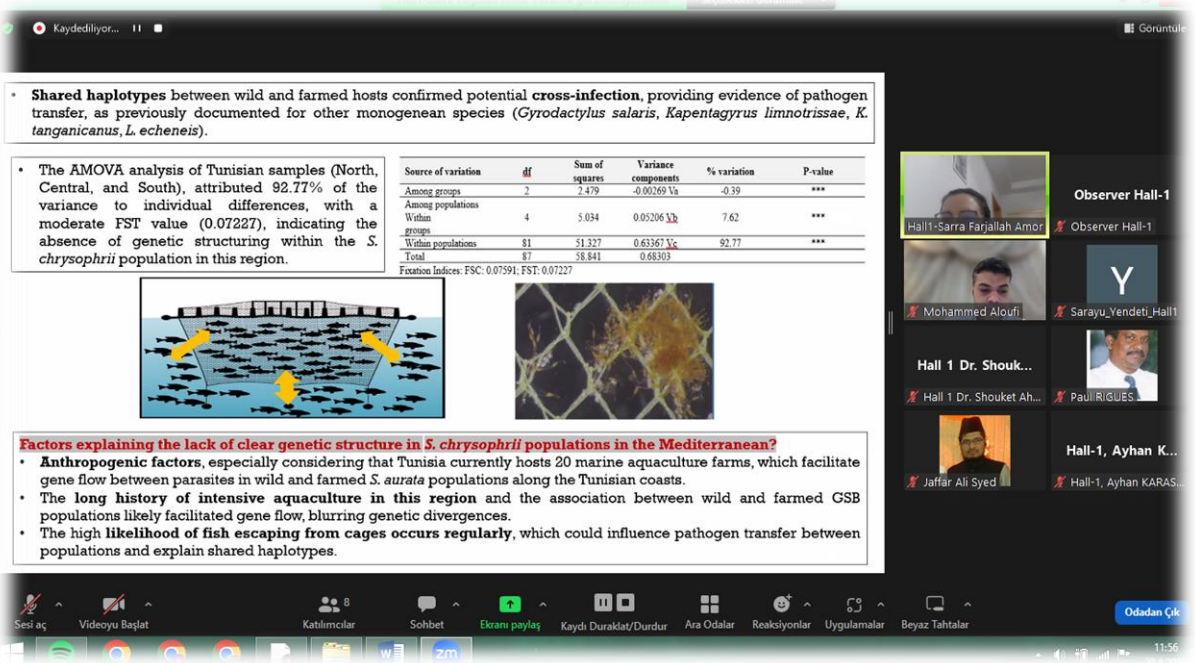

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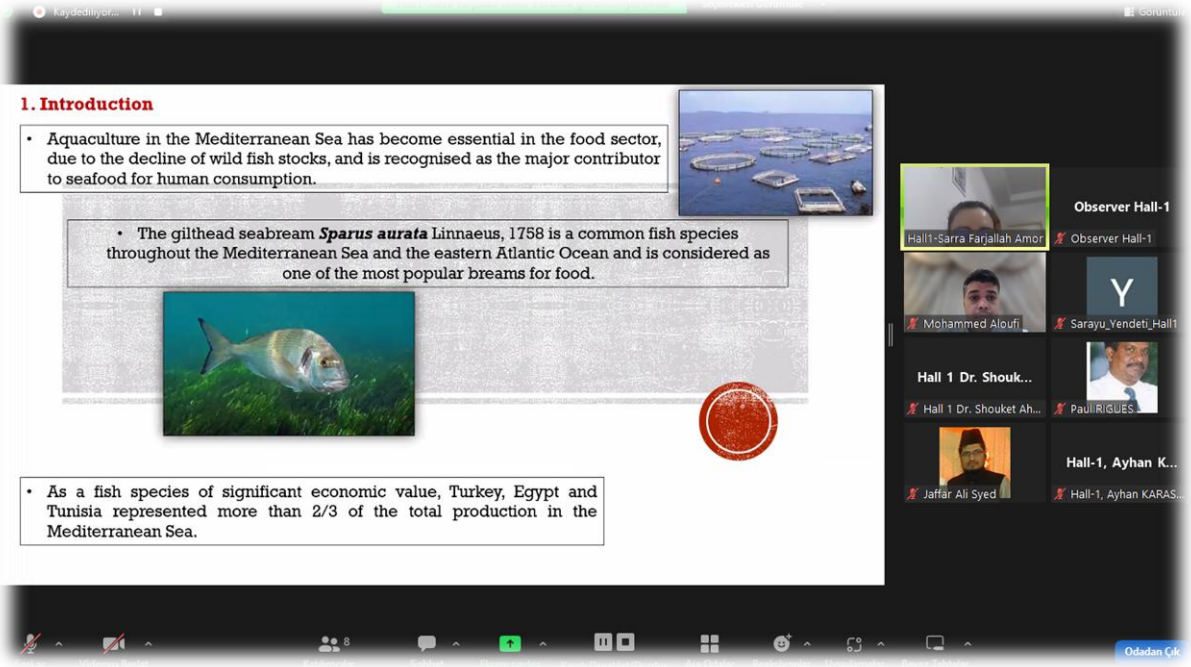

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II. INTERNATIONAL FUTURE ENGINEERING CONFERENCE

APRIL 28-29, 2025 / BAKU, AZERBAIJAN

Baku Engineering University

CONFERENCE PROGRAM

Zoom Meeting ID: 862 1528 3413
Zoom Passcode: 282928

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Participant Countries (19): Azerbaijan, Türkiye, Kazakhstan, Indonesia, Israel, Morocco, United Kingdom, Pakistan, Nigeria, Algeria, Russia, Romania, Kosovo, Hungary, Czech Republic, Tunisia, Saudi Arabia, India, France

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Baku Engineering University
28.04.2025
Baku Local Time: 11:00 – 12:00
Ankara Local Time: 10:00 – 11:00
Zoom Meeting ID: 862 1528 3413 / Zoom Passcode: 282928
https://us02web.zoom.us/j/86215283413?pwd=nDqzuNrtv2OR6hMh0wJrZIUvC3uqGD.1

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Dr. Alvan CAFAOV
Head of IKSAD Azerbaijan

28.04.2025 / FACE-TO-FACE SESSION- H1
Baku Engineering University
Baku Local Time: 13:30 – 15:30
Ankara Local Time: 12:30 – 14:30
Moderator:

Title	Author(s)	Affiliation
CYBER ATTACKS ON SMART GRIDS	Dr. Abdulla Asim Ayaz	Nakhchivan State University, Azerbaijan
NONCOVALENT INTERACTION OF PHENYLHYDRAZONES	Prof. Dr. Namiq Shikhaliyev Dr. Gulnar Atakishiyeva Ayten Qajar Shafiga İbrahimova Arzu Nifteliyeva Irada Shikhaliyeva Abel Maharramov	Baku Engineering University, Azerbaijan
BOLD THE IMPACT OF ARTIFICIAL INTELLIGENCE IN ARCHITECTURE AND INTERIOR ARCHITECTURE EDUCATION ON THE LEARNING PROCESS	Assoc. Prof. Dr. Arzu MAMMADOVA	Baku Engineering University, Azerbaijan
COMPARATIVE ANALYSIS OF FORECASTING METHODS FOR AZERBAIJAN'S GDP	Elvin Nasirov Ulvi Suleymanov	Baku Engineering University, Azerbaijan
BIS(4-AMINOPHENYL)METHANONE DERIVATIVES FOR PEROVSKITE SOLAR CELLS	Ravan Rahimov Narmina Guliyeva Narmin Gojali Eldaniz Nubar Musazada Eldar Elsun Azizov	Baku Engineering University, Azerbaijan University of Strasbourg, France
ENVIRONMENTAL ASPECTS OF THE USE OF BENZALDEHYDE IN THE SYNTHESIS OF DICARBOXYLATES	Namiq Shikhaliyev Narmina Guliyeva Seljan Hasanli Mehman Aysel Bashirova Nurida Farzaliyeva	Baku Engineering University, Azerbaijan
SYNTHESIS OF PHENYLHYDRAZONES BASED ON O, M, P-NITROBENZALDEHYDES	Prof. Dr. Namiq Shikhaliyev Dr. Gulnar Atakishiyeva Dr. Nigar Ahmedova Dr. Sevinç Muhtarova Assoc. Prof. Dr. Gulnara Babayeva Ayten Qajar Nurana Gurbanova	Baku Engineering University, Azerbaijan Baku State University, Azerbaijan Baku State University, Azerbaijan Azerbaijan Technical University, Azerbaijan Azerbaijan State Pedagogical University, Azerbaijan Baku State University, Azerbaijan Baku State University, Azerbaijan
CASE STUDIES ON PARTIAL DISCHARGES IN AIS: THE ROLE OF HUMIDITY AND DESIGN DEFECTS	Sahib Ibrahimkhalilov	Azerbaijan State Oil and Industry University, Azerbaijan
FARMING IN SADAR. CULTIVATED AREAS AND IRRIGATION SYSTEMS	Sənan İbrahimov	Independent Researcher, Azerbaijan

28.04.2025 / FACE-TO-FACE SESSION-H2
Baku Engineering University
Baku Local Time: 13:30 – 15:30
Ankara Local Time: 12:30 – 14:30
Moderator:

Title	Author(s)	Affiliation
OXIDATION OF LIGNITE AND DETERMINATION OF FUNCTIONAL GROUPS USING FTIR	Assoc. Prof. Dr. Ferda MİNDİVAN Assist. Prof. Dr. Meryem GÖKTAŞ Züleyha TAŞKAN Prof. Dr. Ali BAYRAM	Bilecik Şeyh Edebali University, Türkiye Bursa Uludağ University, Türkiye
EFFECT OF DIFFERENT NEEDLE TIPS ON THE NANOFIBER DIAMETER AND CONTACT ANGLE OF ELECTROSPUN PAN NANOFIBERS	Assoc. Prof. Dr. Ferda MİNDİVAN Assist. Prof. Dr. Meryem GÖKTAŞ Prof. Dr. Harun MİNDİVAN Prof. Dr. Ali BAYRAM	Bilecik Şeyh Edebali University, Türkiye Bursa Uludağ University, Türkiye
FLOATING SOLAR POWER PLANTS FOR ELECTRIFICATION OF ON-CAMPUS TRANSPORTATION	Eyyub URAL Prof. Dr. Mehmet Azmi AKTACİR Assoc. Prof. Dr. Kemal KOCA Eyüp BEKÇİ	Harran University, Türkiye Abdullah Gül University, Türkiye Gazi University, Türkiye
EXAMINATION OF DESIGN MODELS OF FLOATING SOLAR POWER PLANTS	Eyyub URAL Prof. Dr. Mehmet Azmi AKTACİR Assoc. Prof. Dr. Kemal KOCA Eyüp BEKÇİ	Harran University, Türkiye Abdullah Gül University, Türkiye Gazi University, Türkiye
REALIZATION OF SOLAR POWER PLANT ELECTRICITY PRODUCTION ESTIMATION WITH MACHINE LEARNING ALGORITHMS: XGBOOST, LIGHTGBM	Assoc. Prof. Dr. Ömer Faruk EFE Jalilov Vugar	Bursa Technical University, Türkiye
INDUSTRIAL WASTEWATER TREATMENT USING HYBRID CRANBERRY (CORNUS MAS) SEEDS POWDER AND IRON SULFATE COAGULATION	Prof. Dr. Sakine UGURLU KARAAĞAÇ	Karabük University, Türkiye
INVESTIGATION OF THE SYNERGISTIC EFFECT ON FLAME RETARDANCY AND MECHANICAL PROPERTIES OF LDPE COMPOSITES OBTAINED BY USING KAOLIN WITH HUNTITE AND HYDROMAGNESITE	Pegah OSKOOEI Prof. Dr. Gül YILMAZ ATAY	Izmir Katip Çelebi University, Türkiye

29.04.2025 / Session-1, Hall-1
Baku Local Time: 10:00 – 12:00
Ankara Local Time: 09:00 – 11:00
Meeting ID: 862 1528 3413 / Passcode: 282928
Moderator: Dr. Edip TAŞKESEN

Title	Author(s)	Affiliation
PERSONALIZED TRAVEL MANAGEMENT AND SUGGESTION SYSTEM	Demet AYAZGÜN Zubair Tahir Yiğit Emre TÜRKKAN İlhan TARIMER	FreeLancer Software Engineer, Pakistan Muğla Sıtkı Koçman University, Türkiye
A TECHNOLOGICAL WEAPON: CYBER DEATH CHAIN	Mehmet Ali TEKELİ Prof. Dr. Fatih BAŞÇİFTÇİ	Selcuk University, Türkiye
AI AND THE FUTURE OF INDUSTRY: FROM AUTOMATION TO INTELLIGENT DECISION-MAKING	A. BECHCHAR A. SOULHI O. AKOURRI	Ecole Nationale Supérieur de Mines de Rabat, Morocco
MACHINE LEARNING APPROACHES FOR INTRUSION DETECTION IN WIRELESS NETWORKS	Asstt. Prof. Dr. Jogendra Kumar	G.B.Pant Institute of Engineeing and Technology Pauri Garhwal Uttarakhand, India
INVESTIGATION ON TÜRKİYE AND AZERBAIJAN HIGHWAY SAFETY SYSTEMS AND TRAFFIC ACCIDENTS	Assist. Prof. Dr. Adem AHISKALI	Kastamonu University, Türkiye
VIRTUAL FITTING: POSSIBILITIES OF MODERN 3D CLOTHING DESIGN SOFTWARE FOR VISUALISATION OF DIPLOMA PRODUCTS	Belova Ekaterina Vyacheslavovna Kiseleva Marianna Vladimirovna	Russian State University A.N. Kosygin, Russia
POTENTIAL RISKS OF FOSSIL FUELS ON HUMAN AND ENVIRONMENTAL HEALTH	Mahsum KAZAN Dr. Edip TAŞKESEN	Şırnak University, Türkiye

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29.04.2025 / Session-1, Hall-2
Baku Local Time: 10:00 – 12:00
Ankara Local Time: 09:00 – 11:00
Meeting ID: 862 1528 3413 / Passcode: 282928
Moderator: Prof. Dr. Idris KABALCI

Title	Author(s)	Affiliation
EFFECT OF Ni AND Cu ADDITION TO CoCrMo ALLOY ON MECHANICAL PROPERTIES AND CORROSION RESISTANCE	Ömer Faruk GÜDER Prof. Dr. Aysel ERSOY	Istanbul University-Cerrahpaşa, Türkiye
DEVELOPMENT OF BORON AND GRAPHENE ADDITIVE PACKAGING MATERIAL	Berrin TONYALI Prof. Dr. Fatih AKKURT Prof. Dr. Bilal DEMİREL	Gazi University, Türkiye Erciyes University, Türkiye
EVALUATION AND OPTIMIZATION OF TREATMENT PROCESSES FOR INDUSTRIAL WASTEWATER	FATIMA El Hankouri OUMAIMA Fraiha Bahouch Mohamed M'HAMED Ahari	Abdelmalek Essaadi University, Morocco
PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES OF LEGUMES UNDER DROUGHT AND SALINITY STRESS	Assist. Prof. Dr. Murat TUNC Süreyya Betül RUFAIOGLU	Harran University, Türkiye
MACHINE LEARNING-BASED YIELD AND QUALITY PREDICTION MODELS	Süreyya Betül RUFAIOGLU Assist. Prof. Dr. Murat TUNC	Harran University, Türkiye
OPTIMAL CONCENTRATION EFFECT ON PHOTOLUMINESCENCE OF Mo 3+ ACTIVATED SOFT GLASSES NEAR IR EXCITATION FOR PHOTONIC APPLICATIONS	Prof. Dr. Idris KABALCI Assoc. Prof. Dr. Taimuratova Lidiya UNGARBAEVNA Prof. Dr. Ahmad MARZUKI	Uşak University, Türkiye Şırnak University, Türkiye Yessenov University, Kazakhstan Sebelas Maret University, Indonesia

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29.04.2025 / Session-1, Hall-3
Baku Local Time: 10:00 – 12:00
Ankara Local Time: 09:00 – 11:00
Meeting ID: 862 1528 3413 / Passcode: 282928
Moderator: Assoc. Prof. Dr. Şengül ŞANLIER UÇAK

Title	Author(s)	Affiliation
NUMERICAL INVESTIGATION OF HYDRODYNAMIC BEHAVIOR OF FLOATING AGRICULTURAL APPLICATIONS PLATFORMS	Doğan TUPTAŞ Assoc. Prof. Dr. Ahmet YURTSEVEN	Yıldız Technical University, Türkiye
ENERGY CONSUMPTION AND LIFE CYCLE EMISSION ANALYSIS BASED ON OUTDOOR METEOROLOGICAL PARAMETERS IN PUBLIC AND SERVICE BUILDINGS	Assoc. Prof. Dr. Okan KON Prof. Dr. Bedri YÜKSEL	Balıkesir University, Türkiye İstanbul Gelişim University, Türkiye
ZERO-CARBON FUTURE IN MARITIME TRANSPORT: THE POTENTIAL AND CHALLENGES OF AMMONIA FUEL	Assoc. Prof. Dr. Şengül ŞANLIER UÇAK	Recep Tayyip Erdogan University, Türkiye
MITIGATING GREENHOUSE GAS EMISSIONS IN CEMENT MANUFACTURING: A COMPREHENSIVE REVIEW OF SOLUTIONS AND STRATEGIES	Agnes Oboh Fidelis Abam Michael Bassey	University of Uyo, Nigeria University of Calabar, Nigeria University of Uyo, Nigeria
THE ROLE OF FUMES/SMOKE EXTRACTION SYSTEMS IN FIRE OUTBREAK FROM DOMESTIC AND INDUSTRIAL SECTORS	Imoh Ime Ekanem Imo Moses Akpan Ndifreke Etebom Itiat	Akwa Ibom State Polytechnic, Nigeria
A TECHNICAL SURVEY ON MECHANICAL PLUMBING AND RETICULATION SYSTEMS IN CONVENTIONAL ENGINEERING APPLICATIONS	Aniekan Essienubong Ikpe Imoh Ime Ekanem Emem Okon Ikpe	Akwa Ibom State Polytechnic, Nigeria
THE AGEING PHENOMENON AND THE POSSIBILITY OF LEARNING FROM THIS TYPE OF ACCIDENTS	David Krivanek	Brno University of Technology, Czech Republic
INVESTIGATION OF NITROGEN OXIDE EMISSIONS IN A HYDROGEN/DIESEL DUAL-FUEL INTERNAL COMBUSTION ENGINE	İsmail SEVEN Assoc. Prof. Dr. Hüseyin GÜRBÜZ Prof. Dr. Tarkan SANDALCI	Sirnak University, Türkiye
HYDROGEN-BASED PEM FUEL CELLS AND BATTERIES IN SUSTAINABLE ENERGY SYSTEMS: A COMPARISON IN TERMS OF PERFORMANCE, ENERGY DENSITY, AND APPLICATION AREAS	Assoc. Prof. Dr. Hüseyin GÜRBÜZ Selman İLBEYOĞLU	Sirnak University, Türkiye

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29.04.2025 / Session-1, Hall-4
Baku Local Time: 10:00 – 12:00
Ankara Local Time: 09:00 – 11:00
Meeting ID: 862 1528 3413 / Passcode: 282928
Moderator: Assoc. Prof. Dr. Semra ÇİÇEK

Title	Author(s)	Affiliation
FIR FILTER DESIGN AND IMPLEMENTATION IN RASPBERRY Pİ ENVIRONMENT	Sıdıka KAHVECİOĞLU Assoc. Prof. Dr. Turgay KAYA	Fırat University, Türkiye
NUMERICAL INVESTIGATION AND OPTIMIZATION OF CENTRIFUGAL FAN PERFORMANCE IN HOUSEHOLD HEAT PUMP TUMBLE DRYER	Fazıl Erinç YAVUZ	Haier Europe, Türkiye
LONG-TERM BEHAVIOR OF ZEOLITE $Na_8Al_8Si_{12}O_{48}$ IN HEAT PUMP DRYER APPLICATIONS	Baran BULGURCU Fazıl Erinç YAVUZ	Haier Europe, Türkiye
ROBUST NON-LINEAR CONTROL OF A DOUBLY-FED INDUCTION GENERATOR	Mohammed OUINTEN Riyadh ROUABHI Abdelghafour HERIZI	Mohamed Boudiaf University of M'sila, Algeria
OPTIMIZING HARMONIC REDUCTION AND VOLTAGE OUTPUT IN INDUCTION MOTORS USING SVPWM WITH VFD	Uran Rakovica Dr. Qamil Kabashi Dr. Sabrije Osmanaj Dr. Milaim Zabeli	University of Prishtina, Kosovo
DESIGN OF A STANDALONE SOLAR-POWERED WATER PUMPING SYSTEM WITH A SINGLE-PHASE SINUS-PWM PUSH-PULL INVERTER FOR GREENHOUSE APPLICATIONS USING A 1 KW PUMP	Uran Rakovica Dr. Qamil Kabashi Dr. Sabrije Osmanaj Dr. Milaim Zabeli	University of Prishtina, Kosovo
STABILITY ANALYSIS OF AUTOMATIC VOLTAGE REGULATOR SYSTEM WITH FRACTIONAL PI CONTROLLER	Lect. Eyyüp ŞEVGİN Assoc. Prof. Dr. Vedat ÇELİK	Van Yüzüncü Yıl University, Türkiye Fırat University, Türkiye
SMART MANAGEMENT SOLUTIONS FOR FOOD WASTE: DEEP LEARNING AND IoT TECHNOLOGIES	Assoc. Prof. Dr. Semra ÇİÇEK	Atatürk University, Türkiye
ANALYSIS OF SURFACTANT ADSORPTION ON ROCK SURFACES TO OPTIMIZE SURFACE TENSION	Ilkin Ismayilov	Azerbaijan State Oil and Industry University, Azerbaijan

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29.04.2025 / Session-2, Hall-1
Baku Local Time: 12:30 – 14:30
Ankara Local Time: 11:30 – 13:30
Meeting ID: 862 1528 3413 / Passcode: 282928
Moderator: Dr. Shouket Ahmad Kouchay

Title	Author(s)	Affiliation
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Moderator: Assoc. Prof. Dr. Mahmut DİRİK

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Meeting ID: 862 1528 3413 / Passcode: 282928
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Saygıdeğer Bilim İnsanları, Değerli Katılımcılar, Kıymetli Misafirler,

Sizleri, 2. Uluslararası Geleceğin Mühendisliği Kongresi'nde (IFEC2025) en içten duygularımla selamlamaktan büyük bir memnuniyet duyuyorum.

Bugün burada, mühendislik dünyasının uluslararası temsilcileriyle birlikte, geleceğe yön verecek bilimsel gelişmeleri ve yenilikçi teknolojileri ele almak üzere bir araya gelmiş bulunmaktayız. Bu kongrenin, sadece bir bilimsel paylaşım ortamı değil; aynı zamanda bir fikir alışverişi ve iş birliği zemini olduğuna inanıyorum.

Kongremize bu yıl ev sahipliği yapan Bakü Mühendislik Üniversitesi'ne ve Rektörü Sayın Prof. Dr. Yakup Piriyev Bey'e ve kıymetli ekibine şükranlarımı sunuyorum. Bu güçlü organizasyonun arkasındaki tüm akademik ve idari emek sahiplerine içtenlikle teşekkür ederim.

Şırnak Üniversitesi Rektörü olarak burada bulunmaktan büyük bir onur duyuyorum.

İçinde bulunduğumuz çağda; dijitalleşme, yapay zekâ ve sürdürülebilirlik gibi kavramlar, mühendislik anlayışımızı yeniden şekillendirmekte ve bizlere yeni sorumluluklar yüklemektedir. Üniversiteler olarak, bu dönüşümde aktif rol almak ve bilimsel rehberlik sunmak temel görevimizdir. Bu görevimizi icra ederken dikkate almamız gereken prensiplerin başında insanlık âlemine faydalı bilgiler ve teknolojiler üretmektir. Kongremizin başlığından yer alan "Geleceğin Mühendisliği" ibaresinin köken ve dallarına baktığımızda her yönüyle ihtişam dolu bir gelişim, değişim ve dönüşümle karşılaşıyoruz. Kâinâtın oluşumu, insanın yaratılışı mükemmel bir donanım ve yazılımda olduğu gibi kâinâtta ve insanda yeni mühendislikler için var olan istidat bilim adamlarını hayretler içerisinde bırakmaktadır. Kâinâtta var olan yer ve gök cisimleri harika mühendislikler neticesinde oluşturulmuş olduğu gibi insan unsuru da bu mühendisliklere harika mühendislikler katabilecek durumdadır. Bu konuda önümüzdeki yıllarda Biyomedikal Mühendisliği, Doku Mühendisliği, Biyoteknoloji Mühendisliği, Havacılık ve Uzay Mühendisliği, Yapay Zeka Mühendisliği ve Çevre Mühendisliği alanında büyük atılımların gerçekleştirileceğine inanıyorum.

(Bu arada ara bir not olarak şunu da söyleyeyim ki, dünyanın önde gelen üniversiteleri şimdiden kendilerini buna hazırlamaya başladılar. Gelişmiş ülkeler üniversitelerini bu konuda hızla değiştirmeye ve dönüştürmeye çalışıyorlar. Ders müfredatı kökten yeniden şekillendiriliyor. Bu durum siyasi arenada da kartların yeniden karılmasına ve dağıtılmasına neden olacaktır.)

Yukarıda bahsini ettiğim mühendislik alanları başta olmak üzere temel bilim alanlarında, insan nev'inin ve çevresinin yararını oldukça önemsiyorum. Tüm mühendisliklerde olduğu gibi bu mühendislikler de içerisinde oldukça büyük riskler taşımaktadır. Örneğin insanın fıtratı ve tabiatı ile ilgili, ileri mühendislikler gerçekleştirilerek insanın hem donanımına hem de yazılımına ciddi müdâheleler yapılabilecektir. Bu müdâhale durumu içerisinde çok büyük fırsatlar barındırdığı gibi çok ciddi tehlikeler de barındırmaktadır. En basitinden bu nevî bir müdâhale ile bir insan beyni rahatlıkla hacklenebilecektir. Hayati bir önem taşıyan bu gelişmelerden dolayı geleceğe yönelik olarak Şırnak Üniversitesi olarak mottomuzu "Harsı ve Nesli Koru" şeklinde belirledik.

Kıymetli bilim adamları, kıymetli katılımcılar,

Takdir edersiniz ki; mühendisliğin özü; hayatı kolaylaştırmak, çevreyle uyumlu çözümler üretmek ve topluma hizmet etmektir. Bu kongrede sunulacak bildirilerin; yalnızca bilgi üretimine değil, aynı zamanda insanlık yararına kullanılacak teknolojilere de kapı aralayacağına gönülden inanıyorum.

Şırnak Üniversitesi olarak bizler de, mühendislik ve teknoloji odaklı çalışmaları desteklemeyi, uluslararası iş birliklerini artırmayı ve özellikle genç araştırmacılarımıza rehberlik etmeyi öncelikli görevimiz olarak görmekteyiz.

IFEC2025'in, bilim dünyasında kalıcı etkiler bırakacağına, yeni projelere, ortaklıklara ve ilham verici akademik ağlara vesile olacağına inancımız tamdır.

Bu düşüncelerle; başta ev sahibi üniversite olmak üzere, kongreye katkı sunan tüm bilim insanlarına, araştırmacılara ve katılımcılara teşekkür ediyor; kongrenin başarılı ve verimli geçmesini temenni ediyorum.

Prof. Dr. Abdurrahim ALKIŞ

Rektör – Şırnak Üniversitesi

IFEC2025 Onursal Başkanı (Türkiye)

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CYBER ATTACKS ON SMART GRIDS

AKILLI ŞEBEKELERDE SIBER SALDIRILAR

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ABSTRACT

The integration of digital technologies into energy infrastructures has made smart grids more efficient, flexible, and sustainable. However, this transformation has also introduced significant cybersecurity threats. Since 2020, cyber attacks targeting smart grids have increased substantially, making energy sector security a global priority. These attacks on critical infrastructure not only result in financial losses but also lead to large-scale power outages and national security risks.

Smart grids, which operate at the intersection of Information Technology (IT) and Operational Technology (OT) systems, are vulnerable to various types of cyber threats. These include ransomware attacks, Distributed Denial-of-Service (DDoS) attacks, False Data Injection (FDI), Advanced Persistent Threats (APT), and supply chain attacks. The centralized and distributed structures of smart grids further amplify the impact of these threats.

This paper analyzes cyber attacks on smart grids based on research conducted between 2020 and 2024 and examines current security strategies. Specifically, it explores innovative approaches such as AI-driven anomaly detection, Zero Trust Architecture (ZTA), cyber-physical system security, and blockchain-based security solutions.

Keywords: Smart grids, critical infrastructures, cyber-physical systems, ransomware, threat modeling, Zero Trust Architecture, blockchain security.

Özet

Dijital teknolojilerin enerji altyapılarına entegrasyonu, akıllı şebekeleri daha verimli, esnek ve sürdürülebilir hale getirmiştir. Ancak bu dönüşüm, siber güvenlik tehditlerini de beraberinde getirmiştir. 2020 sonrası dönemde, akıllı şebekelere yönelik siber saldırılar önemli ölçüde artmış ve enerji sektörünün güvenliği küresel bir öncelik haline gelmiştir. Kritik altyapılara yönelik bu saldırılar, yalnızca finansal kayıplara yol açmakla kalmayıp, geniş çaplı enerji kesintilerine ve ulusal güvenlik risklerine de neden olmaktadır.

Akıllı şebekeler, bilgi teknolojileri (BT) ve operasyonel teknoloji (OT) sistemlerinin birleşiminden oluştuğu için, farklı saldırı türlerine karşı savunmasız hale gelmektedir. Bu saldırılar arasında fidye yazılımı (ransomware), dağıtılmış hizmet reddi (DDoS), yanlış veri enjeksiyonu (False Data Injection - FDI), gelişmiş kalıcı tehditler (APT) ve tedarik zinciri saldırıları öne çıkmaktadır. Akıllı şebekelerin merkezi ve dağıtık yapıları, bu tehditlerin etkisini daha da artırmaktadır.

Bu makale, 2020-2024 yılları arasında yapılan araştırmalara dayanarak, akıllı şebekelere yönelik siber saldırıları analiz etmekte ve mevcut güvenlik stratejilerini incelemektedir. Özellikle, yapay zeka destekli anomali tespiti, sıfır güven mimarisi (Zero Trust Architecture), siber-fiziksel sistem güvenliği ve blokzincir tabanlı çözümler gibi yenilikçi yaklaşımlar ele alınmaktadır.

Anahtar Kelimeler: Akıllı şebekeler, kritik altyapılar, siber-fiziksel sistemler, fidye yazılımı, tehdit modelleme, sıfır güven mimarisi, blokzincir güvenliği.

NONCOVALENT INTERACTION OF PHENYLHYDRAZONES

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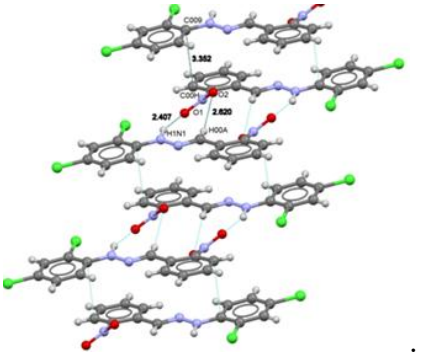
Abstract

A non-covalent bond is a relatively weak chemical bond that is not based on the sharing of electrons. Taking into account the recent interest in these bonds, syntheticists have been conducting their targeted syntheses in this direction. We, in turn, have set the goal of studying this type of bond in the compounds we have synthesized. Therefore, it has been observed that different designs are formed during the crystal packing of the corresponding phenylhydrazones synthesized by us, depending on the positions of the nitro groups and chlorine atoms in the benzene ring. From this, we can conclude that by changing the positions of the nitro group in benzoyl aldehyde and the Cl atoms in phenylhydrazine, a new design can be given to the crystal lattice. It should be noted that, despite the presence of two chlorine atoms in hydrazine molecules, unlike dichlorodiazadienes, Cl···Cl bonds were not observed in these molecules. This was due to the formation of strong intermolecular hydrogen bonds in phenylhydrazones, the maximum distance of the Cl atoms from each other in the crystal packing, in other words, the arrangement of the molecules according to the “head-to-tail” principle. The role of mainly non-covalent interactions in the formation of crystals of synthesized phenylhydrazones has been established.



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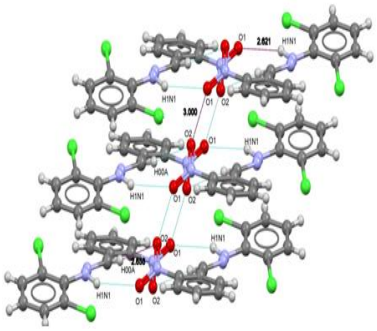

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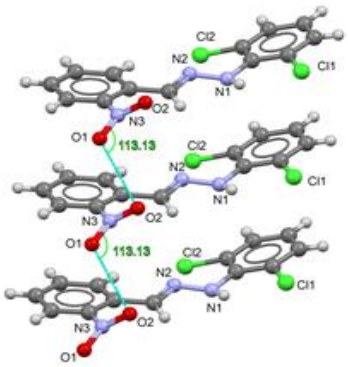

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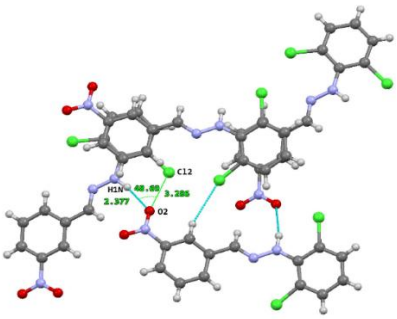

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Keywords: dichlorodiazadiene, noncovalent interactions

BOLD THE IMPACT OF ARTIFICIAL INTELLIGENCE IN ARCHITECTURE AND INTERIOR ARCHITECTURE EDUCATION ON THE LEARNING PROCESS

MIMARLIK VE İÇ MIMARLIK DERSLERINDE YAPAY ZEKA KULLANIMININ EĞITIM - ÖĞRETIM SÜRECINE ETKILERI

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ÖZET

Günümüzde mimarlık ve iç mimarlık alanları gelişen ve yenilenen teknolojiler sayesinde hayli ilerleme kaydetmektedir. Bu bağlamda her iki alanın uzmanları geçmiş deneyim ve gelecek perspektifiyle, yarını bugünden tasarlayarak malzeme, yapı bilgisi, çizim programları vs gibi alanlarda yetenekler edinerek diğer meslektaşlarından öne çıkabilmektedirler.

Son dönemlerde üniversitelerin mimarlık ve iç mimarlık bölümlerindeki öğrencilerin tasarım ve proje derslerinde yanı sıra araştırma ödevlerinde mesleki yönümlü bilgisayar programlarıyla birlikte yapay zeka (YZ) teknolojilerini de kullandıkları sıkca görülmektedir.

Bu makalede, yapay zekanın, verilen ödev tasarım süreçlerini hızlandırması, özelleştirme olanakları sunması ve veri analizi yetenekleri ile öğrencilere katkıları araştırılmış, buna karşın, insan yaratıcılığının azalması riski ve etik sorunlar gibi dezavantajları da ele alınmıştır.

Mimarlık ve iç mimarlık eğitiminde yapay zeka (YZ) teknolojilerinin kullanımı, doğru yönlendirilmesinin önemi ve promptların eğitim sürecindeki etkileri incelenmiştir. YZ'nin yaratıcı süreçlerde ve tasarım odaklı eğitimlerde sunduğu avantajlar, aynı zamanda öğretmenler ve öğrenciler arasında şeffaflığın eksik olduğu durumlarda ortaya çıkan etik ve pedagojik sorunlar ele alınmıştır.

Bu çalışma, öğrencilerin, özellikle YZ araçlarının promptlarla nasıl doğru bir şekilde yönlendirilmesi gerektiğini, bu sürecin tasarım kalitesi üzerindeki etkilerini, eğitimde etik yaklaşımların önemini ve ödev değerlendirilmesi meselelerini ele almaktadır. Ayrıca, YZ'nin geleneksel öğrenme süreçlerine entegrasyonu ve yaratıcılığı destekleyici bir araç olarak kullanımına yönelik, öğrencilerin teslim ettikleri ödevlerle örneklendirilerek somut öneriler sunulmaktadır.

Araştırma görsellerle zenginleştirilmiştir.

Anahtar kelimeler: mimarlık, iç mimarlık, eğitim, yapay zeka, ödev, prompt

ABSTRACT

In contemporary architecture and interior architecture, significant progress has been achieved through the development and application of evolving technologies. In this context, professionals in both fields distinguish themselves by mastering materials, construction techniques, and digital design tools, while integrating past experiences with future-oriented perspectives.

Recently, it has been increasingly common for students in architecture and interior architecture programs to incorporate artificial intelligence (AI) technologies into their design and project assignments, in addition to utilizing specialized professional software.

This paper explores the contributions of AI in accelerating design processes, offering customization opportunities, and enhancing data analysis capabilities. At the same time, it addresses potential disadvantages, such as the risk of diminishing human creativity and ethical concerns.

The use of AI in architectural and interior design education, the importance of proper guidance, and the impact of prompts on the learning process are critically examined. The study discusses how AI can enhance creative processes and design-focused education, while also highlighting the ethical and pedagogical issues that arise when transparency between educators and students is lacking.

This study not only discusses the advantages and disadvantages of AI in education but also examines its role in shaping students' design processes and decision-making skills. Furthermore, it provides concrete recommendations based on AI-integrated student projects, emphasizing AI's role not as a replacement for human creativity, but as a complementary tool that enhances traditional learning and design methodologies.

The research is enriched with visual representations.

Keywords: architecture, interior architecture, education, artificial intelligence, assignment, prompt

GİRİŞ

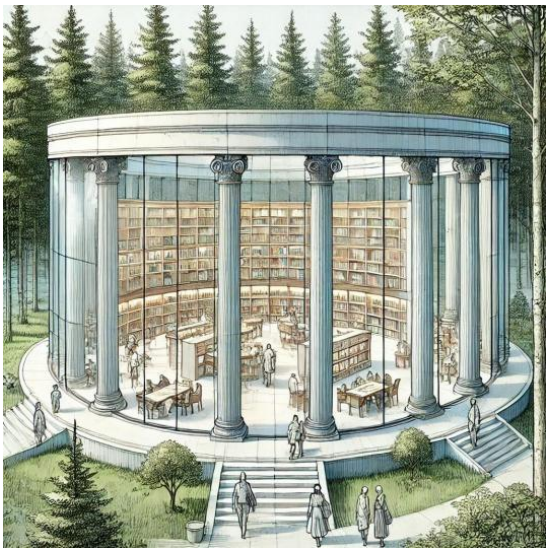
Günümüzde mimarlık ve iç mimarlık alanları, sürekli gelişen ve yenilenen teknolojiler sayesinde önemli ilerlemeler kaydetmektedir. Bu bağlamda, her iki alanın uzmanları, geçmiş deneyimlerden yararlanarak ve geleceğe yönelik bir perspektif benimseyerek, malzeme bilgisi, yapı sistemleri, çizim programları, yapay zeka gibi alanlarda yeni yetkinlikler kazanmakta ve meslektaşlarından ayrışarak öne çıkabilmektedirler. Bu perspektiften baktığımızda şimdiki mimarlık ve iç mimarlık öğrencilerinin de geleceğin tasarımcıları olarak yaratıcılığı destekleyen teknolojilerden faydalandığı görülmektedir.

Son dönemlerde üniversitelerin mimarlık ve iç mimarlık bölümlerindeki öğrencilerin tasarım ve proje derslerinde yanı sıra araştırma ödevlerinde mesleki yönümlü bilgisayar programlarıyla birlikte yapay zeka (YZ) teknolojilerini de kullandıkları sıkca gözlemlenmektedir. Yapay zeka İngilizcede "Artificial Intelligence" (kısaca AI) olarak ifade edilir (Artificial: Yapay, insan yapımı. Intelligence: Zeka, akıl, düşünme yeteneği. Bu iki sözün birlikte kullanılması ise makinelerin insan zekasını taklit etme yeteneği anlamına gelir.).

Tanımı: Bilgisayarların insanlar gibi "akıllı" davranmasını sağlayan algoritmaların ve sistemlerin geliştirilmesi. Amaç: Öğrenme, problem çözme, karar verme, tasarlama, dil anlama ve tahmin gibi insana özgü yetenekleri simüle etmekdir.

Kullanım Alanları: Tasarım ve Görselleştirme Önerileri:

Örneğin: Tasarım yaparken bir yapay zeka aracı (örneğin MidJourney veya DALL·E vs) kullanılabilir. Bu araç, verilen anahtar kelimelere (prompt'lara) göre modern, organik ya da klasik tarzda mimari görseller önerebilir.



Şekil 1.

Şekil 2.

Öğrenci, eskizlerini yükleyerek yeni ve farklı tasarım önerileri alabilir.

Şekil 3.

Şekil 4.

Malzeme Öneri Sistemleri:

Örneğin: Bir yapının iç mekan tasarımı için uygun malzemeleri seçerken, YZ tabanlı bir sistem geçmiş projelere, estetik tercihlerine ve fonksiyonel gerekliliklere göre malzeme önerilerinde bulunabilir. Dijital malzemeler ve parametrik tasarım konularında 3D baskı ya da CNC uyumlu malzemeler öneren YZ sistemleri kullanılabilir.

Tasarım Süreci Analizi ve Geliştirme:

Örnek: YZ, mimari tasarımlardaki ergonomi ve işlevsellik ilişkisini analiz ederek daha iyi bir tasarım için öneriler sunabilir. "Mimarli tasarım muhitində işlevsellik və ergonomi bağlantıları" konulu derslerde YZ araçları bu tür analizlerle dersleri zenginleştirir. Mimarlık bölümü öğrencilerinin: Restorasyon, Kentsel yeşillendirme ve peyzaj, Çevre tasarımı, Mimari iç mekan tasarımı gibi ders ödevlerinde sıklıkla kullanılmaktadır.

Kullanıcı Deneyimine Göre Öneriler:

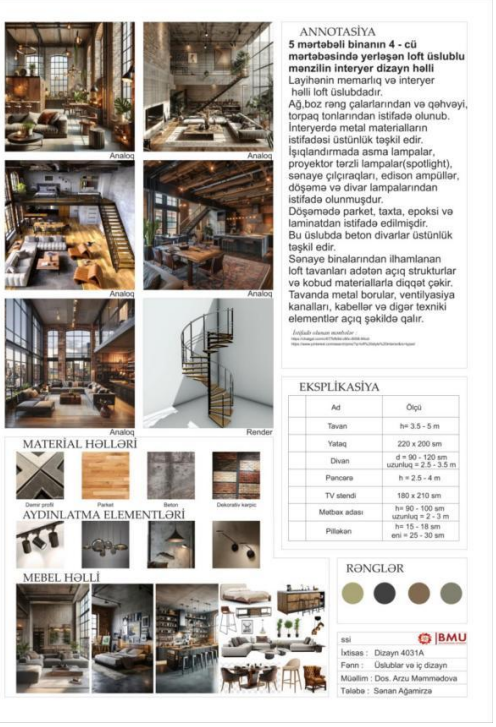
Örneğin: İç mekan tasarımı için bir yapay zeka sistemi, kullanıcıların yaşam tarzını analiz ederek kişiselleştirilmiş mobilya düzenlemeleri veya aydınlatma önerileri sunar. Mimarlık ve interyer stilleri ve ergonomi gibi konularda YZ, tasarımlar ve kullanıcı odaklı çözümleri önererek projelere ilham olabilir. Ayrıca, YZ destekli öneri sistemleri, dersler için yeni içerik fikirleri veya akademik kaynaklar sunabilir.

Bunların yanı sıra, ders müfredatlarını ve makaleleri zenginleştirmek için faydalanmak da mümkündür.

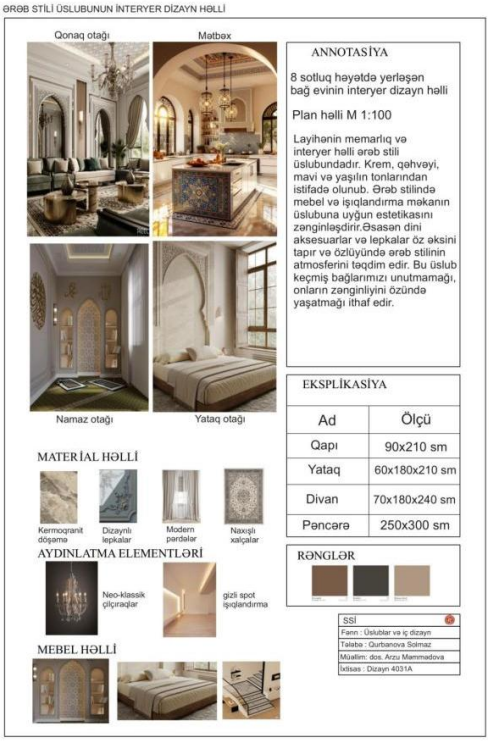
BULGULAR

Bu makalede, yapay zekanın, verilen ödev tasarım süreçlerini hızlandırması, özelleştirme olanakları sunması ve veri analizi yetenekleri ile öğrencilere katkıları araştırılmış, buna karşın, insan yaratıcılığının azalması riski ve etik sorunlar gibi dezavantajları da ele alınmıştır. Ayrıca, YZ'nin geleneksel öğrenme süreçlerine entegrasyonu ve yaratıcılığı destekleyici bir araç olarak kullanımına yönelik, öğrencilerin teslim ettikleri ödevlerle örneklendirilerek somut öneriler sunulmaktadır. Örneğin; interyer dizaynı ve stiller dersinde öğrenci ödevleri;

Şekil 5.



Şekil 6.



Şekil 7.

Şekil 8.

Yapay Zeka Teknolojilerinin Tanımı ve Potansiyeli

Yapay zeka (YZ), insan zekasını taklit ederek problem çözme, öğrenme ve karar verme gibi fonksiyonları yerine getiren teknolojilerdir. Tüm bunlarla birlikte yapay zeka, öğrencilerin düşünmemiş olabilecekleri benzersiz ve yenilikçi tasarım fikirleri üreterek onlara yardımcı olmaktadır. Verileri analiz ederek, çeşitli tasarım olasılıklarını sunmakta ve yaratıcı çözümler de önermektedir.

Şekil 9.

Şekil 10.

Yapay zekayı kullanarak farklı formlar, düzenler ve malzemeler deneyebilir ve tasarıma yeni yaklaşımlar ilham eden taze, alışılmadık konseptler ortaya çıkarabilir. Deep Dream Generator, SketchUp Free, Planner 5D, HomeByMe, AutoDraw, DeepAI, Roomstyler vs tasarım programlarından istifade edilir. Örneğin; aşağıdakı çalışmalarda veriler için ChatGpt, görsel sunumlar için ise Krea Aİ ve Kling Aİ, Midjourney vs kullanılmışdır.

İstemlerde (promptlarda) Art Deco, Streamline Moderne ve Bauhaus tarzlarının sentezinden bir tarz yaratmak için kullanılabilecek uygun cümleler kullanıldı.

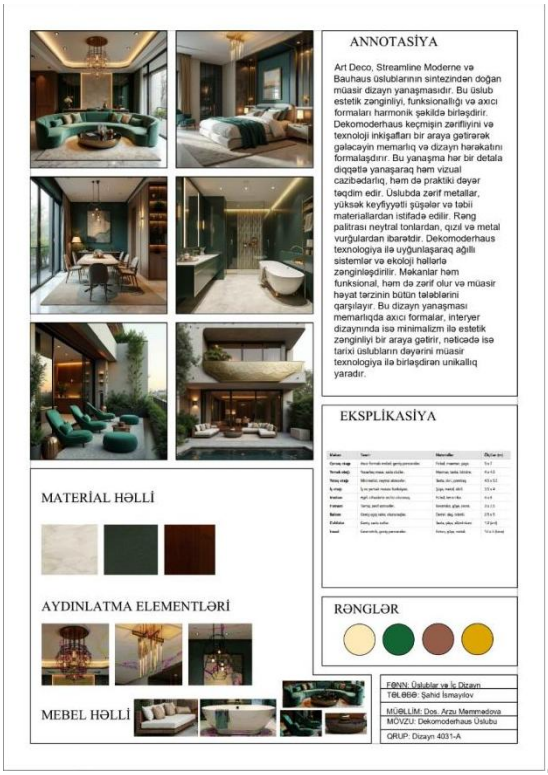
Örnek olarak bu üç üslup arasındaki benzerlikler ve farklılıklar belirtilmiş ve uygun bir tanımlama yapılarak ortak bir üslup yaratılmaya çalışılmıştır (Şekil 11).

Yapay zeka, mimarlık ve iç mimarlıkta tasarım sürecini hızlandırma, yaratıcılığı arttırma ve öğrencilere yeni bakış açıları kazandırma gibi çeşitli avantajlar sunmaktadır. Bu teknolojilerin temel uygulamalarından bazıları şunlardır:

Parametrik Tasarım: YZ destekli parametrik modelleme yazılımları, öğrencilere karmaşık geometri ve formları kolayca oluşturma fırsatı sunmaktadır (Şəkil 12).

Malzeme Seçimi ve Optimizasyonu: YZ, malzeme performansı ve sürdürülebilirlik kriterlerine dayalı en uygun seçenekleri belirleyerek tasarım süreçlerinde verimliliği artırır.

Görsel Tasarım Araçları: YZ destekli render ve simülasyon yazılımları, tasarımların gerçekçi görünümlerini oluşturur.



Şekil 11.

Şekil 12.

Yapay Zeka Kullanımında Promptların Rolü

Türkçe'de istem anlamına gelen 'prompt' kavramı yapay zekadan isteğe uygun çıktılar vermektedir, yani yapay zeka modellerine verilen talimatları ifade eder. Bu talimatlar, YZ'nin kullanıcı isteğine uygun bir çıktı sunması için önemli bir rol oynar. Mimarlık ve iç mimarlık derslerinde, etkili promptlar sayesinde öğrenciler yaratıcı fikirler geliştirip uygulayabilirler. Örneğin, "Doğal ışık alan minimalist bir oturma odası tasarımı" şeklinde bir prompt, daha özgün ve minimalist odaklı bir çıktı sağlar.

Etkili Promt Hazırlama Yöntemleri

Açıklık ve Spesifiklik: Promtlar, ne kadar net ve detaylı olursa sonuçlar da o kadar kaliteli olur.

Amaç Odaklı Yaklaşım: Tasarımın hedeflerini netleştirerek, YZ'den beklenen sonucun şeklini belirlemek.

Kısa ve Net Talimatlar: Fazla karmaşık olmayan ifadeler kullanılması, YZ'nin yanlış anlama olasılığını azaltır.

Eğitim Sürecine Etkisi

Promt hazırlama, öğrencilere analitik düşünme ve problem çözme becerileri kazandırabilir. Bununla birlikte, doğru promtların eğitimdeki avantajları şunları içerir:

Yaratıcı tasarım fikirlerinin ortaya çıkması.

Zamandan tasarruf etmek.

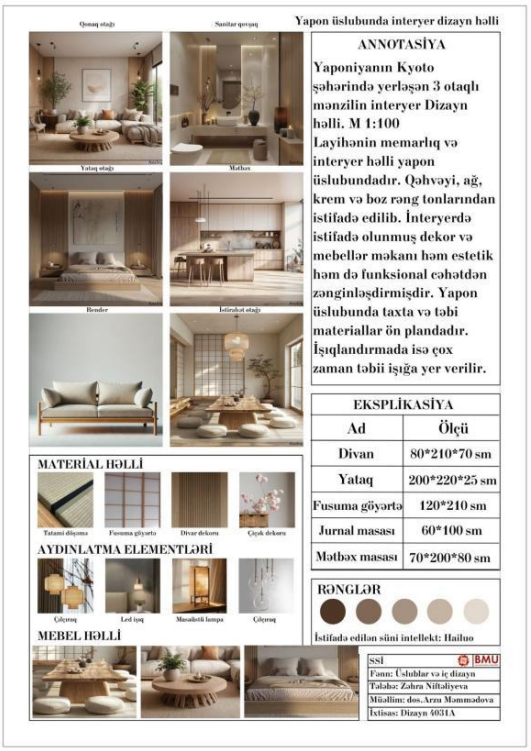
Gerçek dünyadaki tasarım problemlerinin simüle edilmesi.

Örnek Promptlar

"Maksimum 50 m² olan, sürdürülebilir malzemelerle tasarlanmış bir stüdyo dairesi için modern bir iç mekan tasarımı."

"Organik formlardan ilham alan parametrik bir cephe tasarımı."

"Minimalist bir kütüphane tasarımı, çevre dostu malzemeler kullanılarak" vs gibi.



Şekil 13.

Şekil 14.

Üniversitelerin İlgili Bölümlerindeki Eğitiminde Yapay Zeka Ağırlıklı Görsel Tasarımlarda Gelecek Perspektifi ve Öneriler

Üniversitelerde yapay zeka destekli eğitim süreci, sadece teknik bilgi ve becerileri değil, aynı zamanda stratejik düşünme ve inovasyonu da öne çıkarmaktadır. Şu öneriler, gelecekte YZ'nin eğitimdeki etkisini daha fazla artırabilmekte, dolayısıyle de gerekli kılmaktadır:

YZ Teknolojilerinin Müfredata Entegrasyonu: Görsel Eğitim programlarının YZ odaklı projelerle desteklenmesi.

Şekil 15. Tamara Ağayeva (Yüksek Lisans 2. sınıf)

Eğitimciler için YZ Kullanımına Yönelik Eğitimler: Akademisyenlerin bu teknolojiyi etkili bir şekilde kullanmalarını sağlamak.

Etik Farkındalığının Artırılması: YZ'nin olası yan etkilerine ve etik sorulara öğrencilerin hazırlanması, konuya ilişkin temel bilgilere ve beceriklere sahip olarak YZ"dan yaralanmak daha sağlıklıdır. Örneğin, Ergonomika dersinde teslim edilen öğrenci araştırma ödevinde YZ giriş kapı genişliğini 60 - 70 cm ölçülerinde verdi, bu ise öğrenci ödev hazırlama sürecinde dikkatinden kaçmıştır. Diğer bir öğrenci proje ödevinde çocuk oyun park alanlarında ergonomik ölçüler doğru verilmedi vs.

SONUÇ

İlk olarak 1950 yıllardan itibaren teknoloji dünyasında yerini alan yapay zeka, hızla ilerleyerek mimarlık ve iç mimarlıktakı görsel tasarım eğitiminde de kendini var etmiştir. Doğru şekilde hazırrlanmış promptların eğitim sürecine olumlu katkıları görülmekte ve gelecekte bu teknolojinin daha etkili kullanılmasını kaçınılmaz etmektedir. Yapay zeka destekli eğitim, yaratıcılığı ve teknik bilgi birikimini birleştirerek mimarlık ve iç mimarlık eğitiminde devrim yaratma potansiyeline sahiptir.

Bu çalışmada, mimarlık ve iç mimarlık eğitiminde yapay zekanın kullanımının, öğrencilerin yaratıcı düşünme süreçlerini nasıl dönüştürdüğü incelenmiştir. Elde edilen bulgular, yapay zekanın öğrencilere tasarım süreçlerinde hız ve verimlilik sağlarken, aynı zamanda yaratıcı düşünme becerilerini artırabildiğini göstermektedir. Bunun yanı sıra, yapay zeka ile yapılan işbirliği, geleneksel yöntemlerle kıyaslandığında öğrencilere yeni fikirler sunarak tasarım özgürlüğünü desteklemektedir. Bu bağlamda, öğrenci çalışmalarının değerlendirilmesi ve puan verilmesi sürecinin de yeniden şekillendirilmesi gerektiği açıktır. Yapay zeka, öğrencilerin bireysel gelişimlerini daha iyi izleme ve doğru değerlendirme yapabilme potansiyeline sahiptir. Ancak, bu teknolojinin ödev değerlendirme süreçlerine dahil edilmesi, adil ve objektif puanlamayı sağlamak için dikkatlice tasarlanmalıdır. Gelecekte, öğrenci çalışmalarının değerlendirilmesinde (kalite, yaratıcılık ve süreç) yapay zeka destekli sistemlerin nasıl daha etkin kullanılabileceği üzerine daha fazla araştırma yapılması önemlidir. Ayrıca, yapay zekanın sınıflandırma ve geri bildirim süreçlerine entegrasyonu, öğrencilerin daha hızlı ve verimli şekilde gelişmelerine yardımcı olacaktır. Ancak, bu geçişin eğitimdeki tüm katmanlara entegre edilmesi için daha fazla araştırma ve uygulama gereklidir. Gelenekten geleceğe geçişte eğitimle ilgili kurumlar (üniversiteler, eğitim kurumları, öğretim üyeleri ve eğitim politika belirleyiciler) öğrenci çalışmalarının değerlendirilmesi ve yapay zeka teknolojilerinin entegrasyonu konusunda önemli adım atmalıdır.

Bu bağlamda Sayın Cumhurbaşkanımız İlham Aliyev"in 19 Mart 2025 tarihli "Azerbaycan Respublikasının 2025 - 2028 yılları üçün Yapay Zeka Stratejisi"nin onaylanmasına ilişkin Kararnamesi çok anlamlı ve önemli bir adım olarak ülkemizde bu alana verilen çok önemli bir destektir.

Yapay zeka teknolojilerinin eğitim süreçlerine entegrasyonunu sağlarken, öğrenci değerlendirme sistemlerini yeniden gözden geçirmeli, şeffaf ve adil bir puanlama süreci için gerekli altyapıyı kurmalıdır. Ayrıca, yapay zekanın etik ve güvenlik standartları çerçevesinde kullanılmasını sağlamak için ulusal ve uluslararası düzeyde işbirlikleri de oluşturulmalıdır.

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Şekiller - BMU Mimarlık ve Tasarım Bölümleri öğrencilerinin ödevlerinden alınmıştır.

COMPARATIVE ANALYSIS OF FORECASTING METHODS FOR AZERBAIJAN'S GDP

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ABSTRACT

This study focuses on expenditures in the manufacturing industries in Azerbaijan, attempting to build a forecast model based on various estimation techniques. It investigates the efficiency of forecasting models such as Naive Forecasting, Exponential Smoothing, Moving Averages, Weighted Moving Averages, and Regression Analysis. The analysis is focused around error measurement with primary metrics being Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE). The results give an organized evaluation of forecasting models which can greatly aid economic planning and policymaking processes.

Keywords: Forecasting, Naive method, Exponential smoothing, Moving average, Mean Absolute Percentage Error, Regression analysis

INTRODUCTION

Manufacturing sector GDP forecasting is an essential aspect of formulating policies and making investment choices for fostering sustainable growth. Such developments in Azerbaijan are important from GDP growth cycle perspective as they aid to unlock GDP potential. Over the last several decades, the economy of Azerbaijan has undergone profound changes which has progressed the diversification of economic activities across regions. Moreover, For the last few years more attention is paid on accurate forecasting of the GDP of manufacturing sector due to its increasing importance for decision making. There are numerous gaps in the accuracy of forecast due to volatility and varied changes in dynamics posed by the contemporary environment.

The focus of this project is applying the various forecasting techniques for the period of 2010-2023 to the GDP of Manufacturing sector of Azerbaijan. In particular, we focus on the accuracy of Naïve Forecasting, Moving Average, WMA, Exponential Smoothing, and Regression Analysis methods on calculated errors. The research expects to sharpen the level of appropriate methods for strategic planning towards the answer of optimal construction of system of monitoring, which helps to make mid-tern economic plans.

LITERATURE REVIEW

Many have attempted to predict the value of economic indicators such as GDP (Gardner, 2006). Traditional approaches like the Moving Averages and Exponential Smoothing models have always received attention for being straightforward and requiring little computation (Brown, 1963). In the words of Armstrong et al. (1992), the selection of a particular forecasting method is heavily influenced by both the dataset and the time span needed for forecasting.

Naive Forecasting is criticized for its simplicity, yet it's common knowledge that it works well when making short-term forecasts in stable environments (Makridakis et al., 1998). Both Moving Averages and Weighted Moving Averages are effective in minimizing lower-level deviations while giving special importance to long-term changes (Silver et al, 1998). As for Exponential Smoothing methods, those with an optimized alpha value are especially reliable because they provide adaptive forecasting by placing greater emphasis on more recent data (Hyndman & Athanasopoulos, 2018).

Regression analysis has a wider scope of applicability as it examines the relationship between a certain time period and GDP value, making it easier to project the trend. Regression models have a clear upper hand when data is available with obvious pre-defined directional trends as pointed out by Diebold (2012). Contending angles in this case involve overfitting and assumptions of the model.

MATERIALS AND METHODS

Data Sources

For carrying out this study, we utilized the quarterly GDP data corresponding to the manufacturing sector from 2010 to 2023 for Azerbaijan. The figures were downloaded from the country's statistical bodies and transformed into annual figures from quarterly data to enhance uniformity and comparability.

Forecasting Methods Applied:

- **Naive Forecasting:** Forecasts the next year's GDP using the previous year's actual GDP value.
- **Moving Average (MA):** Uses a three-year window to calculate the average of prior years.
- **Weighted Moving Average (WMA):** Applies weights (1, 3, 5) to three years, giving greater significance to more recent data.
- **Exponential Smoothing (ES):** Applies a smoothing constant of $\alpha = 0.3$, giving exponentially decreasing weights to past observations.
- **Regression Analysis:** Implements simple linear regression using time as an independent variable and GDP as the dependent variable.

Evaluation Metrics

The forecasting methods were evaluated using:

- **Mean Absolute Deviation (MAD):** Measures the average magnitude of errors.
- **Mean Squared Error (MSE):** Penalizes larger errors by squaring them.
- **Mean Absolute Percentage Error (MAPE):** Represents error as a percentage for comparability.

Description of the Processing System

The aim of this article is to assess the manufacturing sector of Azerbaijan with a specific reference to the proportion of its contribution to the economy through GDP between 2010 and 2023. The raw data included the quarterly GDP statistics for the manufacturing sub- sector over the period of 13 years. In order to provide for better comparability and less cluttered structure for analysis, the data was analyzed based on annual rates rather than quarterly rates. Such changes make it easier to analyze trends and patterns that are relevant to explore the manufacturing sector contribution to the country's development during this period.[1]:

A. Naive method.

B. Moving average.

C. Weighted moving average.

D. Exponential smoothing.

E. Regression analysis.

F. Error measurement methods.

Naive method.

The Naive Method is a basic form of time series forecasting in which the forecast for any given period is equivalent to the actual value of the prior period. When applying the Naive Method, the data from the previous year was used as the forecast for the next year; for instance, data from 2013 was used for 2014, 2014 for 2015, and so forth.[7]

TABLE I. IMPLEMANTATION OF NAIVE METHOD

		Naive forecasting	
Periods	Years	Actual data	Forecasting
1	2010	2041	
2	2011	2077	2041
3	2012	1153	2077
4	2013	2452	1153
5	2014	2776	2452
6	2015	2756	2776
7	2016	3063	2756
8	2017	3393	3063
9	2018	3849	3393
10	2019	4256	3849
11	2020	4486	4256
12	2021	5982	4486
13	2022	7078	5982
14	2023	7107	7078

Moving average.

The Moving Average Method is one of the forecast techniques with the capacity to predict future values through averaging data collected from a particular number of prior periods. In this study, the moving average technique was done over three-year period whereby the actual data for each year was computed by averaging out the actuals of the three prior years to provide a forecast for a given year (for instance the forecast for 2013 was arrived at through an average of the actuals of 2010, 2011and 2012 actuals). The equation of moving average is as follows: [3]

$$MA_t = \frac{X_{t-1} + X_{t-2} + X_{t-3}}{3}$$

TABLE II. IMPLEMANTATION OF MOVING AVERAGE

		Moving average	
Periods	Years	Actual data	Forecasting
1	2010	2041	
2	2011	2077	
3	2012	1153	
4	2013	2452	1757
5	2014	2776	1894
6	2015	2756	2127
7	2016	3063	2661
8	2017	3393	2865
9	2018	3849	3071
10	2019	4256	3435
11	2020	4486	3833
12	2021	5982	4197
13	2022	7078	4908
14	2023	7107	5849

Weighted moving average

Weighted Moving Average Method is referred to as a system of forecasting where certain proportion is given to certain periods. Unlike the simple moving average, this method is flexible enough to allow for weighting by importance of more recent data, or other preferences.[10] It has to be underscored that no single set of weights can be appropriate for all kinds of forecasting conditions. In this study, the most accurate outcomes are attained when using weights of 1, 3 and 5. The equation of weighted moving average is: [5]

$$WMA = \frac{P_1 * W_1 + P_2 * W_2 + \ldots + P_n * W_n}{W_1 + W_2 + \ldots + W_n}$$

TABLE III. IMPLEMANTATION OF WEIGHTED MOVING AVERAGE WITH 1, 3, 5 WEIGHTS

		WMA 1, 3, 5	
Periods	Years	Actual data	Forecasting
1	2010	2041	
2	2011	2077	
3	2012	1153	
4	2013	2452	1560
5	2014	2776	1977
6	2015	2756	2488
7	2016	3063	2729
8	2017	3393	2929
9	2018	3849	3212
10	2019	4256	3610
11	2020	4486	4024
12	2021	5982	4339
13	2022	7078	5292
14	2023	7107	6425

Exponential smoothing

Exponential Smoothing is leading approach of a forecasting technique that uses a declining trend of weights and the most recent data having the highest weights. Analyzing this technique, there is a neutral parameter known as alpha (α) that is used to determine the weight that is placed on the most recent data. It should be noted that alpha values that are normally used for researches lies between

0.1 and 0.5. As for the alpha values, different options were considered, and it was concluded that an alpha value of 0,3 offered the best forecasts. Due to forecasting for the first period is not eligible with this method, the first year's given 2000. [6]

$$F_t = \alpha X_{t-1} + (1-\alpha)F_{t-1}$$

TABLE IV. IMPLEMANTATION OF EXPONENTIAL SMOOTING WITH 0.3 ALPHA VALUE

		Expo Smoo (0,3)	0,3
Periods	Years	Actual data	Forecasting
1	2010	2041	2000
2	2011	2077	2012
3	2012	1153	2032
4	2013	2452	1768
5	2014	2776	1973
6	2015	2756	2214
7	2016	3063	2377
8	2017	3393	2583
9	2018	3849	2826
10	2019	4256	3133
11	2020	4486	3470
12	2021	5982	3775
13	2022	7078	4437
14	2023	7107	5229

Regression analysis

Regression Analysis is a statistical technique used to establish the measurable link between a variable and one or more other variables. In this study simple linear regression model was used where time acted as the predictor variable a manufacturing sector's gross domestic product as the response variable. The model was then applied to forecast future values rounded off the identified trend in the subsequent years. After calculations, the equation for regression analysis determined:[8]

TABLE V. IMPLEMANTATION OF IMPLEMANTATION OF REGRESSION ANALYSIS

$$Y = 416{,}65 + 622$$

Error measurement methods.

		Regression Analysis					
Periods	Years	Actual data	x-Mx	y-My	(x-Mx)*(x-Mx)	(x-Mx)*(y-Mx)	Forecasting
1	2010	2041	-6,5	-1706,8	42,25	11094,2	1040
2	2011	2077	-5,5	-1670,8	30,25	9189,4	1456
3	2012	1153	-4,5	-2594,8	20,25	11676,6	1872
4	2013	2452	-3,5	-1295,8	12,25	4535,3	2290
5	2014	2776	-2,5	-971,79	6,25	2429,5	2706
6	2015	2756	-1,5	-991,79	2,25	1487,7	3123
7	2016	3063	-0,5	-684,79	0,25	342,4	3540
8	2017	3393	0,5	-354,79	0,25	-177,4	3956
9	2018	3849	1,5	101,21	2,25	151,8	4373
10	2019	4256	2,5	508,21	6,25	1270,5	4790
11	2020	4486	3,5	738,21	12,25	2583,7	5206
12	2021	5982	4,5	2234,21	20,25	10053,9	5623
13	2022	7078	5,5	3330,21	30,25	18316,2	6040
14	2023	7107	6,5	3359,21	42,25	21834,9	6456

To evaluate the accuracy of the forecasting methods, three error measurements were used: Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE). MAD simply takes the average of the absolute differences between the actual and the forecasted values in a simple assessment of error. MSE finds the mean of the squared variation which

gives bigger errors much more importance. MAPE formulates the error percentage based on the actual values increasing its effectiveness in comparing the overall accuracy with different data sets. All those were computed and compared to find the best method of forecasting for the given data-set.

The equation of MAD is: [9]

$$MAD = \frac{\sum |Actual - Forecast|}{n}$$

The equation of MSE is: [4]

$$MSE = \frac{\sum (Actual - Forecast)^2}{n}$$

The equation for MAPE is: [2]

$$MAPE = \frac{\sum (\frac{|Actual - Forecast|}{Actual})}{n} \times 100$$

Calculation of error measurement for all 5 forecasting methods are as given:

TABLE VI. ERROR MEASUREMENT OF NAIVE METHOD

Actual data	Naive method	Error	Squared error	Percentage
2041				
2077	2041	36	1296	1,73%
1153	2077	924	853776	80,14%
2452	1153	1299	1687401	52,98%
2776	2452	324	104976	11,67%
2756	2776	20	400	0,73%
3063	2756	307	94249	10,02%
3393	3063	330	108900	9,73%
3849	3393	456	207936	11,85%
4256	3849	407	165649	9,56%
4486	4256	230	52900	5,13%
5982	4486	1496	2238016	25,01%
7078	5982	1096	1201216	15,48%
7107	7078	29	841	0,41%
		6954	6717556	234,43%
		535	516735	18,03%

TABLE VII. ERROR MEASUREMENT OF MOVING AVERAGE AND WEIGHTED MOVING AVERAGE

Actual data	Moving average	Error	Squared errors	Percentage
2041				
2077				
1153				
2452	1757	695	483025	28,34%
2776	1894	882	777924	31,77%
2756	2127	629	395641	22,82%
3063	2661	402	161336	13,11%
3393	2865	528	278784	15,56%
3849	3071	778	605803	20,22%
4256	3435	821	674041	19,29%
4486	3833	653	426844	14,56%
5982	4197	1785	3186225	29,84%
7078	4908	2170	4708900	30,66%
7107	5849	1258	1583403	17,71%
		10602	13281926	243,89%
		964	1207448	22,17%

Actual data	WMA	Error	Squared Error	Percentage
2041				
2077				
1153				
2452	1560	892	796259	36,39%
2776	1977	799	637868	28,77%
2756	2488	268	72003	9,74%
3063	2729	334	111630	10,91%
3393	2929	464	215502	13,68%
3849	3212	637	405486	16,54%
4256	3610	646	417747	15,19%
4486	4024	462	213034	10,29%
5982	4339	1643	2700910	27,47%
7078	5292	1786	3191384	25,24%
7107	6425	682	465579	9,60%
		8615	9227401	203,82%
		783	838855	18,53%

TABLE VIII. ERROR MEASUREMENT OF EXPONENTIAL SMOOTHING

Actual data	Expo Smoothing	Error	Squared Error	Percentage
2041	2000			
2077	2012	65	4186	3,12%
1153	2032	879	772131	76,21%
2452	1768	684	467723	27,89%
2776	1973	803	644379	28,92%
2756	2214	542	293669	19,66%
3063	2377	686	471061	22,41%
3393	2583	810	656808	23,89%
3849	2826	1023	1047155	26,59%
4256	3133	1123	1261835	26,39%
4486	3470	1016	1032906	22,66%
5982	3775	2207	4872720	36,90%
7078	4437	2641	6975920	37,32%
7107	5229	1878	3526275	26,42%
		14358	22026769	378,36%
		1104	1694367	29,10%

TABLE IX. ERROR MEASUREMENT OF REGRESSION ANALYSIS

Actual data	Regression	Error	Squared Error	Percentage
2041	1040	1001	1002001	49,04%
2077	1456	621	385641	29,90%
1153	1872	719	516961	62,36%
2452	2290	162	26244	6,61%
2776	2706	70	4900	2,52%
2756	3123	367	134689	13,32%
3063	3540	477	227529	15,57%
3393	3956	563	316969	16,59%
3849	4373	524	274576	13,61%
4256	4790	534	285156	12,55%
4486	5206	720	518400	16,05%
5982	5623	359	128881	6,00%
7078	6040	1038	1077444	14,67%
7107	6456	651	423801	9,16%
		7806	5323192	267,95%
		558	380228	19,14%

TABLE X. COMPARISON OF FORECASTING METHODS

	Naive	Moving average	WMA	Expo Smoo	Regression
MAD	535	964	783	1104	558
MSE	516735	1207448	838855	1694367	380228
MAPE	18,03%	22,17%	18,53%	29,10%	19,14%

FINDINGS and DISCUSSION

Comparative Performance

Method	**MAD**	**MSE**	**MAPE**
Naive	535	516,735	18.03%
Moving Average	964	1,207,448	22.17%
Weighted Moving Average	783	838,855	18.53%
Exponential Smoothing	1,104	1,694,367	29.10%
Regression Analysis	558	380,228	19.14%

The Naive approach achieved the lowest MAD and MAPE, showcasing its effectiveness in short-term forecasting. Regression Analysis outperformed in capturing long-term trends of GDP growth forecasting by depicting the lowest MSE.

Error Analysis

Violent movements in the economy were tied to higher error margins in Exponential Smoothing and Moving Average methods. Weighted Moving Average showed improvements in accuracy by focusing on newer data points, but not significantly enough to overcome the aforementioned methods.

Problem Identification

Through this analysis, the need for short-term and long-term forecasts to have consistently high accuracy was identified as one of the trouble areas. Single approaches tend to succeed in short-term or long-term forecasting, but not both.

Conclusion

This study assessed the performance of five forecasting methods on Azerbaijan's manufacturing GDP data. The Naive method emerged as the most suitable for short-term forecasts due to its simplicity and low error rates, while Regression Analysis was best for understanding long-term growth trends. Based on these findings, a hybrid approach combining Naïve Forecasting for immediate planning and Regression Analysis for strategic forecasting is recommended. Future studies could integrate macroeconomic indicators and machine learning models to further enhance forecasting accuracy.

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BIS (4-AMINOPHENYL) METHANONE DERIVATIVES FOR PEROVSKITE SOLAR CELLS

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Abstract

In this study, four newly synthesized derivatives of bis(4-aminophenyl) methanone incorporating different electron-donating groups were obtained through a palladium-catalyzed Buchwald–Hartwig cross-coupling reaction. The products were purified by column chromatography and isolated in their pure form as crystalline solids. Thermogravimetric analysis showed that the compounds exhibit high thermal stability, with 5% weight loss occurring in the temperature range of 394 to 507 C. The melting points of the obtained compounds were measured and found to fall between 76 and 165 C, which reflects their well-defined and stable structures. These compounds were further investigated as hole-transporting materials (HTMs) in inverted perovskite solar cell architectures. While their thermal and physical properties were promising, the devices based on these materials demonstrated power conversion efficiencies (PCEs) of less than 5%. This indicates that although the materials are structurally and thermally robust, additional molecular design strategies are required to improve their optoelectronic performance in photovoltaic applications. Furthermore, a practical and efficient synthetic methodology was developed for the preparation of bis(4-(bis(4-(methylthio)phenyl)amino)phenyl)methanone, which contains strong electron-donating arylamino groups. The versatility and reproducibility of this method suggest it could be adapted for the synthesis of a wide range of related functional molecules. Overall, this work provides a foundation for future development of novel organic semiconductors with potential applications in solar energy conversion, light-emitting devices, and other advanced optoelectronic systems.

Keywords: Perovskite solar cells, Hole-transporting materials, Bis(4-aminophenyl)methanone derivatives, Buchwald–Hartwig amination, Organic semiconductors

ENVIRONMENTAL ASPECTS OF THE USE OF BENZALDEHYDE IN THE SYNTHESIS OF DICARBOXYLATES

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Abstract

Benzaldehyde is a valuable and versatile reagent in organic chemistry, widely used as a key intermediate in the synthesis of dicarboxylates and other functional compounds. Owing to its pronounced electrophilic properties, benzaldehyde readily reacts with nucleophilic substrates such as malonic acid and its salts, enabling the formation of -dicarboxylate derivatives. These products serve as important precursors in the construction of more complex molecular structures, including-unsaturated carboxylic acids, which are of great relevance in pharmaceutical synthesis and materials science. Applications of such compounds extend to drug development, polymer production, and the creation of various functional materials.

The underlying reaction mechanism is based on nucleophilic addition and substitution, where the aldehyde group plays a central role in facilitating the transformation. However, alongside its synthetic advantages, benzaldehyde poses significant environmental and health-related concerns. Improper handling or disposal can lead to its release into air or water, potentially causing toxic effects on both ecosystems and human health. As a result, safety measures and environmental controls are essential in its industrial application. To address these challenges, modern chemical technologies are increasingly focused on developing greener synthetic approaches involving benzaldehyde. These include the use of closed reaction systems, environmentally benign catalysts, and alternative solvents to reduce emissions and environmental burden. Overall, while benzaldehyde remains a crucial reagent in organic synthesis, its use must be accompanied by strict adherence to ecological and safety standards to ensure responsible and sustainable chemical production.

Keywords: Benzaldehyde, Dicarboxylates, Organic synthesis, Green chemistry, Environmental safety

SYNTHESIS OF PHENYLHYDRAZONES BASED ON O, M, P-NITROBENZALDEHYDES

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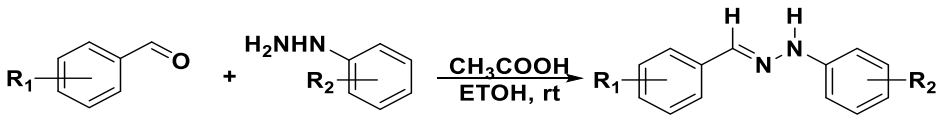
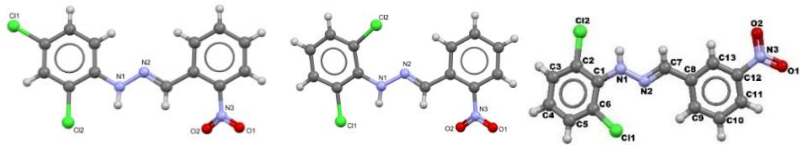
Abstract

Studies have been continued with precisely designed 2,4-; 2,6-; 3,4-dichloro-phenylhydrazines, which were synthesized on the basis of o, m, p-Nitrobenzaldehydes and have halogen atoms in the para position in the hydrazate fragment, to show that the halogen atom has a fundamental effect on the crystal. The main goal here was to study the effect of the number of C atoms in the hydrazine fragment and the position on the crystal design. In addition to the synthesis of dichlorodiazadienes from the synthesized phenylhydrazones, RQA studies were carried out designed to establish the effect of the structure of the functional groups in the benzene ring on the crystal.



R_1=o, m, p-NO_2-, R_2=2,4-dixlor-, 2,6-dixlor-, 3,4-dixlor-.



Keywords: dichlorodiazadiene, X-ray İnvestigations

CASE STUDIES ON PARTIAL DISCHARGES IN AIS: THE ROLE OF HUMIDITY AND DESIGN DEFECTS

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ABSTRACT

Partial discharge (PD) is a significant concern in air-insulated switchgear (AIS), as it can lead to insulation failure, equipment damage, and system downtime. This study presents two real-world case studies where humidity and design flaws played a critical role in PD formation in medium- and high-voltage AIS systems. The first case investigates corona discharges caused by improper component placement and high humidity, which eventually led to an arc flash event. The second case examines surface tracking discharges, where contamination and moisture accumulation created conductive paths on insulating surfaces, accelerating insulation degradation.To detect and analyze PD activity, multiple diagnostic tools were used, including transient earth voltage (TEV) measurements, ultraviolet (UV) imaging, and insulation resistance testing. The results highlight that high humidity increases moisture retention, reducing insulation resistance and promoting PD activity. Additionally, poor equipment design, such as sharp edges on conductive parts and improper spacing between components, contributes to stronger electric fields, increasing the risk of PD.The findings emphasize the need for proactive condition monitoring and preventive maintenance to reduce PD risks in AIS. Implementing solutions such as real-time humidity control, better insulation design, and scheduled diagnostic inspections can significantly improve system reliability and prevent costly failures. Moreover, the study highlights the importance of early PD detection methods, as timely intervention can prevent small discharge activity from escalating into major failures. Future research will focus on developing predictive approach to quantify the relationship between humidity levels and PD intensity. This would enable engineers to design more robust high-voltage equipment and optimize maintenance schedules based on environmental conditions. By addressing these challenges, the reliability, safety, and efficiency of AIS installations can be significantly improved.

Keywords: Partial Discharges (PD), Corona Discharge, Surface Tracking, Humidity Effects, Air-Insulated Switchgear (AIS), Condition Monitoring

INTRODUCTION

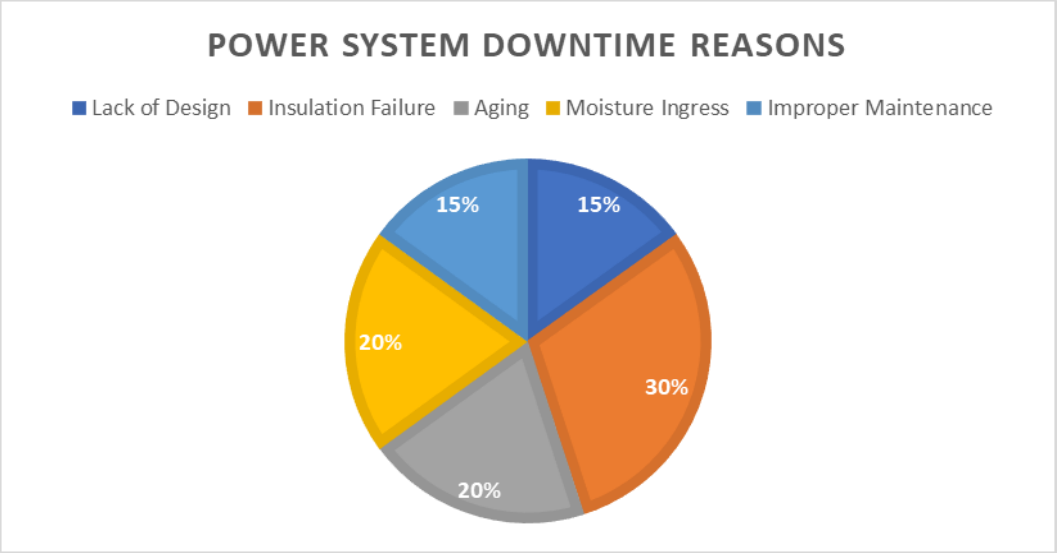
Medium voltage equipment plays a critical role in the transmission and distribution of electrical power in systems. This thesis emphasizes the importance of integrating condition-based and time-based monitoring approaches, especially for VIP assets. Condition based monitoring involves continuous assessment of equipment health through diagnostic tools, while Time Based Monitoring focuses on periodic scheduled inspections regardless of condition. Together, they provide a comprehensive approach to minimizing operational risks and ensuring long-term equipment performance.

The significance of these monitoring techniques is evident in provided case studies where the lack of proper monitoring resulted in costly downtime and repairs. For instance, Case Study #1 describes how the absence of effective condition monitoring led to repeated repairs of cable connections due to discharges at terminations. Further ignorance of condition monitoring led to two costly repairs, one complete reinstalling of switchgear, and arc flash half year after. Early condition monitoring could

have revealed corona issues due to incorrect placement of voltage and current transformers, as well as elevated humidity levels constantly contributing to worsening of condition resulting in failures.

In the opposite to mentioned case study is Case Study #2 where scheduled; 7 consecutive yearly condition monitoring revealed the problem at early stage which then was addressed potentially saving dividends and downtimes at factory.

Globally, downtime in medium-voltage systems due to insulation failures, including partial discharges, can be substantial. For example, studies have shown that unplanned electrical failures in MV systems can contribute to 30% to 50% [1] (Figure 1) of overall downtime in industrial and utility sectors, often due to insulation degradation, moisture ingress, and improper maintenance routines [2].



INTRODUCTION TO PARTIAL DISCHARGE (PD) AND ITS HARMFUL EFFECTS

Partial Discharge (PD) is a localized electrical discharge that occurs inside of the insulation systems of high-voltage equipment [3]. PD commonly starts to reach problem levels when the electric field strength exceeds the dielectric breakdown strength of the insulating material. But insulation is not completely breached making it a “partial” rather than complete dielectric failure.

PD is a significant problem in high-voltage systems as it often indicates how bad insulation is, which can eventually lead to complete insulation breakdown. The discharge is common to occur in voids inside the insulation layers, surface defects, or along interfaces between insulating materials. When appeared, PD emits sound, electromagnetic pulses, and in some cases light, all of which can be detected through previously mentioned condition-based monitoring diagnostic techniques.

2.1 MECHANISMS OF PARTIAL DISCHARGE

PD can be classified into three main types based on its location and origin factors:

Internal Discharge: Occurs within voids or gas-filled cavities inside solid insulation due to trapped air pockets where the dielectric strength is lower than the surrounding material.

Corona Discharge: An ionization process in the air around sharp conductive edges, leading to localized ionization without immediate insulation failure. This was observed in Case Study #1.

Surface Discharge: Happens along the surface of insulating materials, often due to contamination or moisture, as seen in Case Study #2.

Why Humidity Increases PD Risk?

Humidity plays a critical role in enhancing partial discharge activity due to its impact on insulation properties. Moisture can reduce the insulation resistance and create conductive paths on insulating surfaces, leading to:

Lower Insulation Resistance: increased moisture lowers resistance, making PD more intensive.

Surface Conductivity: Moisture combined with contamination can create conductive films on insulation surfaces, increasing chanses of surface discharges (as seen in Case Study #2).

METHODS AND MATERIALS

This study involved several diagnostic instruments and procedures written following standards. They were utilized to evaluate partial discharge severity and analyze possible preventive measures. Some of the equipment and methodologies employed are below:

Insulation Resistance Testing: The Megger MIT 515 insulation resistance tester was employed following the standard IEC 60034-27-4:2018 [4] to measure insulation resistance and identify insulation aging potential PD spots indicated by reduced dielectric strength.

Ultraviolet (UV) Imaging: Corona discharges were visually detected using a CoroCAM UV camera, aligning with practices recommended in IEEE Std 1829-2017 [5], which senses UV emissions that are invisible to the naked eye, identifying corona discharge locations on conductive parts.

Transient Earth Voltage (TEV) and Ultrasonic Detection: The UltraTEV Plus² from EA Technology was used following guidelines set by IEC 60270:2000 [3] and IEEE 400.3-2006 [6] standards to detect both TEV signals and acoustic signals aroused with PD. The device was helping to quantify and localize discharge activities, helping the early-stage diagnostics.

CASE STUDY 1: CORONA DISCHARGES DUE TO ENVIRONMENTAL CONDITIONS AND POOR INTERNAL DESIGN

In this case, we are examining an outdoor air-insulated switchgear that was installed in 2019 and running at 35 kV (Figure 2). This switch gear is housed in an unsealed metal enclosure without a concrete base, that exposes it to atmospheric conditions. Six months prior to the first condition monitoring, expensive repairs of whole switchgear and equipment replacement by third party was made. The latest condition monitoring revealed that similar faults occurred again. Signs like white nitric powder traces and charring around the cable terminations indicated ongoing partial discharges.

This proactive condition monitoring was initiated by business owner because of hissing/ buzzing sounds coming out of switchgear in rainy weather, bearing previous experience, identifying these issues would be first priority but due to some unknown reasons maintenance actions were delayed, leading to arc flash on rainy day. As revealed after inspection corona discharge evolved to an arc channel primarily due to short distance between current transformer and circuit breaker, causing outbreak fault which led to an outage and damage to electrical system again.

Figure 2. Side view of examined 35kV switchgear**.**

Figure 3. Relative humidity beneath subjected switchgear

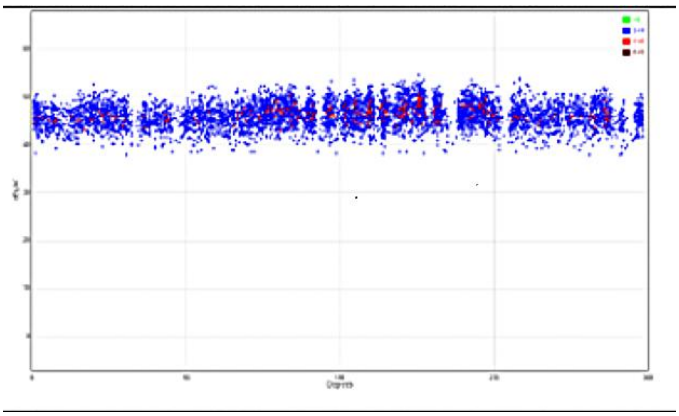
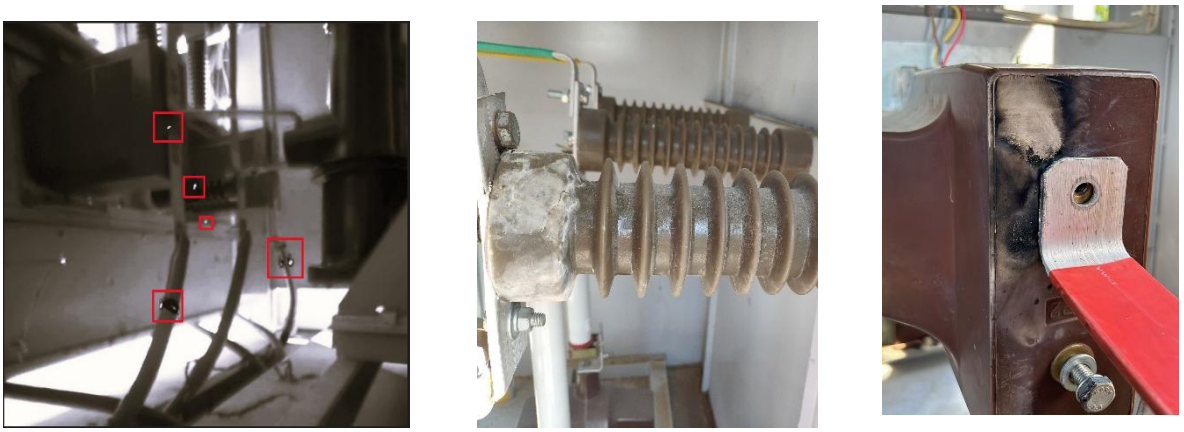


Figure 4. TEV readings on outer metal parts



Figures 5. Marked spots affected by corona discharge. Close examination

Observations:

- **Corona and Partial Discharges:** Preliminary tests took place weeks before the incident and were in dry weather. Tests involved the use of hand-held partial discharge detector that revealed high 2.83 PPC (pulse per cycle) (Figure 4). Further tests involved the use of corona UV light detecting camera which suggested that improper placement of busbars and their design—specifically, the pointy edges of the aluminum busbars are causing multiple sources of corona discharge [7] (Figures 5). Elevated levels of corona were observed between the busbar and CT terminal (photo taken after arc flash incedent).

- **Humidity Influence:** Humidity meter device registered relative humidity up to 85%, (Figure 3). The lack of a concrete base allows the ground moisture to be preserved under enclosure, raising

the humidity levels. This factor, combined with the fact that the space heaters were not working, adds to the partial discharge problem by creating a friendly environment [8]for these discharges to occur.

- **Breakdown Incident:** During a routine maintenance check, observed: improper placement of conductive parts, also poorly manufactured aluminum busbars placed on current transformers (CTs), and voltage transformers (VTs).

- Six months prior to the first condition monitoring, expensive repairs of whole switchgear and equipment replacement by third party was made. The latest condition monitoring revealed that similar faults occurred again. Physical signs like white powder traces and charring around the cable terminations indicated ongoing partial discharges, flagging them as potential failures. Proactive condition monitoring before any breakdown was crucial in identifying these issues early, but no actions regarding root causes were made, leading to an arc flash on rainy day.

Along with repair and some preventive modifications were taken to address the issues: Modification to existing design and busbars were manufactured without sharp edges to eliminate the cause of partial discharges. More heaters were installed inside the compartment to manage moisture, while special ventilation holes were added to the brick wall beneath it to improve airflow and reduce humidity accumulation. Additionally, modofications were taken to seal the metal hood of the switchgear, preventing potential seep of rainwater inside of switchgear, reducing potential risk of moisture ingress.

CASE STUDY 2: SURFACE TRACKING DISCHARGE DUE TO HUMIDITY

This case study examines an enclosed air-insulated switchgear SIEMENS SIMOPRIME running at 15 kV, located inside a factory's HV switch room (Figure 7). The temperature is kept at a normal level, but occasional high humidity levels are a concern due to an improperly maintained underground canalization and cooling system. The uneven design of concrete beneath the switchgear occasionally allows drainage water to pool under the switchgear, worsening the problem. However the relative humidity in switch room is watched and kept stable, the switchgear happens to tend as a hood above the flooding lower level, so switchgear itself becomes humid. Scheduled maintenance revealed some partial discharge signals both on hand-held device (Figure 9) and monitoring system. Which led to further investigation process on scheduled plant blackout.

Figure 8. Flood under switchgear

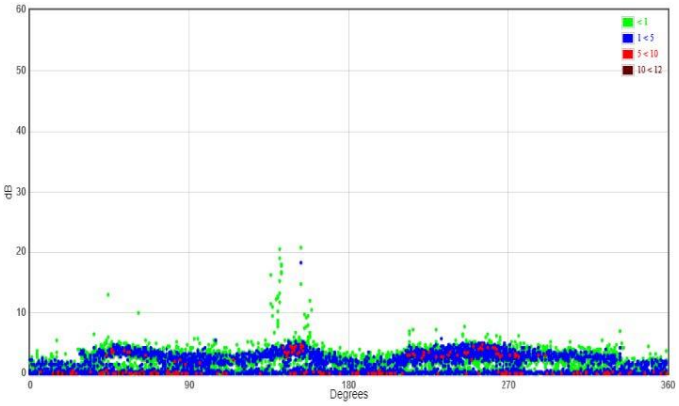


Figure 9. Transient voltage PRPD pattern

This case study examines an enclosed air-insulated switchgear SIEMENS SIMOPRIME running at 15 kV, located inside a factory's HV switch room (Figure 7). The temperature is kept at a normal level, but occasional high humidity levels are a concern due to an improperly maintained underground canalization and cooling system. The uneven design of concrete beneath the switchgear occasionally allows drainage water to pool under the switchgear, worsening the problem. However the relative humidity in switch room is watched and kept stable, the switchgear happens to tend as a hood above the flooding lower level, so switchgear itself becomes humid. Scheduled maintenance revealed some partial discharge signals both on hand-held device (Figure 9) and monitoring system. Which led to further investigation process on scheduled plant blackout.

Observations:

- Due to drainage water system's improper maintenance leads to periodic flooding. This causes technical water to seep beneath the switchgear, raising humidity levels within the enclosure (Figure 8).

- As always routine tests such as insulation resistance (IR) are a part of every high voltage appliance. Typically, the IR test is not suitable to identify and locate PD presence however in this case, 5kV insulation test revealed significantly low insulation resistance in one of the busbars, considering though switchgear was tidy inside, following high discrepancies between phases were concerning. While phases U and V show around 100 Giga-ohm, phase W busbar insulation struggled to reach 10 Giga-ohm. To find an exact place that causes a drop in IR numbers, all internal isolators and busbar supports were cleaned. The retest was not successful, and it was decided to disassemble the busbar by splitting it in half and testing separately the left and right side of it. This technique allowed me to find bad busbar section and cubicle.

- **Voltage Injection Test:** By injecting DC 15kV, the location of the partial discharge was found to be between the circuit breaker busbar socket and its plastic shroud (Figure 10). Photographic evidence was also collected to document the problem area (Figure 11). Discharges were seen occurring more strongly when shutters were closed.

Examination of affected area showed that the probable cause of the tracking discharge was due to contact grease from the high-voltage contacts of the circuit breaker. This grease contamination and

humidity adhered to the plastic insulating part, creating a conductive path for partial discharge to track along the insulator's surface [9]. Cleaning the grease did not resolve the issue, so the insulation parts were replaced to fully mitigate the tracking discharge.

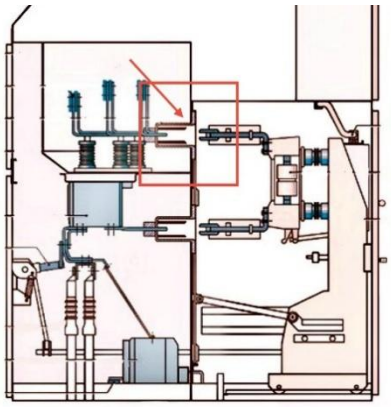


Figure 10. Side view on switchgear indicating discharge spots

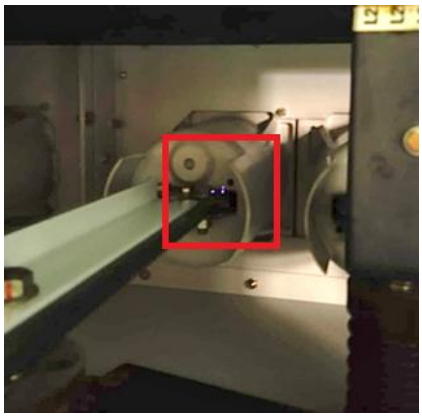


Figure 11. Actual photo of defect

CONCLUSION

The two cases presented highlight the critical importance of planned maintenance, incorporating partial discharge (PD) monitoring and employing a range of diagnostic tools and techniques. Proactive identification and mitigation of PD not only prevent system faults but also save considerable time and financial resources for companies.

While high humidity was not the primary issue in either case, it acted as a catalyst, accelerating the onset and severity of partial discharges. In the first case, humidity intensified corona discharges, eventually leading to an arc fault. In the second case, moisture combined with contaminants created a thin conductive layer, enabling tracking discharges.

The second case demonstrated that while insulation resistance testing is not ideal for partial discharge (PD) detection, even at low injection voltages it can effectively indicate the phase affected by PD. In my situation, utilizing a second insulation resistance testing device with higher voltage helped the localization of the spark spot.

RECOMMENDATIONS

This paper emphasizes the need for further research into the role of environmental factors in the evolution of partial discharges. A deeper understanding of the relationship between humidity levels, contamination, and PD intensity could help understanding concepts to slow or mitigate this destructive process. Future studies might focus on proving practical quantitative relations to predict PD behavior under varying humidity levels.

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FARMING IN SADAR. CULTIVATED AREAS AND IRRIGATION SYSTEMS

SƏDƏRƏKDƏ TƏSƏRRÜFAT. ƏKİN SAHƏLƏRİ VƏ SUVARMA SİSTEMLƏRİ

ЗЕМЛЕДЕЛИЕ В САДАРЕ. ПОХОДНЫЕ ПЛОЩАДИ И ОРОШИТЕЛЬНЫЕ СИСТЕМЫ

Sənan İbrahimov

Azərbaycan Respublikası

ABSTRACT

The farm in Sadarak uses various technologies to regulate and automate the crop growing processes. This is important for improving product quality, managing labor and resources effectively, and increasing field productivity.

Croplands are areas used for growing crops and should be supported by effective irrigation systems. Irrigation systems play an important role in meeting the water needs of plants and increasing crop productivity. Efficient irrigation systems ensure proper and rigorous supply of water and improve plant health and crop quality. Application of effective measures and technologies in these areas, increasing crop productivity and ensuring the development of agriculture are among the main issues.

Key words: Water management, arable land, irrigation, crop cultivation, technologies, productivity

XÜLASƏ

Sədərəkdə təsərrüfat, məhsul yetişdirmə proseslərini tənzimləmək və avtomatlaşdırmaq üçün müxtəlif texnologiyalardan istifadə edir. Bu, məhsul keyfiyyətini artırmaq, işçilik və resursları effektiv şəkildə idarə etmək və sahənin məhsuldarlığını artırmaq üçün əhəmiyyətlidir.

Əkin sahələri, məhsul yetişdirmək üçün istifadə olunan sahələrdir və effektiv suvarma sistemləri ilə dəstəklənməlidir. Suvarma sistemləri, bitkilərin su ehtiyacını təmin etmək və məhsul verimliliyini artırmaq üçün əhəmiyyətli bir rol oynayır. Effektiv suvarma sistemləri, suyun düzgün və ciddi təminatını təmin edir və bitkilərin sağlamlığını və məhsul keyfiyyətini artırır. Bu sahələrdə effektiv tədbirlər və texnologiyaların tətbiqi, məhsul verimliliyini artırmaq və kənd təsərrüfatının inkişafını təmin etmək əsas məsələlərdəndir.

Açar sözlər: Su təsərrüfatı, əkin sahəsi, suvarma, məhsul yetişdirmə, texnologiyalar, məhsuldarlığ

Резюме

Ферма в Садарак использует различные технологии для регулирования и автоматизации процессов выращивания сельскохозяйственных культур. Это важно для улучшения качества продукции, эффективного управления рабочей силой и ресурсами, а также повышения производительности на местах.

Пахотные земли это территории, используемые для выращивания сельскохозяйственных культур, и их следует поддерживать эффективными ирригационными системами. Ирригационные системы играют важную роль в удовлетворении потребностей растений в воде

и повышении урожайности сельскохозяйственных культур. Эффективные ирригационные системы обеспечивают правильную и надежную подачу воды, улучшают здоровье растений и качество урожая. Среди основных вопросов – применение эффективных мер и технологий в этих сферах, повышение урожайности сельскохозяйственных культур и обеспечение развития сельского хозяйства.

Ключевые слова: Водное хозяйство, пашня, орошение, выращивание сельскохозяйственных культур, технологии, продуктивность.

Giriş

Sədərək rayonu 28 avqust 1990-cı ildə Şərur rayonunun tərkibindən ayrılaraq rayon statusu almışdır.Mərkəzi Heydərabad qəsəbəsidir.

Sədərək rayonu cənub-qərbdən Türkiyə Cümhuriyyəti ilə (Türkiyə ilə Azərbaycanın həmsərhəd olduğu 15 km məsafə yalnız buradadır), şimal-qərbdən Ermənistan Respublikası ilə 24 km və cənub-şərqdən Şərur rayonu ilə 27 km həmsərhəddir.

Rayonun ərazisi əsasən düzənlikdən ibarət olub «Ucubiz, Əjdəkan, Vəlidağ və Tejqar» dağ silsilələri ilə əhatə olunmuşdur. Türkiyə ilə Sədərək arasında sərhəd boyu Araz çayı axır.

Azərbaycan xalqının ümummilli lideri Heydər Əliyevin təşəbbüsü ilə 1992-ci ildə Araz çayı üzərində Türkiyə ilə Azərbaycanı birləşdirən «Ümid» körpüsü tikildi, Gömrük keçid məntəqəsi yaradıldı. Türkiyədən Sədərəyə yüksək gərginlikli elektrik xətti çəkildi.

Sədərək rayonu Heydərabad qəsəbəsi, Sədərək, Qaraağac və Kərki kənd inzibati ərazi dairələrindən ibarətdir.

Heydərabad qəsəbəsinin əsası 1982-ci ildə ümummilli liderimiz Heydər Əliyev tərəfindən qoyulmuşdur. 23 mart 2000-ci ildə qəsəbə statusu almışdır. Sədərək rayonunun mərkəzidir.

Qaraağac kəndi 1997-ci ildə Sədərək kəndindən ayrılmışdır. Qaraağac kənd icra nümayəndəliyi yaradılmışdır.

Kərki kəndi 1990-cı ildən işğal altındadır.“Naxçıvan Muxtar Respublikasının Şərur və Sədərək rayonlarının inzibati ərazi bölgüsündə qismən dəyişikliklər edilməsi haqqında” 2021-ci il 23 fevral tarixli Azərbaycan Respublikasının Qanununa əsasən Şərur rayonunun inzibati ərazi bölgüsünə daxil olan Dəmirçi kəndi Sədərək rayonunun inzibati ərazi bölgüsünə daxil edilmişdir.Əhalisi məcburi köçkün kimi respublikamızın müxtəlif yerlərində məskunlaşmışdır.

1990-1993-cü illərdə erməni silahlı birləşməsi Sədərək üzərinə 14 dəfə güclü hücum etmiş, 1990-cı il yanvarın 16-da Kərki kəndi işğal olunmuş, Qanlı yanvar faciəsinin ilk şəhidləri Sədərəyin müdafiəsi zamanı verilmişdir (1990-1993-cü illərdə Sədərəyin müdafiəsində 108 nəfər şəhid olmuşdur).

Bu müddət ərzində 500 yaxın yaşayış evi, məktəblər, inzibati binalar dağıntılara məruz qalmışdır. Azərbaycan xalqının ümummilli lideri Heydər Əliyev Naxçıvanda yaşayıb, fəaliyyət göstərdiyi dövrdə digər sərhəd bölgələri kimi Sədərək də işğal təhlükəsindən xilas olmuşdur.

Ümummilli liderimiz Sədərəyi Naxçıvanın «Qeyrət qalası» adlandıraraq demişdir: «Muxtar respublikanın sərhəd kəndləri dəfələrlə silahlı təcavüzə məruz qalmışdır. Lakin biz hamımız yaxşı bilirik ki, əsas ağırlıq Sədərəyin üzərinə düşmüşdür. Sədərəkdə vəziyyət tamam başqadır. Burada əsil müharibə gedib, atışmalar olub».

Sədərək rayonunda maili düzənlik Arazboyu düzənliklərdən biridir. Cənub-şərqdən Dəhnə və Vəli dağ yüksəklikləri ilə Şərur düzündən ayrılır. Şimal-qərbdən Ağrı düzənliyi ilə birləşir. Cənub-qərbdə Araza qovuşur. 800-940 metr yüksəkliyə malik olan Sədərək düzü cənuba və qərbdən-şərqə doğru meyillidir. Sədərək düzünün mərkəzi hissəsindən kənd təsərrüfatı məqsədləri üçün istifadə olunur.

Rayon ərazisində düzənlikdə müasir (allüvial-prolüvial), dağlıq hissədə Devon, qismən Tabaşir çöküntüləri yayılmışdır. Burada gil, mərmərləşmiş əhəngdaşı yataqları və təzahürləri, mineral su yataqları vardır. Quru kontinental iqlimə malikdir. Yayı isti, qışı soyuqdur. Ərazidən Qaraçay, Çapan çayı və Türkiyə sərhədi boyunca Araz çayı axır. Əsasən, boz torpaqlar yayılmışdır. Sədərək düzünün Arazyanı hissəsində çəmən-ot bitkiləri inkişaf etmişdir.

Sədərək, əsasən, kənd təsərrüfatı rayonudur. Taxılçılıq, üzümçülük, meyvə-tərəvəzçilik və maldarlıq inkişaf etmişdir.

Sədərəkdə əkin sahələri maksimum dərəcədə istifadə olunur.

Naxçıvan Muxtar Respublikasının Kənd Təsərrüfatı Nazirliyində elektron informasiya sistemi yaradılana və Azərbaycan Respublikasının "Elektron kənd təsərrüfatı" informasiya sisteminə inteqrasiya olunmazdan əvvəl "Fiziki və hüquqi şəxslərə subsidiyaların verilməsi haqqında" Müvəqqəti Qaydaların layihəsi "Naxçıvan Muxtar Respublikasında kənd təsərrüfatı məhsulları haqqında" Naxçıvan Muxtar Respublikasının büdcəsi hesabına Naxçıvan Muxtar Respublikasında kənd təsərrüfatı məhsulları istehsalına dair "Ailələrinə (pətəklərinə) subsidiyaların verilməsi Qaydaları"nın müddəalarına uyğun olaraq istehsalı haqqında" adlı qərar Azərbaycan Respublikasında 2018-ci ildə fəaliyyət göstərən arıçılara ödənilməmiş subsidiya məbləğinin 18 sentyabr 2018-ci il tarixindən etibarən hər il verilməsi nəzərdə tutulur. Qaydalara əsasən, Naxçıvan Muxtar Respublikasının Kənd Təsərrüfatı, İqtisadiyyat, Maliyyə və Dövlət Statistika nazirlikləri tərəfindən Kənd Təsərrüfatı Subsidiyaları Şurası, komitə işçilərindən ibarət bir şura yaratmaq üçün nümayəndələr ayırmaq üçün qurumlara göndərildi. Sədərəkdə Daşınmaz Əmlak və Torpaq Məsələləri Dövlət Xidməti yaradılıb və eyni zamanda Ailə Təsərrüfatları İctimai Birliyinə üzv olub. Parlamentin qərarı ilə payızlıq və yazlıq bitkilər əkən fermerlərə gübrə verilib, payızlıq əkinlərə verilən dəstək məbləğinin 25 faizi təsərrüfat kartlarına köçürülərək yazlıq əkinlər üçün davam etdirilib.

Kənd Təsərrüfatı Nazirliyinin Sədərək rayon icra hakimiyyəti ilə birgə təşkil etdiyi görüşdə belə fikirlər səsləndirilib. İşğaldan azad edilmiş torpaqlarda əkilən qarğıdalı sahəsində keçirilən tədbirdə ailə fermerlərinə qarğıdalının iqtisadi əhəmiyyəti və əkinçilik texnikası ilə bağlı təlimlər keçirilib.

Sərhəd bölgəsində əkin sahələrinin maksimum səviyyədə istifadə olunduğu vurğulanıb. Taxıllara və paxlalılara, xüsusən də dənli bitkilərə və qarğıdalılara üstünlük verilir. Bu il 2357 hektar sahədə taxıl əkilmişdir. Artıq sonuncu hektarın da biçini aparılıb.

Muxtar respublikanın digər rayonları ilə müqayisədə məhsuldarlıq yüksəkdir. Sərfəli qarğıdalı zavoduna maraq artıb. 2020-ci ildə 25 hektar sahədə qarğıdalı səpən ailə fermerləri bu il əkin sahələrini 89 hektara çatdırıblar. Bunun 73 hektarı işğaldan azad edilmiş münbit torpaqlara aiddir.

Tədbirdə ailə təsərrüfatı ilə bağlı suallar cavablandırılıb, fikir mübadiləsi aparılıb. Təsərrüfatda xüsusilə də bol su olan nümunəvi şərait yaradan maarifləndirici söhbətlərin məhsuldarlığa müsbət təsir etdiyi bildirilir.

Şəkil 1. Kənd Təsərrüfatı Nazirliyinin Sədərək rayon icra hakimiyyəti ilə birgə təşkil etdiyi görüş

Sədərəkdə kənd təsərrüfatı sektoru kifayət qədər inkişaf edib. Bunu statistik rəqəmlər də təsdiq edir. Belə ki, təkcə ötən il 2472 hektar əkin aparılıb. Bu əkinin 1718 hektarını buğda, 754 hektarını isə arpa təşkil edib. 2019-cu ildə yaradılan bu şəraitdən istifadə edən təsərrüfatçılar yüksək məhsuldarlığa nail olublar. Onlardan Fuad Qədimov 50 hektar sahədən 54 sentner, Qafar Zeynalov 52 hektardan 51 sentner, Nurəddin Əliyev 16 hektardan 45 sentner, Elsevər Qazıyev 20 hektardan 48 sentner taxıl əldə ediblər. Arif Məmmədov isə 6 hektar sahədə bostan-tərəvəz bitkiləri əkib və 590 sentner məhsul götürüb.

Dövlətimizin təsərrüfatçılara göstərdiyi diqqət və qayğıdan ürəkdolusu danışmaq olar. Sədərəkdə əkinçiliklə məşğul olmaq, ailə təsərrüfatının fəaliyyətini genişləndirmək üçün hər cür şərait yaradılıb. Bu məsələdə hər kəsə lazımi dəstək verilir. Yanacağın, motor yağının, gübrənin alınmasına çəkilən xərclərin 50 faizi dövlət tərəfindən ödənilir. Taxıl əkinlərinə görə subsidiyalar verilir. Bu da əkinçiliyin inkişafına yol açır, əkin sahələri və məhsuldarlıq ilbəil artır.

Fermerlər vurğulayırlar ki, bu gün zəhmətkeşlərin güzəranı, yaxşı şəraiti var, məhsul əvvəlki kimi israf olunmur. Çünki kənd təsərrüfatı yarmarkalarına, festivallarına çıxarılan bir məhsul belə geri qaytarılmır, hamısı satılır. Qalanları soyuducuda saxlamaq olar. Zamanı gələndə onu da yaxşı qazanc üçün satmaq olar.

2019-cu ildə “Naxçıvan Aqrolizinq” ASC tərəfindən Sədərək rayon bazasına 1 “New Holland” markalı kombayn, 1 traktor, 2 kotan, 1 toxumsəpən, 2 kanalaçan və 1 yemqıran aqreqat verilib, sahibkarlardan 2 nəfərə isə lizinq yolu ilə kipvuran satılıb. 2019-cu ilin yaz-payız əkinlərinə görə 580 nəfər torpaq mülkiyyətçisinə 505 min 180 ton güzəştli şərtlərlə gübrə paylanılıb.

Bütün bunlar heyvandarlığın inkişafı üçün də münbit zəmin yaradıb. Bunun nəticəsində təkcə 2019-cu ildə Sədərək rayonunda diri çəkidə 458 ton ət, 1850 ton süd, 1 milyon 428 min ədəd yumurta, 22,3 ton yun istehsal edilib. 2018-ci illə müqayisədə ət istehsalı 2,9 faiz, süd istehsalı 2,2 faiz, yumurta istehsalı 1,1 faiz, yun istehsalı 1,4 faiz artıb.

2019-cu ildə Sədərək rayonunda, ümumilikdə, 19 milyon 84 min 400 manatlıq kənd təsərrüfatı məhsulu istehsal edilib ki, bu da 2018-ci il ilə müqayisədə 4,7 faiz çoxdur.

Hazırda rayonda 2987 baş iribuynuzlu mal-qara, 16 min 987 baş xırdabuynuzlu heyvan, 18 min 356 baş quş və 896 arı ailəsi var. Rayon sakinlərinin təsərrüfatında olan 411 baş iribuynuzlu mal-qarada

süni mayalanma işləri aparılıb, bunlardan 355 baş buzov əldə olunub. Hər baş buzova görə 100 manat subsidiya verilib.

Bölgədə arıçılıq təsərrüfatları da inkişaf etdirilir. Ötən il Naxçıvan şəhərində keçirilən "Arıçılıq məhsulları - bal" festivalında Sədərək rayonundan olan arıçılar da iştirak edib, bir arıçı keyfiyyətli bal istehsal etdiyinə görə 3-cü yerə layiq görülüb və diplomla təltif olunub. "Ailə təsərrüfatı məhsulları" festivalında isə Sədərək rayonundan, ümumilikdə, 108 növdə 5014 qablaşdırılmış məhsul çıxarılıb. Məhsulların növünün çoxluğu iştirakçıların da diqqətini cəlb edib. İstehsal etdiyi məhsulun sayına və keyfiyyətinə görə rayonun bir ailə təsərrüfatçısı 1-ci yerə layiq görülüb.

Naxçıvanda 2023-cü ilin ötən dövrü bütün sahələrdə olduğu kimi, aqrar sektorda da keyfiyyət dəyişikliklərinə yol açacaq addımlardan biri, bəlkə də, elə birincisi yerlərdə vətəndaşlarla görüşlərin keçirilməsi və reallaşdırılacaq layihələrin məhz insanların təklif-tövsiyələrinə, problemlərin həlli yollarına uyğun hazırlanmasıdır. Bu məqsədlə mart ayının əvvəllərindən başlayaraq Naxçıvan Muxtar Respublikası Kənd Təsərrüfatı Nazirliyinin əməkdaşları tərəfindən mütəmadi şəkildə təsərrüfat sahibləri ilə görüşlər keçirilib, onların problemləri dinlənilib, nöqsanların aradan qaldırılması üçün müvafiq tədbirlər görülüb, aqrar sahənin müasir dövrün tələblərinə uyğun, innovasiya yönümlü inkişafının təmin edilməsi məqsədilə tövsiyələr verilib.

Fermerləri daha çox narahat edən suvarma ilə bağlı problemlərin həlli üçün Naxçıvan Muxtar Respublikası Meliorasiya və Su Təsərrüfatı Açıq Səhmdar Cəmiyyətinin məsul işçiləri də işə qarışaraq Qahab Babək kəndinin suvarma suyuna olan tələbatını ödəmək üçün əlavə su ilə təmin ediblər. sahə. Xarici investorun nümayəndələri ilə yerli fermerlər arasında dostluq əlaqələrinin inkişaf etdirilməsi məqsədilə Şərur rayonunun Zeyvə kəndinin əkin sahələrinə baxış keçirilib, təkliflər verilib. Sədərək rayonunda balıqçılığın və camışçılığın inkişaf imkanlarını müəyyən etmək məqsədilə rayonda mövcud su anbarlarında araşdırmalar aparılaraq investorların cəlb edilməsi istiqamətində araşdırmalara başlanılıb. Təsərrüfat sahibləri tərəfindən dilə gətirilən problemlərlə bağlı rayon və şəhər inzibati orqanlarına müraciətlər edilib, gübrə, toxum və pestisid istehsalı alətlərinə olan tələbat müəyyən edilərək lazımi tədbirlər görülüb.

2023-cü ilin əvvəlindən bəri istehsalat təqviminə nəzər saldıqda ilk nəzərəçarpan uğur göstəricisi, heç şübhəsiz, bütün naxçıvanlı təsərrüfat adamları üçün ən əlamətdar hadisələrdən sayılan mayın 17-19-da Bakı Ekspo Mərkəzində təşkil olunan 16-cı Azərbaycan Beynəlxalq Kənd Təsərrüfatı - "Caspian Agro" və 28-ci Azərbaycan Beynəlxalq Qida Sənayesi - "InterFood Azerbaijan" sərgiləridir. Naxçıvan Muxtar Respublikası Kənd Təsərrüfatı Nazirliyi, fermerlər, ailə təsərrüfatçıları ilk dəfə Bakı şəhərində keçirilən beynəlxalq bir tədbirdə birgə iştirak etdilər. Sərgilərdə 60 nəfər heyətlə, çoxlu sayda bir-birindən dəyərli, müxtəlif çeşidli kənd təsərrüfatı məhsulları ilə muxtar respublika layiqli şəkildə təmsil olundu. "Orqanik Naxçıvan" brendi ilə həm hazır məhsullar, həm də təbii bitkilər Naxçıvan pavilyonunda yer almışdı.

Bir-iki faktı qeyd etmək kifayətdir ki, sərgilərə necə cidd-cəhdlə hazırlıq aparıldığı barədə dolğun təsəvvür yaranmış olsun. Dağ bitkiləri, arıçılıq məhsulları, konservləşdirilmiş məhsullar, turşular, şirələr, mineral içkilər, quru meyvələr, tərəvəzlər, o cümlədən tezyetişən əriklər, gilas, gilənar, çiyələk, kartof, alma, qablaşdırılmış dərman bitkiləri, süd və ət məhsulları ilə yanaşı, Naxçıvandan diri halda sazan balığı, dibçəkdə Ordubad limonu da aparılmışdı ki, bu da, təbii olaraq, qonaqlarda xüsusi maraq oyatdı.

Muxtar respublikanın ən kiçik rayonu Sədərəkdən bir ailə təsərrüfatçısı 37 növdən çox məhsulu sərgiyə çıxarmışdı. Sərgidə iştirak edən ölkə başçısı cənab İlham Əliyev və birinci xanım Mehriban Əliyevanın Naxçıvan pavilyonuna gəlişi, məhsulların yüksək qiymətləndirilməsi bütün naxçıvanlı fermerlərə, eyni zamanda kənd təsərrüfatı sahəsində sonrakı dövr islahatlarına bir dəstək, stimul rolunu oynadı.

1970-1990 cı illərə qədər Sədərəkdə istixanalar olub əsasən qərənfil gülü istixanaları Sədərək iqtisadiyatına mühüm təkan verirdi.

1990-cı hadisələrinə qədər Sədərəkdə yetişdirilən qərənfil sortları rusiyada keçmiş sovet respublikalarında satılırdı.

Günəş enerjisi radiasiya və işıq şəklində Günəşdən gələn enerjidir. Bu enerji əsasən iqlimi və havanı idarə edir və həyatın əsasını təşkil edir.

Günəş enerjisi ilə istiliyi təmin olunsa bu gün də bu istixanalar nəinki Sədərək Naxçıvan üçün də əlverişli olar.

Nəticə

Sədərəkdə sakinlərin gündəlik həyatının daim yaxşılaşdırılması şəraitində aqrar sahənin inkişafı, yeni istehsal sahələrinin yaradılması artıq öz müsbət nəticələrini verir, insanlar işlə təmin olunur, məşğulluq təmin edilir. Bu sahələrdə böyük irəliləyiş əldə edilmişdir.

Muxtar respublikada taxıl məhsulunun vaxtında, itkisiz toplanması və anbarlara daşınması, həmçinin biçin başa çatdıqdan sonra zəruri aqrotexniki tədbirlərin həyata keçirilməsi nazirliyin əsas vəzifələrindəndir. Bu məqsədlə nazirlikdə Mərkəzi Qərargah yaradılıb. Muxtar respublikada 2023-cü il avqustun 1-dək 19 min 478,4 hektar əkin sahəsində taxıl biçilib, 48 min 736,8 ton məhsul yığılıb, orta məhsuldarlıq 25 sent/ha olub. Şərur rayonunda - 4184,3, Babək rayonunda - 5883, Culfa rayonunda - 1821,7, Ordubad rayonunda - 856, Şahbuz rayonunda - 580,2, Kəngərli rayonunda - 3584, Sədərək rayonunda - 1880,7 və Naxçıvan şəhərində - 188,4. hektar sahədən taxıl yığılıb. Fermerlər tərəfindən toxumun düzgün seçilməməsi, aqrotexniki qulluq qaydalarına vaxtında və düzgün əməl edilməməsi, suvarma suyunun olmaması məhsuldarlığın azalmasına səbəb olub. Bu səbəblərdən 1456 hektar sahədə bitki örtüyü quruyub. Taxıl biçini başa çatdıqdan sonra taxıl səpini və yekun nəticələrlə bağlı müşavirənin keçirilməsi nəzərdə tutulur.

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OXIDATION OF LIGNITE AND DETERMINATION OF FUNCTIONAL GROUPS USING FTIR

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ABSTRACT

In this study, oxide lignite samples were produced using three different oxidation methods to expand their application area, enhance their solubility and dispersion properties in various solvents. The functional groups of three different oxide lignite samples were characterized by Fourier-transform infrared spectroscopy (FTIR). The oxide-lignite sample 1 was synthesized using the modified Hummers method, the oxide-lignite sample 2 using Hummers without hydrogen peroxide (H_2O_2) and the oxide-lignite sample 3 using the acid oxidation method. The FTIR test results showed that the oxide lignite 3 sample that was oxidized with a mix of sulfuric acid and nitric acid had more oxygen-containing functional groups (carboxylic acid (-COOH), aromatic carbonyl or carboxyl (-C=O), $-NO_2$, epoxides (-C-O-C)) than the oxide lignite samples 1 and 2. Only phenolic hydroxyl (-OH) peaks showed the most intense peaks in the oxide lignite sample 1 and the lowest intensity peaks in the oxide lignite sample 2. This result demonstrated hydrogen peroxide's efficacy on phenolic -OH groups. In oxide lignite samples 1 and 2, the methylene ($-CH_2$) group's stretching and rocking vibration bands were more dominant. The acid oxidation method provided more oxygen-containing groups but reduced the $-CH_2$ groups. The functional groups of the oxide lignite samples identified in this study suggested that the acid oxidation method is the most effective way to oxidize lignite.

Keywords: Oxide lignite, Functional groups, Oxidation methods, FTIR analysis

INTRODUCTION

Coal has a higher carbon content (50–98%) than organic polymers do, making it a more cost-effective carbon source for high-value organic fine chemical synthesis, the creation of carbon nanofibers, and the use of carbon fillers in polymer composites [1,2]. However, it is more challenging to generate a coal-containing solution due to the low solubility and poor dispersion of raw coal. The capacity of the raw coal to dissolve well in organic solvents is therefore thought to be crucial to the application areas [1]. Low-rank coals, such lignite and brown coal, are plentiful resources that are frequently used

to generate electricity. Because of their high moisture content, these coals are generally not applied very often. Low rank coals have the potential to be used in low-temperature oxidation processes to produce high-value organic compounds, though, due to their strong reactivity. Various oxidation methods such as oxygen/air Oxidation, Ozone Oxidation, Ruthenium Ion-Catalyzed Oxidation, Oxidizing Acid Oxidation, Sodium Hypochlorite Oxidation, Hydrogen Peroxide Oxidation and Electrochemical Oxidation, are used to expand the usage area of raw coals, including lignite, and to improve their properties [2]. The literature primarily uses acid oxidation to produce carbon fiber from raw coal [3], with a study involving oxidation reactions with potassium permanganate [1]. This study selected lignite as the raw coal source, or carbon source, due to its slightly better condition compared to anthracite and other coal derivatives in Turkey. We oxidized the lignite sample from the Turkish Coal Enterprises, Garp Lignite Enterprise, Tavşanlı, Kütahya, Türkiye using acid and potassium permanganate oxidation synthesis found in the literature. We present a novel approach to treat the lignite using the Hummers method, a technique commonly employed in the synthesis of graphene from graphite. Several characteristics were investigated using these techniques, including as mass change, heat evolution, oxygen consumption, gaseous product type, and the concentration of bound oxygen and oxygenated complexes at coal surfaces [4]. Fourier-transform infrared spectroscopy (FTIR) has been employed to explore the functional groups of oxidation techniques that bind to the surface and are present on the surface [5]. In this study, FTIR analysis compared the functional groups on the surfaces of three different oxidized lignite samples using these three different methods.

MATERIALS AND METHODS

Lignite was obtained from the Turkish Coal Enterprises, Garp Lignite Enterprise, Tavşanlı, Kütahya, Türkiye. Firstly, the lignite was pulverized and sieved with a 200mesh standard sieve. Then, the synthesis methods along with the codes of three different oxide lignite samples obtained by three different synthesis methods are explained below:

The modified Hummers method synthesized the oxide-lignite sample 1:

Lignite (4 g) was mixed with 100 mL of concentrated H_2SO_4, and the mixture was stirred in an ice bath for around 2 hours. After homogeneous dispersion of the lignite in the solution was obtained, potassium permanganate ($KMnO_4$) (12 g) was added slowly to the solution and the reaction mixture was stirred for 15 min. Then, the ice bath was removed and the mixture was stirred at 35 °C overnight until obtaining a thick paste. Afterward, 180 mL of deionized (DI) water was added slowly into the reaction solution to avoid the reaction temperature rising to a limit of 98 °C. After 45 minute of vigorous stirring, 70 mL of 30% hydrogen peroxide (H_2O_2) was added and the color turned light brown immediately. Finally, the mixture was then filtered and washed several times with 3% HCl and DI water and dried at 65 °C for 12 h [6].

The Hummers without H_2O_2 synthesized the oxide-lignite sample 2:

Using the same amounts and the same chemicals as described above for the oxide-lignite sample 1, the oxide-lignite sample 2 was synthesized, only without the use of H_2O_2.

The acid oxidation method synthesized the oxide-lignite sample 3:

Lignite (5 g) was carefully added into a flask containing 500 mL of a mixture. Prepare the mixture of HNO_3 (63%) and H_2SO_4 (98%) in an ice bath. The bath is designed to absorb the heat generated during the reaction. The flask was left overnight and diluted with deionized water. The obtained product was vacuum filtrated and washed with deionized water several times until the pH value approached neutral [3]. Finally, dark brown powder was obtained. Figure 1 displayed images taken during the production of oxide lignite samples.

Fig. 1. The production of oxide lignite samples.

RESULTS AND DISCUSSION

FTIR analysis were carried out to determine the functional groups of three different oxide lignite samples. Figure 2 presents the FTIR spectra of oxide lignite samples within the wavenumber range of 4000–2800 cm^{-1}. Figure 2 showed that oxide lignite 1 had deeper bands in the wavenumber range of 3600–3200 cm^{-1}, which were caused by phenolic -OH stretching vibrations [7,8]. On the other hand, oxide lignite 3 had deeper broad bands in the wavenumber range of 3000–3500 cm^{-1}, which were caused by carboxylic -OH [8]. The FTIR spectra of the oxide lignite samples revealed that the Hummers method synthesized oxide lignite sample 1 had more phenolic -OH groups, while the acid oxidation method synthesized oxide lignite sample 3 had more carboxylic -COOH groups. Oxide lignite sample 2, produced without using hydrogen peroxide, had fewer -OH and -COOH groups than the other two samples. This result showed that hydrogen peroxide provided more phenolic -OH groups than potassium permanganate. In Figure 2, the band attributed to the stretching vibration bands of the $-CH_2$ group [9] at wavenumber values of approximately 2910 cm^{-1} in the FTIR spectra of the oxide lignite samples was observed with the lowest intensity in the oxide lignite 3 sample. This result showed that the acid oxidation process was the best method that provided a significant effect on the methylene groups because the decrease in the peak intensity of this group was attributed to the breakage of alkane chains between large molecules and the decrease in the number of methylene groups [1].

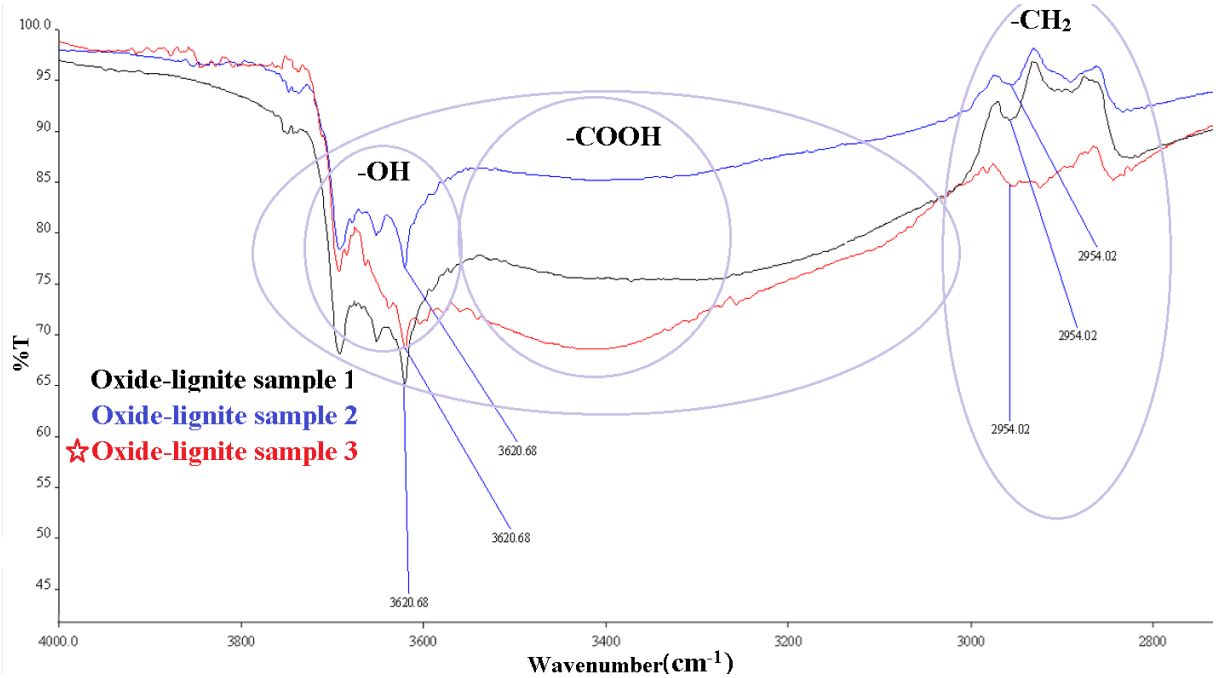

Fig. 2. FTIR spectrum of oxide lignite samples in the wavenumber range of 4000-2800 cm^{-1}.

Figure 3 presents the FTIR spectra of oxide lignite samples within the wavenumber range of 2000–650 cm^{-1}. Figure 3 shows bands at 1714 and 1616 cm^{-1} wavenumber values in oxide lignite samples. It was attributed to the C=O stretching vibration of the aromatic carbonyl or carboxyl group [10] and the C=C bond [11], respectively. The deepest bands were in oxide lignite sample 3. These results were attributed to the presence of stronger electron-withdrawing groups on the branched chains of polycyclic aromatic hydrocarbons after oxidation [1]. In the oxide lignite 3 sample, the characteristic vibration band of the $-NO_2$ group, as evidence of oxidation only with nitric acid at wavenumber values of 1540 cm^{-1}, is clearly seen in Figure 3. Similar results were also reported in the previous studies of Li et al. [12]. The oxide lignite 3 sample exhibited the most intense vibration band, representing the $-NO_2$ group, at 1343 cm^{-1}. The intensities of the oxide lignite sample 1 and 2 were quite low, depending on the production method. He et al. showed peaks of bending and asymmetric stretching vibrations of epoxides (C-O-C) at 850.70 cm^{-1} and 1231.27 cm^{-1}, respectively [1]. In this study, oxide lignite 3 sample exhibited intense asymmetric stretching vibrations of epoxides (C-O-C) at 1231 cm^{-1} and three samples exhibited low intensity bending stretching vibrations of epoxides (C-O-C) peaks at 833 cm^{-1}. All three samples showed a characteristic peak at 753 cm^{-1}, which is associated with methylene ($-CH_2$) rocking vibrations whose intensity is proportional to the number of groups [13].

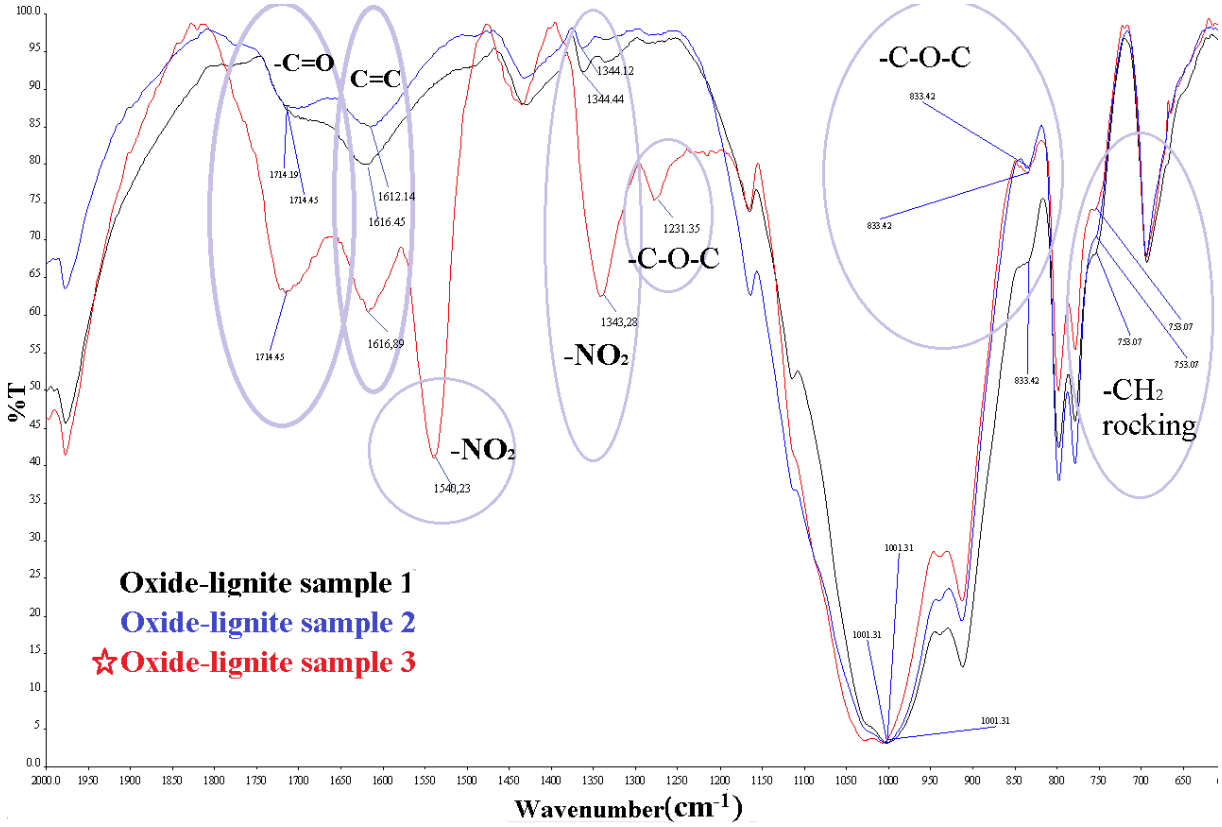

Fig. 3. FTIR spectrum of oxide lignite samples in the wavenumber range of 2000-650 cm^{-1}.

CONCLUSION

In this study, the surface functional groups of oxide lignite samples synthesized by three different methods were determined and compared by FTIR analysis. The bands belonging to the groups COOH, -C-O-C, -C=O and -NO_2, produced by acidic oxidation, appeared more intensely than the other samples. Methylene group vibrations were more dominant in oxide lignite samples 1 and 2 synthesized using the modified Hummers method and modified Hummers method without hydrogen peroxide, respectively. As a result, it was revealed that the acid oxidation process was the most suitable method for the oxidation of lignite. This method was able to break long chains and cause them to have more oxygen-containing functional groups.

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EFFECT OF DIFFERENT NEEDLE TIPS ON THE NANOFIBER DIAMETER AND CONTACT ANGLE OF ELECTROSPUN PAN NANOFIBERS

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ABSTRACT

In this paper, Polyacrylonitrile (PAN) nanofibers were prepared using varied needle tips, which can affect the properties of the PAN nanofibers in terms of nanofiber diameter and contact angle. Electrospinning parameters were fixed as follows: tip-to-collector distance of 15 cm, flow rate of 3.5 ml/h, voltage of 20 kV, PAN concentration of 5.0 wt%, drum rotation speed of 400 rpm, and temperature of 24.5°C.PAN nanofibers produced using 19Ga, 21Ga, and 17Ga needle tips were coded as PAN-1, PAN-2, and PAN-3, respectively. The resulting PAN nanofibers were then analyzed using FE-SEM and contact angle analysis. FE-SEM images showed a continuous, uniform, and smooth surface with a relatively bead-free fibrous structure of electrospun PAN nanofibers. Nanofiber diameters decreased with an increase in needle diameter. The average diameters of PAN-1, PAN-2, and PAN-3 nanofibers were 46.8 nm, 74.2 nm, and 37.5 nm, respectively. The fact that the PAN-2 nanofiber sample, produced using the smallest diameter needle tip, had the thickest nanofibers was attributed to the fact that it was collected before the solvent had completely evaporated. It was determined that PAN nanofibers exhibited hydrophilic properties, with the contact angle measurements found to be 69.59°, 56.34°, and 37.40° for PAN-1, PAN-2, and PAN-3 nanofibers, respectively.

Keywords: Polyacrylonitrile (PAN) nanofibers, Electrospinning, Nanofiber diameter, Contact angle.

INTRODUCTION

Nanofibers are an important research topic in fields such as health (drug delivery systems, tissue engineering), electronics (supercapacitor electrodes), and the environment (air and water filters) due to their numerous advantages and one-dimensional (1D) structure with nanometer dimensions [1]. Electrospinning, a favorable technique that uses an electric current to produce a liquid into thin fibers, is effective for manufacturing carbon nanofibers from a polyacrylonitrile (PAN) polymer [2].

Although cellulose is the initial starting material chosen for carbon fibers, PAN is considered the most important precursor material. PAN is followed by petroleum and/or synthetic pitch. Carbon fibers produced from PAN are preferred due to their superior mechanical properties and high carbon yield. The highest mechanical strength carbon fibers are exclusively produced from PAN copolymer precursors [3]. Many studies on the optimization of PAN nanofiber production via electrospinning are available in the literature. Such as, Gu et al. investigated the morphology of fibers and the distribution of fiber diameters by varying concentration and applied voltage [4]. Moghadam et al. studied the effects of solution concentration (wt.%), applied voltage (kV), tip-to-collector distance (cm), and volume flow rate (ml/h) on the contact angle (CA) of the PAN nanofiber mat [5]. Thorat et al. considered four important controllable parameters that can affect the electrospinning process and the resultant PAN nanofibers: flow rate, applied voltage, concentration, and the distance between the collector drum and syringe tip [6]. Abuzade et al. investigated the PAN fiber size and fiber size distribution for various concentrations, applied voltages, and tip-to-collector distances [7]. Kirecci et al. aimed to determine the most suitable values for process and solution parameters in the electrospinning of PAN nanofibers, including solution concentration, applied voltage, and the working distance between the needle tip and the collector plate. To investigate the effects of these parameters on fiber morphology, nanofiber mat samples were produced by systematically varying the parameter values [8]. Khan et al. explored the effect of solution and electrospinning parameters on the morphology, mechanical properties, and surface characteristics of polyacrylonitrile (PAN) electrospun nanofiber mats. PAN/DMF (Dimethylformamide) solutions with different concentrations were electrospun under various conditions [9]. Altın and Bedeloğlu, found that the nanofiber morphology is significantly affected by process parameters such as polymer concentration, distance, applied voltage, and feed rate during the production of PAN nanofibers via the solution-based electrospinning method. These parameters should be properly optimized [10]. According to the results of all these studies in the literature were examined, it was reported that the variables had significant effects on the structure of the nanofibers. In this report, we used the electrospinning method to synthesize and characterize PAN nanofibers. The morphology and contact angle of PAN-1, PAN-2, and PAN-3 nanofibers were analyzed using SEM and a contact angle device. The effect of needle tips on the morphology, diameter, and surface wettability of the nanofibers was also evaluated.

MATERIALS AND METHODS

Materials

Polyacrylonitrile (PAN) with a molecular weight of 150.000 was purchased from BLD Pharmatech Ltd. and N,N-Dimethylmethanamide (DMF) was purchased from Carlo Erba.

Electrospinning of PAN nanofibers

The concentrations 5 wt.% PAN/DMF solution were stirred by a magnetic stirrer with a rotating speed of 400 rpm at room temperature for 3 h in order to obtain homogenous solution. The electrospinning process and the resulting PAN nanofibers are illustrated in Fig. 1. The electrospinning setup includes a high-voltage power supply, a rotating collector, a syringe pump, and a syringe with three different needle tips: G17, G19, and G21. The codes for the PAN nanofibers produced with three different needle tips, G17, G19, and G21, are provided in Table 1. The temperature and relative humidity for the PAN nanofibers were maintained at 25 ± 0.5°C and 60 ± 10%, respectively. First, the PAN solution was filled into the syringe. It was then pumped by the syringe pump at a constant flow rate of 3.5 mL/h. A positive charge of 20 kV was applied to the needle tip to facilitate the ejection of the PAN solution.

Characterization

The morphologies of electrospun PAN nanofibers were observed using scanning electron microscopy (FE-SEM,Supra 40VP, Zeiss) after platinum coating. The diameters of the PAN nanofibers were

measured on from the FE-SEM images. The contact angles of the nanofibers were measured with the Fytronix 9000 Contact Angle Analyzer device.

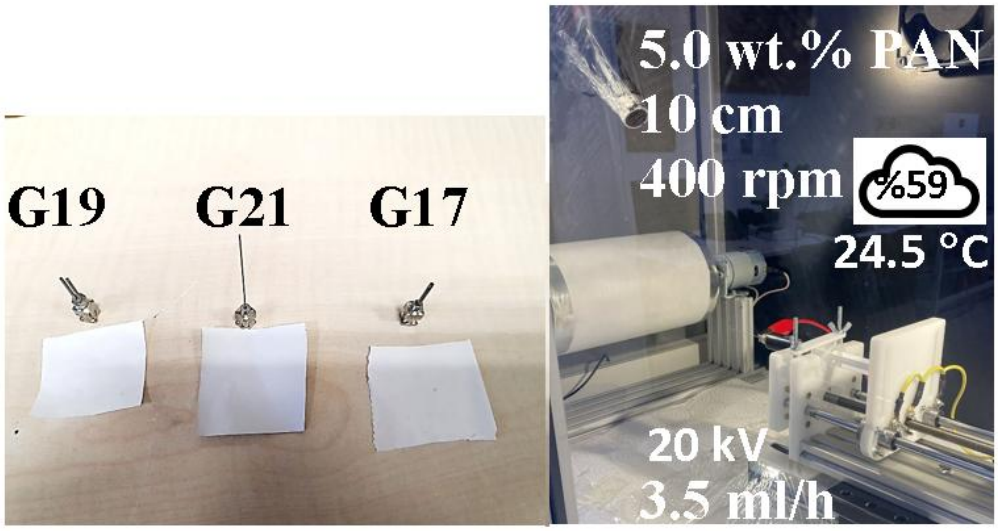

Fig. 1.PAN nanofibers produced using different needle tips and the electrospinning setup.

Table 1:.Codes for PAN nanofibers produced using different needle tips and inner-outside diameters.

Nanofibers	Needle Tip	Needle inner diameter (mm)	Needle outside diameter (mm)
PAN-1	19 Ga	0.67	1.07
PAN-2	21 Ga	0.5	0.8
PAN-3	17 Ga	1.07	1.47

RESULTS AND DISCUSSION

The morphology of PAN-1, PAN-2, and PAN-3 nanofibers are shown in Figure 2. As shown in Figure 2, PAN-1 and PAN-2 exhibit continuous, flawless ribbon-like strands with minimal bead formation, whereas PAN-3 displays a greater amount of bead formation along the continuous ribbon strands compared to the other nanofibers. It has been reported in the literature that the formation of beads varies depending on electrospinning parameters, such as voltage [11], feeding rate [12], polymer solution concentration [13] and needle-tip-to-collector distance, needle length [14]. In this study, all electrospinning parameters were kept constant, and only the needle type was changed. Bead formation was significantly observed in the PAN-3 nanofiber sample produced with a 17Ga needle, which has the largest diameter. Rayleigh's theory explains bead formation: As a droplet evaporates and its size decreases, the charge density on its surface increases. This increase in charge density, caused by Coulomb repulsion, leads to the droplet breaking into smaller droplets, overcoming the surface tension [4]. In this study, the larger the needle diameter, the larger the droplet diameter can be, because the polymer solution exits the needle more slowly and has less time to evaporate compared to the solution exiting a smaller diameter needle. As a result, the droplet may not be able to overcome the surface tension without decreasing in size, thereby increasing bead formation. Smaller needle diameters tend to form more regular and continuous fibers, as the faster evaporating solution is subjected to higher electrical forces. However, larger needle diameters tend to result in more bead formation because the polymer solution evaporates more slowly, and the time available for the

solution to decrease in size and increase charge density is limited. In summary, larger needle diameters generally increase bead formation, while smaller diameters promote the formation of more regular and homogeneous fibers.

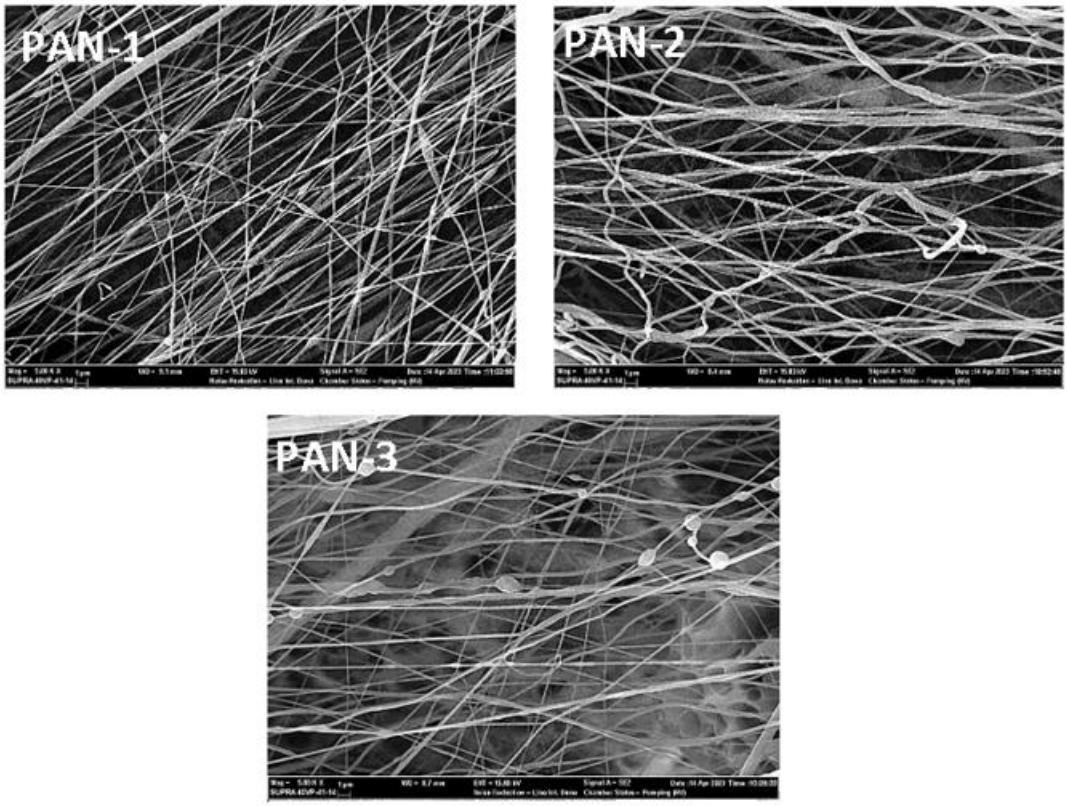

Fig. 2. FE-SEM images of PAN nanofibers

The average diameters of PAN-1, PAN-2, and PAN-3 nanofibers are 46.8 nm, 74.2 nm, and 37.5 nm, respectively (Fig.3). The different needle tips influenced the nanofiber morphology and diameters. As a result, the varying diameters of the needle tips in the electrospinning process affect the formation of PAN nanofibers. As seen in Fig. 3, it was determined that the nanofiber diameters decreased as the needle tip diameter increased, and the PAN-2 nanofiber sample produced with the needle tip (21Ga), which had the smallest needle diameter, exhibited the largest nanofiber diameter. In contrast to our results, Gündüz observed that as the needle diameter increases, the diameter of the PAN nanofibers also increases. This can be attributed to the enlargement of the droplet formed at the needle tip as the needle diameter increases. As the droplet grows, the surface tension decreases. With reduced surface tension, the jet accelerates more due to the applied voltage. Consequently, thicker fibers are produced because the time the jet spends traveling and stretching through the air before reaching the collector is reduced [15]. Macossay et al. noted that there was no correlation between the internal diameter of the needle used and the average nanofiber diameter for poly(methylmethacrylate). However, it was observed that reducing the needle diameter led to an increase in the polydispersity of the nanofiber diameters. This suggests that, although the average nanofiber diameter remained unaffected by the needle diameter, both larger and smaller nanofibers were being produced under these conditions [16]. In a similar finding to this study, Khan et al. in their work on electrospun PAN nanofiber mats stated that it is obvious that with increasing needle diameter, the average fiber diameter decreases. They explained this result by stating that the overall time for nanofiber production is shorter with smaller needle diameters compared to larger ones, which prevents complete solvent evaporation and results in a larger average fiber diameter [17].

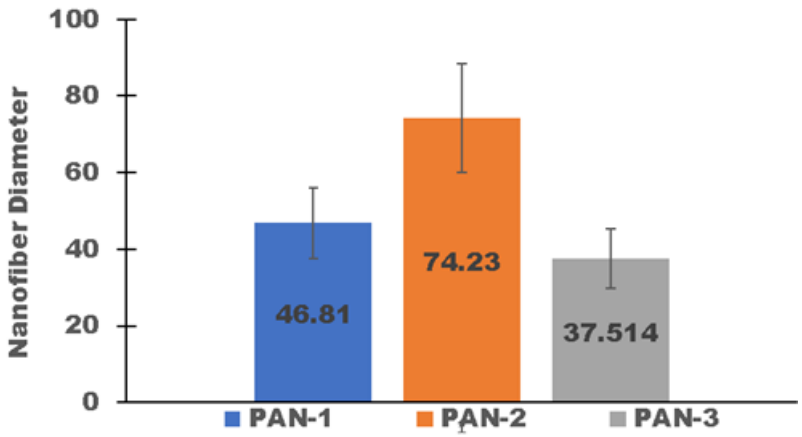

Fig. 3. Average Nanofiber Diameter of PAN nanofibers

The hydrophilic and hydrophobic characteristics of polymer surfaces are determined by the water contact angle formed between a water droplet and the polymer fiber surface. A surface is considered hydrophobic if the water droplet forms a contact angle greater than 90°, while a hydrophilic surface is one where the contact angle is less than 90°. Polymer surfaces with a contact angle between 150° and 180° are classified as superhydrophobic [2]. Figure 4 displays contact angle images of PAN nanofibers. The contact angles were found to be 69.59°, 56.34°, and 37.40° for PAN-1, PAN-2, and PAN-3 nanofibers, respectively, as shown in Fig. 4. Based on these results, no clear correlation between the needle tip and the contact angle could be established. While the nanofibers produced from the needle with the medium diameter and dual tip exhibited the highest contact angle, it was found that the PAN nanofibers produced from the largest and smallest diameter needles displayed hydrophilic properties. It has been reported in the literature that PAN nanofibers produced under different electrospinning conditions exhibit hydrophobic properties as the PAN concentration increases [17]. Additionally, in another study, it was observed that the contact angle decreases as the fiber diameter increases [18].There are also studies in the literature that report the creation of superhydrophobic surfaces through the modification of PAN polymer with various substances [19-20].

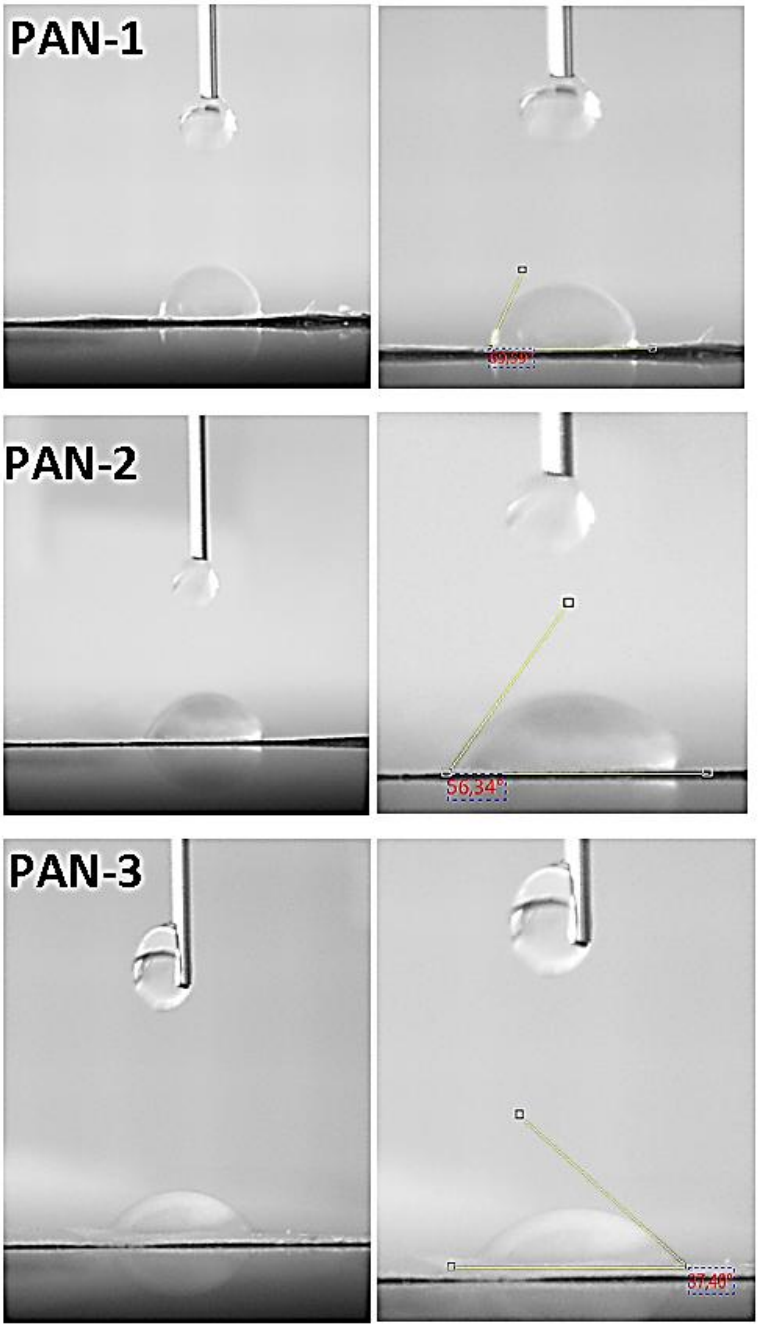

Fig. 4. Contact angles of PAN nanofibers

CONCLUSION

In the present study, the morphology, average nanofiber diameter, and contact angle of PAN nanofibers were investigated by varying the needle tips. PAN nanofibers were produced using three different needle tips, while keeping the other electrospinning conditions constant. FE-SEM images revealed that the PAN-2 coded nanofiber sample, produced with the smallest needle diameter (21Ga), exhibited a regular, continuous, and bead-free morphology. As the needle diameter increased, the average nanofiber diameters decreased. The nanofiber morphology and average fiber diameter results indicated that using smaller diameter needles resulted in the formation of larger, regular, and homogeneous fibers by extending the solvent evaporation time. Contact angle measurement results indicated that the PAN nanofiber samples produced under the selected electrospinning conditions exhibited hydrophilic properties. The hydrophilic PAN nanofibers produced in this study can be recommended for use in biomedical, membrane and adsorption studies.

ACKNOWLEDGMENTS

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FLOATING SOLAR POWER PLANTS FOR ELECTRIFICATION OF ON-CAMPUS TRANSPORTATION

KAMPÜS İÇİ ULAŞIMDA ELEKTRİFİKASYON İÇİN YÜZER GES

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ÖZET

Harran Üniversitesi kampüs alanları içinde, ulaşımda elektrifikasyonun sağlanması adına, enerji ihtiyacını yüzer güneş enerji santralinden sağlayan elektrikli araç şarj istasyon ağı entegrasyonu planlanmaktadır. Üniversite yerleşkesinde bulunan yapay gölet alanı üzerine kurulması planlanan 3 MW gücünde yüzer GES ile farklı kampüs alanları içerisinde 10 adet AC ve 4 adet DC kurulum yapılarak, sürdürülebilir düşük karbonlu yeşil kampüs anlayışına temel oluşturulacaktır. Ayrıca fazla enerji ile kampüs içi ihtiyaçların giderilmesi için olanaklar incelenecektir.

Kampüs içi sürdürülebilir ulaşımın yaygınlaştırılması için planlanan bu proje, Homer PRO yazılımı ile yapılan simülasyon çalışmaları ile teknik kapasite olarak detaylandırılacaktır. Engellenen karbon emisyon miktarı, üretilmesi beklenen güneş enerji miktarı, tüketim grafikleri ve sistemin ekonomisi detaylı olarak incelenecektir. Şarj istasyonlarına ait teknik detaylar ve sistemlerin kurulum planları yine çalışma kapsamında gösterilecektir. Sistem, elektrikli araçların temiz enerji kaynakları ile şarj edilmesini sağlayarak, karbon ayak izinin azaltılmasına ve enerji verimliliğinin ulaşımda sağlanmasına katkı sunacaktır.

Harran Üniversitesi yenilenebilir enerji vizyonunu güçlendirmesine ek olarak, kampüs ölçeğinde elektrikli araçlara yeten bir sistemin geliştirilmesi öncülük eden bir model ortaya koyacaktır. Ulusal ve uluslararası düzeyde örnek teşkil edecek bu çalışma sayesinde, hem akademik anlamda araştırmalara hem de sürdürülebilir enerji uygulamalarının yaygınlaşmasını destekleyen bir girişim olacaktır.

Anahtar Kelimeler: Yüzer GES, Elektrifikasyon, Ulaşım, Şarj, Elektrikli Araç.

ABSTRACT

Within the campus areas of Harran University, an electric vehicle charging station network will be integrated to support transportation electrification, utilizing energy from floating solar power plants.

A 3 MW floating solar power plant will be installed on an artificial pond within the university campus, supplying power to 10 AC and 4 DC charging stations at different locations. This initiative aims to establish a sustainable, low-carbon, green campus. Additionally, options for utilizing excess energy to meet other campus needs will be explored.

The project, planned to promote sustainable transportation on campus, will be analyzed through simulation studies using Homer PRO software. Key aspects such as carbon emissions reduction, expected solar energy generation, consumption patterns, and the economic feasibility of the system will be examined. Technical details of the charging stations and system installation plans will also be presented. By enabling electric vehicle charging with renewable energy sources, the system will contribute to carbon footprint reduction and energy efficiency in transportation.

In addition to strengthening the renewable energy vision of Harran University, the development of a system sufficient for electric vehicles on a campus scale will present a pioneering model. This study, serving as an example at national and international levels, will support both academic research and the broader adoption of sustainable energy practices.

Keywords: Floating Solar, Electrification, Transportation, Charging, Electric Vehicle.

INTRODUCTION

Recently, countries have expanded the use of renewable energy to transition to low carbon emission levels in line with climate targets and the Paris Agreement and Sustainable Development Goals (SDGs) (Renewables, 2012) (Nastasi et al., 2022). This will actually be achieved by providing electrification in every area. The efforts made to provide electrification in transportation are a good example of this. The widespread use of electric vehicles will reduce fossil fuel consumption. However, charging station demands have emerged. Providing the charging demand of electric vehicles with renewable energy is necessary for providing electrification in transportation. Floating solar energy systems have the power to meet this demand. It is shown that if only 1% of the world's potential is used, floating solar energy capacity can reach 400 GW (Kumar et al., 2021).

The most popular solar energy capture methods for energy production in recent years have been floating and ground-mounted solar photovoltaic systems. In particular, the birth of the sector began with the use of ground-mounted systems and has become widely used. With land scarcity becoming an issue to be overcome; floating solar energy systems have emerged as an interesting and creative innovation. With their water-resistant designs, the energy production point of solar panels has begun to be water surfaces (Kumar et al., 2022). The most important benefit of this is the reduction of evaporation and the increase in efficiency by cooling the PV panels (Kumar et al., 2021). Studies have indicated that the cooling effect increases due to the fact that the PV panels are almost in contact with the water (Kjeldstad et al., 2021). Due to these benefits, floating photovoltaic systems are a desirable choice for the development of renewable energy, especially in regions with a lot of water and little land.

This study aims to analyze and evaluate the needs of electric vehicle charging stations with floating solar PV systems installed in the ponds of Harran University located in the climate zone of Şanlıurfa Province, Türkiye. In this context, all simulations will be provided using HOMER-Pro software. The study aims to shed light on electrification in transportation by conducting a comprehensive performance evaluation.

Literature rewiew

Government support policies have led to the widespread use of floating photovoltaic (FPV) systems worldwide due to their various benefits. There have been many developments on reducing land use, preventing evaporation and benefit cooling effects. The biggest question mark has been on their environmental impacts. Similarly, studies on electric vehicles and charging stations, which are new

technologies, are ongoing. A study examining these two issues together has not yet been conducted. However, studies on their progress will be reviewed in this section. Rahaman et al. (2023) conducted a study to analyze the temperature distribution of floating solar PV panels using various techniques, including **thermal analysis, empirical measurements, and Computational Fluid Dynamics (CFD) simulations**. The findings indicated that while existing FPV models exhibited a higher **Root Mean Square Error (RMSE)** compared to the ground-based Sandia model, the proposed thermal model demonstrated a strong correlation with the collected data. Similarly, Elminshawy et al. (2022) explored the **electro-thermal performance** of partially submerged FPV systems by implementing an innovative passive cooling technique. The results revealed that the **daily average electrical efficiency increased proportionally** with the submerged ratio, highlighting the effectiveness of the cooling approach. The interaction between panel efficiency and temperature has been a significant research focus in floating solar power plants. Since increasing temperatures negatively impact energy production, the effects of thermal conductivity in different system configurations were examined by Micheli (2022). In this study, the impact of temperature on FPV systems was analyzed, and the findings revealed that **open-water floating systems achieved better thermal conductivity coefficients**. Due to the diversity of floating solar designs, the researchers emphasized the need for further studies to optimize performance across various configurations. In another research endeavour by Koca (2024), a floating photovoltaic system installed on the water surface of a dam in Türkiye and an integrated hydrogen production unit were studied in order to compensate energy demand of public transport. By Shree Das (2025) It has been stated that the efficient integration of renewable energy and electric vehicles into unregulated smart power systems is of great importance for energy management and environmental sustainability. Smart grids enable cleaner, more sustainable energy management with renewable energy and electrification. Electric vehicles have been found to increase sustainability and provide long-term savings by reducing emissions when charged with renewable energy. On the other hand, Suvvala (2024) stated that the integration of renewable energy sources is of critical importance for increasing the energy efficiency of charging stations and reducing carbon emissions. It has been determined that DC charging infrastructures offer significant advantages in providing grid load balance, especially when used with hybrid energy systems. The study by Booysen (2022) examines the integration of electric vehicles with solar energy for sustainable informal public transport in Uganda. The adoption of electric minibus taxis is seen as an important step towards sustainable transport solutions. Tina and Scavo (2022) focused on evaluating the **energy performance of floating solar systems equipped with tracking technology**. Their findings highlighted the advantages of **tracking mechanisms, natural cooling effects, and bifacial panels** in enhancing energy production. Liu et al. (2017) conducted a study assessing the feasibility and efficiency of FPV-based energy generation in China. Their results indicated that **FPV systems not only optimize land and water use but also generate electricity more efficiently than conventional ground-mounted PV systems**. A novel approach combining MATLAB and Rhino/Grasshopper was applied to analyze FPV performance in a case study conducted in **Štěchovice, Czechia** (Sahu et al., 2016). Climate-aware simulations demonstrated that FPV systems performed **3% better than their land-based counterparts**. Another study found that floating PV systems can **reduce water evaporation by up to 70%, inhibit algae growth, and benefit from a cooling effect that enhances energy efficiency by 11%** (Sahu et al., 2016). Additionally, a HOMER-based study conducted under Jordanian climate conditions reported a **payback period of 8.4 years for a 300 kW FPV installation**. Additionally, 141 T of CO_2 emissions per year were prevented (Farrar et al., 2022). A simulation study was carried out using the PVsyst program for Bangladesh. In this densely populated and land-scarce region, the levelized energy cost (LCOE) of a 50 MW FSPV power plant was found to be 0.051 $/kWh (Kevser et al., 2023).

When the literature was examined, it was deemed appropriate to use floating systems to cover the electricity costs of charging stations. In this study, an FPV is proposed for the artificial ponds of the university in Şanlıurfa province of Türkiye, as shown in figure 1 the main purpose of this study is to analyze the simulation results of the floating solar power plant in the Şanlıurfa climate zone and to

reduce the charging station consumption. The artificial pond in the university campus was determined as the location to meet the electricity costs of the Harran University charging network.

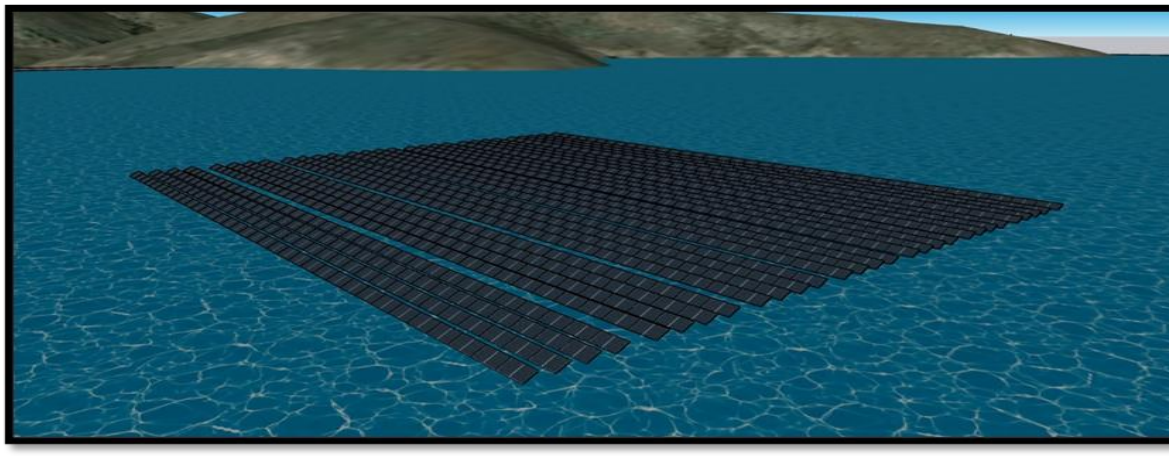

Figure 1. A sketch of the FPV system on the surface of the pond

Therefore, the novelty of this research can be summarized as follows:

- It will be the first time that a green campus concept will be explored within the university area via floating solar power plant.
- It will be the first time to use floating solar power plant for to meet charging consumption.

Beyond the aspects mentioned above, this study's key contribution to the literature is a **replicable framework** that evaluates the **multi-dimensional benefits of FPV-integrated EV charging stations**, extending beyond just techno-economic factors. This approach enhances our understanding of how to **accelerate the clean energy transition** in a more **sustainable and socially accepted manner**, while also optimizing local FPV potential for electrified transportation solutions.

METHODOLOGICAL FRAMEWORK

The locations of proposed FPV plants for different provinces of Türkiye are demonstrated in Figure 2.a. The position of Şanlıurfa is located in the southeastern part of the country. The populations Şanlıurfa are nearly 2.2 million, respectively. Şanlıurfa has a semi-arid and continental climate. In Şanlıurfa, summer temperatures can increase up to 40°C. In Şanlıurfa, winters are relatively mild, and temperatures infrequently drop below 0 °C. The primary motivation for this study is the crucial role universities play in promoting recognition, awareness, and widespread adoption of FPV systems across the country. Currently, the entire installed photovoltaic capacity in our country consists of land-based and rooftop photovoltaic power plants. Unfortunately, apart from a few pilot projects, no significant floating photovoltaic systems are in operation. The scheme of the PV solar energy system designed for the university is given in figure 2.b.

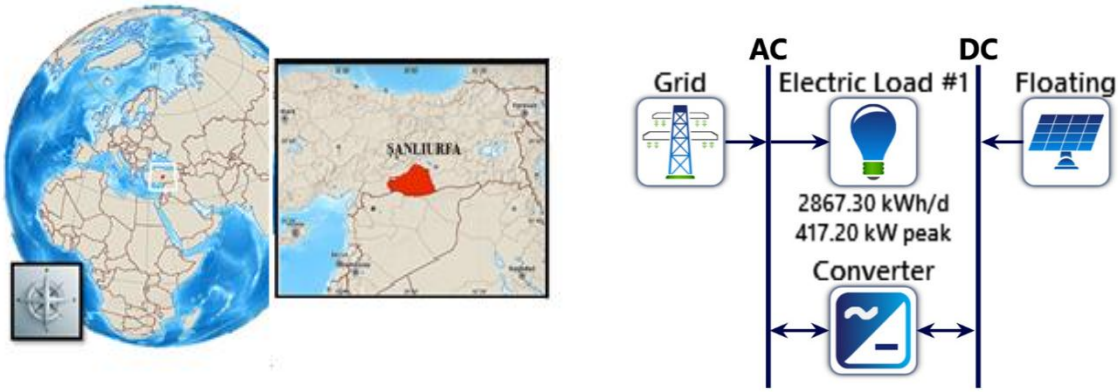

Figure 2. a) Study region and b)The scheme of FPV system

The reasons for proposing FPV plants in these regions could be fourfold:

(*i*) The primary reason for installing FPV plants is to compensate for electricity consumption from charging by utilizing artificial ponds on university campuses. Thus, a land-neutral effect is achieved by using idle pond areas instead of valuable university land for photovoltaic system installation.

(*ii*) It is foreseen that utilizing artificial ponds within universities might develop the idea of a green campus, resulting in the presence of awareness among the university community and students. This might enable an increase in social acceptance in terms of a better understanding of FPV (Rodriguez et al., 2023).

(*iii*) The third reason is how water bodies help floating photovoltaic panels cool down. Based on the study performed by Elminshawy et al. (2022), since FPV plants benefit from water bodies, their production is higher than that of solar PV plants installed on land.

(*iv*) The fourth reason is water conservation in ponds. It means, eveporation amount reduce.

Regarding the technical explanation, water surface areas to be discussed within the scope of the study were determined as artificial ponds within Harran University, located. Harran University artificial ponds, a total of 4 independent ponds, are located within the university campus area. The total usable floating solar power area of the ponds is calculated as 324.000 m². Figure 3 shows area where installation is planned and charging station image.

Figure 3. a)Artificial ponds in Harran University, b) Charging station 120 kW DC and 22 kW AC

This section provides detailed information and explanations about FPV and charging stations. Table 1 mentions the planned system components and technical specifications of DC and AC charging units.

The proposed system is a grid-connected PV system and aims to provide electricity from solar energy throughout the day. This model is called the self-consumption model and is designed to meet the university's energy needs (Alamoudi et al., 2021). Here, the plan will be to reduce the energy needs of the charging stations.

Table 1. FPV System and charging station descriptions for HU

FPV	***DC Unit***	***AC Unit***
Total Capacity 3000 kW	Total 4*120 kW	Total 10*22 kW
Module Efficiency % 21.4	Output Volt Ampere 920 V- 300 A	Output Volt Ampere 400 V- 32 A
PV Module Power 545 Watt	Connector Amount 2	Connector AC Type 2
Inverter 1806 kW	Model EVC03	Model EVC04

Calculations will be made on scenarios for the Homer PRO analysis of the system. First of all, the planned installation capacity in the artificial pond area for the floating solar power plant was selected as 3000 kW. This capacity was found based on the total amount of water surface areas that are not shaded and are suitable for use as infrastructure. The consumption of electric vehicle charging stations was designed according to the total energy amounts to be needed over 2 scenarios, considering weekday and weekend use. Since DC stations can charge quickly, their daily usage was determined as 4 hours on weekdays and 1.5 hours on weekends. Since AC devices provide slower charging, their daily usage was determined as 7 hours on weekdays and 3 hours on weekends.

RESULT AND DISCUSSION

The results obtained regarding monthly electricity consumption and production will be examined in this section. The monthly consumption amount required by the planned installation of 4 120 kW DC and 10 22 kW AC electric vehicle charging stations is shown in figure 4.a Here, the electricity need of the electric vehicle charging stations was found to be 22.1%. Similarly, the electricity amount sold to the grid was calculated as 77.9%. The electricity production amount shown in figure 4.b was provided by a floating solar power plant with an installed capacity of 3000 kW. 93.9% of the current electricity need was met by renewable energy. The remaining 6.1% shows the amount taken from the grid. The main reason for this amount is that electricity production is not carried out at nightSince this is a university, nighttime consumption has been planned to be slightly lower. However, the renewable energy source installed has the capacity to feed the charging stations in sufficient quantities.

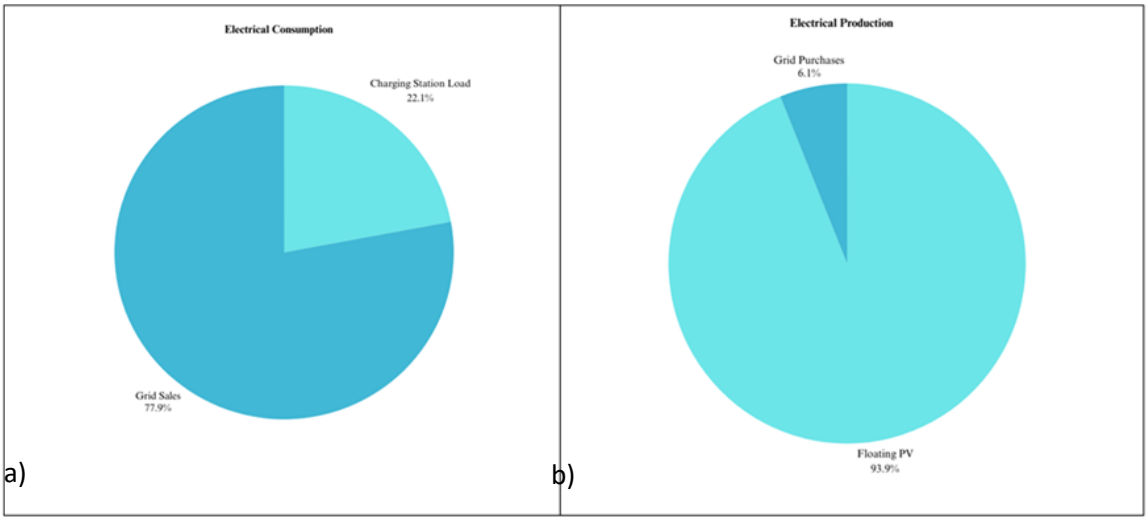

Figure 4. a)Electrical consumpition b) Electrical production

Another graph comparing electricity production and consumption is shown in figure 5 it has been observed that electricity production reaches its peak in the summer months for Şanlıurfa climate conditions. The most intensive production amount was in July. Similarly, it can be said that the lowest production was experienced in the December-January transition. In this graph, which was created by predicting that consumption will change stably, it is seen that all consumption is met by renewable energy in both summer and winter months.

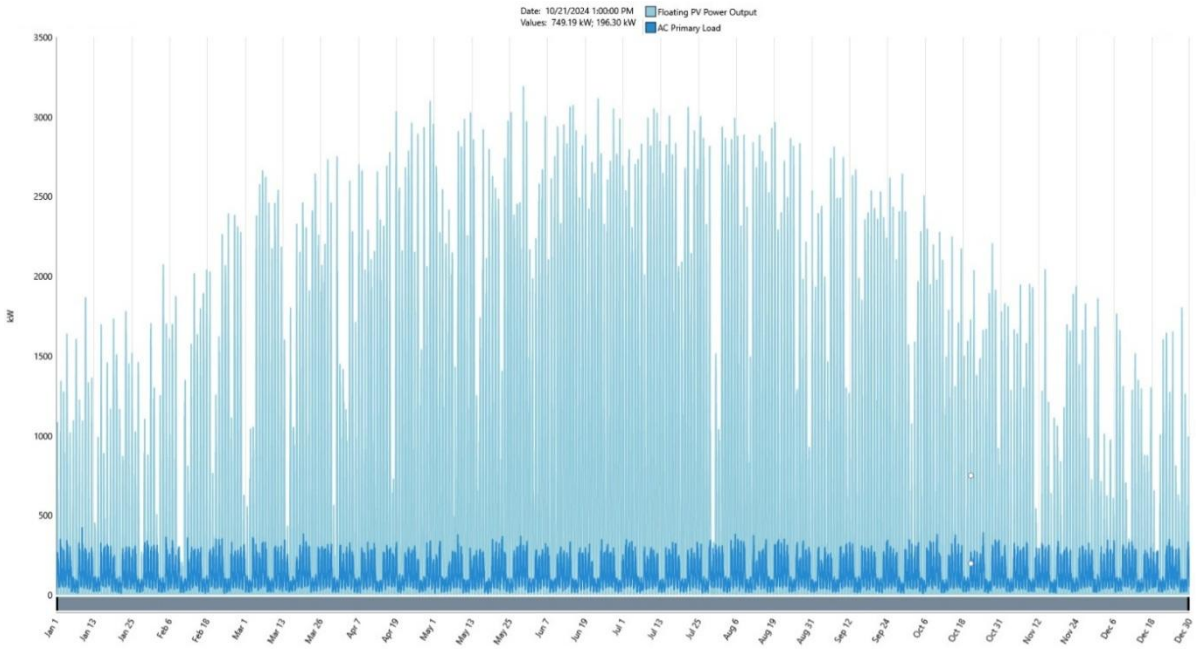

Figure 5. Floating PV power output and charge load graph

The changes in the amount of electricity production and the amount of energy needed from the grid during the day are shown in figure 6. When figure 6. a) is examined carefully, the energy produced by the floating solar power plant during the day is between 06:00 and 18:00. Therefore, the amount of energy needed from the grid shown in Figure 6. b) is almost negligible during the day. Again, due to the decreasing demand on weekends, dark lines are formed at certain intervals. If a location with high charging density is selected at night, the amount of energy to be drawn from the grid may be much higher. Therefore, energy produced from renewable energy can be stored.

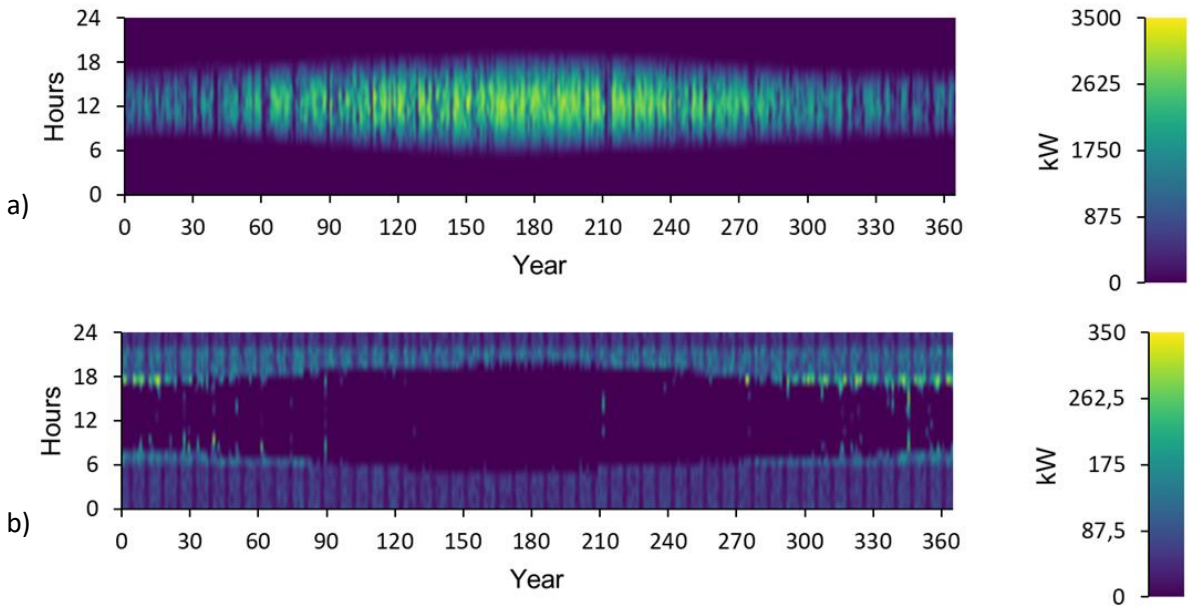

Figure 6. a) Floating PV power output b) Energy purchased from gird

The self-sufficiency ratio is found by dividing the amount of production by the current consumption of the system. If this ratio is above 1, the system can meet its needs. The amount of floating solar power plants calculated for Harran University is shown in figure 7, which more than meets the current electricity needs of the charging stations. The self sufficiency ratio shows an average rate of around 4. The importance of the use of renewable energy systems can only be seen in the amount calculated for charging. For this reason, the self-sufficiency ratio was also calculated to meet the energy needs of other consumption points on the university campus and is given in the graph. In the given graph, when the charging station consumptions and the university needs are intended to be met together; the most efficient months are April and May. On average, the system can meet half of the current consumption.

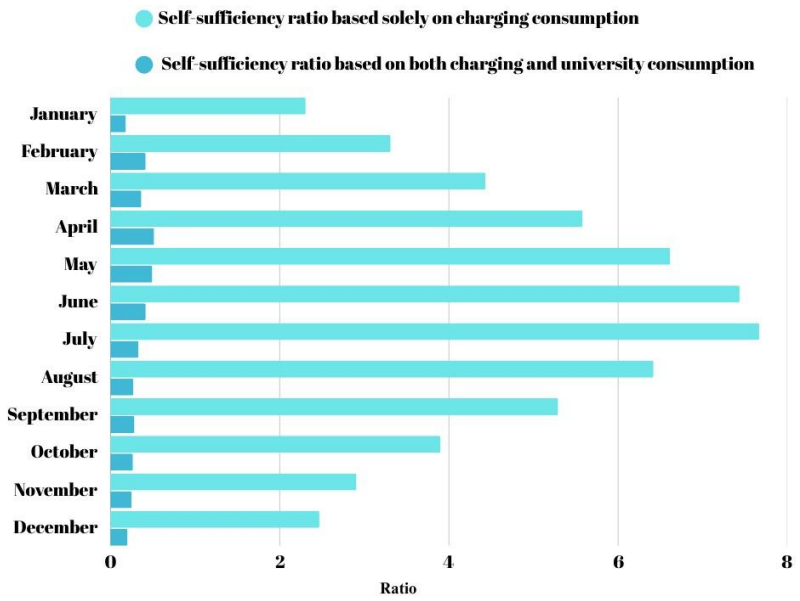

Figure 7. Self Sufficiency ratio on two situtaion

CONCLUSIONS

In this study, it is suggested that charging stations should be established and the required electricity should be provided by floating solar power plants, which are renewable energy sources, in order to provide electrification in transportation within the Harran University campus. The findings and suggestions obtained according to the simulation results applied with Homer PRO are listed below.

- The energy required by the charging stations, which are designed to be installed as 4 units of 120 kW DC and 10 units of 22 kW AC, according to the weekend and weekday scenarios, is calculated as 22.1% of the total consumption. Similarly, the monthly energy amount provided by floating solar power plants is found to be 93.9%. Considering that electric vehicles will increase day by day, new scenarios need to be created and calculated.
- The amount of consumption during the day can be provided in sufficient quantities for charging stations. When night consumption is also taken into account, the amount of energy to be loaded into the system should be evaluated and calculated according to the density of the charging stations.
- If the working hours of the charging stations will be busy when there is no sun, studies should be carried out to store the electricity obtained with renewable energy.
- While the self-sufficiency ratio gives an average result of around 4 when only charging stations are considered, when other consumption centers within the university are included in the system, it decreases to around 0.5. Despite this, renewable energy is of great importance in meeting the energy need. At the same time, it is the absolute solution for providing electrification in transportation.
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EXAMINATION OF DESIGN MODELS OF FLOATING SOLAR POWER PLANTS

YÜZER GÜNEŞ ENERJİ SANTRALLERİNİN TASARIM MODELLERİNİN İNCELENMESİ

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ÖZET

Dünya genelinde fosil yakıtların çevresel etkileri nedeniyle, yenilenebilir enerji kaynaklarına yönelim sürdürülebilir bir şekilde artış göstermektedir. Güneş enerjisi ise yenilenebilir kaynaklar içinde en yaygın kullanım şekilleri ile insanoğluna temiz ve sınırsız bir kaynak sunmaktadır. Ancak güneş enerji sistemlerinin geniş arazilere ihtiyaç duyması ve tarım arazilerine bilinçsizce yapılan kurulumlar, doğal ekosistem için olumsuz bir baskı oluşturmaktadır. Yaşanan bu sorunlar su yüzeylerinin enerji üretimi için değerlendirilmesi fikrini ortaya çıkarmıştır. Yüzer güneş enerji santralleri (YGES) konsepti bu sayede enerji üretimin yeni bir sahası olarak hayat bulmuştur.

YGES sistemleri, arazi sorunlarını çözüme kavuştururken, gölet, baraj, ve denizler gibi su yüzeylerine kurulumları sayesinde suyun buharlaşmasını engelleyerek su kaynaklarının korunması için katkı sağlama potansiyeline sahiptir. Ayrıca suyun doğal serinliği sayesinde PV panel sıcaklıklarının düşümüne yol açarak, enerji üretiminde verimliliği sağlayan yenilikçi bir çözümdür.

Bu çalışmada, çok fazla kurulum modeli bulunan YGES uygulamalarının tasarım sınıfları tarihsel kronolojik sıra ile incelenecektir. Sistem bileşenleri, yüzdürme teknolojileri, avantaj ve dezavantajları sıralanacaktır. YGES teknolojisinin verimini arttırmaya yönelik yapılan çalışmalar üzerine detaylı incelemeler yapılacak ve gelecek projeksiyona yönelik öngörülerde bulunulacaktır.

Anahtar Kelimeler: Yüzer GES, Enerji, Tasarım, Verimlilik, Model.

ABSTRACT

Due to the environmental impacts of fossil fuels worldwide, the tendency towards renewable energy sources is increasing sustainably. Solar energy, offers a clean and unlimited source to humanity with the most common usage patterns among renewable sources. However, the fact that solar energy systems require large land areas and unconscious installations on agricultural lands creates negative pressure on the natural ecosystem. These problems have led to evaluating water surfaces for energy

production. The concept of floating solar power plants (FPP) has thus come to life as a new field of energy production.

While FPP systems solve land problems, they have the potential to contribute to the protection of water resources by preventing water evaporation thanks to their installations on water surfaces such as ponds, dams, and seas. In addition, it is an innovative solution that provides efficiency in energy production by reducing PV panel temperatures thanks to the natural coolness of the water.

In this study, the design classes of FPP applications, which have many installation models, will be examined in historical chronological order. System components, floating technologies, advantages, and disadvantages will be listed. Detailed studies will be conducted on the studies carried out to increase the efficiency of YGES technology, and predictions will be made for future projections.

Keywords: Floating Solar, Energy, Design, Efficiency, Model.

INTRODUCTION

With the increasing global energy demand, the environmental impacts of fossil fuels and sustainability concerns have made the use of renewable energy sources mandatory. Solar energy is increasingly preferred because it is a clean and unlimited source. However, the need for large areas of solar panels on land creates pressure on agricultural lands and natural ecosystems. For this reason, the idea of evaluating water surfaces for energy production has emerged and the concept of YGES has been developed.

YGES systems are an innovative solution consisting of photovoltaic panels placed on the water surface, which reduce the panel temperature and increase efficiency by using the natural cooling effect of water. Floating systems can be applied to various areas such as ponds, dams, water channels and sea surfaces. At the same time, it has the potential to reduce evaporation by covering water surfaces and contribute to the protection of water resources.

Although studies in the field of solar energy around the world began to show themselves commercially at the beginning of the 21st century, when the studies on floating solar power plants are examined, it is seen that they do not have a very distant past.

Its first developments were realized with the birth of the floating photovoltaic power plant established in Japan in 2007. The aim of this application, which was established by the National Institute of Advanced Industrial Science and Technology of Japan in a south-sloping way in the water reservoir of a Hydroelectric Dam in Aichi, was to evaluate the performance of water and air-cooled photovoltaic systems (Ueda et al., 2008).

Ueda et al. (2012) conducted their studies on the prototype application in Aichi. They carried out cleaning operations with dam water on the established system and observed that the efficiency was low despite the use of cooling facilities with sprays. They indicated that the reason for this was the formation of dust and dirt originating from the environment. They concluded that importance should be given to panel cleaning in order to maintain and increase the efficiency of the system they developed (Ueda et al., 2012).

Far Niente Wineries commissioned the first significant grid-connected solar system on water in California in 2008. The system, installed by SPG Solar, consists of modular crystalline PV panels mounted on floats in a pool. The floating structure is equipped with built-in walkways between each row of panels to provide easy access for cleaning and maintenance of the panels (Smyth et al., 2011).

A second vineyard in California, Gundlach Bundschu, adopted the same approach as the one built at Far Niente. Installation work was again managed by SPG Solar in 2008. The difference between the two systems is striking: the system installed in a pool at Far Niente exceeded 175 kWp, while the system at Gundlach Bundschu was completed at 30 kWp (Patil et al., 2017).

Tina et al. (2011) conducted a study by adding reflectors to floating solar energy systems. In particular, the effect of different connections (serial and/or parallel) of PV cell arrays forming a PV module was analyzed theoretically and experimentally. In addition, the presence of a water cooling system that keeps the temperature of the PV cells low and uniform was also carefully evaluated. By placing a series of reflectors behind the PV panel, the plant efficiency was increased. However, the created reflection system caused different temperature and radiation fluctuations. On the other hand, it was suggested that the efficiency increased by 60%-70% (Tina et al., 2011).

Trapani and Santafe (2014) suggested the use of a floating flexible film photovoltaic cell structure that can be applied in open seas as well as in lakes. In the measurements made, a 5% increase in efficiency compared to land was found. Although the direct contact of the system with water causes dirt accumulation, it suggested the need for new studies on cleaning itself (Trapani and Santafe, 2014).

Choi et al. (2014) implemented the first tracking system in water with their solar tracking floating solar power plant study. The system that tracks the inclination and azimuth angle is equipped with a new tracking mechanism for 100 kW and 500 kW and has been developed in Hapcheon Dam. The floating tracking type PV structure is expanded by combining 4 unit structures, and the internal rectangular structure houses the working device for rotation and various electrical devices. In addition, the external fixing structure is designed to be used as a maintenance road by connecting the quadrilateral structures together (Choi et al., 2014).

Sahu et al. (2016) examined the general characteristics of floating photovoltaic systems in their study. In terms of the environment, they stated that it reduces the evaporation rate of water by up to 70%, prevents algae from forming in the water, and the cooling effect contributes to floating PV systems. In the study, which also touched on the negative effects of floating solar power plants, they stated that the development of floating solar power plants is hampered by issues such as the lack of development of food resources, disruption of fishing activities, corrosion, and the extra cost required compared to land installation (Sahu et al., 2016).

Liu et al. (2017), in their study conducted in China, examined and analyzed the energy production efficiency of the PV element used in floating solar power plants. They found that it was approximately 2% more efficient than land-based models due to the water cooling effect. They also suggested that the floating solar power plant potential in China was around 160 GW and that if this installation were to be realized, 2*1027 m3 of water would be saved from evaporation annually (Liu et al., 2017).

Perez et al. (2018) examined the electricity production potential and water evaporation reduction of floating photovoltaic systems to be installed in 128 hydroelectric reservoirs in the USA. They found that they had a total installation capacity of 1,100 GW and an annual electricity production of 9,300 kWh. In the analyses conducted using 1.5% of the dams' capacity, they found that they had the same electricity production capacity as hydroelectric power plants (Perez et al., 2018).

In his study, Yıldız (2020) determined 7 locations in the Aegean and Mediterranean Regions and made comparisons on the subjects where floating solar power systems can compete with wind power plants established on the sea. A simple cost estimate was also made for a fixed offshore photovoltaic power plant. It was revealed that offshore photovoltaic energy can compete with wind energy and may be more suitable for some regions with low wind energy potential, and argued that this system may be the only applicable solution for coastlines with high solar potential but not sufficient wind intensity (Yıldız, 2020).

In his study, Sanchez et al. (2021) examined the benefits of floating solar power plants against possible drought conditions, based on the dependence of African countries on hydroelectric power plants. He argued that the integrated floating solar power plant would prevent the decline in hydroelectric production. He also suggested that floating solar power plants should be established as a precaution against water evaporation. Using accurate data from the continent's 146 largest hydroelectric power plants, it was concluded that if the total coverage is less than 1%, the power

capacity of the existing hydroelectric power plants will double and electricity production will increase by 58% (Sanchez et al., 2021).

In his study on the establishment of floating solar power plants on the Yamula Dam, Dal (2021) examined the potential that would be created by installing 10% of the dam's minimum water level area. According to the results he found through the simulation; the installed power potential was calculated as 576.4 MW and the annual electricity amount it will produce as 802.4 GWh. In addition, it was determined that 378,336.3 tons of CO2 emissions will be prevented per year thanks to this production. During the study, Global Solar Atlas (GSA) simulation was used for electricity production calculations and RETScreen applications were used for greenhouse gas emission analysis (Dal, 2021).

Kaymak (2021) conducted studies on 3 different systems in Büyükçekmece Lake. The first two potential 90 kWp and 30 kWp installations were realized, but the desired efficiency could not be achieved due to harsh weather conditions and densities. An advanced design was developed after the models applied in systems generally installed in calm waters. The products they made, the floating GES system, achieved land-based solar energy system energy values despite harsh weather conditions and wave loads (Kaymak, 2021).

Pouran et al. (2022) developed the floating GES data of their studies and investigated the technical results. Floating GES results highlighted more efficiency at more points than systems installed on land. They considered water protection and land reduction as another positive effect. According to Pouran; The first reason for preventing floating GES efficiencies was that the state did not provide the systems. In addition, they stated that the fact that long-term performance and reliability were not fully tested could lead to financial concerns in Floating GES systems. They mentioned the use of seas rather than inland waters to increase the development of these systems (Pouran et al., 2022).

Goel et al. (2022), the success of which was carried out in the Jhumka Dam lake of Bhubaneswar, a 12 kW floating system design. These effects were carried out using the PVSYST 7.1 simulation program. The photovoltaic system he designed had a payback period of 11.9 years and an investment return of 78.2%, and concluded that the system was economical (Goel et al., 2022).

METHODOLOGY AND FINDINGS

Floating solar power plants, in recent years, the increase in global warming awareness, efforts to prevent evaporation loss of water, the desire to utilize empty areas on the water surface, etc. have led to the emergence and rapid development of floating solar power plants. Many factors such as the fact that the established plants perform more efficient production compared to land with the cooling effect of water, do not harm aquatic organisms, the transportation material is made of renewable materials, prevents algae growth in water, does not have land costs, etc. support that floating plants will have an important place among future solar power plants. The system components of floating solar power plants are similar to systems established on land. Since the place where the tower is built is above the water, floating equipment must be used, unlike the land type. The components of the system are broadly illustrated in Figure 1.

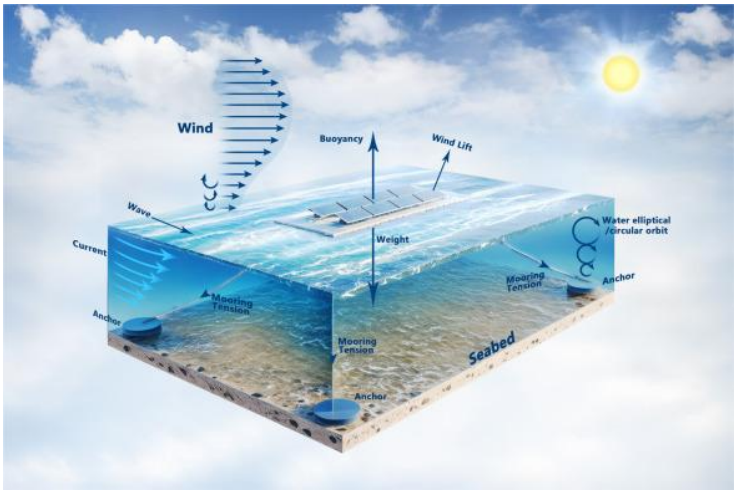

Figure 1. FPV system components

The components of floating solar power plants generally consist of 5 parts (Ramasamy and Margolis, 2021). Although there are different types of installation models and R&D studies, the first of these systems is; photovoltaic panels as the basic building block of electricity production. The second is; floating systems that carry the panels over the water. Thirdly, supporting structures for the placement of panels on the floating structure. Panels can be placed on these systems with the help of poles or construction. The fourth system component is the anchor and connection structure that ensures the floating system remains stable. This component is used to protect the changes in the water level and the direction of the sun. Finally, the electrical connection elements that enable the transformation and transmission of the obtained electricity (Choi et al., 2014).

Design Classes

The design of floating solar energy systems has emerged in many different ways in the world. It can be said that there are many models, especially for difficult weather conditions, wave loads, sea or closed basin installations. Knowledge and experience on the subject are actually low. However, in recent years, with the increase in installations, there has been a concentration on certain models. Some basic points to consider for floating solar energy systems are as follows:

Cost; In order to reach a level that can compete with land installations, models that will minimize the cost of floating solar energy plants are needed. When cost elements are considered, cable distances should be adjusted correctly, construction use should be reduced according to the condition of the water, and it can be said that determining the number of pontoons exactly enough to balance the buoyancy force will be design factors that reduce expenditure items.

Resistance to weather conditions; when the environment where the floating solar power plant is located is considered, an important detail that needs to be solved is resistance to harsh environments. Possible wave and wind loads should be determined in advance and the design model should be determined. In addition, since the temperature and humidity of the water will affect the amount of electricity production, it is necessary to plan designs that will minimize these effects.

Ease of installation; In order for the system to be planned to be completed with a minimum level of labor, the installation model and location should be determined correctly.

Maintenance, repair facilities; Since floating solar energy systems are located on water, ease of maintenance and repair is an important factor in model design. Accessibility should be provided for each panel and array.

Resistance to biological factors; When creating the model of the system, it is an important criterion to select materials by considering the effect of water. The corrosion effect due to the salinity of the water and the possible accumulation of plants on the structure are design elements that should be considered.

Site selection; It is mandatory to determine the measurements of the area where the floating solar energy system will be located before the project phase. Otherwise, the depth of the water and the annual change in the water level can cause serious damage. Site selection is of great importance in terms of the strength of the anchor system to be made on the ground or shore.

Many design models of floating solar energy systems are observed. Especially in freshwater areas, a large number and an increasing number of designs have been deployed. In open sea environments, there is a more difficult design process. The wave and depth conditions brought by the marine environment are shown as the reason for this difficulty. When Figure 2 is examined, some classifications of basic design models are shown (Claus and Lopez, 2022).

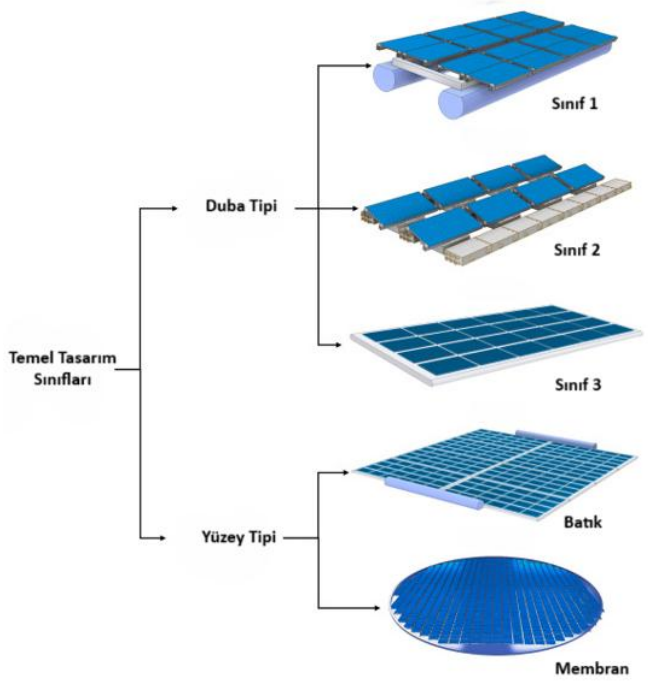

Figure 2. Essential Design Classes

Floating solar energy systems can be divided into two basic classes. The reason for this distinction is the contact of PV modules with water. While the pontoon type design classes are shown in the first section, the surface designs, that is, designs in direct contact with water, are shown in the second section. Design classes also differ in the pontoon type and surface models. Three classes will be examined in pontoon type designs. The first class will show the buoy supported construction resistant model, the second class will show the plastic based model, and the third class will show the hybrid island model.

Pontoon Type

The main idea in pontoon type designs is to create a floating platform for the solar power plant to be built on. Electrical connections are generally carried on pontoons. With the increase in the number of large-scale projects, electrical conversion equipment such as inverters and panels have also begun to be placed on floats.

Class 1 Raft Model

This system, which is floated thanks to the mutual arrangement of high-density polyethylene cylinder pipes, can actually be described as the first applications. The system, which acts as a raft thanks to the pipes, is a design model applied to keep PV modules above the water level with various metal parts. They can generally perform single-axis tracking. When compared to other models, it is seen that it is a little more expensive to install in fresh waters.

This system, which is more preferred for installations made in open seas, still has problems that need to be solved. The first thing that stands out is the negative effects that the salt in seawater can create on the constructions. In addition, various fatigue and fractures may occur in places where wave loads are high. In the structure built on the floating pontoon, the parts that hold the units together and the panel supporting construction structure are used (Cazzaniga, 2020).

The 200 kW floating solar power plant established in the Suvareto region of Italy is a typical example of this class. The system, which was connected to the grid in 2011, still exists today. An image of this system is given in figure 3 Steel structures were used to provide the lifting force and a single-axis installation was carried out by adjusting the optimum inclination angle. However, there are problems in preventing water evaporation. The part in contact with water is 20% of the total area (Cazzaniga, 2020).

Figure 3. 200 kW system installed in Suvareto area

Class 2 HDPE Pontoon Model

This class, specially designed to float PV panels directly on HDPE pontoons, is quite popular. The simplicity of the system's installation and assembly work is one of the reasons for preference. It can also be scaled due to its modular design. There are very few metal parts in the system that will be exposed to corrosion. Although the system is resistant to wave movements, breakage of the connection elements may occur if exposed to strong winds and violent wave movements. Another disadvantage is the initial investment cost due to the high logistics and production costs of polyethylene pontoons.

Ciel & Terre, a French company and technology provider, has been producing under this class in the sector since 2011. In particular, they have installed over 300 MW in 25 countries between 2016 and 2018. The first 5 MW power plant and walking pontoon made by Ciel & Terre are shown in figure 4 (Ciel & Terre, 2022).

Figure 4. Class 2 Model made by Ciel & Terre

Class 3 Hybrid Design

Floating islands designed as hybrid designs were produced as a solution to the problems experienced by polyethylene pontoon designs mentioned in class 2. In other words, they were developed as a solution to wave loads found in open seas. They are equipped with very robust supporting structures that can carry multiple modules. Since they are built on a platform, there is no need for extra roads such as walking pontoons.

The first example of this class was developed by NRG-Energia in 2009. Figure 5. a. shows the first system installed in the Bubano region of Italy. In the design where two units are combined and 40 PV modules are used, carrier platforms and structures are used (Cazzaniga, 2020).

The platform created as a draft by Moss Maritime is given in Figure 5. b. The company, which has been building oil exploration platforms for more than 20 years, has presented a model in this class for floating solar power plants (Cazzaniga, 2020).

Figure 5. a) desingned by NRG-Energia in Bubano **b)** Model designed by Moss Maritime

In fact, it offers a hybrid model as a mixture of class 1 and class 2. The platform is supported by various floating elements such as standard sea pontoons and offshore oil extraction platform technologies. Figure 6. a. shows a 500 kW floating solar power plant installed in class 3 format by the Indian company Adtechindia (Kumar et al. 2021).

A similar installation example was developed by the Australian company Swimsol for salt water and open seas. Figure 6. b. shows a 24 kW system installed in the Maldives. The design generates electricity with PV modules laid on a rigid platform (Cazzaniga, 2020).

It has been suggested that a balanced structure will be formed thanks to the metal frame-based system developed by Nemo Eng, a Korean company. It is also thought that wave and heat changes that could damage the system will be eliminated thanks to this system. The project with 36 PV modules is shown in figure 6.c (Kumar et al., 2021).

Figure 6. a) model designed by Adtechindia as 500 kW **b)** Swimsol model **c)** Model by Nemo ENG class 3

Surface Type Design Classes

Surface type design classes are a floating solar energy type class that is being worked on. The developed models are evaluated as submerged and membrane. However, although the submerged model remains in the R&D stage, installations of the membrane model are encountered.

Submerged Model

The submerged model floating solar power plants are produced by mounting them directly on the water surface. This model, designed to reduce module temperatures, has increased energy production efficiency. In addition, thanks to the flexible panel used in the floating system, more resistance has begun to be shown against wind and wave loads. However, it is estimated that the system will have a long life due to its durability and high water conductivity (Trapani and Millar, 2014).

There are important points to consider in the design of thin film flexible panels in water. The system must be designed to be not exceeding half a meter in depth. In order to remain at this depth, the changing buoyancy must be calculated correctly. Because it should not be forgotten that wave and wind effects will force the system to move in three dimensions. The structure to be used as an anchor should be designed with a flexible element with a buoy (TERI, 2019).

After the first trials of the application of thin films in Sudbury, Canada were carried out with 0.5 kWp prototype productions, the Trapani (2014) system was further developed. In the study presented in Figure 7.a., a waterborne installation with a 570 Wp thin film flexible PV module was installed. As a result of the measurements made for 45 days, a 5% increase in efficiency was determined compared to land type installations. However, it was suggested that it should be developed with a self-cleaning design for dirt and dust (Trapani and Millar, 2014).

Designed in 2012 under the name SUNdy, the model was developed by Det Norske Veritas to produce a total of 2 MW with 4,200 flexible panels of 560 W power. As shown in figure 7 b, it has been suggested that it can withstand wave resistance while generating electricity with panels arranged around a central core with a structure reminiscent of a spider web (Sahu et al., 2016).

Figure 7.a) Designed by Trapani **b)** SUNdy spider web model

Membrane Model

In this design, which is not widely used, the water is covered with a membrane material. This is a good option to significantly reduce water evaporation, but it is site-specific and not scalable. The membrane is opened tensely and placed on the round design. A structure resistant to wave loads is created (TERI, 2019).

Some companies have started to develop these structures for fish farms. At this point, their installations are now observed in many places. The cooling effect is an important advantage for PV modules. Because the system is in direct contact with water. However, the newness of its technology is higher in terms of cost compared to other models, as in the submerged design.

Ocean Sun, a Norwegian company, is a pioneer in this type of installation. In their design, they perform flexible panel placement by stretching a reinforced membrane on a skeleton structure formed with rubber materials. They use pumps to backpress possible water masses at various points of the system. In addition, the inverter is installed in the system and the electricity generated is converted on the water. The company guarantees the membrane life of 20 years (Ocean Sun, 2022).

The first example of the design was realized upon the request of a fish farm in Kyrholmen, Norway. The installed power was set at 100 kWp and was installed on a 50-meter diameter mechanism (TERI 2020). In July 2022, trials for a new 1.5 MWp system were started near Jurong Island in Singapore, again under the supervision of Ocean Sun and with the contractor Keppel Energy Nexus. The project shown in figure 8 was developed to partially reduce the climate impact of industrial enterprises operating on the island. The project, supported by the state, was chosen for this region due to the commercial potential of the region (Ocean Sun, 2022).

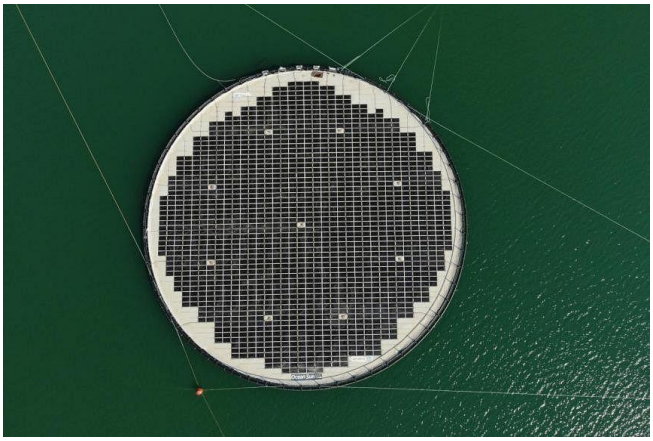

Figure 8. Model made by Ocean Sun & Keppel Energy Nexus in Singapur

Factors Affecting Productivity

In the design of floating solar power plants, production data is very important as in other installation models. Installation models have generally come to the present day by making improvements that will positively improve efficiency. The system has been tested in many aspects and it has been determined that the most common installation model is the plastic model in class 2. Despite this, various studies are still ongoing.

Reaching full capacity in energy production is very valuable for solar energy. Because PV modules can already convert radiation to electricity at a certain rate. There are different factors that affect the efficiency of design models. In this sense, the studies conducted have been addressed separately for each aspect of the system. The factors affecting the efficiency, which are especially encountered in land installations, have been examined in order.

Tracking System

Solar energy tracking has been shown as an increasing model in land installations in recent years. Its contribution to efficiency in particular has been proven by many authorities and investors are applying different varieties of this model to their plants. The applications of these systems, which increase the efficiency of the PV module, are not yet very common in floating solar power plants. However, studies have found that they contribute to an increase in efficiency between 20% and 30% (Tina and Scavo, 2022).

While there is a fixed and smooth ground in land installations, the application of this sensor-based application in floating solar power plants is therefore more challenging. Because the effect of waves and wind can constantly affect the direction. In addition, the effect of water can also cause deterioration in the tracking mechanism. Various studies have been tried in the solar tracking system. Some of them will be examined in this section.

This type of tracking in floating solar power plants was developed by Clot and is shown in Figure 9.a. The system, which is surrounded by a fixed circular structure skeleton, is partially rotated by a suitable electric motor. Although it is better than a fixed installation model in terms of performance, it has remained in the background due to installation cost (Clot and Tina, 2020).

The model, which is set up with the help of a rope wrapped around the circular platform, is given in Figure 9.b. The rotator-supported mechanism fixed to a different location moves the rope in two directions and provides sun tracking. It was not preferred because it did not provide a very good contribution in terms of system efficiency (Cazzaniga et al., 2018).

In this model, which is held by three anchors fixed to the ground, an empty tank is mounted on the floating system as shown in Figure 9.c. The pressure is created differently by changing the air and water ratios in the tank. In this way, the tracking mechanism is activated. Although this approach does not have a wide-scale application, it has been tried for small systems (Cazzaniga et al., 2018).

This model is created using a pusher system with two or more propellers given in Figure 9.d. The software-supported propellers are controlled by a central system and sun tracking is performed. It is preferred more than others due to its cost-effectiveness (Clot and Tina, 2020).

Horizontal axis tracking is given in figure 9.e as another solar tracking model design. This model, established in a triangular structure, has been proposed for east-west axis tracking. It is said that the biggest obstacle for this system may be the shading effect. Since a wide-range design is needed, it increases the cost and space requirement (Clot and Tina, 2020).

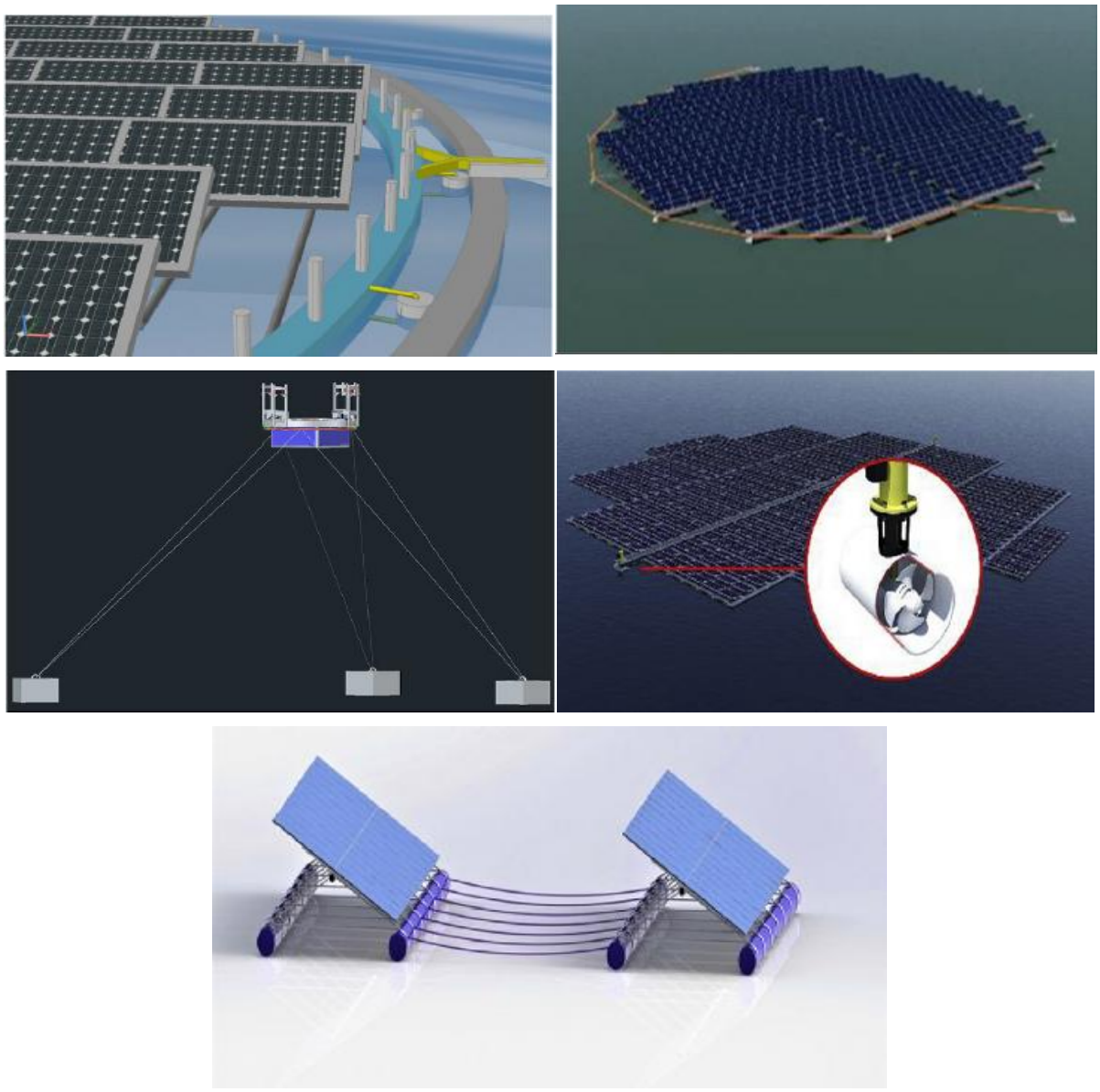

Figure 9. a) Single-axis structure with solar tracking system **b)** Cable-supported single-axis solar tracking system **c)** Propeller-assisted solar tracking system **d)** Propeller-driven model **e)** Horizontal-axis triangular solar tracking system

Use of Reflective Surfaces

In their studies on concentrating light on the PV module using reflective surfaces, Tina et al. examined different models. In their first study, they placed reflectors on the back surface. It was proven that the efficiency increased but there was an irregular heat distribution due to shading. However, it was suggested that if the V-shaped design and cooling process was carried out with the help of cooling

sprays from the water environment, the efficiency would increase by around 60%. It is thought that the reflector surfaces and the cooling effect affect the efficiency increase here (Tina et al., 2011).

This model shown in figure 10.a with reflector support was realized in Korea in 2012 as a hybrid design of the three-class model. The system was supported with reflective surfaces and cooling sprays. The installation was completed by using 6 panels on each stand at a 35-degree angle and reflectors opposite them. The 200 kW project established in the Suvereto region was used as the design. While the PV module construction was completed with galvanized steel, a pontoon system was created with HDPE-supported walkways. Figure 10.b. shows the application of this model on a frozen lake (Kim et al., 2016). Reflective surface supported floating solar power plants have not become sustainable in the market due to their high cost. However, development studies continue.

Figure 10.a) Reflective surface supported system in Korea **b)** İnstallation in Korea

Use of Bifacial Panel

In recent years, bifacial solar panels, which have been used quite a lot, give positive signals for land installations. Capturing the sun's radiation reflected on the ground has improved the efficiency in a positive way. It has also become quite attractive in terms of levelized energy cost.

This situation has also started to be considered for floating solar energy systems, which have been a popular application in recent years. However, bringing these two applications together is quite complicated. Because floating solar energy platforms that want to use the cooling effect of water have to be installed very close to the water. For this reason, it is quite difficult to benefit from the amount of light passing to the platform or water.

As a solution model, it has been suggested to place the system at a slightly greater angle to the water. The model developed by Sunflot is given in Figure 11.a. The model, which was established as a prototype on a basin in the Netherlands in 2013, was established on a strong structure with wide intervals. In this way, the radiation that may be reflected from the water surface has been turned into an opportunity for the panels behind (Cazzagani, 2020).

Another design model, installed in 2015 by Sunfloat, is given in Figure 11.b. The company calculated that efficiency was increased by 30% with the use of double-sided panels. However, it was seen that this installation was preferred in calm waters. It is open to discussion how it will cope with wind and wave loads in offshore applications (Cazzagani, 2020).

Figure 11.a) Developed by Sunflot model **b)** Systme design using bifacial PV modules by Sunflot

Cooling

It is known that PV modules are designed to convert solar radiation into electricity. However, not all of the incoming radiation is used for electrical conversion and some of it is converted into heat on the module. The increasing temperature value is a negative situation for PV modules. It has been shown in many studies that efficiency decreases with temperature. In addition, temperature is shown as the main factor in the deterioration of modules.

Companies have carried out various studies to reduce the temperature. Studies that increase heat transfer from the front and back surfaces have been examined as active and passive cooling models.

The results of active and passive, i.e. air cooling effects in floating solar energy systems have been reported by researchers. For example, it has been suggested that a 500 kW system installed in Bubano provided a 20% increase in efficiency thanks to passive cooling (Trapani and Millar, 2013).

In another study comparing land and floating systems, Golroodbari and Sark (2020) compared photovoltaic systems to be installed on land and sea surfaces. In order to make a fair comparison, they took into account the effects of sea waves, wind speed and relative humidity. As a result of the study, they concluded that the photovoltaic system on the sea produces 12.96% more energy than the photovoltaic system on land, and even this rate goes up to 18% in some months (Golroodbari and Sark, 2020).

In the same way, the study conducted by Liu proved that floating systems provide efficiency increase at lower temperatures compared to land installations. What is interesting in this study is that the temperature formed on the panels at night is lower in land installations (Liu et al., 2018).

Kjelstad, who examined another working model, the active water-cooled model, achieved relatively good results. In his active water-cooled PV module examination, he obtained a thermal transmittance value well above air-cooled land and floating systems. In the study, a 5% efficiency increase was determined with a 6-month examination. The heat transmittance coefficient achieved was 81 W/m2 K (Kjeldstad et al., 2021).

Dörenkamper, who conducted studies specifically in Singapore and the Netherlands in 2021, measured a value of 57 W/m2 K in an open-structured design, that is, the back surface of which directly sees the water surface. Similarly, in closed model designs, this value varies between 36 and 41 W/m2 K (Dörenkamper et al., 2021).

In the study conducted by Micheli, data obtained from three separate researchers and the PVSYST program for land and floating installations are shown in figure 12 The first of the data used in the study shows the measurements made by Kjeldstad. The second shows the data provided by Liu, while the third data set was provided by Dörenkamper. In the fourth data set, values were created using the PVSYST program (Micheli, 2022).

As a result, it was determined that the effect of temperature can be reduced by active cooling with water or passive cooling with air. The common view for the temperature effect on the modules, which is open to discussion and development, is to increase the use of floating solar energy systems.

RESULTS AND DISCUSSION

In this study; the development of floating solar power plants, efficiency-increasing studies and especially design classes were examined. While Asian countries are leaders in the field of floating solar power plants, it can be said that they will continue to increase their market share in the coming years with various studies in other continents. The studies conducted have observed that the cooling effect caused by the coolness of the water causes an increase in efficiency in the efficiency of floating solar power plants.

When the literature is examined, it has been determined that there are parts of the system that are open to development in terms of design. First of all, the floating system and anchor structures have been studied with very different models. It can be said that this issue constitutes the most important design detail in the sector.

At the same time, since the parts affecting the efficiency are touched by the floating structure, a lot of attention has been paid to models in this area. It was determined during the study that the dominant model in the market is the pontoon type class 2 model. For the PV module, the use of single-sided and double-sided panels was opened to discussion. It has been determined that the studies conducted on this subject contribute to a 30% increase in efficiency. It has been proven that it will be seen more in the future since the module temperature is lower in double-sided panels.

Another part that is subject to efficiency increase is the sun tracking model. Studies in this area have been shown to provide an effect of 20% on efficiency increase. However, it is open to research how the equipment used will affect the cost-return balance. Similarly, studies on the use of reflective surfaces have been mentioned. It has been argued that there may be a 60% efficiency increase. Despite the positive increase in efficiency, it has been revealed that heat distribution and shadow problems are a problem that needs to be solved in this area.

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REALIZATION OF SOLAR POWER PLANT ELECTRICITY PRODUCTION ESTIMATION WITH MACHINE LEARNING ALGORITHMS: XGBOOST, LIGHTGBM

GÜNEŞ ENERJİSİ SANTRALİ ELEKTRİK ÜRETİMİ TAHMİNİNİN MAKİNE ÖĞRENMESİ ALGORİTMALARIYLA GERÇEKLEŞTİRİLMESİ: XGBOOST, LİGHTGBM

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ÖZET

Bu çalışmanın amacı, bir güneş enerjisi santralinde elektrik üretimini makine öğrenmesi algoritmaları (XGBoost, LightGBM) kullanarak tahmin etmek ve bu modellerin performanslarını karşılaştırmaktır. Çalışmada, saatlik ve günlük elektrik üretim verileri analiz edilmiş ve her bir modelin tahmin doğruluğu MAE, MSE ve R^2 gibi metrikler ile değerlendirilmiştir. Ayrıca, modellerin farklı üretim seviyelerindeki tahminleri günlük bazda grafiklerle desteklenmiştir.

Elde edilen bulgular, XGBoost algoritmasının günlük tahminlerde en düşük ortalama hataya (MAE: 2.438) sahip olduğunu, ancak veri setindeki varyansın açıklanmasında sınırlı bir başarı (R^2: 0.362) performansı ortaya koymuştur. LightGBM algoritması, veri varyansının %56'sını açıklayarak (R^2: 0.561) diğer modellere göre daha geniş bir kapsama sahip olmuş, ancak hata değerleri (MAE: 2024,321 ve MSE: 8.143.625,10) görece daha yüksek bulunmuştur. Genel olarak, modellerin yüksek ve orta üretim seviyelerinde başarılı olduğu, ancak düşük üretim seviyelerinde ve ani dalgalanmalarda performanslarının sınırlı kaldığı belirlenmiştir. Sonuç olarak, güneş enerjisi santralinden elektrik üretimini tahmin etmede kullanılan makine öğrenmesi algoritmaları, özellikle yüksek üretim dönemlerinde başarılı sonuçlar gösterirken, düşük üretim seviyelerinde hata oranlarının arttığı görülmüştür.

Anahtar kelimeler: Güneş Enerjisi, Elektrik Üretimi, Makine Öğrenmesi, XGBoost, LightGBM, Enerji Tahmni.

ABSTRACT

The aim of this study is to predict electricity production in a solar power plant using machine learning algorithms (XGBoost, LightGBM) and compare the performances of these models. In the study, hourly and daily electricity production data were analyzed and the prediction accuracy of each model was evaluated with metrics such as MAE, MSE and R^2. In addition, the predictions of the models at different production levels were supported with graphs on a daily basis.

The findings showed that the XGBoost algorithm had the lowest average error (MAE: 2.438) in daily predictions, but limited success (R^2: 0.362) in explaining the variance in the data set. The LightGBM algorithm had a wider coverage than the other models by explaining 56% of the data variance (R^2: 0.561), but the error values (MAE: 2024.321 and MSE: 8,143,625.10) were found to be relatively higher. In general, it was determined that the models were successful at high and medium production

levels, but their performance was limited at low production levels and sudden fluctuations. As a result, while the machine learning algorithms used to estimate electricity production from solar power plants showed successful results, especially during high production periods, it was observed that error rates increased at low production levels.

Keywords: Solar Energy, Electricity Production, Machine Learning, XGBoost, LightGBM, Energy Estimation.

GİRİŞ

Dünya genelinde enerji üretiminde fosil yakıtların baskın bir rol oynaması, yalnızca çevresel kirliliğe ve iklim değişikliğine katkıda bulunmakla kalmayıp, aynı zamanda insan, hayvan ve bitki sağlığı üzerinde de ciddi olumsuz etkiler yaratmaktadır. Fosil yakıtların sınırlı olması, maliyetlerinin artması ve çevresel etkilerinin giderek daha fazla hissedilmesi, yenilenebilir enerji kaynaklarının önemini her geçen gün artırmaktadır (Abdel-Nasser ve Mahmoud, 2017). Bu bağlamda, güneş enerjisi santralleri (GES), yenilenebilir enerji kaynakları arasında öne çıkan bir konuma sahiptir. GES'ler, temiz enerji üretimi sağlayarak çevresel etkilerin azaltılmasına katkıda bulunmakta ve sürdürülebilir enerji üretiminde önemli bir alternatif sunmaktadır (Ghofrani ve Alolayan, 2018).

Güneş enerjisine dayalı üretimdeki dalgalanmalar, mevsimsellik, bulutluluk, ışınım yoğunluğu ve diğer çevresel faktörler gibi değişkenlerden kaynaklanmaktadır (Gensler ve ark., 2016). Bu durum, elektrik üretim sürecinde güvenilir tahminlerin yapılmasını kritik hale getirmektedir. Elektrik üretim verimliliğini artırmak, arz-talep dengesini sağlamak ve karlı elektrik satışı gerçekleştirebilmek için üreticilerin, geçmiş verilere dayalı olarak ileriye dönük tahminler yapabilmesi büyük bir gerekliliktir. Bu doğrultuda, gelişmiş veri analitiği teknikleri ve yapay zeka tabanlı yöntemler, tahmin doğruluğunu artırmada önemli bir araç olarak öne çıkmaktadır.

GEREÇ VE YÖNTEM

Bu bölümde, güneş enerjisi santrallerindeki elektrik üretim tahminini gerçekleştirmek amacıyla kullanılan makine öğrenmesi tabanlı iki farklı algoritmanın (XGBoost, LightGBM) tanımları, deneysel kurulum süreci ve elde edilen sonuçların karşılaştırmalı analizi sunulmaktadır.

XGBoost modeli: XGBoost (eXtreme Gradient Boosting), gradient boosting algoritmalarının gelişmiş bir versiyonudur ve performans artırıcı bir dizi optimizasyon tekniği ile öne çıkmaktadır. Bu modelin temel özellikleri şunlardır:

- XGBoost, büyük veri setlerinin işlenmesinde işlem süresini önemli ölçüde kısaltır ve daha hızlı sonuçlar üretir.
- Sparse veri işleme özelliği sayesinde eksik verilerle çalışırken doğruluğu korur.
- Modelin karmaşık yapıdaki veri setlerinde genelleme yapabilme yeteneğini artırır.

XGBoost, güneş enerjisi üretiminde farklı zaman dilimlerinde meydana gelen dalgalanmaları etkili bir şekilde analiz edebilir. Örneğin, güneş ışınımındaki ani değişiklikler veya meteorolojik koşulların etkisi, XGBoost'un parametrik yapısı sayesinde modele dahil edilebilir ve bu da yüksek doğruluk oranlarına ulaşılmasını sağlar.

LightGBM modeli: LightGBM (Light Gradient Boosting Machine), Microsoft Research tarafından geliştirilen ve özellikle büyük veri setleri üzerinde verimliliği artırmayı hedefleyen bir gradient boosting algoritmasıdır. Modelin öne çıkan özellikleri şu şekildedir:

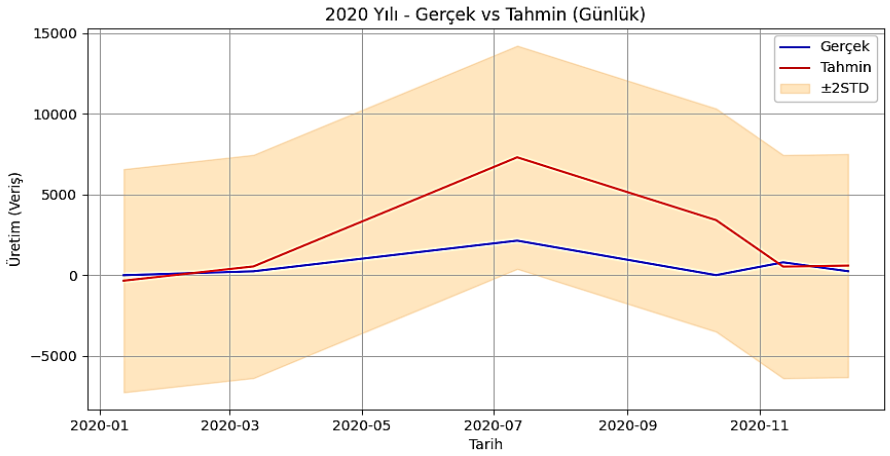
- Ağaçların asimetrik büyümesini sağlayarak daha doğru tahminler üretir. Bu strateji, karmaşık veri setlerinin dinamik yapısını modellemek için idealdir.

- Bu yöntem, veri işleme hızını artırırken aynı zamanda bellek kullanımını önemli ölçüde azaltır.

LightGBM, güneş enerjisi tahmininde sıklıkla karşılaşılan yüksek boyutlu ve mevsimsel dalgalanmaların bulunduğu veri setlerinde başarılı sonuçlar vermektedir.

BULGULAR

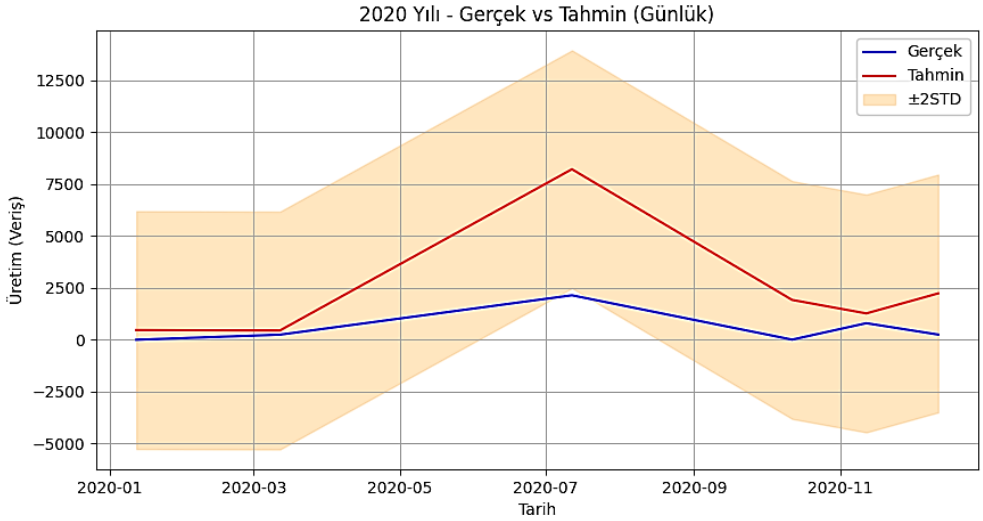
XGBoost Algoritmasına İlişkin Bulgular



Şekil 1. 2020 Yılı Günlük Gerçek ve XGBoost algoritmasıyla elde edilen günlük Tahmin Değerleri

Şekil 1'de, 2020 yılına ait gün bazında gerçek üretim ve XGBoost modelinin tahmin değerlerinin karşılaştırılması gösterilmektedir. Orta ve yüksek üretim seviyeleri çoğunlukla gerçek değerlere yakın seyrederken (örneğin 2020-04-12 tarihli 5764,95 birime karşılık 5737,07 birimlik tahmin, 2020-05-12 tarihli 6908,625 birime karşılık 6931,131 birimlik tahmin), 2020-01-12 gibi sıfıra yakın üretim görülen günlerde ise modelin -337,61 gibi beklenenden uzak değerler ürettiği gözlemlenmektedir.

LightGBM Algoritmasına İlişkin Bulgular



Şekil 2. 2020 Yılı Günlük Gerçek ve LightGBM algoritmasıyla elde edilen günlük Tahmin Değerleri

Şekil 2'de, LightGBM modelinin 2020 yılına ait gün bazında tahmin performansı incelendiğinde, modelin bazı günlerde ciddi sapmalar gösterdiği, bununla birlikte belirli eğilimleri yakalayabildiği

görülmektedir. Örneğin, 2020-05-12 tarihinde model, gerçek üretim olan 6908,625 birimi oldukça düşük bir değerle, 3310,56 birim olarak tahmin etmiş, 2020-07-12 tarihinde ise gerçek üretim olan 2142,45 birimi ciddi şekilde aşarak 8222,31 birim öngörmüştür. Bu tür ekstrem sapmalar, modelin belirli durumlarda gerçek üretim değerlerini yansıtmakta zorluk yaşadığını ortaya koymaktadır. Benzer şekilde, sıfıra yakın üretim görülen günlerde (örneğin, 2020-01-12 ve 2020-02-12) pozitif tahmin değerleri üretmesi, modelin düşük üretim seviyelerinde güvenilirliğinin sınırlı olduğunu göstermektedir. Buna karşılık, modelin bazı günlerde üretim değerlerinin genel eğilimini belli bir doğrulukla yakalayabildiği de gözlemlenmiştir. Örneğin, 2020-03-12 ve 2020-09-12 tarihlerinde, modelin tahminleri gerçek değerlere kıyasla sapma gösterse de üretim eğilimine yakın sonuçlar sunmuştur. Bu durum, modelin özellikle orta üretim seviyelerinde daha tutarlı bir performans sergileyebildiğini ortaya koymaktadır. Sonuç olarak, LightGBM modeli, 2020 yılı verileri bazında genel eğilimleri kısmen yakalayabilmiş olsa da düşük ve yüksek uçlardaki tahmin performansı sınırlı kalmıştır.

SONUÇ

Bu çalışmada, XGBoost ve LightGBM algoritmalarının günlük bazda güneş enerjisi üretim tahmin performansları değerlendirilmiştir. Her modelin, farklı yıllara ait günlük veriler üzerindeki tahmin doğrulukları, MAE, MSE ve R^2 gibi performans ölçütleriyle karşılaştırılmıştır. Elde edilen bulgular, her modelin güçlü yönleri ve sınırlılıklarına ışık tutmakta, ayrıca bu algoritmaların güneş enerjisi üretim tahminindeki etkinliklerine dair karşılaştırmalı bir değerlendirme sunmaktadır.

Bu iki modelin karşılaştırılmasında, XGBoost'un yüksek üretim seviyelerinde daha az hata yaptığı ve daha istikrarlı bir performans sergilediği söylenebilir. Bununla birlikte, LightGBM yüksek üretim seviyelerinde tahminlerin genel doğruluğunu yakalamış olsalar da zaman zaman ekstrem sapmalar göstermişlerdir.

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INDUSTRIAL WASTEWATER TREATMENT USING HYBRID CRANBERRY (CORNUS MAS) SEEDS POWDER AND IRON SULFATE COAGULATION

HİBRİT KIZILCIK (CORNUS MAS) ÇEKİRDEĞİ TOZU VE DEMİR SÜLFAT KOAGÜLASYONU KULLANARAK ENDÜSTRİYEL ATIKSU ARITIMI

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ABSTRACT

In recent years, because of the rapid increase in industrial development, the production of waste originating from different industrial processes has also increased. Wastewater with high heavy metal and pollutant content causes significant environmental problems due to its toxicity to living organisms and ecosystems. Traditional chemical coagulant methods are successfully used to remove heavy metals from industrial wastewater. However, chemical coagulants produce highly toxic sewage sludge that must be handled safely. Natural coagulants are cost-effective, sustainable, safer to use, locally available, and have the potential to recover resources. These advantages make natural coagulants a promising alternative to replace chemical coagulants. This study aims to investigate a hybrid coagulation approach to determine the optimal conditions for the removal of color and ammonium nitrogen (NH_3-N) from textile wastewater. The approach involves testing various doses of cranberry seed powder (CSP) and iron (II) sulfate heptahydrate ($FeSO_4*7H_2O$) under different pH conditions to identify the optimal dose and pH level for maximum removal efficiency. Jar Test equipment was used for the coagulation test. The results obtained from this study, in natural coagulant experiments conducted with only cranberry seed powder, showed that the highest removal efficiency for color and ammonium nitrogen was determined to be 76.28% and 97.06%, respectively, at a 0.25 g/l dose. In the experiment conducted using the optimum dose of natural coagulant and different doses of chemical coagulant iron sulfate (0.5, 1, 1.5, and 2 g/l doses), the best removal efficiency was obtained in the hybrid application using 0.5 g of cranberry seed powder and 1.5 g of FeSO4*7H2O/l. The optimum hybrid dose for color removal was 0.5 g Natural coagulant + 2.0 g FeSO4 in the hybrid application. In this study, no significant effect of pH change on removal efficiency was observed. According to the results obtained from this study, the hybrid natural/chemical application was more successful than the natural coagulant application alone.

Keywords: Water pollution, Wastewater treatment, Natural coagulant, Hybrid wastewater treatment.

ÖZET

Son yıllarda, endüstriyel gelişimin hızla artması nedeniyle, farklı endüstriyel süreçlerden kaynaklanan atık üretimi de artmıştır. Yüksek ağır metal ve kirletici içeriğine sahip atık sular, canlı organizmalar ve ekosistemler için toksisitesi nedeniyle önemli çevre sorunlarına neden olmaktadır. Geleneksel kimyasal koagülant yöntemleri, endüstriyel atık sulardan ağır metalleri gidermek için başarıyla kullanılmaktadır. Ancak, kimyasal koagülantlar güvenli bir şekilde işlenmesi gereken son derece toksik kanalizasyon çamuru üretir. Doğal koagülantlar uygun maliyetli, sürdürülebilir, kullanımı daha güvenli, yerel olarak temin edilebilir ve kaynakları geri kazanma potansiyeline sahiptir. Bu avantajlar, doğal koagülantları kimyasal koagülantların yerini alacak umut verici bir alternatif haline getirmektedir. Bu çalışma, tekstil atık suyundan renk ve amonyum azotunun (NH_3-

N) giderilmesi için optimum koşulları belirlemek üzere hibrit bir koagülasyon yaklaşımını araştırmayı amaçlamaktadır. Yaklaşım, maksimum giderme verimliliği için optimum dozu ve pH seviyesini belirlemek üzere farklı pH koşulları altında çeşitli dozlarda kızılcık çekirdeği tozu (CSP) ve demir (II) sülfat heptahidrat (FeSO4*7H2O) deneylerini içermektedir. Koagülasyon testi için Jar Test ekipmanı kullanılmıştır. Bu çalışmadan elde edilen sonuçlar, sadece kızılcık çekirdeği tozu ile yapılan doğal koagülant denemelerinde, renk ve amonyum azotu için en yüksek giderim veriminin 0,25 g/l dozunda sırasıyla %76,28 ve %97,06 olarak belirlendiğini göstermiştir. Optimum dozda doğal koagülant ve farklı dozlarda kimyasal koagülant, demir (II) sülfat heptahidrat (0,5, 1, 1,5 ve 2 g/l dozları) kullanılarak yapılan deneyde, amonyum azotu için en iyi giderim verimi, 0,5 g kızılcık çekirdeği tozu ve 1,5 g $FeSO4*7H_2O$/l kullanılan hibrit uygulamada elde edilmiştir. Renk giderimi için optimum hibrit dozu, hibrit uygulamada 0,5 g Doğal koagülant + 2,0 g $FeSO_4*7H_2O$ olmuştur. Bu çalışmada, pH değişiminin giderim verimi üzerinde önemli bir etkisi gözlenmemiştir. Bu çalışmadan elde edilen sonuçlara göre, hibrit doğal/kimyasal uygulama, sadece doğal koagülant uygulamasına göre daha başarılı olmuştur.

Anahtar Kelimeler: Su kirliliği, atıksu arıtımı, doğal koagulant, hibrit atıksu arıtımı

INTRODUCTION

The rapid development of industries has significantly contributed to the global use of water [1]. Industrial wastewater often contains a variety of inorganic pollutants, which can pose significant environmental hazards and serious health risks [2]. Among the various sources of environmental pollution, industrial wastewater discharged by various industries is considered the main source of environmental pollution.

The textile industry is among the leading contributors to heavy metal contamination in natural water bodies. This sector utilizes a wide range of chemicals, including bleaches, acids, alkalis, salts, dispersants, and, in some cases, heavy metals, all of which can contribute to environmental pollution [3,4].

To date, many technologies have been developed to solve this problem. The coagulation-flocculation technique has emerged as the most common and cost-effective approach in wastewater treatment [5]

Chemical coagulation method is a process that requires additional chemicals to neutralize or reduce the electrical charges of colloidal pollutants, and accordingly begins with the selection of a coagulant. In this process, various chemicals in the iron and aluminum-based coagulant class, especially iron/aluminum sulfate and iron/aluminum chloride, are used extensively [6].

Natural coagulants can be derived from a variety of sources, including plants and animals. Numerous studies have identified a wide range of natural materials suitable for producing bio-based coagulants [7,8]. Natural substances with high molecular weight often contain long-chain polymers, which can enhance the coagulation efficiency [9–11]. These materials have been widely explored for the treatment of various wastewater types, such as textile, dairy, and domestic effluents [12,13]. Additionally, animal-derived wastes like bones and shells have also been used as sources of coagulants [14]. A significant challenge in the application of natural coagulants, particularly those of animal origin, is ensuring a consistent supply for large-scale water treatment processes [14].

The present study was aimed at the application of cranberry seed powder as a natural coagulant in iron and steel wastewater treatment, in terms of COD, TSS, Ammonia-nitrogen NH_3-N, and heavy metals removal. The influence of the dose of date stone coagulant and pH range on removal efficiency was investigated in this work. Moreover, chemical composition and morphology of cranberry seed powder, were characterized by Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM techniques). In this experimental research, whether coagulation/flocculation is effective or ineffective in the Karabuk iron and steel industry effluent near Karabuk University in Turkey was investigated.

MATERIAL AND METHODS

Sample Collection

Raw industrial effluent was obtained from an Integrated iron and steel factory in Türkiye. The wastewater sample was collected at the discharge point and taken to the laboratory directly in a cool box within one hour of collection and utilized; otherwise, the samples were stored at 4°C in the dark and utilized as and when needed.

Preparation of Cranberry Seed Powder

Cranberry seeds were collected and washed using distilled water to remove any sticking particles. The seeds were first allowed to dry at room temperature before they were put in an oven at 50°C for eight (8) hours. The above procedures were conducted so that it would become easy to crush the cranberry seeds. As indicated in Fig. 1, date stones were crushed to minimize the size through a (Retsch RS 200) grinder in order to get a homogenized powder form utilized as a coagulant in the experiments.

Figure 1. Cranberry (*Cornus mas* L) fruits and seed powder

Experimental Procedure

For the simulation of the coagulation-flocculation process, Orbital shaker (Type: PSU-10i, No:010144-1404-0228, Latvia) and three 500 ml beakers were utilized to simulate the impact of the dose of coagulant. 200 ml of sample was placed in each beaker. The auto controller of the shaker apparatus was used to program timing and speed for fast and slow mixing. Coagulation-flocculation process in the present investigation consisted of 15 minutes of vigorous mixing at 200 rpm, then 30 minutes of gentle mixing at 60 rpm and subsequently 60 minutes of settling [15] to analyze further for percentage removal of COD. During this experiment, the natural pH value of the sample (pH 8) was not corrected, and coagulation was quantified based on the removal efficiency of color and NH_3-N.

The optimal dose of date stone powder derived from the preceding experimental stage was also assessed based on the effect of pH (range 5 to 10) on removal efficiency for the parameters of interest. The pH was adjusted before adding the coagulant using 1M hydrochloric acid solution and 1M sodium hydroxide solution. Industrial wastewater samples were shaken well before coagulation to reduce the risk of particle settlements; removal efficiency is estimated as follows:

$$Removal\ efficiency(\%) = \left[1 - \left(\frac{C_f}{C_i}\right)\right] * 100 \quad (1)$$

where C_i and C_f refer to the original and the obtained levels of each parameter

RESULT AND DISCUSSION

Characterization of Cranberry seed powder using scanning electron microscopy (SEM) imaging

Scanning electron microscopy (SEM) analysis shows a description of the morphology of cranberry seed powder. It has a brick-shaped condensed crystal structure. The analysis included images from several dimensions, as shown in Figure 2.

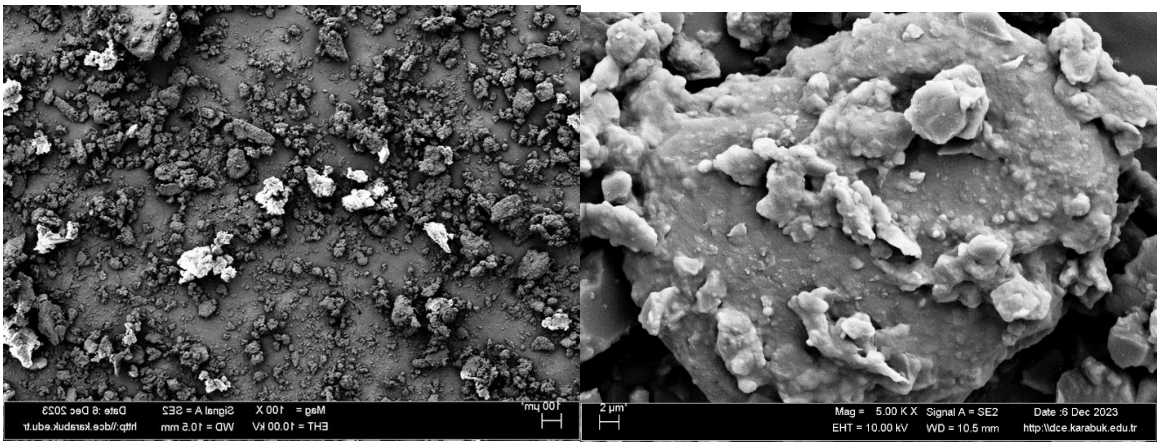

Figure 2. SEM images of cranberry seed powder

The irregular shapes and surface roughness of the molecules contribute to flocculation and sedimentation during coagulation. The surface of CS powder particles has varying degrees of roughness; high roughness indicates more active sites for reactions with contaminants and facilitates the coagulation process.

Fourier-transform infrared spectroscopy (FTIR) analysis

The FTIR spectrum of Cornus mas biomass, as presented in Figure 3, is a fingerprint profile of the material's functional groups. The functional groups are important in biosorption mechanisms when the material is applied in the removal of heavy metals from aqueous solutions. The FTIR analysis indicates that Cornus mas contains a number of oxygenated functional groups—hydroxyl, carboxyl, and carbonyl—that are typically found in its natural biopolymers like lignin, cellulose, hemicellulose, and pectin.

Figure 3. Fourier transform infrared (FTIR) spectroscopy curve for date stone powder.

These groups interact with heavy metals through Complexation and chelation with lone pairs of oxygen/nitrogen atoms, Ion-exchange where metal cations replace H^+ or Na^+ in carboxyl/hydroxyl sites, and electrostatic attraction between negatively charged functional groups. These mechanisms are accountable for the biosorptive ability of the biomass, making Cornus mas a potential, environmentally friendly adsorbent for environmental clean-up. FTIR of Cornus mas biomass reveals the presence of functional groups (–OH, –COOH, C=O, C–O–C) that are accountable for the adsorption of heavy metals. The functional groups are responsible for interaction with heavy metal ions owing to electrostatic, ion-exchange, and complexation. Hence, Cornus mas presents a low-cost, eco-friendly wastewater treatment technology option for heavy metal removal.

Characterization of textile wastewater

The wastewater from the textile factory exhibited diverse characteristics, as presented in Table 2.

Table. 2. Characteristic of industrial (Textile Factory) wastewater.

Wastewater parameters	**Unit**	**Results**
pH	-	11.9
Color	Pt-Co	1572.44
TSS	mg/L	159
COD	mg/L	3305.72
Ammonia-nitrogen (NH3–N)	mg/L	6.33
Copper Cu	mg/L	0.025
Iron Fe	mg/L	0.666
Zinc Zn	mg/L	0.119
Aluminium Al	mg/L	0.600

Effect of Cranberry Seed Powder Dosage on color and ammonia nitrogen removal

The following parameters were measured using different concentrations (g/l) to find the best concentration required to obtain the best possible removal yield: removal of %Color, and % ammonium-nitrogen, as presented in Table 3.

Table 3. Determination of optimum natural coagulant (CSP) concentration for COD, Color, and NH3-N removal

Dose (g/200ml)	**Color (%)**	**NH_3-N (%)**
0.05 g	76,28	97,06
0.1 g	63,85	97,06
0.5 g	55,12	97,06
1,0 g	25,29	94,39
1.5 g	17,16	91,62

The effect of pH for Color, and ammonia-nitrogen (NH_3–N) removal efficiency

The effect of pH of wastewater on the removal of color and ammonia-nitrogen was investigated. The pH value of the wastewater influences both the surface charge of the coagulant and the degree of stability [16]. The experiments were conducted at pH values of 5, 7, 9, and 11, with an optimal coagulant concentration of 0,5 g/200 ml and agitation at 200 rpm for 15 minutes, followed by 90 rpm for 30 minutes at room temperature.

Table 4. Effects of pH on Color and ammonia-nitrogen (NH3–N), COD, and Iron removal at optimum (0.5 g) coagulant dose.

pH	**Color %**	**NH_3-N %**
5	80,29	88,16
7	68,26	90,32
9	56,55	92,74
11	36,91	96,71

The optimal pH range for heavy metal removal is crucial, as it influences the surface charge of coagulants and particles, affecting coagulation and precipitation reactions.

In this study, a pH of 5 appears to provide an optimal environment for CSP-induced coagulation in removing color from the textile factory wastewater. However, for the removal of NH_3-N, pH 11 is optimal. There is no one optimal pH for color and NH_3–N removal from textile wastewater.

The effect of hybrid natural and chemical coagulant dosage on the removal of Color and ammonia-nitrogen (NH_3–N)

The hybrid application provided a significant increase in removal efficiency of color at a dose of 0.5 g CSP+ 0.4 g $FeSO_4*7H_2O$ /200 ml and removal efficiency of NH_3-N at a dose of 0.5 g CSP+ 0.5 g $FeSO_4*7H_2O$ g / 200 ml.

Table 5. The effect of hybrid natural and chemical coagulant dosage on the removal of Color and ammonia-nitrogen (NH3–N), COD, and Iron removal

Hybrid Doses	Color (%)	NH_3-N (%)
0.5 g CSP+0,3 g $FeSO_4*7H_2O$	79,41	98,27
0.5 g CSP+0,4 g FeSO4*7H2O	92,64	98,27
0.5 g CSP+0,5 g FeSO4*7H2O	90,97	98,27

CONCLUSION

In this work, the treatment of textile wastewater with the hybrid natural coagulant CSP and FeSO4*7H2O was investigated. The influence of the dosage, pH, and hybrid natural and chemical coagulation on the removal efficiency of color and ammonia-nitrogen was investigated. The optimal dose of CSP was determined to be 0.5 g / 200 ml for the removal of color and ammonia nitrogen.

Optimum pH varies depending on the parameters and is not the same for two parameters. The hybrid application provided a significant increase in removal efficiency for two parameters tested at a dose of 0.5 g natural coagulant (CSP) + 0.4 g chemical ($FeSO4*7H_2O$). The treatment of textile wastewater by coagulation and flocculation using hybrid natural/chemical coagulation methods enables the effective removal of pollutants. These results indicate that it can be recommended to use CSP and hybrid coagulation for wastewater treatment. The use of natural coagulants can reduce financial costs because they are widely available and provide greater public health safety due to their biodegradability. In addition, they can serve as nutrients for microorganisms.

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INVESTIGATION OF THE SYNERGISTIC EFFECT ON FLAME RETARDANCY AND MECHANICAL PROPERTIES OF LDPE COMPOSITES OBTAINED BY USING KAOLIN WITH HUNTITE AND HYDROMAGNESITE

HUNTİT VE HİDROMANYEZİT İLE BİRLİKTE KAOLİN KULLANILARAK ELDE EDİLEN LDPE KOMPOZİTLERİN ALEV GECİKTİRİCİLİK VE MEKANİK ÖZELLİKLERİNDE MEYDANA GELEN SİNERJİK ETKİNİN ARAŞTIRILMASI

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ÖZET

Yüksek molekül ağırlıklı zincirlerden oluşan polimerler, maliyet etkinliği, işlenebilirliği ve çok yönlülüğü nedeniyle 20. yüzyılın başlarından itibaren çeşitli endüstrilerde vazgeçilmez hale gelmiştir. Polimerler arasında Düşük Yoğunluklu Polietilen (LDPE), plastik ambalaj filmi, tek kullanımlık plastik ürünler, borular ve tıbbi/sağlık ürünleri gibi çeşitli alanlarda geniş bir kullanım alanına sahiptir. LDPE'nin yangın tehlikesine maruz kalabilecek ürünlerde yaygın olarak kullanılması nedeniyle, yangına dayanıklılığını artırmak, güvenlik standartlarını iyileştirmek ve yangınla ilgili yaralanmaları ve ölümleri azaltmak açısından hayati önem taşımaktadır. Bu alanda kullanılan yangın geciktiriciler, tutuşmayı geciktirerek ve alevlerin yayılmasını en aza indirerek polimerik malzemelerin yangın güvenliğini artırmada kritik bir rol oynar. Huntit ve hidromagnezit gibi mineral bazlı yangın geciktiriciler daha çevre dostu bir alternatif sunar. Bu doğal mineraller endotermik olarak ayrışarak su ve karbondioksit açığa çıkarır, bu da malzemeyi soğutur ve yanıcı gazları seyrelterek yangın riskini azaltır. Bu çalışmada, kaolin mineralleri huntit ve hidromagnezit ile birlikte kullanılmış ve üretilen LDPE kompozitlerinde olası bir sinerjik etki araştırılmıştır. Kompozitlerin morfolojik ve yapısal özellikleri XRD ve Taramalı Elektron Mikroskobu (SEM) ile incelenmiştir. Mekanik özellikler çekme ve eğme testleri ile incelenmiştir. Termal davranışlar Termal Gravimetrik Analiz (TGA) ile değerlendirilmiş ve alev geciktirici özellikler Underwriters Laboratuvar Testi (UL-94) ile incelenmiştir. Sonuçta huntit ve hidromagnezit minerallerinin kaolin ile birlikte sinerjik etkileri elde edilmiş ve yangın geciktirici kapasiteleri arttığı tespit edilmiştir. Bulgular, daha güvenli ve daha çevre dostu yangın geciktirici malzemelerin geliştirilmesi için değerli bilgiler sağlayarak hem malzeme bilimi hem de yangın güvenliği mühendisliğindeki gelişmelere katkıda bulunmaktadır.

Anahtar Kelimeler: Alev geciktiricilik, Huntite and hydromagnesite, Kaolin, UL-94, Mekanik özellikler, Sinerjistik etki.

ABSTRACT

Polymers consisting of high molecular weight chains have become indispensable in various industries since the early 20th century due to their cost-effectiveness, processability and versatility. Among polymers, Low Density Polyethylene (LDPE) has a wide range of uses in various areas such as plastic packaging film, disposable plastic products, pipes and medical/health products. Due to the

widespread use of LDPE in products that may be exposed to fire hazards, increasing its fire resistance is vital in terms of improving safety standards and reducing fire-related injuries and deaths. Fire retardants used in this field play a critical role in increasing the fire safety of polymeric materials by delaying ignition and minimizing the spread of flames. Mineral-based fire retardants such as huntite and hydromagnesite offer a more environmentally benign alternative. These natural minerals endothermically decompose, releasing water and carbon dioxide, which cools the material and dilutes flammable gases, reducing the risk of fire. In this study, kaolin minerals were used together with huntite and hydromagnesite and a possible synergistic effect was investigated in the produced LDPE composites. The morphological and structural properties of the composites were examined by XRD and Scanning Electron Microscope (SEM). Mechanical properties were investigated by tensile and bending tests. Thermal behaviours were evaluated by Thermal Gravimetric Analysis (TGA) and flame retardant properties were examined by Underwriters Laboratory Test (UL-94). In this way, the synergistic effects of huntite and hydromagnesite minerals in combination with kaolin were demonstrated and increased fire retardant capacities were obtained. The findings contribute to advances in both materials science and fire safety engineering by providing valuable information for the development of safer and more environmentally friendly fire retardant materials.

Keywords: Flame retardancy, Huntite and hydromagnesite, Kaolin, UL-94, Mechanical properties, Synergistic effect.

PERSONALIZED TRAVEL MANAGEMENT AND SUGGESTION SYSTEM

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Abstract

This paper presents a travel management and recommendation system developed to improve travel planning and management processes and provide a more efficient, winterized experience in these areas. The main goal is to effectively analyze users' travel history and provide meaningful and customized recommendations based on this data. The system allows users to visualize their travel destinations on an interactive world map. This map allows users to review their past travels, see travel statistics in detail and optimize future travel plans based on this information. The map provides users with detailed information about the selected countries such as visa requirements, population, official language, currency, quality of life, economic freedom and even happiness index to facilitate their travel decision-making process. Furthermore, the system's recommendation mechanism considers users' individual interests and travel history to suggest new countries or destinations that may be of interest to them. This recommendation system helps users to identify new travel routes more easily, saving them time and effort. The system design utilizes modern web technologies and integrates React.js, Firebase and Firestore, which provide a user-friendly interface and efficient data management. These technologies have made it possible to store data securely, synchronize it in real time and respond quickly to users' requests. As a result, the study offers an innovative solution for individuals who want to manage their travel planning and management processes in a more organized, knowledge-based and winterized manner. The system aims to increase user satisfaction by providing a data-driven and modern approach while improving individuals' travel experiences.

Keywords: Travelling, management, data, visualization, interface, travel recommendation.

Introduction

This study aims to develop a platform that will enable users to effectively manage their travel experience using modern web technologies. Nowadays, the need to travel is rapidly increasing for both business and touristic purposes. This increase creates the need to manage personal travel history

in an organized and accessible way. Accurate and fast visualization of travel data allows users to better analyze their past experiences and organize their future plans more effectively.

The research enables users to mark the countries they are traveling to on an interactive world map, access detailed information on each country and easily learn about visa requirements. It also gives users access to personal travel statistics, allowing them to analyze their individual travel habits. In addition, the system's recommendation mechanism provides users with country recommendations based on their interests and travel history.

The application developed in this context aims to meet the demand for personalized data management and analysis in the digital transformation process. The project aims to create a fast, secure and user-friendly platform using modern web technologies such as React.js and Firebase. From the user interface to data management, each stage is designed to improve the user experience and make the travel process more enjoyable and organized.

In today's rapidly globalizing world, the frequency with which individuals travel for business or leisure is increasing. However, this increase has led to an increase in the for effective management of travel plans and past travel information. Recording countries visited and visually analyzing travel data is often a laborious process for users. In addition, learning the visa requirements of different countries quickly and accurately can lead users to waste time and receive incorrect information.

Another major problem faced by users during travel planning is the lack of personalized and meaningful travel recommendations. Existing systems fall short in providing recommendations based on users' individual preferences and past travel experiences. Moreover, the majority of existing applications fail to provide a user-friendly interface and cannot effectively perform basic functions such as real-time data synchronization.

Given all these challenges, there is a need for a platform using modern technologies that allows users to manage their travel experience more easily and effectively. In this context, the system to be developed is intended to support users to record and analyze their travel history and organize their future plans. At the same time, it is aimed to make the system more attractive and functional with a mechanism that offers suggestions tailored to the individual needs of users.

Literature studies on travel tracking systems and recommendation mechanisms provide an important basis for understanding approaches and technological advances in this field. Such systems allow users to more easily plan their trips, organize past trips and discover new destinations.

The development of modern web technologies, especially the widespread use of tools such as React.js, Node.js and Firebase, have made the development of such applications more accessible. React.js facilitates the creation of dynamic and user-friendly interfaces, while Firebase provides real-time data synchronization and secure data management. In the literature, it has been reported that the use of these technologies improves the user experience and accelerates data processing (Polat, 2017). Travel tracking applications often have limitations in terms of user interface design and data synchronization. Smart Travel Planning System (ASPS) for Izmir is an example of such an application studied by (Dalkılıç et al., 2014). This study was developed to encourage the efficient use of public transportation and to enable users to choose the optimal route between origin and destination points. ASPS has shown that route optimization contributes significantly to saving users' time and costs. In addition, it was emphasized that personalized recommendation mechanisms and route visualizations improve the user experience (Dalkılıç et al., 2014).

In travel planning applications, recommendation mechanisms facilitate travel decisions by providing personalized recommendations based on users' individual needs. In the literature, it has been reported that personalized systems increase user satisfaction and make travel planning more effective. For example, the "Trip Planner" application developed by (Vigneshwari et al., 2022). This study allows users to view nearby attractions and accommodation options with the integration of Google Maps

API. In addition, time and cost savings were achieved by optimizing travel routes (Vigneshwari, et.al., 2022).

Studies on the visualization of travel data and the use of dynamic maps have helped users evaluate their past trips and optimize their future plans. Dynamic color coding and interactive maps enable users to perform data analysis more easily. The contribution of such visualization tools to user experience was also emphasized in the study (Dalkılıç et al., 2022). Interactive and customizable systems increase the user loyalty of travel applications and enable more effective use of the system (Vigneshwari, et.al., 2022).

Technologies and Methods

In this section, the technologies used in the study and the methods followed in the development of the application are explained in detail. The functions of technologies such as React**.**js, Firebase, Firestore, SVG and Node**.**js and their contributions to the project are discussed. In addition, important processes such as interface design and database management are also detailed under this heading.

The technologies used in the project are integrated to fulfill specific functions. Node**.**js was used to manage backend operations and run API services. React.js was preferred to create the user interface and provide dynamic interactions with a component-based structure. SVG was used to create interactive graphics and scalable visuals within the application. Firebase and Firestore were integrated into the project to store user data, manage authentication processes and provide real-time data synchronization. These technologies increased the performance of the project while optimizing data management and user experience.

Application Development

The app's interface has been developed with an intuitive and modern design approach. The home page includes an interactive world map where users can mark the countries they are traveling to. This map allows users to navigate between countries and update their travel status.

Entry and registration system

Firebase Authentication was implemented as an authentication service that allows users to securely register, log in and manage their sessions. User registration processes were realized with *createUserWithEmailAndPassword* and login processes were realized with *signInWithEmailAndPassword* methods. Error management mechanisms were activated in these processes, providing instant feedback to the user and providing an uninterrupted authentication experience. The logout process was completed securely with the *signOut* method to protect user data.

The user interface of the application was developed using React.js and designed to provide an intuitive experience. On the member registration page, a simple structure has been adopted so that users can create an account quickly and effortlessly. Email and password verification mechanisms ensure security, while the user-friendly interface simplifies the process. During registration, incorrect or incomplete entries are immediately detected and feedback is provided to the user. As shown in Figure 1, the member registration process is structured to include basic data entry fields.

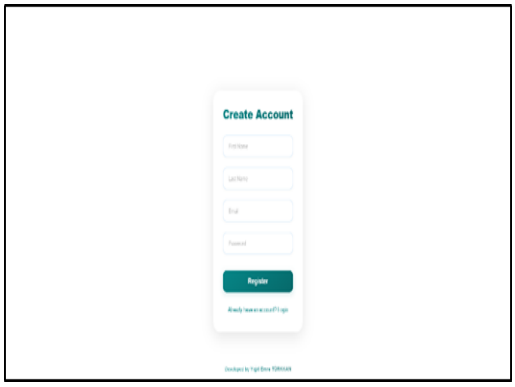

Figure 1. **General view of the member registration page**

The login page has been optimized to provide users with secure and fast access to the system. Account security has been increased with the verification processes provided by Firebase Authentication, and instant notification mechanisms have been activated for possible errors in the login process. In case users enter the wrong e-mail or password, error messages are displayed to ensure that the process proceeds efficiently. The login page design is detailed in Figure 2.

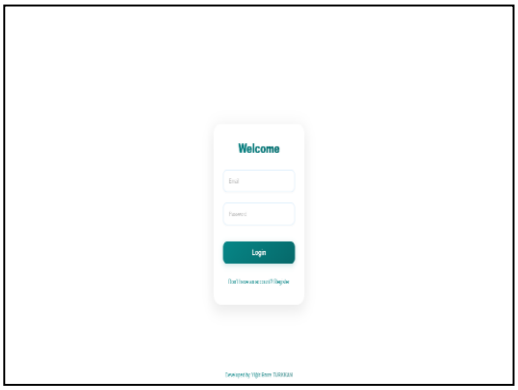

Figure 2. **General view of the member login page**

In addition, unauthorized access has been prevented by implementing additional security measures during the user login process. Advanced security mechanisms such as multi-factor authentication (MFA) have been supported, thus protecting accounts against malicious login attempts.

Country Information Panel

The country dashboard has been developed as a core component that facilitates users' travel planning and helps them make informed decisions. The dashboard includes basic information about the selected country such as capital city, official language, currency and population, as well as detailed metrics such as happiness index, internet speeds, quality of life, economic freedom and crime rate. When users click on a country on the map, the relevant data is pulled from the Firebase Firestore database and transferred to the panel. Missing information is indicated with "Unknown" to provide a transparent user experience. The technical infrastructure starts with taking the name of the country selected by the user as the *countryName* parameter and passing it to the *fetchCountryDetails* function. This function queries the relevant country information from the Firestore database and integrates it into the interface. The obtained data is dynamically added to DOM elements such as *infoBox* and *countryTitle*, and the basic properties of the selected country are automatically updated. As shown in Figure 3, this structure provides users with personalized information.

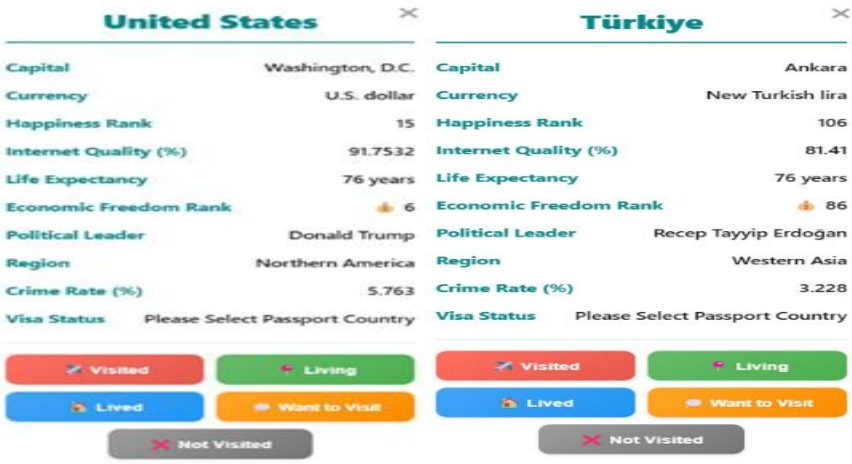

Figure 3. Country information panels for the US and Turkey

In terms of user experience, the real-time integration of the dashboards with the Firestore database ensures that up-to-date and reliable data is instantly accessible.

Passport Selection Panel

The passport selection panel has been developed as an important component that allows users to personalize their travel plans. This panel allows the user to select the passport country and dynamically display the visa requirements in different countries based on this selection. Thus, users can make informed decisions by directly learning the visa requirements for the countries they want to travel to. The dynamic nature of the panel facilitates the travel process by updating information on visa regimes in real time.

The technical infrastructure starts with the user selecting the passport country. This information is assigned to the *selectedCountry* variable and the relevant visa information is retrieved from the Firestore database through the *fetchVisaRequirements function*. According to the selected passport, visa requirements are reflected on the user interface and an interactive experience is provided. When the user does not select a passport country, the system returns an empty value by default, preventing the display of unnecessary information and maintaining simplicity in the interface. Error management mechanisms increase the reliability of the system by notifying the user in case of missing or erroneous data and providing error logs to the developers. As shown in Fig. 4.

Figure 4. Passport selection panel

In terms of user experience, the passport selection panel is presented with an intuitive design and facilitates the travel planning process.

Discovered Country Counter

The explored country counter has been developed as a key component that allows users to track the countries they have traveled to and visualize their global exploration process. When users mark a country on the map as "Gone to", "Living in" or "Lived in", the counter is automatically updated to

calculate the total number of countries explored and their percentage. This system increases users' motivation by giving them a clear view of their travel history and making it easier for them to set new goals. The counter is supported by an interactive progress bar, allowing users to see their progress in real time.

The technical infrastructure is developed with React.js' *useEffect* hook and the countries selected by the users are stored in the countries object. The system determines the total number of discovered countries by filtering the marked countries and reflects this value to the interface by calculating a percentage. The counter, which is integrated with the Firestore database, updates the data in real time and every change is instantly reflected on. The countries marked by the user are visualized with the help of a progress bar, while the percentage value is displayed as text. This structure functions as an effective tool that makes it easier for users to plan the process of reaching their travel goals. As shown in Fig. 5.

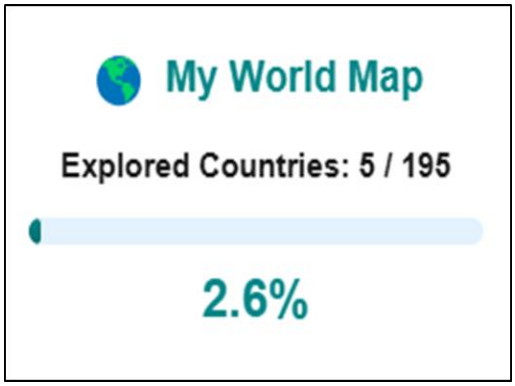

Figure 5. Discovered country counter

In terms of user experience, the explored country counter is designed as both an informative and motivational component. The counter provides a visual and numerical representation of the user's exploration rate around the world, making it easier for them to understand their progress.

Recommended Countries Panel

The recommended countries panel is designed as a component that allows users to receive personalized travel recommendations based on their travel history and preferences. The panel recommends new destinations by analyzing the countries the user has visited before, their travel frequency and interests. The recommendation system selects the three most suitable countries based on metrics such as crime rate, happiness ranking and internet quality. This mechanism contributes to a safe and quality travel experience for users and increases their motivation to explore new destinations.

The technical infrastructure works by analyzing country data from the Firestore database. After the countries that the user has visited before are removed from the list, the remaining countries are filtered and scored according to certain criteria. The scoring system, which is based on criteria weights such as crime rate, happiness ranking and internet quality, determines the countries with the highest scores and adds them to the recommendation list. As shown in Fig. 6, the recommendations are dynamically updated in case of a change in user preferences and presented with the latest travel data.

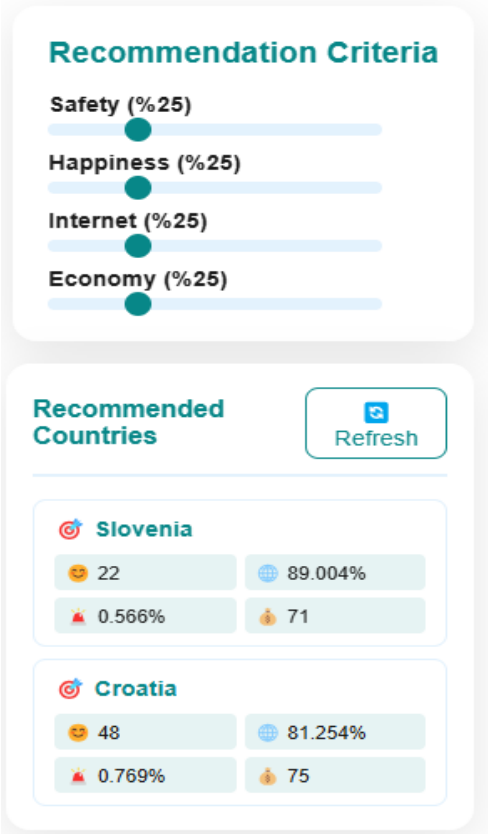

Figure 6. Proposed countries panel

This structure helps users optimize their travel plans, while at the same time making the exploration process more efficient and enjoyable.

User Experience

The home page of the app is designed as a central platform that allows users to manage their travel plans, visualize their exploration process and navigate interactively on the world map. As shown in Fig. 7 and Fig. 8, this page provides the user with a comprehensive experience by combining key components such as the explored country counter, recommended countries panel and interactive map.

Figure 7. General view of the homepage

One of the most striking features of the homepage is the color coding and zoom functions offered on the interactive SVG map. Users can mark countries on the map according to their travel history and have this information visualized in colors. As shown in Fig. 8, countries visited are shown in red,

countries lived in are shown in blue, countries currently lived in are shown in green, countries to be visited are shown in orange and countries not yet visited are shown in gray. This color-coding system makes it easier for the user to understand the travel situation at a glance and helps them to plan more consciously.

Figure 8. Panel of color coding of countries

In addition, thanks to the zoom feature, users can zoom in on the areas they want on the map and examine them in more detail.

Data Management

The app's data management is designed as a core component, allowing users to securely store their travel history, preferences and plans. Thanks to the Firestore database integration, users can update the information on the map in real time and access the same data by logging in from different devices. This dynamic structure enriches the user experience by increasing both data security and accessibility. As shown in Fig. 9, users' data is organized in a hierarchical structure in Firestore.

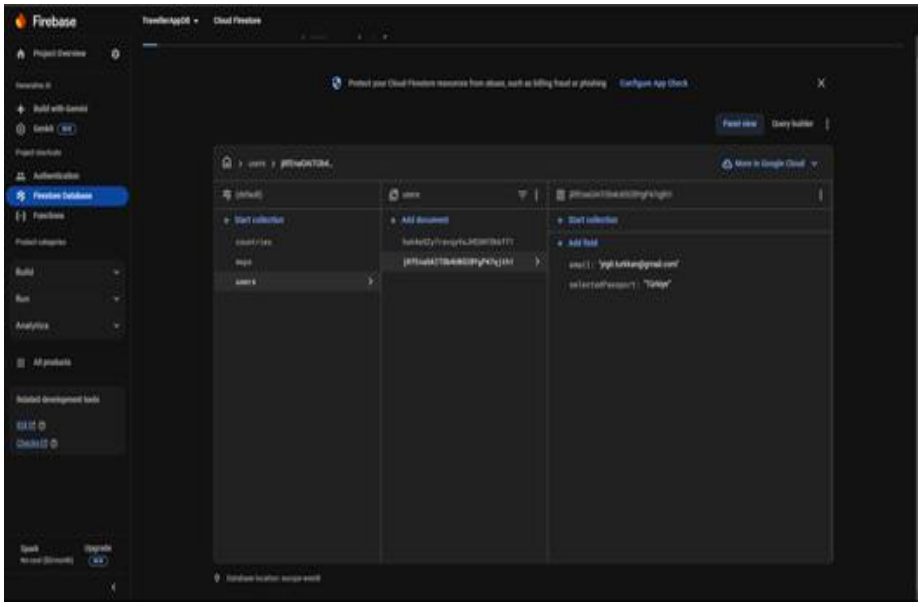

Figure 9. Firestore user data panel

User data is securely managed through Firebase Authentication. Users' personal information and travel history are stored associated with a unique ID (userId) for each user. Country data includes information about countries around the world, such as capital, population, official language, currency, happiness index and security level, and is stored in the Firestore database under the "countries" collection. Users can click on a country on the map and instantly view the details of that country. As

shown in Fig. 10, a separate document has been created for each country in Firestore and regularly updated.

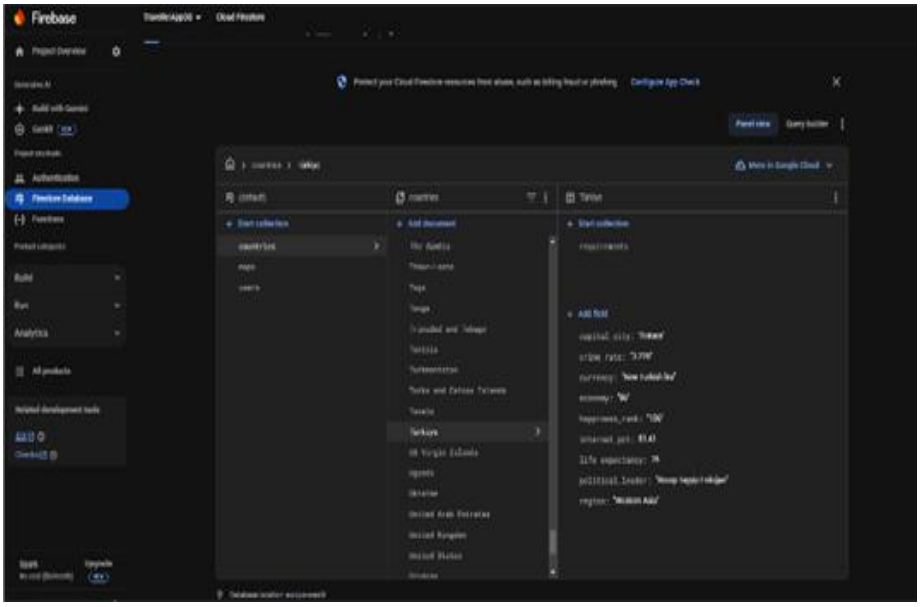

Figure 10. Firestore country data panel

Visa information is stored in Firestore in "*visas/{passportCountry}/{destinationCountry}*" format according to the user's passport country and destination country. Users can view the visa status of the country they want to travel to through the passport selection panel. As shown in Fig. 11, a custom data structure has been created for each passport-destination country pair in Firestore.

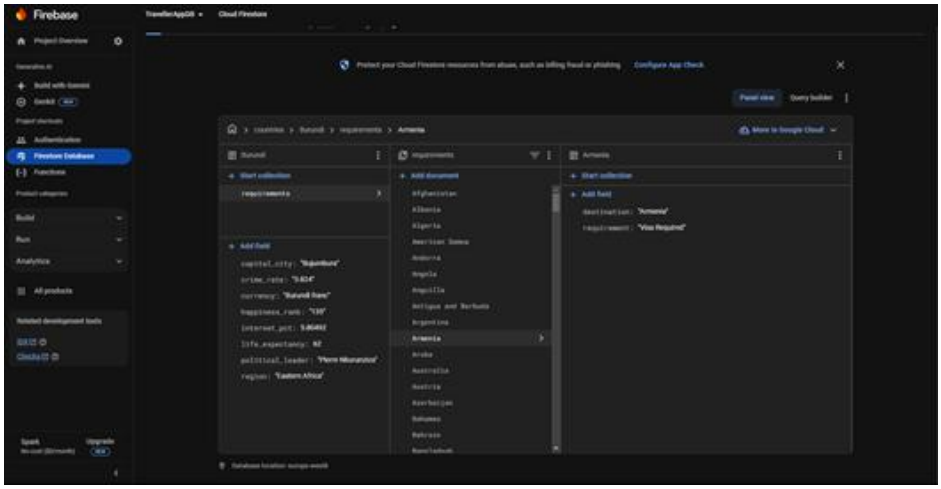

Figure 11. Firestore visa information data panel

Map data provides an interactive structure that allows users to visualize their travel history. The countries marked by users are stored in Firestore's "mapData" collection and updated in real time. As shown in Fig. 12, the map data has an organized structure within the Firestore database.

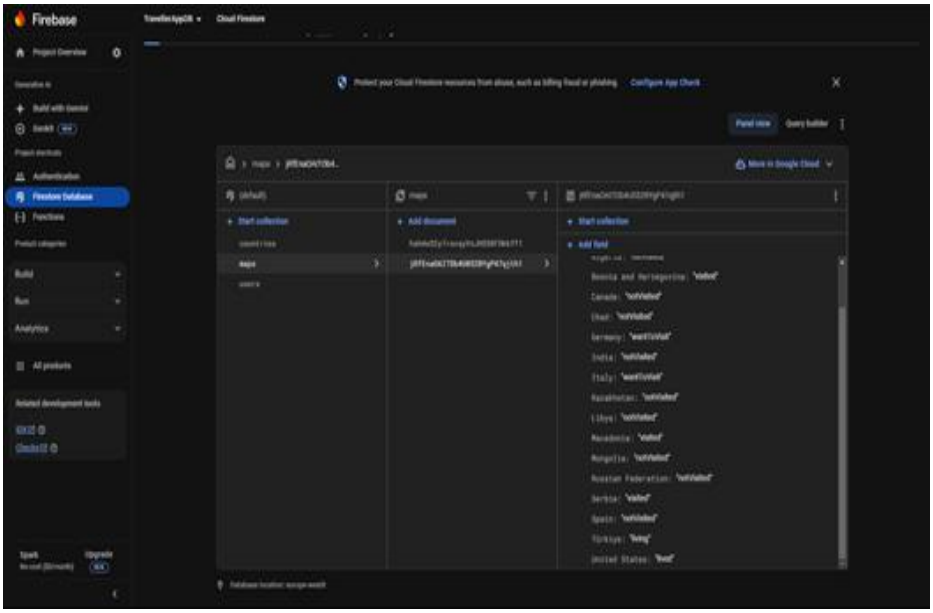

Figure 12. Firestore map data panel

This data management structure allows users to easily organize their travel plans, while the flexible structure offered by Firestore ensures that data is stored quickly and securely. With a user-friendly interface and dynamic data management, the application offers a travel management platform that is both scalable and reliable.

Conclusion and Recommendations

This project was successfully developed as a platform designed to enable users to manage their travel experience more effectively in a digital environment. Using modern web technologies, this application allowed users to interactively record their travel history on a map, access detailed information about countries and plan their travel more efficiently. Thanks to technologies such as Firebase and React.js, a system that meets high standards in terms of security and performance has been created.

The developed interactive map allowed users to categorize their travel status and these categories (such as "I have been", "I want to go", "I live") were dynamically visualized on the map. This feature facilitated both the understanding of travel history and more informed future travel planning. In addition, the application enhances the user experience by providing real-time data synchronization, which is an important advantage. Making critical data, such as visa information, quickly accessible to users allowed for more reliable travel planning. The platform offers a versatile and user-friendly solution that addresses the shortcomings of existing travel applications.

The project faced some technical and organizational challenges. The integration of accurate and up-to-date country data was time-consuming due to the need to collect data from different sources. In particular, the changing nature of visa information in different countries made the integration more complex. This necessitated the inclusion of more data sources and automatic update processes. In addition, the performance of the interactions on the map was sometimes below the expected level, especially on mobile devices. While these issues have been largely addressed with SVG-based map optimizations, they can be completely solved with more advanced optimization techniques.

Several suggestions for future development of the project are presented. An artificial intelligence system that can provide personalized destination recommendations based on users' past travel habits and interests could be integrated. This feature can not only increase user satisfaction but also strengthen loyalty to the platform. In addition, the app's multilingual support system will allow it to

reach a global user base. A multilingual structure can help the app appeal to a wider audience by increasing its accessibility.

Furthermore, the functionality of the app can be enhanced by integrating a diary system where users can add travel notes and a tool to plan their travel routes in detail. In addition, diversifying data sources and developing automatic update systems to ensure the security and timeliness of user data will expand the accuracy and scope of the app. Such features will contribute to making the platform a more comprehensive solution for both individual users and the travel industry.

Overall, this project is a strong example of modern travel apps. The platform is both user-friendly and technically efficient, simplifying users' travel experiences and making the planning process more accessible. The successes have laid a solid foundation for the app's existing user base, while offering significant potential for future expansion and new markets. The continuous development of innovative features will ensure that the app will be a benchmark for both today's and tomorrow's travel apps.

This project work has offered an innovative solution for individuals to organize their travel experiences in the best way possible in a digitalized world and has demonstrated a user satisfaction-oriented approach. This platform, which has the potential to increase its success by appealing to a wider user base in the future, stands out as an important step towards redefining the modern understanding of travel.

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Appendices

Annex 1. Software Codes of the Application (GitHub Link)

Y. E. Türkkan, "Traveller App," GitHub. [Online]. Access Address (26.04.25): https://github.com/YigitEmreTurkkan/ traveller_app.

A TECHNOLOGICAL WEAPON: CYBER DEATH CHAIN

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Abstarct

The cyber death chain defines the cascading effects of adverse events occurring in the digital world. As technology has integrated into our daily lives, the risks of cyber threats and violations of digital privacy have increased. With the rapid advancement of the internet and digital communication, individuals and communities have become more vulnerable to cyber threats. The cyber death chain creates a vicious cycle triggered by situations such as the exposure of personal information, cyberbullying, and violations of digital privacy. In this article, the structure and functioning of the cyber death chain, as well as its effects on institutions and organizations with critical infrastructures, will be examined in detail. Additionally, the importance of ensuring cybersecurity, digital awareness, and ethical issues will be emphasized as efforts to create a safer environment in today's digital age are discussed. In this context, enhancing cybersecurity awareness and the significance of digital ethics will be highlighted.

Keywords: Cyber Death Chain, Digital Privacy, Cyberbullying, Internet Security

INTRODUCTION

Today, technology has become deeply integrated into every aspect of our lives. The opportunities provided by internet technologies have significantly facilitated people's daily lives. However, alongside the positive aspects brought by this digital transformation, there are also serious risks and dangers.

The concept of cyber refers to the abstract and very broad structure working in the infrastructure of information systems. The concept of cyber is also referred to as the cyber environment. Cyber security is the protection of the security and privacy of the cyber environment (Çubukçu & Bayram, 2013). Internet technologies and information and communication technologies used by millions of people have also spread rapidly. As a result, the amount of data produced in the cyber environment has increased exponentially. The importance of the data of institutions, organizations and individuals in the virtual environment has increased even more. Information technology infrastructures are developing faster than information systems security technology. As a result of this rapid change and development, the cyber environment has become vulnerable to attacks and threats and has become an action center for organized crime and terrorist organizations.

The cyber death chain shows how the negative interactions triggered by an event follow each other, creating a vicious circle that expands. Situations such as disclosure of personal information and

violation of the privacy of individuals may have various consequences; Cyberbullying can lead to tragic consequences such as psychological effects and even suicide. In this study, what the cyber death chain is, what factors trigger this chain, and the risks that this phenomenon poses for individuals and communities are examined. Our aim is to become aware of this dark phenomenon in the cyber world and to reveal the steps to be taken to create a safer digital environment.

Cyber Attack Analysis Methods

Cyber attack analysis is the whole of the processes and techniques used to examine and evaluate attacks that occur in the field of cyber security. This analysis allows security professionals to understand potential threats and assess the impact of attacks. Cyber attack analysis methods are various techniques and processes used to detect, analyze, and prevent attacks in the field of cyber security. Some commonly used cyber attack analysis methods are listed below.

Observation and Log Analysis: To detect abnormal or suspicious activities by examining system and network logs. This is important for tracking the trail of cyberattacks.

Network Traffic Analysis: To determine the differences between normal traffic and abnormal traffic by monitoring data packets on the network. This method helps to identify attacks that take place on the network.

Behavioral Analysis: To learn the normal behaviors of users and systems and to detect deviations in these behaviors. Abnormal activity is indicative of a potential attack.

Threat Intelligence: Utilizing information gathered from various sources to gain insights into potential threats and attack techniques.

Attack Simulation: Conduct penetration tests or breach tests to uncover security vulnerabilities in systems and evaluate defense strategies against cyber attacks.

Malware Analysis: Examination of malicious software; this enables an understanding of how malware operates and infiltrates systems.

Vector Analysis: Identifying the pathways through which attacks are executed. This aids in comprehending the source and target of the attack.

Incident Response: Implementation of incident response plans when a cyber attack occurs is essential to minimize the impact of the attack.

Forensic Analysis: Examination of digital evidence obtained from the incident following the attack. This helps to understand when, how, and by whom the attack was carried out.

Risk Assessment: Identification of potential vulnerabilities and threats by evaluating the security status of systems and networks. Risk mitigation strategies are developed.

These analysis methods help cybersecurity professionals detect, understand, and take action against attacks. Each method can be suitable for different types of attacks, and the most effective security strategies are often created by using a combination of multiple methods.

Various models have been developed to analyze actual or planned cyber attacks. These models are; In order to determine the cyber attack method used in the cyber attacks, the stages of the attack, the possible vulnerabilities in the system and to prevent the attack, in the planned attacks; It is used for the purpose of reconnaissance of the target system, attack stages and carrying out the attack.

Models developed to plan and carry out cyber attacks are also used to combat attacks and create defense strategies. The objectives of cybersecurity models are shown in Figure 1.

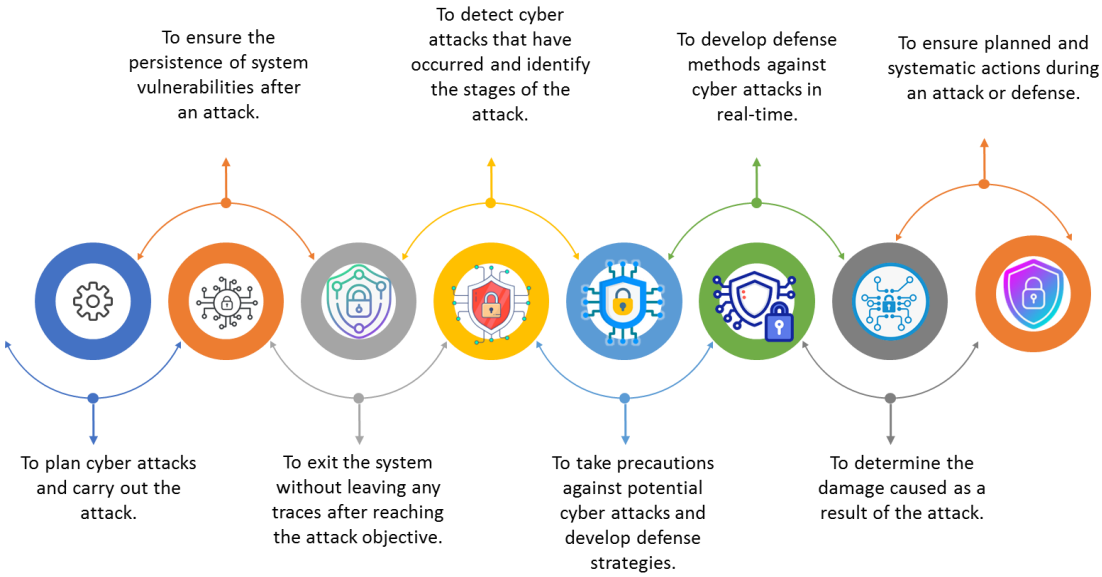

Figure 1. Objectives of Cyber Security Models

Models developed to manage and analyze cyber attacks/defenses can be used for the following purposes.

1) Planning and carrying out cyber attacks,

2) To ensure the continuity of system vulnerabilities after the attack,

3) Leaving the system without leaving a trace after the attack target is achieved,

4) To detect cyber attacks and determine the attack stages,

5) To take precautions against possible cyber attacks and to develop defense strategies,

6) To develop a defense method against cyber attacks,

7) To determine the damage caused as a result of the attack,

8) To ensure that planned and systematic action is taken during attack or defense.

Commonly used cyber attack and defense models are listed below.

- Cyber Kill Chain
- MITRE Offensive Tactics, Techniques and Common Knowledge-MITRE ATT&CK Framework (Adversarial Tactics, Techniques and Common Knowledge)
    - MITRE Enterprise Matrix (Enterprise ATT&CK Matrix)
    - MITRE Mobile Matrix (Mobile ATT&CK Matrix)
    - MITRE Industrial Matrix (Industrial Control Systems (ICS) ATT&CK Matrix)

Material Method

Cyber Kill Chain

Various models have been developed to analyze actual or planned cyber attacks. These models are used for reconnaissance, planning, and attack phases of cyber attacks and to perform or prevent the attack.

The model called "Cyber Kill Chain", developed by Lockheed Martin in 2011, is a 7-stage model created to carry out or prevent the attack and shown in Figure 2 (Kill Chain, 2022).

1) Reconnaissance
2) Weaponization
3) Transportation
4) Exploitation
5) Installation
6) Command and Control
7) Actions

Figure 2. **Cyber Kill Chain Stages (Cyber Kill Chain, 2025)**

The cyber death chain method has been developed primarily to identify and classify the tactical, cyber technical and cyber attack methods applied by the attacker in order to complete the cyber defense process without any problems.

Cyberattacks happen in stages. Controls set up for attacks at each stage will make it easier to prevent or eliminate attacks. The cyber chain of death model has been adopted by many people or institutions working in the field of cyber security.

The steps of the Cyber Chain of Death method, the stages of which are indicated in Figure 3, are explained below.

1) **Reconnaissance:** After determining the target to be attacked, the characteristics of the target are investigated and the vulnerabilities on the network are tried to be accessed. Information about the target that can be used in the attack is collected.

2) Weaponization: Based on the vulnerabilities and vulnerabilities identified during the reconnaissance phase, the appropriate weapon (virus, software to serve the purpose, etc.) is prepared. At this stage, where the attack method is determined, the attack center, other people or technical personnel who will serve the attack are also determined.

3) **Transportation (Transmission):** The software prepared as a weapon in line with the identified vulnerabilities transmits to the target via digital communication platforms or physical devices.

4) **Exploitation:** When the prepared weapon (software, virus, etc.) is delivered to the target system, it works in line with the purpose of the attack by taking advantage of the vulnerabilities detected.

5) **Installation:** It is the process of installing malicious software created by attackers to build a foothold in the target network.

6) **Command and Control:** It is the process by which the attacker/attackers have permanent access and remote control privileges over the target network.

7) **Action:** The attacker(s) take action to achieve their goals such as stealing data, deleting data, locking files for a ransom demand, disrupting service and causing hardware damage.

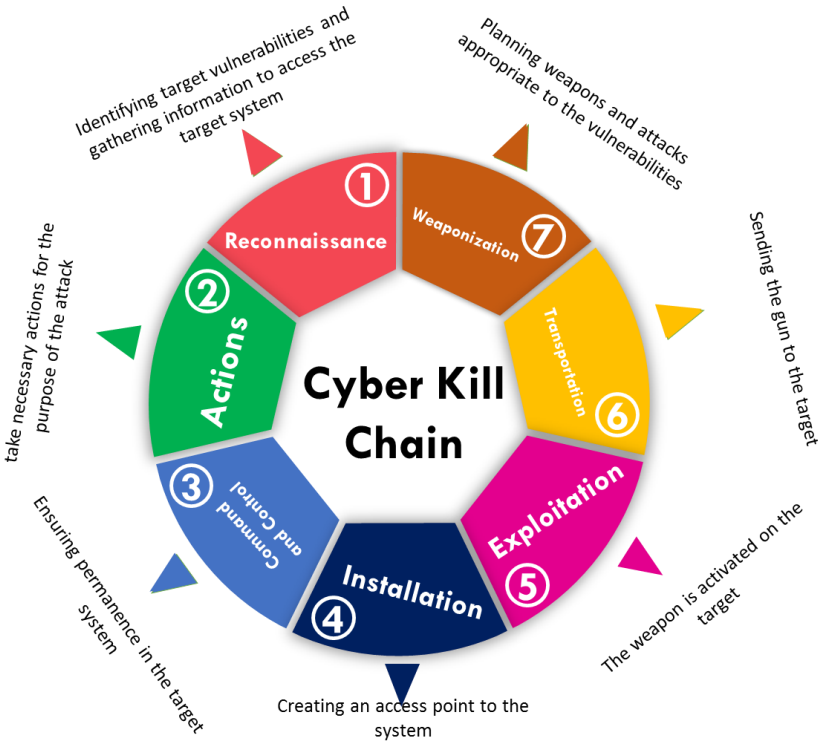

Figure 3. **Cyber Kill Chain**

In Table 1, a sample application of the cyber death chain method is carried out.

Table 1. **Cyber Chain of Death Case Study**

Attack Stages	**Actions Performed**
1. Reconnaissance	Target email addresses are identified.
2. Weaponization	A malicious .doc file is prepared.
3. Delivery	The malicious .doc file is sent to the target via email.
4. Exploitation	The CVE-2017-8570 vulnerability is exploited.
5. Installation	The malware adds itself to the registry file. (HKEY_CURRENT_USER\Software\Microsoft\Windows\Current\Version\Run)
6. Command & Control	Communicates with xx.77.87 via HTTPS.
7. Actions on Objectives	Sends files containing corporate data to the command and control center.

In the reconnaissance phase, general research reveals a remote code execution vulnerability in Microsoft Office software when it fails to properly handle objects in memory (CVE-2017-8570, 2022). This vulnerability in Microsoft Office allows the prepared file to perform actions on behalf of the logged-in user with the same permissions (CVE-2017-8570, 2022).

After determining the target, the target's email address is identified in the reconnaissance phase. A malicious .doc file is prepared to exploit the CVE-2017-8570 vulnerability. The prepared file is sent to the target via email. The file attempts to embed itself in the system by adding itself to the registry area. In the command and control step, the file installed on the system communicates with a remote computer using the HTTPS port and sends the specified type of files from the target to the control center.

The Cyber Kill Chain is an important model for cyber attack stages. However, an important vulnerability in this model is that the reconnaissance operations in the first stage are performed outside the target network. It will be difficult to detect the system vulnerabilities and weaknesses of the target.

The Cyber Kill Chain model is insufficient in the case of an internal threat to the system. When an attack is carried out within the company/institution since the attacker knows the system infrastructure, steps such as reconnaissance, delivery, and installation in the model will have already been bypassed.

The Cyber Kill Chain model can be used for attack planning and execution as well as for counter-defense purposes. The following steps are applied for defense against attacks.

1) Detect: Determining whether there is unusual activity in the system. For this purpose, developed antivirus systems, Endpoint Detection and Response (EDR) solutions, and Security Information and Event Management (SIEM) are used.

2) Deny: When unusual activity is detected in the system, measures should be taken to prevent the information from being exposed.

3) Disrupt the Attack: When signs of an attack are detected in the system, the outgoing traffic should be stopped or the traffic flow should be changed to disrupt the attack.

4) Reduce the Threat Level: The method and action of the attack on the system are tried to be detected, and countermeasures are taken against the method to minimize the action (data theft, data deletion, locking files for ransom demands, service disruption, and hardware damage).

5) Deceive: According to the detected action, the locations of the data or hardware elements in the target are virtually changed to prevent reaching the actual target.

6) Contain: Determining the attack method and closing the vulnerabilities in the system. It also includes restoring damaged information, documents, or hardware to ensure service continuity.

Cyber attacks are logical and virtual events. They occur with the direct or indirect involvement of human factors using information technology infrastructure (Herrmann, 2007). According to the documents used in the "Certified Ethical Hacking (CEH)" or "White Hat Hacker" training programs, cyber attacks are grouped under five main headings (CEH, 2022). The stages of cyber attacks in white hat hacker training programs are explained below.

First Stage: Reconnaissance and Recognition

This is the stage where the attacker collects information about the target from resources accessible to all users. In this stage, which forms the basis of the attack, detailed information about the target institution/organization or individual is collected. Information such as business processes used by the target, technical personnel details, devices in critical infrastructure, and security measures are collected using the following methods and tools (CEH, 2022).

- Internet search engines
- Social engineering
- Dumpster diving
- DNS management/searches
- Non-intrusive network scanning

Since information about institutions/organizations can be shared from various sources on the internet, this stage is the most difficult stage to take security measures. Information about institutions/organizations can be shared by various service providers as well as by personnel working in institutions/organizations. The aim of reconnaissance/recognition studies is to obtain important information for the planned attack on the software and hardware assets in the target infrastructure. Based on the information obtained from reconnaissance/recognition studies, the attack method, the number of attackers, and the attack target will be determined.

Second Stage: Scanning

After the attacker obtains sufficient information about the target, attempts are made to access the following vulnerabilities in the target's internet-exposed and critical infrastructure devices (CEH, 2022).

- Open ports on network devices,
- Service vulnerabilities in software used on the network,
- Known cybersecurity vulnerabilities in operating systems and software,
- Failure to take security measures during data copying or transfer operations,
- Detection of possible vulnerabilities in devices on the target network through simulations.

Third Stage: Gaining Access

This is the stage where the attacker gains access to intervene in the target's system. The attacker aims to either directly benefit from the target's information technology system or use the target's systems

as a resource to attack another target. For both purposes, the attacker must have full or partial access to the target system (CEH, 2022).

Fourth Stage: Maintaining Access

This is the process of maintaining permanent or long-term access to the target system after the hacker reaches it. If the target is to be used for another attack, access must be maintained until the attack process is completed. If access is gained for purposes such as data theft, encryption, or damaging critical infrastructure, access must be maintained until these purposes are achieved (CEH, 2022).

Fifth Stage: Covering Tracks

These are the operations performed by the attacker to hide the path followed to access the target system and to prevent system administrators from detecting the attack method after achieving the purpose.

Protecting Against Cyber Kill Chain Attacks

To understand and prevent the effects of the cyber kill chain, comprehensive training on cyber threats, attack types, and ways to protect against them should be provided to raise awareness of threats. Institutions and organizations should determine their own security standards and protocols based on international security standards, which is the most important layer in protecting against attacks.

Especially in institutions and organizations with critical infrastructure, establishing real-time monitoring systems and performing log analysis to detect abnormal activities are very important. Detecting abnormalities on the system is a very important situation to survive cyber attacks with minimal damage.

To ensure cybersecurity, penetration tests should be performed to detect security vulnerabilities against cyber attacks, and urgent measures should be developed against these possible vulnerabilities.

A special team should be established to detect attacks and intervene in attacks, and security measures should be taken in case of any attack. While performing penetration tests, attack simulations should be created to determine how attack detection and intervention teams will behave in an active attack. Necessary technical training should be organized to eliminate the deficiencies seen in the personnel.

Possible attacks should be planned, and the measures to be taken against these attacks and what needs to be done during the attack should be planned in detail, and the technical team should be divided into tasks. Steps should be developed to intervene quickly in case of an attack.

Encryption methods and firewalls should be used to protect data, and measures should be taken in advance against possible external threats. Data should be regularly backed up, and recovery plans should be prepared in case of an extraordinary situation.

Regular evaluation and updating of security vulnerabilities are important to respond quickly to changes in cyber threats. Security measures and physical infrastructure and software used for security purposes should be kept up to date.

Comprehensive reports should be prepared after a real attack or test attacks, and it should be evaluated which strategy is effective and which areas need improvement, and studies should be carried out in these areas. Continuous improvements should be made in cybersecurity strategies based on the data and analysis obtained.

The implementation of these steps is necessary to limit the effects of the cyber kill chain and make institutions and organizations more resilient to cyber threats. Considering the increasing cyber attacks on a global scale, taking such preventive measures is of critical importance for the security of individuals, institutions, and organizations.

Various Cyber Attacks Carried Out Using the Cyber Kill Chain Method

Various cyber attacks carried out using the cyber kill chain method are generally multi-stage and complex structures. Below are some notable examples of cyber attacks carried out using this method:

1. Sony PlayStation Network Attack

Sony's PlayStation Network service was subjected to a major cyber attack in 2011. The attackers gained access to user information and stole the personal data of approximately 77 million users. The attackers infiltrated the PSN system by exploiting social engineering and software vulnerabilities. The theft of data led to the misuse of users' account information and Sony falling into a major security breach (Sony PlayStation Hack, 2025).

2. Target Data Breach

Attackers gained access to an external supplier of Target, infiltrated the POS systems, and caused a major data breach in 2013. 40 million credit card information and 70 million users' personal information on Target were stolen. This process occurred with the use of malicious software and the takeover of the system. After the attack, Target's brand reputation was greatly damaged (Target Hack,2025)

3. Equifax Data Breach

Equifax, a financial institution processing credit information, was subjected to a significant cyber attack in 2017. The attackers used a vulnerability in the Apache Struts software to steal the personal information of 147 million people. After gaining access to the data, the data was transferred outside due to inadequate security measures (Equifax Hack, 2025).

4. WannaCry Ransomware Attack

Attackers used a zero-day vulnerability in Microsoft's Windows operating system to spread malicious software, causing a ransomware attack affecting many institutions worldwide in 2017. More than 200,000 computers were affected, and users' files were encrypted. A ransom was demanded to recover the data on the affected systems (WannaCry Hack, 2025).

5. SolarWinds Attack

SolarWinds, a worldwide software company, was the target of a complex cyber attack affecting many large companies and government agencies in 2020. As a result of this attack, many critical structures were infiltrated. The attackers used SolarWinds' update mechanism and placed malicious software in the update, gaining widespread access to target systems. This attack remained hidden in the systems for a long time and caused large information leaks (SolarWinds Hack, 2025).

6. Colonial Pipeline Attack

The cyber attack on Colonial Pipeline, operating in the energy sector in 2021, greatly affected the fuel flow on the east coast of the USA. The attackers used ransomware to stop the service. The attackers captured a user account and entered the system, the company had to pay the ransom, and fuel shortages occurred in many states after this attack (Colonial Hack, 2025).

7. Kaseya Attack

A major ransomware attack was carried out against Kaseya, a management software provider, in 2021. The attack affected more than 1,500 small businesses worldwide. The attackers injected malicious software into Kaseya's update server and gained access to their customers' systems. As a result of this operation, a ransom was demanded from the affected businesses (Kaseya Hack, 2025).

8. Facebook Data Breach

In 2021, a cyber attack was carried out by exploiting various security vulnerabilities, resulting in the leakage of phone numbers and personal information of 533 million Facebook users. This data, including user information from 106 countries, also included information from 19,638,821 people from Turkey. The sale of user data on various forums seriously affected the platform's reliability (Facebook Hack, 2025).

9. JBS Attack

JBS, one of the world's largest meat processing companies, was subjected to a ransomware attack in 2021. As a result of the attack, the company's operations in North America and Australia were halted. The attackers infiltrated the company's systems and encrypted the files, demanding a ransom from JBS. JBS agreed to pay an $11 million ransom to bring the affected systems back to normal (JBS Hack, 2025).

10. Microsoft Exchange Server Attacks

In 2021, thousands of companies worldwide were targeted by exploiting four zero-day vulnerabilities in Microsoft Exchange servers. The attackers used these vulnerabilities to infiltrate the email servers of more than 250,000 organizations. This process allowed the theft of user data and the placement of backdoors. Microsoft quickly released patches for users to update their systems and provide protection (Microsoft Hack, 2025).

11. LAPSUS$ Group Attacks

A hacker group named LAPSUS$ carried out cyber attacks against many large technology companies. Targets included large firms such as NVIDIA, Vodafone, Samsung, and Microsoft. The attacker group used social engineering, credential theft, and vulnerabilities in various software to infiltrate their targets' systems leaked internal information of the companies and demanded ransom by blackmailing (Lapsus Hack, 2025).

12. Cisco Attack

A cyber attack on Cisco systems in early 2022 led to a major security breach. The attackers captured the credentials of a Cisco employee and infiltrated the organization, stealing important data (Cisco Hack, 2025).

13. Okta Attack

Okta, an authentication and user management platform, was subjected to a significant cyber attack in 2022. The attackers infiltrated Okta's partner service provider and captured user credentials to access customer accounts. This situation endangered the security of many companies (Okta Hack, 2025).

These recent cyber attacks show how widespread and complex cyber threats have become. Each attack provides important lessons in the field of cybersecurity and serves as an encouraging factor for organizations to increase their security measures. Since cybersecurity is a constantly evolving field, continuous monitoring, training, and updates are of critical importance.

RESULTS

The rapid advancement of technology leads to the emergence of new threats in the field of cybersecurity. The cyber kill chain is an important concept that helps us understand the cascading effects of adverse events in the digital world. In this study, the structure, functioning, and effects of the cyber kill chain on institutions with critical infrastructure have been examined in detail. The Cyber Kill Chain systematically explains the processes of attackers infiltrating target systems, maintaining persistence in these systems, and achieving their ultimate goals. This model is of critical importance both for understanding attackers' strategies and for developing defense mechanisms. In an

increasingly digitalized world, individuals and communities are becoming more vulnerable to cyber threats.

Table 2 shows the consequences of cyber attacks and the financial losses experienced after the attacks. It has been observed that cyber attacks not only cause financial losses but also affect the reputation of companies, institutions, or even countries. The study emphasizes that traditional security measures are insufficient in the face of the increasing complexity and target-oriented nature of cyber attacks. Especially the use of technologies such as artificial intelligence, machine learning, and big data analytics by cyber attackers further increases the scale of threats. Therefore, cybersecurity strategies need to be continuously updated and a proactive approach needs to be adopted.

Table 2. Cyber Attacks and Financial Damages

Attack Name	**Year**	**Estimated Financial Damage**	**Results**
Sony PlayStation Network Attack	2011	171 million USD	Personal information and credit card details of 77 million users were stolen, and services were significantly disrupted after the attack.
Target Data Breach	2013	162 million USD	40 million credit card details and 70 million users' personal information were stolen, and customer trust was damaged after the attack.
Equifax Data Breach	2017	1.4 billion USD	The personal information of 147 million people was stolen, and the company suffered a loss of reputation after the attack.
WannaCry Ransomware Attack	2017	4 billion USD	More than 200,000 computers were affected by the attack targeting the healthcare sector. Major disruptions occurred in healthcare services, and hospitals and related business operations were halted.
SolarWinds Attack	2020	18 billion USD	Many US government agencies and institutions were infiltrated, and important data was accessed.
Colonial Pipeline Attack	2021	4.4 billion USD	The fuel supply chain in the US was disrupted, and the attack was stopped by paying the ransom.
Kaseya Attack	2021	70 million USD	More than 1,500 businesses were affected, and many small businesses were unable to provide services after the attack.
Facebook Data Breach	2021	5 billion USD	Phone numbers and personal information of 533 million Facebook users were leaked. This data included user information from 106 countries, including 19,638,821 people from Turkey.
JBS Attack	2021	11 million USD	JBS, the world's largest meat producer, had to halt operations and pay the ransom to end the attack.
Microsoft Exchange Server Attacks	2021	Unknown	Email servers of more than 250,000 organizations were compromised, malicious software was leaked, and personal data was stolen after the attack.
Cisco Attack	2022	Unknown	Cisco employees' credentials were stolen, access to the internal network was gained, and important company data was stolen.
Okta Attack	2022	Unknown	The systems of Okta, an authentication service provider, were compromised, and access to customer accounts was gained.

Additionally, it has been observed that cyber attacks have not only technological but also social, economic, and political consequences. Attacks on critical infrastructure, financial systems, and government institutions can have consequences that affect the entire society. Therefore, cybersecurity

should be addressed not only as a technical issue but also as a national and international security issue.

Increasing cybersecurity awareness and strengthening training on digital ethics are essential to create a safer digital environment in the future. International collaborations, the establishment of standards, and effective policy development processes will provide an effective roadmap in the fight against cyber threats.

In conclusion, the Cyber Kill Chain model provides an important framework for understanding cyber threats and developing effective defense mechanisms against these threats. However, to achieve success in the field of cybersecurity, in addition to technological solutions, elements such as education, awareness, and international cooperation should not be overlooked. As cyber threats are expected to become even more complex in the future, the importance of studies in this field will gradually increase.

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AI AND THE FUTURE OF INDUSTRY: FROM AUTOMATION TO INTELLIGENT DECISION-MAKING

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Abstract

Artificial Intelligence (AI) is profoundly transforming the industrial sector by enhancing production, quality control, and process optimization. This revolution is driven by the increasing availability of data, greater computational power, and significant mathematical advancements. Despite rapid adoption—70% of industrial companies have already implemented AI—several challenges hinder its expansion, including a lack of skilled talent, integration issues with existing systems, and high costs.

Deep learning plays a crucial role in **resolving industrial problems** by leveraging historical data to predict failures and optimize quality assurance. In **predictive maintenance**, AI models analyze **sensor data and historical failure records** to detect early signs of anomalies, allowing companies to anticipate breakdowns and reduce unplanned downtime. Techniques such as **LSTMs, autoencoders, and transformers** enable accurate failure prediction and real-time monitoring of industrial equipment.

Similarly, in **quality inspection**, deep learning models such as **CNNs, YOLO, and Vision Transformers** process large datasets of historical defects to improve defect detection accuracy. By learning from past manufacturing errors, AI-driven vision systems enhance **automated defect classification, anomaly detection, and process optimization**, ensuring continuous quality improvement.

To successfully implement AI-driven maintenance and quality solutions, companies must adopt a data-driven approach, integrate AI into existing workflows, and collaborate with technological and academic partners. The future of industrial AI is heading toward **self-optimizing production lines, real-time predictive analytics, and enhanced human-AI collaboration**, leading to more reliable and efficient industrial processes.

Keywords: Artificial Intelligence (AI), Industry 4.0, Smart Manufacturing, Industrial Automation, Digital Transformation. Deep learning

MACHINE LEARNING APPROACHES FOR INTRUSION DETECTION IN WIRELESS NETWORKS

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Abstract

Wireless networks are highly susceptible to cyber threats due to their open, decentralized nature. Traditional security measures, such as firewalls and signature-based intrusion detection systems (IDS), often struggle to detect sophisticated and evolving attacks. As cyber threats become more complex, there is a growing need for more advanced and adaptive intrusion detection strategies to safeguard wireless networks from threats such as denial-of-service (DoS) attacks, unauthorized access, and malicious data injections. This paper discusses various approaches to improving intrusion detection accuracy in wireless environments. We examine methods like behavior-based anomaly detection, heuristic analysis, and rule-based filtering to identify both known and emerging threats. Furthermore, we discuss how decentralized security frameworks and network segmentation strategies enhance resilience against cyber attacks. One of the key challenges in deploying IDS on wireless networks is ensuring access to high-quality threat intelligence and minimizing false positives. This paper highlights the importance of robust encryption, secure authentication protocols, and real-time traffic analysis for strengthening network defenses. Furthermore, recent advancements in distributed security architectures and edge computing offer new possibilities for proactive and responsive threat mitigation. Our findings indicate that an effective IDS must integrate multiple security layers, including encryption, authentication, and real-time monitoring, to provide comprehensive protection against cyber threats

Keywords: IDS, Real Time Traffic, Cyber Security, DoS attack, Wireless Networks.

INVESTIGATION ON TÜRKİYE AND AZERBAIJAN HIGHWAY SAFETY SYSTEMS AND TRAFFIC ACCIDENTS

TÜRKİYE VE AZERBAYCAN KARAYOLU GÜVENLİK SİSTEMLERİ VE TRAFIK KAZALARI ÜZERINE İNCELEME

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ÖZET

Bu çalışmada, karayolu güvenliğinin ve trafik kazalarının, Türkiye ve Azerbaycan ülkeleri arasındaki konumlandırılmış yerini, alınan önemleri ve etkilerini, yıllara göre yenilikçi yaklaşımların etkisinin yerel olarak hissedilmesi gibi önemli ana başlıklarda incelenmesi yapılmaya çalışılmıştır. Türkiye ve Azerbaycan, güvenli karayolu ulaşımının kritik önemini giderek daha fazla vurgulamaktadır. İki ülke arasındaki trafik yoğunluğunun artması, karayolu güvenlik sistemlerini iyileştirmek için yeni imkanlar sunmaktadır. Türkiye, uluslararası standartlarla uyumlu güvenlik sistemleri geliştirmeyi hedefleyerek, trafik kazalarını önlemeye yönelik çeşitli teknolojik çözümler uygulamaktadır. Bu nedenle, her iki ülkenin karayolu güvenliğini artırmak için gösterdiği çaba, bölgede ulaşım güvenliğini sağlamak açısından kilit bir önem taşımaktadır. Karayolu bağlantılarının güçlendirilmesi, ekonomik işbirliğinin yanı sıra, güvenlik önlemlerinin de artırılmasını zorunlu kılmaktadır. Bu bağlamda, trafik kazalarının önlenmesi, Türkiye ve Azerbaycan için öncelikli hedeflerden biri haline gelmiştir. Bu iki ülkede her yıl meydana gelen trafik kazaları, ciddi can kayıplarına ve yaralanmalara yol açmakta olup, karayolu güvenliğinin iyileştirilmesi gereksinimini daha da acil hale getirmektedir. Bu durum, her iki ülkenin karayolu güvenliğini artırma çabalarının önemini daha da artırmaktadır. Güvenli karayolları sağlamak, hem ekonomik gelişim hem de vatandaşların güvenliği açısından son derece kritik bir konudur. Bu nedenle, Türkiye ve Azerbaycan, bu alandaki işbirliklerini güçlendirerek trafik kazalarını azaltma hedeflerine ulaşmayı planlamaktadır. Bu işbirlikleri, her iki ülkenin ulaşım altyapısını geliştirme konusundaki stratejilerinin daha etkili bir şekilde hayata geçirilmesine olanak tanımaktadır. Buna ek olarak gelişim ve geliştirme konularında güncelliği takip edip sürdürülebilirlik alanında da aktif çalışmalara destek olunmalıdır. Bu çalışma iki ülkenin kendi içerisinde uyguladığı ulaşım güvenliği politikaları ve yansımaları konusunda değerlendirmeler içermektedir.

Anahtar Kelimeler: Karayolu Güvenliği, Trafik Kazaları, Ulaşım Ağları, Karayolu Trafiği

ABSTRACT

In this study, it has been tried to investigate the positioned position of highway safety and traffic accidents between Türkiye and Azerbaijan countries, their importance and effects, and the local feeling of the impact of innovative approaches over the years in important main topics Dec. Türkiye and Azerbaijan are increasingly emphasizing the critical importance of safe road transport. The increase in traffic density between the two countries offers new opportunities to improve road safety systems. Dec. Türkiye aims to develop safety systems that are compatible with international standards and applies various technological solutions to prevent traffic accidents. Therefore, the efforts made by both countries to improve road safety are of key importance in terms of ensuring transportation safety in the region. Strengthening highway connections necessitates increasing security measures as

well as economic cooperation. In this context, the prevention of traffic accidents has become one of the priority goals for Türkiye and Azerbaijan. Traffic accidents that occur every year in these two countries lead to serious loss of life and injuries, making the need to improve road safety even more urgent. This situation further increases the importance of the efforts of both countries to improve road safety. Providing safe highways is an extremely critical issue both for economic development and for the safety of citizens. For this reason, Türkiye and Azerbaijan plan to achieve their goals of reducing traffic accidents by strengthening their cooperation in this area. These collaborations enable the implementation of the strategies of both countries in developing the transportation infrastructure in a more effective way. In addition, it should follow the topicality in development and development issues and support active work in the field of sustainability. Oct. This study includes assessments on the transportation security policies implemented by the two countries and their reflections.

Keywords: Road Safety, Traffic Accidents, Transportation Networks, Highway Traffic

GİRİŞ

Türkiye ile Azerbaycan arasındaki güvenli karayollarının önemi, iki ülke arasındaki trafik akışının artmasıyla birlikte daha da belirgin hale gelmiştir. Bu durum, karayolu güvenlik sistemlerinin geliştirilmesi için yeni fırsatlar sunmaktadır. Türkiye, uluslararası standartlara uygun güvenlik sistemleri oluşturma çabası içinde, trafik kazalarını önlemek amacıyla çeşitli teknolojilerden yararlanmaktadır. İki ülke arasındaki karayolu bağlantılarının güçlenmesi, sadece ekonomik işbirliğini değil, aynı zamanda güvenlik önlemlerinin de geliştirilmesini zorunlu kılmaktadır. Türkiye'nin bu alandaki çabaları, hem ulusal hem de uluslararası düzeyde güvenli bir ulaşım ağı oluşturma amacını taşımaktadır. Bu bağlamda, karayolu güvenlik sistemlerinin sürekli olarak yenilenmesi ve iyileştirilmesi büyük önem arz etmektedir. Türkiye ve Azerbaycan, sınır karayollarının güvenliğini sağlamak için ortak bir çaba içinde bulunmaktadır. Bu kapsamda, yollara yerleştirilecek olan güvenlik sistemleri, her iki ülkenin de güvenlik standartlarını yükseltmeyi amaçlamaktadır. İki ülke arasındaki bu işbirliği, sınır bölgelerindeki karayollarının güvenliğini sağlamak için önemli bir adım olarak değerlendirilmektedir.

Türkiye ve Azerbaycan'da trafik kazalarının önlenmesi, her iki ülkenin de öncelikli hedefleri arasında yer almaktadır. Her yıl, bu ülkelerde meydana gelen trafik kazaları, ciddi can kayıplarına ve yaralanmalara neden olmaktadır. Bu tür kazaların azaltılması, ekonomik kalkınmanın yanı sıra, bireylerin sağlık ve güvenliğini de olumlu yönde etkilemektedir. Türkiye ile Azerbaycan, karayolu güvenliğini artırmak ve trafik kazalarını önlemek amacıyla sürekli bir işbirliği içinde bulunmaktadır. Bu işbirliği çerçevesinde, her iki ülke, yeni teknolojilerin geliştirilmesi ve hayata geçirilmesi, eğitim ile danışmanlık hizmetlerinin sunulması gibi çeşitli adımlar atmaktadır. İki ülke arasındaki bu işbirliği, karayolu güvenlik sistemlerinin iyileştirilmesi için önemli bir zemin oluşturmaktadır. Türkiye ve Azerbaycan, trafik kazalarının azaltılması hedefi doğrultusunda, yenilikçi çözümler üzerinde çalışmakta ve bu alanda bilgi paylaşımında bulunmaktadır. İki ülke, karayolu güvenliğini sağlamak ve trafik kazalarının önüne geçmek için sürekli bir işbirliği içinde olmalıdır.

Türkiye ve Azerbaycan'ın yol altyapısı, karayolları açısından değerlendirildiğinde, Türkiye'de 2020 yılı itibarıyla toplam 1.525.872 kilometre yol bulunmaktadır. Öte yandan, Azerbaycan'da 2018 yılı itibarıyla toplam 10.976 kilometre karayolu mevcuttur. Bu veriler, her iki ülkenin ulaşım altyapısının büyüklüğünü ve gelişim düzeyini göstermektedir. Türkiye'deki karayollarında trafik kazalarının sayısı, 2019 yılında 57.180 olarak kaydedilmiştir. Azerbaycan'da ise 2018 yılında meydana gelen trafik kazası sayısı 3.782'dir. Bu veriler, her iki ülkedeki trafik güvenliği durumunu karşılaştırmak açısından önem taşımaktadır. Türkiye'de trafik kazalarının dakika başına ortalaması 6,57 olarak hesaplanırken, Azerbaycan'da bu oran 0,79 olarak belirlenmiştir. Bu istatistikler, her iki ülkenin trafik kazalarıyla ilgili durumunu daha iyi anlamak için kullanılabilir. Bu bilgilerin doğruluğu ve güncelliği belirtilen kaynaklardan elde edilmiştir.[1], [2], [3]

ARAŞTIRMA VE BULGULAR

Türkiye ve Azerbaycan Karayolu Güvenlik Sistemleri

Yol güvenliği sistemlerinin uygulanması ve iki ülke arasındaki güvenlik sistemlerinin çeşitlendirilmesi konusunda ortak bir anlayışa sahiptirler. Bu anlayış, yasalar, yaptırımlar, altyapı, eğitim, acil durum hizmetleri ve teknolojiyi kapsamaktadır. Türkiye'nin yol güvenliğine yönelik önemli yatırımlar yaptığı bilinmektedir. Ülkede, hız limitleri ve emniyet kemeri kullanımı gibi katı trafik yasaları mevcuttur. Uygulama aşamasında, trafik polisleri ve kameralarla desteklenen etkili bir denetim sistemi bulunmaktadır. Altyapı, daha iyi otoyollar ve güvenli kavşaklarla önemli ölçüde iyileştirilmiştir. Sürücüler ve yayalar için düzenlenen eğitim kampanyaları oldukça yaygındır. Acil servisler, iyi bir organizasyon yapısına sahip olup, trafik yönetim sistemleri gibi modern teknolojilerle desteklenmektedir. Bu unsurlar, yol güvenliğini artırmaya yönelik bütüncül bir yaklaşımın parçasını oluşturmaktadır. Azerbaycan son dönemlerde yol güvenliği sistemlerini iyileştirme çabası içerisindedir. Yasal düzenlemelerini güncelleyerek uygulama aşamasında ilerleme kaydetmeye çalışıyorlar; ancak bu uygulamalar, Türkiye'deki kadar sıkı olmayabilir. Altyapı, özellikle Bakü çevresinde gelişim gösterirken, kırsal bölgelerde bazı zorluklarla karşılaşılabilir. Kamuoyunun yol güvenliği konusundaki farkındalığı giderek artmakta, ancak bu konuda daha fazla çaba sarf edilmesi gerekmektedir. Acil servislerin durumu da iyileşmekte olup, trafik yönetiminde teknolojik yeniliklerden faydalanmaya başlamışlardır.

Bu gelişmeler, yol güvenliğini artırma yönünde önemli adımlar olarak değerlendirilmektedir. Azerbaycan'ın yol güvenliği alanındaki çabaları, hem yasal hem de altyapısal düzeyde ilerleme kaydetmesine rağmen, hala geliştirilmesi gereken yönler bulunmaktadır. Kırsal alanlardaki zorluklar ve kamu bilincinin artırılması, bu sürecin önemli bileşenleridir. Gelecekte, acil servislerin ve teknolojinin entegrasyonu ile daha güvenli bir trafik ortamı sağlanması hedeflenmektedir. Türkiye, altyapı ve uygulama alanında daha gelişmiş bir görünüm sergilemektedir. Azerbaycan ise hızla ilerlemekte ve daha fazla gelişim potansiyeline sahip bir konumdadır. Her iki ülke de sürücü davranışları ve kırsal bölgelerdeki altyapı eksiklikleri gibi ortak zorluklarla mücadele etmektedir. Her iki ülke teknoloji kullanımında aktif bir rol oynamaktadır; ancak Türkiye, bu alanda daha fazla entegrasyon sağlamış gibi görünmektedir. Bu durum, Türkiye'nin altyapı ve uygulama konusundaki avantajını pekiştirmektedir. Azerbaycan'ın ise bu alanda daha fazla gelişim göstermesi beklenmektedir. Türkiye ve Azerbaycan, benzer zorluklarla karşılaşsalar da, Türkiye'nin mevcut altyapı ve uygulama düzeyi, Azerbaycan'ın gelişim sürecine göre daha ileri bir noktadadır. Varılan bu varsayımları ve elde edilen verileri dijital kaynakların el verdiği sürece erişilebilmiştir. Her iki ülkenin de teknolojiye olan yaklaşımı, bu zorlukların üstesinden gelme çabalarını etkilemektedir.

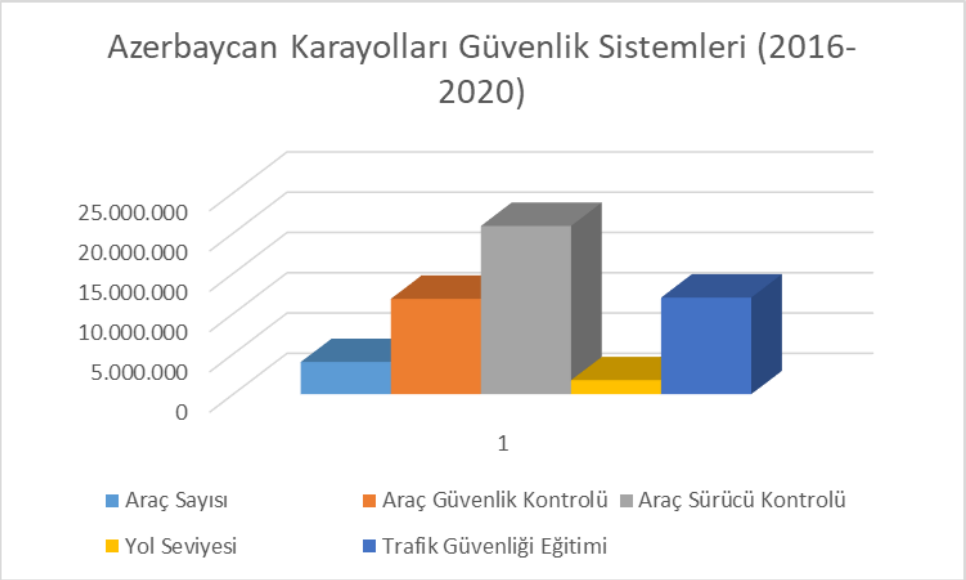
Azerbaycan Karayolu Güvenlik Sistemleri

Azerbaycan karayolu güvenlik sitemlerinde incelenmesi gereken temel bazı unsurlar vardır.

- Yasal Düzenlemeler: Azerbaycan'daki ulaşım bağlantıları, belirli kurallar çerçevesinde düzenlenmektedir. Hız sınırları, emniyet kemeri takma zorunluluğu ve sürüş güvenliği gibi çeşitli kurallar uygulanmaktadır. Son dönemlerde, trafik yasalarına ilişkin düzenlemeler gözden geçirilmiş ve güncellenmiştir.
- Altyapı: Azerbaycan, özellikle başkenti Bakü'de çağdaş altyapı projeleri geliştirmek için çaba sarf etmektedir. Bununla birlikte, kırsal alanlarda altyapı ile ilgili bazı sorunlar bulunmaktadır. Yeni yolların inşası ve mevcut yolların onarımı süregelmektedir.
- Denetim ve Uygulama: Trafik denetimleri, polis ve diğer yetkili otoritelerin gözetimi altında gerçekleştirilmektedir. Bu süreçte hız radarları ve trafik kameraları gibi teknolojik araçlar kullanılmaktadır. Ancak, bazı sistemlerin denetim etkinliği beklenen düzeyde olmayabilir.
- Halk Eğitimi: Trafik eğitimi ve farkındalık artırma amacıyla çeşitli kampanyalar düzenlenmektedir. Okullarda trafik kurallarının öğretilmesi teşvik edilmektedir. Toplumun her kesiminde bu konudaki bilinç düzeyinin yükseltilmesi için daha kapsamlı ve sürekli bir yaklaşım benimsenmesi gerekmektedir.

- Acil Durum Hizmetleri: Toplumun güvenliği ve sağlığı açısından kritik bir öneme sahiptir. Ancak, bazı kırsal bölgelerde bu hizmetlere erişim konusunda çeşitli ulaşım zorlukları yaşanabilmektedir. Özellikle, coğrafi engeller, yetersiz altyapı ve uzun mesafeler, acil durumlarda hızlı müdahale gerektiren durumları zorlaştırabilir. Bu nedenle, kırsal alanlarda acil durum hizmetlerinin etkinliği, ulaşım koşullarına bağlı olarak değişkenlik göstermektedir.

Azerbaycan karayolları güvenlik sistemleri üzerine belirli tarih aralığındaki değerlendirilmesi ve verileri Şekil 1 de verilmiş.



Şekil 1 Azerbaycan Karayolu Güvenlik Sistemleri 2016-2020

Türkiye Karayolu Güvenlik Sistemleri

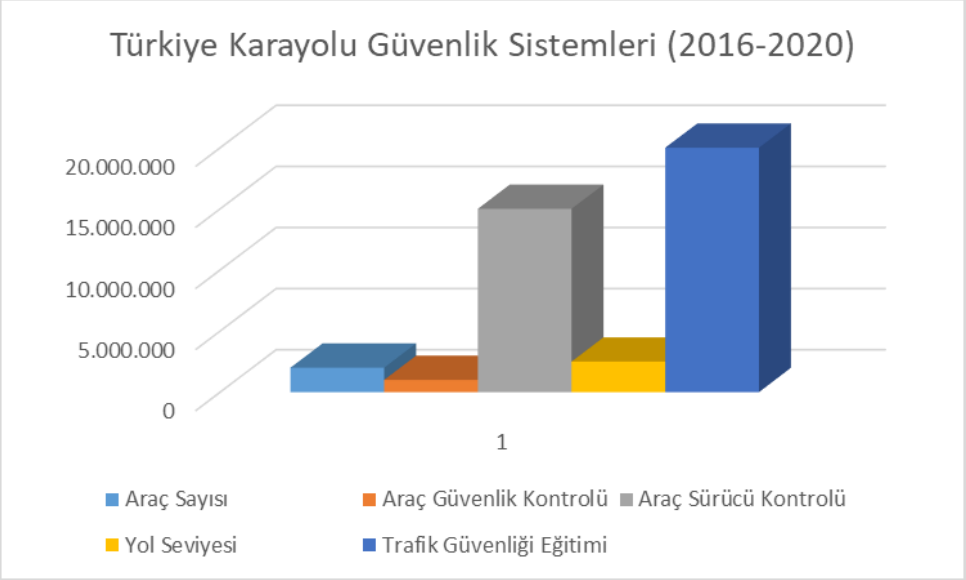
Türkiye karayolu güvenlik sitemlerinde incelenmesi gereken temel bazı unsurlar vardır

- Yasal Düzenlemeler: Türkiye'deki karayolu ağı, 2918 sayılı Karayolları Trafik Kanunu çerçevesinde düzenlenmiştir. Bu kanun, hız limitleri, emniyet kemeri takma zorunluluğu ve özel araçların kullanımına ilişkin koruma gibi çeşitli kuralları içermektedir. Yasal düzenlemelere riayet etmeyen bireyler için çeşitli ceza uygulamaları mevcuttur. Bu yaptırımlar, trafik güvenliğini sağlamak ve kurallara uyumu teşvik etmek amacıyla hayata geçirilmiştir. Trafik kurallarına uyulması, hem sürücülerin hem de yayaların güvenliğini artırmakta önemli bir rol oynamaktadır. Bu nedenle, yasal düzenlemelere uygun hareket etmek, toplumun genel güvenliği açısından büyük bir öneme sahiptir.
- Altyapı: Türkiye, karayolu altyapısını geliştirmek amacıyla kayda değer yatırımlar gerçekleştirmektedir. Modern yollar, özellikle otoyollar ve devlet yolları, trafik akışını düzenlemeye ve güvenliği artırmaya katkı sağlamaktadır. Trafik sinyalleri ve yönlendirme işaretleri, genel olarak belirli standartlara uygun olarak tasarlanmıştır. Bu standartlar, sürücülerin ve yayaların güvenliğini sağlamak için kritik bir rol oynamaktadır. Altyapı yatırımları, ulaşım sisteminin etkinliğini artırarak, hem ekonomik hem de sosyal açıdan önemli faydalar sunmaktadır. Bu bağlamda, Türkiye'nin karayolu projeleri, ülkenin genel ulaşım ağını güçlendirmeyi hedeflemektedir.
- Denetim ve Uygulama: Trafik denetimleri, güvenlik ve düzenin sağlanması amacıyla Jandarma ve Emniyet teşkilatları tarafından titizlikle gerçekleştirilmektedir. Bu denetimler, hem sürücülerin hem de yayaların güvenliğini artırmak için kritik bir öneme sahiptir. Trafik kurallarına uyulup uyulmadığını denetlemek, kazaların önlenmesi ve trafik akışının düzenlenmesi açısından hayati bir rol oynamaktadır. Bu denetimlerde, hız radarları, trafik kameraları ve çeşitli teknolojik araçlar gibi modern ekipmanlar kullanılmaktadır. Bu teknolojik araçlar, trafik ihlallerinin tespit edilmesinde ve kaydedilmesinde büyük kolaylık sağlamaktadır. Özellikle hız radarları, sürücülerin

hız limitlerine uyup uymadığını anlık olarak kontrol etme imkanı sunarak, trafik güvenliğini artırmaya yönelik önemli bir işlev üstlenmektedir.

- Halk Eğitimi: Trafik kuralları ve güvenliği ile ilgili olarak çeşitli halk eğitim programları mevcuttur. Bu programlar, toplumun trafik bilincini artırmayı hedeflemektedir. Okul öncesi ve ilköğretim düzeyinde trafik eğitimi, müfredatın önemli bir parçasını oluşturmaktadır. Bu eğitimler, çocukların trafik güvenliği konusunda bilgi sahibi olmalarını sağlamaktadır. Kamu spotları ve sosyal medya kampanyaları aracılığıyla, halkın trafik güvenliği konusunda bilinçlendirilmesi amacıyla çeşitli çalışmalar yürütülmektedir. Bu tür girişimler, toplumda trafik kurallarına uyumun artırılmasına katkıda bulunmaktadır.
- Acil Durum Hizmetleri: Trafik kazalarının sıkça yaşandığı günümüzde, bu tür olaylara hızlı bir şekilde müdahale edebilmek için acil servisler özel olarak düzenlenmiştir. Bu acil servisler, kazaların meydana geldiği anlarda olay yerine en kısa sürede ulaşarak, yaralılara gerekli tıbbi müdahaleyi yapma yeteneğine sahiptir. Ayrıca, bu hizmetlerin etkinliği, kazaların ardından yaşanan olumsuz sonuçların azaltılmasına katkıda bulunmakta ve toplumda güvenli bir trafik ortamının sağlanmasına yardımcı olmaktadır.

Türkiye karayolu güvenlik sistemlerinin değerlendirilmesi sonucu ve verileri Şekil 2 de verilmiştir.



Şekil 2 Türkiye Karayolu Güvenlik Sistemleri 2016-2020

Türkiye Azerbaycan Trafik Kaza Sayıları

Azerbaycan trafik kaza sayıları

Azerbaycan'daki trafik kazalarına dair güncel ve kapsamlı verilerin sınırlı olduğu görülmektedir. Ancak, 2020 yılında Dünya Sağlık Örgütü (DSÖ) tarafından yayımlanan istatistikler, Azerbaycan'da karayolu trafik kazalarının toplam ölümlerin %0.86'sını, yani 676 can kaybını oluşturduğunu ortaya koymaktadır. Bu bulgular, Azerbaycan'da trafik kazalarının genel ölüm oranının nispeten düşük olduğunu göstermektedir. Azerbaycan'daki trafik kazası istatistikleri, genellikle uluslararası kuruluşlar, özellikle DSÖ tarafından gözlemlenmektedir. Ancak, Azerbaycan'ın kendi resmi istatistik ajansları veya trafik otoriteleri tarafından sağlanan güncel ve ayrıntılı verilere erişim sağlanamamaktadır. Azerbaycan'daki trafik kazalarının sebepleri, çeşitli etkenlere dayanmaktadır. Bu etkenler arasında sürücülerin eğitim durumu, alkol ve uyuşturucu kullanımı, trafik işaretlerinin sayısı ve bunlara uyulup uyulmadığı, zorunlu trafik sigortası uygulaması ve trafik denetimlerinin yetersizliği bulunmaktadır. Bu sorunları ele almak amacıyla Azerbaycan, trafik güvenliğini artırmak için daha fazla önlem alma kararı almıştır. Azerbaycan, trafik güvenliğini sağlamak amacıyla, trafik denetimlerini güçlendirmeye de odaklanmaktadır. Bu denetimlerin artırılması, sürücülerin kurallara uyumunu teşvik edecek ve kazaların önlenmesine katkıda bulunacaktır. Böylece, ülke genelinde trafik

kazalarının azaltılması ve daha güvenli bir ulaşım ortamının oluşturulması amaçlanmaktadır. Bununla ilgili trafik kaza verileri Şekil 3 te verilmiştir.

Şekil 3Azerbaycan Karayolları Trafik Kaza Sayısı 2016-2020[2]

Türkiye trafik kaza sayıları

Türkiye'de trafik kazalarının en sık karşılaşılan sebeplerinden bazıları, aşırı hız, dikkatsiz sürüş, alkol ve uyuşturucu madde kullanımı, gece seyahatleri, sürücülerin araçlarının teknolojik donanımları ve yol altyapısının güvenliği gibi unsurlardır. Bu faktörler, kazaların meydana gelmesinde önemli bir rol oynamaktadır.

Trafik güvenliğini sağlamak için hem sürücülerin bilinçlendirilmesi hem de araç ve yol altyapısının iyileştirilmesi gerekmektedir. Bu iki alanın birlikte ele alınması, Türkiye'deki trafik kazalarının sayısını azaltma konusunda önemli bir adım olacaktır. Trafik kazalarının önlenmesi amacıyla, sürücülerin güvenli ve dikkatli bir şekilde araç kullanmaları büyük önem taşımaktadır. Bunun yanı sıra, araçların teknolojik özelliklerinin geliştirilmesi ve yol altyapısının güvenilirliğinin artırılması da kazaların azaltılmasında etkili olacaktır. Bununla ilgili trafik kaza verileri Şekil 4 te verilmiştir.

Yıl	Toplam kaza sayısı	Ölümlü yaralanmalı kaza sayısı	Maddi hasarlı kaza sayısı	Ölü sayısı			Yaralı sayısı
				Toplam	Kaza yerinde	Kaza sonrası(1)	
2012	**1 296 634**	153 552	1 143 082	**3 750**	3 750	-	268 079
2013	**1 207 354**	161 306	1 046 048	**3 685**	3 685	-	274 829
2014	**1 199 010**	168 512	1 030 498	**3 524**	3 524	-	285 059
2015	**1 313 359**	183 011	1 130 348	**7 530**	3 831	3 699	304 421
2016	**1 182 491**	185 128	997 363	**7 300**	3 493	3 807	303 812
2017	**1 202 716**	182 669	1 020 047	**7 427**	3 534	3 893	300 383
2018	**1 229 364**	186 532	1 042 832	**6 675**	3 368	3 307	307 071
2019	**1 168 144**	174 896	993 248	**5 473**	2 524	2 949	283 234
2020	**983 808**	150 275	833 533	**4 866**	2 197	2 669	226 266
2021	**1 186 353**	187 963	998 390	**5 362**	2 421	2 941	274 615
2022	**1 232 957**	197 261	1 035 696	**5 229**	2 282	2 947	288 696
2023	**1 314 136**	235 071	1 079 065	**6 548**	2 984	3 564	350 855

(1) Trafik kazasında yaralanıp sağlık kuruluşuna sevk edilenlerden kazanın sebep ve tesiriyle 30 gün içinde ölenleri kapsamaktadır.
- Bilgi yoktur.

Şekil 4 Türkiye Karayolları Trafik Kaza Sayısı 2016-2020[4]

Türkiye ve Azerbaycan karayolu güvenlik sistemlerinin ortak noktaları

Türkiye ve Azerbaycan'ın karayolu güvenlik sistemlerinde ortak noktalar ve benzerlikler, her iki ülkenin trafik kazalarını azaltma çabaları ve altyapı geliştirme projeleri kapsamında ele alınabilir. Bu hususlar ışığında diğer önemli noktalar da ayrı bir başlık olarak açıklanabilmektedir.

Trafik Kazalarını Azaltma Hedefi

Trafik kazalarının sayısını azaltmak amacıyla, her iki ülke de trafik kazası istatistiklerini düzenli bir şekilde takip etmektedir. Bu istatistikler, trafik güvenliğinin artırılması için son derece önemli bir temel oluşturmaktadır. Kazaların nedenleri, sıklığı ve sonuçları hakkında elde edilen veriler, ilgili otoritelerin daha etkili önlemler almasına olanak tanımaktadır. Dolayısıyla, bu verilerin analizi, trafik güvenliğini sağlamak için atılacak adımların belirlenmesinde kritik bir rol oynamaktadır. Her iki ülke, trafik kazalarını en aza indirmek amacıyla trafik kazası istatistiklerini izleme faaliyetlerine büyük bir önem vermektedir. Bu istatistikler, kazaların meydana gelme sıklığı ve sebepleri hakkında bilgi sunarak, trafik güvenliğini sağlamak için hayati bir rol üstlenmektedir. İstatistiklerin düzenli olarak güncellenmesi ve analiz edilmesi, trafik güvenliği stratejilerinin geliştirilmesi ve uygulanmasında önemli bir katkı sağlamaktadır. Böylece, kazaların önlenmesi için daha etkili politikalar oluşturulabilmektedir.

Trafik kazalarının önlenmesi amacıyla, her iki ülke de trafik kazası istatistiklerini titizlikle gözlemlemektedir. Bu veriler, trafik güvenliğini geliştirmek adına kritik bir kaynak teşkil etmektedir. Elde edilen bilgiler, kazaların önlenmesi için gerekli önlemlerin belirlenmesine yardımcı olmakta ve bu sayede daha güvenli bir trafik ortamı oluşturulmasına katkıda bulunmaktadır. İstatistiklerin dikkatli bir şekilde incelenmesi, trafik güvenliği alanında yapılacak iyileştirmelerin temelini oluşturmaktadır.

Türkiye ve Azerbaycan, karayolu güvenliğini artırmak amacıyla bir dizi proje yürütmektedir. Bu projelerin temel hedefi, yol altyapısının iyileştirilmesi ve güvenli sürüş koşullarının sağlanmasıdır. Bu kapsamda, yol yapısının modernizasyonu, trafik işaretlerinin uluslararası standartlara uygun hale getirilmesi ve sürücülerin bilgi ve becerilerinin artırılmasına yönelik eğitim faaliyetleri gerçekleştirilmektedir. İki ülke, karayolu güvenliğini artırmak için çeşitli stratejiler geliştirmekte ve uygulamaktadır. Bu stratejiler arasında, yol geometrisinin daha güvenli hale getirilmesi, trafik işaretlerinin belirli standartlara ulaşması ve sürücü eğitim programlarının etkin bir şekilde hayata geçirilmesi yer almaktadır. Bu çabalar, hem mevcut yol ağının güvenliğini artırmayı hem de yeni projelerin planlanmasında dikkate alınacak kriterleri belirlemeyi amaçlamaktadır.

Türkiye ve Azerbaycan, karayolu güvenlik sistemlerinin geliştirilmesi konusunda önemli adımlar atmaktadır. Bu süreçte, yol tasarımının iyileştirilmesi, trafik işaretlerinin standartlaştırılması ve sürücülerin eğitilmesi gibi unsurlar ön plana çıkmaktadır. Bu projeler, her iki ülkenin karayolu güvenliğini artırma hedeflerine ulaşmalarında kritik bir rol oynamaktadır ve bölgesel işbirliğini güçlendirmektedir.

Teknolojik Uygulamalar

Veri paylaşımı açısından, her iki ülkede uygulanan akıllı trafik sistemlerinden elde edilen verilerin, sınır geçiş noktalarında daha verimli bir trafik akışı sağlamak amacıyla paylaşılması mümkündür. Bu tür bir veri entegrasyonu, hem trafik yönetimini iyileştirecek hem de iki ülke arasındaki iş birliğini güçlendirecektir. Böylece, sınır geçişlerinde yaşanan sıkışıklık ve gecikmelerin önüne geçilmesi hedeflenmektedir. Aselsan, Azerbaycan'da akıllı trafik sistemleri geliştirmiştir. Bu sistemler, araçların ağırlık, hız ve plaka bilgilerini anlık olarak izleme imkanı sunarak, trafik yönetiminde önemli bir rol oynamaktadır. Türkiye'de benzer sistemlerin uygulanması, iki ülke arasında teknoloji transferini teşvik edebilir ve bu sayede her iki ülkenin de trafik güvenliğini artırabilir.

ASELSAN'ın geliştirdiği akıllı trafik çözümleri, yalnızca Azerbaycan'da değil, Türkiye'de de uygulanarak, iki ülke arasında teknolojik etkileşimi artırma potansiyeline sahiptir. Bu sistemlerin entegrasyonu, sınır geçişlerinde karşılaşılan sorunların çözümüne önemli katkılarda bulunabilir ve

her iki ülkenin de ulaşım altyapısını modernize etme çabalarına destek sağlayabilir. Azerbaycan'da oluşturulan ana kontrol merkezleri, trafik verilerini anlık olarak takip etmekte ve geçmişe yönelik analizler gerçekleştirmektedir. Bu tür sistemler, Türkiye'de de benzer bir şekilde entegre edilerek uygulanabilir. Böylece, trafik yönetimi ve analiz süreçleri daha etkin bir hale getirilebilir.

Türkiye ve Azerbaycan, uluslararası ulaşım koridorlarını geliştirme sürecinde akıllı ulaşım sistemleri teknolojilerini kullanarak trafik akışını daha verimli hale getirebilir. Bu iki ülke, ulaşım altyapılarını güçlendirirken, modern teknolojilerin sunduğu imkanlardan faydalanarak trafik yönetimini iyileştirme fırsatına sahiptir. Akıllı ulaşım sistemleri, Türkiye ve Azerbaycan'ın ulaşım ağlarını daha etkin bir şekilde yönetmesine olanak tanıyarak, uluslararası ticaretin ve yolcu taşımacılığının hızlanmasına katkıda bulunabilir.[5], [6]

Altyapı Geliştirme

Her iki ülke, karayollarının bakımını sağlamak ve yeni yollar inşa ederek altyapılarını güçlendirmek amacıyla çaba göstermektedir. Azerbaycan, özellikle uluslararası taşımacılık açısından büyük bir öneme sahip olan karayollarının geliştirilmesine odaklanmaktadır. Bu süreç, hem ekonomik büyümeyi desteklemek hem de ulaşım ağını modernize etmek için hayati bir rol oynamaktadır. Ülkeler, mevcut yolların iyileştirilmesi ve yeni güzergahların açılması ile ticaretin ve insan hareketliliğinin artırılmasını hedeflemektedir.

Azerbaycan'ın bu alandaki yatırımları, bölgesel bağlantıları güçlendirerek, uluslararası ticaretin daha verimli hale gelmesine katkıda bulunmaktadır. Bu bağlamda, karayolu altyapısının geliştirilmesi, hem yerel hem de uluslararası düzeyde önemli bir stratejik öncelik olarak öne çıkmaktadır.

Azerbaycan, demiryolu ve hava taşımacılığını geliştirerek karayolu taşımacılığına alternatif seçenekler sunma çabası içindedir. Bu entegrasyon, ulaşım ağının çeşitlendirilmesi ve etkinliğinin artırılması açısından büyük önem taşımaktadır. Ülke, demiryolu ve hava yollarını entegre ederek, karayolu taşımacılığına ek alternatifler oluşturmayı hedeflemektedir. Bu yaklaşım, hem ekonomik hem de çevresel sürdürülebilirlik açısından önemli bir adım olarak değerlendirilmektedir. Azerbaycan'ın bu stratejisi, ulaşım sisteminin modernizasyonunu ve verimliliğini artırmayı amaçlamakta, aynı zamanda bölgesel bağlantıları güçlendirmeyi hedeflemektedir. Böylece, farklı taşıma modları arasında daha iyi bir entegrasyon sağlanması beklenmektedir.[7]

Eğitim ve Farkındalık

Okullarda trafik eğitimi, Türkiye'de Türk Otomobil Sporları Federasyonu (TOSFED) tarafından hayata geçirilen "Ebeveyn Karnesi" gibi projeler aracılığıyla ilkokul öğrencilerine motor sporları ve günlük trafik kuralları hakkında bilgi verilmektedir. Bu girişim, 20.000'den fazla çocuğa ulaşmayı başarmış olup, kapsamı genişletilmeye devam etmektedir. Azerbaycan'da ise AMAK (Azerbaycan Ulusal Otomobil Kulübü), okul çevrelerinde hız limitlerini düşürme ve çocuklara yönelik trafik güvenliği eğitimleri düzenleme gibi çeşitli projeler gerçekleştirmektedir. Örneğin, Sumgayıt'taki bir okul bölgesinde yapılan iyileştirmeler sayesinde güvenlik düzeyi artırılmıştır.[8], [9], [10]

Türkiye'de, 2019 yılı "Yaya Öncelikli Trafik" yılı olarak belirlenmiş ve bu süreçte 10 milyondan fazla birey yaya güvenliği konusunda eğitim almıştır. Bu çerçevede, öğrenciler, sürücüler ve yayalar için kapsamlı farkındalık artırma kampanyaları gerçekleştirilmiştir. Azerbaycan'da ise "Safe Villages" gibi projeler aracılığıyla kırsal alanlarda yaya güvenliğinin artırılması hedeflenmiştir. Özellikle çocukların gece görünürlüğünü artırmak amacıyla reflektörlü malzemelerin dağıtımı yapılmıştır.[11], [12]

Her iki ülke, uluslararası kuruluşlarla işbirliği içinde faaliyet göstermektedir. Türkiye'de, eğitim materyalleri Milli Eğitim Bakanlığı tarafından onaylanarak hazırlanmakta ve geniş bir kitleye ulaştırılmaktadır. Azerbaycan ise EASST (Doğu Avrupa Güvenli ve Sürdürülebilir Taşımacılık İttifakı) ile işbirliği yaparak trafik güvenliği alanında uluslararası standartların benimsenmesine yönelik projeler gerçekleştirmektedir.

Uluslararası İşbirliği

Her iki ülke, trafik güvenliğini artırmak için uluslararası standartlara uyum sağlama yönünde önemli çabalar sergilemektedir. Bu süreç, yalnızca trafik kurallarının standartlaştırılmasını değil, aynı zamanda sürücü eğitimine dair işbirliğini de kapsamaktadır. Bu tür bir işbirliği, her iki ülkenin trafik güvenliği alanındaki hedeflerine ulaşmalarını kolaylaştırmakta ve sürücülerin daha bilinçli ve dikkatli olmalarını sağlamaktadır. Trafik güvenliğini sağlamak amacıyla, her iki ülke uluslararası standartlara uyum sağlama konusunda aktif bir yaklaşım benimsemektedir. Bu çaba, trafik kurallarının standart hale getirilmesi ve sürücü eğitiminde işbirliğini içermektedir. Böylece, her iki ülke de trafik güvenliğini artırmak için gerekli adımları atarak, daha güvenli bir ulaşım ortamı oluşturmayı hedeflemektedir.

Uluslararası standartlara uygunluk, her iki ülkenin trafik güvenliği konusundaki ortak hedeflerinden biri olarak öne çıkmaktadır. Bu hedefe ulaşmak için, trafik kurallarının birleştirilmesi ve sürücü eğitimine yönelik ortak çalışmalar yürütülmektedir. Bu tür bir işbirliği, her iki ülkenin de trafik kazalarını azaltma ve genel güvenliği artırma konusundaki kararlılığını pekiştirmektedir.

Türkiye ve Azerbaycan arasındaki bölgesel işbirliği, trafik güvenliği alanında deneyim paylaşımını teşvik ederek, sınır geçiş noktalarında trafik akışının düzenlenmesine katkıda bulunabilir. Bu tür bir işbirliği, her iki ülkenin de trafik güvenliğini artırma hedeflerine ulaşmalarına yardımcı olacaktır. İki ülke, bölgesel işbirliği çerçevesinde trafik güvenliği konularında bilgi ve deneyim alışverişinde bulunarak, sınır geçiş noktalarında trafik akışını daha iyi düzenleyebilirler. Bu tür bir işbirliği, her iki taraf için de faydalı sonuçlar doğurabilir.

Türkiye ve Azerbaycan, bölgesel işbirliği kapsamında trafik güvenliği ile ilgili deneyimlerini paylaşma fırsatına sahiptir. Bu durum, özellikle sınır geçiş noktalarında trafik akışının etkin bir şekilde yönetilmesi açısından büyük bir öneme sahiptir.

Yasal Düzenlemeler

Türkiye'de hız sınırlarını aşmanın sonuçları, aşım oranına göre değişiklik göstermektedir. Hız sınırını %10 ile %30 arasında aşan sürücüler 2.168 TL, %30 ile %50 arasında aşanlar 4.512 TL ve %50'den fazla aşım yapanlar ise 9.268 TL ceza ile karşılaşmaktadır. Azerbaycan'da şehir merkezlerinde hız sınırı 60 km/sa, kırsal alanlarda 90 km/sa ve otoyollarda ise 110 km/sa olarak belirlenmiştir. Ancak, hız sınırı ihlalleri için uygulanacak cezalara dair bilgiler oldukça sınırlıdır. Her iki ülkede de hız sınırlarının aşılması, sürücülerin karşılaşabileceği mali yaptırımlarla sonuçlanmaktadır.[13], [14], [15], [16]

Türkiye'de, sürücülerin kanındaki alkol oranı 0,50 promili aşmamalıdır. Alkollü araç kullanımı tespit edilen sürücüler, ilk yakalanmalarında 9.268 TL para cezası ile karşılaşmaktadır. Azerbaycan'da ise yasal alkol sınırı, mililitre başına 0,3 olarak belirlenmiştir. Bu sınırı aşan sürücüler, 400 AZN para cezası ile cezalandırılabilir veya sürüş hakları kısıtlanabilir. Her iki ülkede de alkol tüketiminin sürüş üzerindeki etkileri göz önünde bulundurularak, sürücülerin güvenliğini sağlamak amacıyla sıkı yasalar uygulanmaktadır.[13], [14], [17]

SONUÇ ve Öneriler

Türkiye ve Azerbaycan, karayolu güvenliği ile trafik kazalarının azaltılması konusunda benzer zorluklarla karşılaşmakta, ancak bu sorunlara yönelik farklı yaklaşımlar benimsemektedir. Her iki ülkede de altyapı eksiklikleri, sürücü davranışlarındaki olumsuzluklar ve denetim mekanizmalarının yetersizliği, kazaların başlıca sebepleri arasında yer almaktadır. Türkiye, teknolojik gelişmeler ve yasal düzenlemelerde ilerleme kaydetmiş olsa da, kırsal bölgelerdeki yol kalitesi ve sürücü eğitimi konusundaki eksiklikler hala önemli bir sorun teşkil etmektedir. Azerbaycan ise, Sovyet dönemine ait eski altyapıyı modernize etme çabaları içinde olsa da, denetim eksiklikleri ve sürücü bilincinin düşük olması kazaların artmasına neden olmaktadır. Trafik kazalarının her iki ülkede de ekonomik ve sosyal açıdan yüksek maliyetleri bulunmaktadır. Türkiye'de her yıl yaklaşık 5.000, Azerbaycan'da ise 1.200 civarında ölümle sonuçlanan kazalar, toplum sağlığı ve kalkınma hedefleri açısından önemli bir engel

teşkil etmektedir. Bu durum, her iki ülkenin de trafik güvenliği alanında daha etkili stratejiler geliştirmesi gerektiğini göstermektedir. Kazaların yol açtığı kayıplar, yalnızca bireyler için değil, aynı zamanda toplumun genel refahı için de ciddi tehditler oluşturmaktadır. Türkiye ve Azerbaycan, trafik kazalarını azaltmak için benzer sorunlarla karşı karşıya kalmalarına rağmen, farklı stratejiler izlemektedir. Her iki ülkenin de trafik güvenliği konusunda daha fazla önlem alması ve mevcut sorunları çözmek için işbirliği yapması, kazaların azaltılmasına katkı sağlayacaktır. Bu bağlamda, altyapı iyileştirmeleri, sürücü eğitimi ve denetim mekanizmalarının güçlendirilmesi büyük önem taşımaktadır. Bu tür önlemler, hem kazaların sayısını azaltacak hem de toplumda trafik güvenliği bilincini artıracaktır. Arttırılması gereken önlemleri sıralı bir şekilde aşağıda belirtilmiştir.

1. Altyapı ve Teknoloji Temelli Çözümler

- *Yol Standartlarının Geliştirilmesi*: Kırsal ve şehirlerarası yolların dar virajları, yetersiz aydınlatma ve işaretlemeleri acil bir şekilde modernize edilmelidir. Bu bağlamda, Azerbaycan'ın Bakü-Tiflis-Kars gibi büyük ölçekli projelerde olduğu gibi, uluslararası standartlara uygun otoyollar inşa etme hedefini benimsemesi önemlidir. Türkiye ise, özellikle Doğu Anadolu ve Güneydoğu Anadolu bölgelerindeki yolların yeniden yapılandırılmasına öncelik vermelidir.
- *Akıllı Ulaşım Sistemlerinin Geliştirilmesi*: Türkiye'de MOBESE ve Akıllı Ulaşım Sistemleri (AUS) tüm illerde entegre bir şekilde uygulanmalıdır. Azerbaycan, Türkiye'nin bu alandaki tecrübelerinden yararlanarak otomatik hız kontrol sistemleri ve akıllı trafik ışıkları gibi teknolojileri devreye almalıdır. Bu tür sistemlerin yaygınlaştırılması, ulaşım güvenliğini artıracak ve trafik akışını daha verimli hale getirecektir.

2. Eğitim ve Toplumsal Farkındalık

- *Sürücü Eğitimlerinin Sıkılaştırılması:* Sürücü eğitimlerinin kalitesini artırmak için, sürücü kurslarında uygulamalı eğitim sürelerinin uzatılması gerekmektedir. Bu, aday sürücülerin gerçek trafik koşullarında daha fazla deneyim kazanmasını sağlayacak ve pratik becerilerini geliştirecektir. Ayrıca, psikoteknik testlerin zorunlu hale getirilmesi, sürücülerin psikolojik durumlarının ve karar verme yeteneklerinin değerlendirilmesine olanak tanıyacak, böylece daha güvenli sürücüler yetiştirilmesine katkıda bulunacaktır. Azerbaycan'daki teorik eğitim programlarının, trafik psikolojisi ve risk yönetimi gibi ek modüllerle zenginleştirilmesi önemlidir. Bu tür modüller, sürücülerin trafik ortamındaki davranışlarını anlamalarına yardımcı olacak ve potansiyel tehlikeleri önceden tespit etme yeteneklerini artıracaktır. Eğitim programlarının bu şekilde genişletilmesi, sürücülerin sadece kuralları öğrenmelerini değil, aynı zamanda bu kuralların arkasındaki psikolojik ve sosyal dinamikleri de kavramalarını sağlayacaktır. Bu önerilen değişiklikler, sürücülerin trafikte daha donanımlı ve bilinçli bir şekilde yer almasını sağlayarak, genel trafik güvenliğini artırma potansiyeline sahiptir. Eğitim süreçlerinin iyileştirilmesi, sürücülerin karşılaşabilecekleri tehlikeleri daha iyi değerlendirmelerine ve bu tehlikelerle başa çıkma becerilerini geliştirmelerine yardımcı olacaktır. Sonuç olarak, bu tür reformlar, trafik kazalarının azaltılmasına ve daha güvenli bir ulaşım ortamının oluşturulmasına katkıda bulunacaktır.
- *Kampanyalar ve Medya Desteği:* Türkiye'de, trafik kazalarının önlenmesi ve toplumda trafik güvenliği bilincinin artırılması amacıyla "Trafikte Hayat Kurtarma" gibi ulusal düzeyde farkındalık yaratmayı hedefleyen kampanyaların hayata geçirilmesi büyük bir önem taşımaktadır. Bu tür kampanyalar, sadece sürücüleri değil, aynı zamanda yayaları ve bisikletlileri de kapsayarak geniş bir kitleye ulaşmayı amaçlamaktadır. Eğitim programları, seminerler ve medya aracılığıyla gerçekleştirilecek bu farkındalık çalışmaları, trafik kazalarının azaltılmasına ve güvenli bir trafik ortamının oluşturulmasına katkı sağlayacaktır. Azerbaycan'da, genç nesillerin trafik güvenliği konusunda bilinçlendirilmesi için okullarda zorunlu trafik derslerinin müfredata dahil edilmesi kritik bir adım olarak değerlendirilmektedir. Bu dersler, öğrencilere trafik kurallarını öğretmenin yanı sıra, güvenli sürüş alışkanlıkları kazandırmayı ve trafik kazalarının önlenmesine yönelik farkındalık oluşturmayı hedeflemektedir. Eğitim sistemine entegre edilecek bu tür programlar, gençlerin trafik güvenliği konusundaki bilgi ve becerilerini artırarak, gelecekte daha bilinçli sürücüler ve yayalar yetiştirilmesine katkıda bulunacaktır. Hem Türkiye hem de Azerbaycan'da trafik güvenliği konusunda atılacak adımlar, toplumun her kesiminde farkındalık yaratmayı ve güvenli bir trafik

kültürü oluşturmayı amaçlamaktadır. Bu bağlamda, ulusal kampanyalar ve eğitim programları, bireylerin trafik kurallarına uyumunu artırarak, kazaların önlenmesine yardımcı olacaktır. Ayrıca, bu tür girişimler, toplumda trafik güvenliği bilincinin yerleşmesine ve uzun vadede daha güvenli bir ulaşım sisteminin inşa edilmesine katkıda bulunacaktır.

3. Yasal Düzenlemeler ve Denetim

- *Ceza Politikalarının Caydırıcı Hale Getirilmesi:* Ceza politikalarının etkinliğini artırmak, trafik güvenliğini sağlamak adına kritik bir adımdır. Özellikle alkollü araç kullanımı, emniyet kemeri takmama ve çocuk koltuğu kullanmama gibi ihlaller, hem bireylerin hem de toplumun güvenliğini tehdit eden önemli sorunlardır. Bu nedenle, bu tür ihlallere uygulanan cezaların artırılması, sürücülerin ve yolcuların güvenliğini sağlamak için elzemdir. Cezaların caydırıcı bir etkisi olması, bu tür davranışların azaltılmasına katkıda bulunacaktır. Azerbaycan'da trafik güvenliğini artırmak amacıyla, yeterli sayıda trafik polisi, denetimlerin daha etkin bir şekilde gerçekleştirilmesine olanak tanıyacak ve ihlallerin tespit edilmesini kolaylaştıracaktır. Bunun yanı sıra, trafik polislerinin ekipmanlarının kalitesinin iyileştirilmesi de gereklidir. Modern ve etkili ekipmanlar, polislerin görevlerini daha verimli bir şekilde yerine getirmelerine yardımcı olacak ve trafik güvenliğini artıracaktır. Azerbaycan'da trafik güvenliğini sağlamak için ceza politikalarının gözden geçirilmesi ve trafik polislerinin güçlendirilmesi, atılacak önemli adımlardan birkaçıdır. Bu önlemler, sadece cezaların artırılmasıyla sınırlı kalmamalı, aynı zamanda eğitim ve farkındalık kampanyalarıyla desteklenmelidir. Sürücülerin ve yolcuların trafik kurallarına uyumunu artırmak, uzun vadede daha güvenli bir trafik ortamı yaratacaktır.
- *Veri Tabanı ve Analiz:* Her iki ülkede kaza istatistiklerinin düzenli olarak güncellenmesi ve veriye dayalı politika geliştirme süreçlerinin oluşturulması gerekmektedir. Kaza istatistiklerinin her iki ülkede sürekli olarak güncellenmesi, aynı zamanda veriye dayalı politika oluşturma mekanizmalarının geliştirilmesi önem arz etmektedir. Bu bağlamda, her iki ülkenin kaza istatistiklerini düzenli bir şekilde güncelleyerek, veriye dayalı politika üretiminde etkili mekanizmalar geliştirmesi elzemdir.

4. Bölgesel İş Birliği

Türkiye ve Azerbaycan, Türk Devletleri Teşkilatı (TDT) gibi uluslararası platformlarda ortak trafik güvenliği projeleri geliştirme çabalarını daha da güçlendirmelidir. Bu tür projeler, her iki ülkenin trafik güvenliği alanındaki deneyimlerini ve bilgi birikimlerini paylaşmalarına olanak tanırken, aynı zamanda bölgesel iş birliğini de pekiştirecektir. Ortaklaşa yürütülecek çalışmalar, trafik kazalarının azaltılması ve güvenli sürüş alışkanlıklarının teşvik edilmesi gibi hedeflere ulaşmada önemli bir rol oynayabilir. İki ülke arasında sürücü eğitim standartlarının yükseltilmesi ve teknoloji transferi konularında iş birliği olanakları artırılmalıdır. Bu bağlamda, her iki ülkenin eğitim kurumları ve trafik güvenliği otoriteleri arasında iş birliği sağlanarak, modern eğitim yöntemleri ve teknolojik yeniliklerin entegrasyonu mümkün hale getirilebilir. Böylece, sürücülerin bilgi ve becerilerinin geliştirilmesi, trafik güvenliğinin artırılması açısından kritik bir adım olacaktır. Türkiye ve Azerbaycan, trafik güvenliği alanında ortak araştırma projeleri ve seminerler düzenleyerek, uzmanların bir araya gelmesini teşvik etmelidir. Bu tür etkinlikler, her iki ülkenin trafik güvenliği stratejilerini gözden geçirmesine ve en iyi uygulamaları paylaşmasına olanak tanıyacaktır. Sonuç olarak, bu iş birliği, hem Türkiye hem de Azerbaycan için daha güvenli bir trafik ortamı yaratma hedefini destekleyecektir.

Trafik kazaları, yalnızca bir teknik sorun olmanın ötesinde, toplumsal bir tepki ve kültürel bir mesele olarak da değerlendirilmektedir. Türkiye ve Azerbaycan, karayolu güvenliğini artırmak amacıyla altyapı, eğitim, teknoloji ve hukukun entegrasyonunu içeren kapsamlı bir strateji geliştirmelidir. Bu bütüncül yaklaşım, trafik kazalarından kaynaklanan can kayıplarını azaltmayı ve sürdürülebilir bir ulaşım sistemi kurmayı mümkün kılacaktır.

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VIRTUAL FITTING: POSSIBILITIES OF MODERN 3D CLOTHING DESIGN SOFTWARE FOR VISUALISATION OF DIPLOMA PRODUCTS

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Abstract

3D visualization software is rapidly gaining popularity due to the increasing number of designers and modelers working remotely. This is due to the growing need for effective tools for the interaction of professionals located in different parts of the world. In the context of active international cooperation, traditional methods of presenting projects are becoming less effective, giving way to new technologies that improve communication and improve the quality of work. One of these solutions is 3D visualization, which opens up new horizons for collaboration, allowing specialists to freely exchange ideas and develop projects regardless of geographical location.

In this article, special attention is paid to the consideration of existing methods of virtual fitting, suitable programs and their capabilities, as well as visualization of the graduation product. The main focus is on two popular programs — Marvelous Designer and CLO 3D. The comparison made it possible to identify both common features and unique features of each of these tools. In particular, it was noted that CLO 3D has more flexibility and functionality, which makes it the preferred choice for performing complex tasks related to virtual product fitting.

The study provides detailed instructions on how to work with avatar patterns and settings in the CLO 3D program. The step-by-step process helps users master the basic functions of the program and achieve a high level of realism in the end result. The result of the work was the creation of a visualization of the thesis project, demonstrating the extensive capabilities of the software.

Keywords: Virtual fitting, 3D visualisation software, CLO 3D

Introductıon

The popularity of 3D visualization software is growing rapidly, largely due to the increasing number of designers and fashion designers working remotely. Active international cooperation requires new ways of demonstrating and developing projects together. 3D visualization has become an indispensable tool that allows professionals from different countries to effectively interact with each other and with customers, regardless of their location. In the article, we will consider the existing ways of conducting a virtual fitting, suitable programs and their capabilities, as well as testing the layout of the graduation product.

Materıals and methods

At the moment, there are a sufficient number of programs for 3D visualization of sewing products, but the most popular are CLO 3D and Marvelous Designer. Let's look at each one separately and compare them to choose the most convenient for virtual product fitting.

Dıscussıon

Marvelous Designer is a program widely used in the gaming industry, in film production, as well as in the field of design. The program supports the following actions: working with patterns, textures, prints; adding small finishing elements (buttons, zippers, etc.), virtual fitting (figure 1) [1, 2, 3].

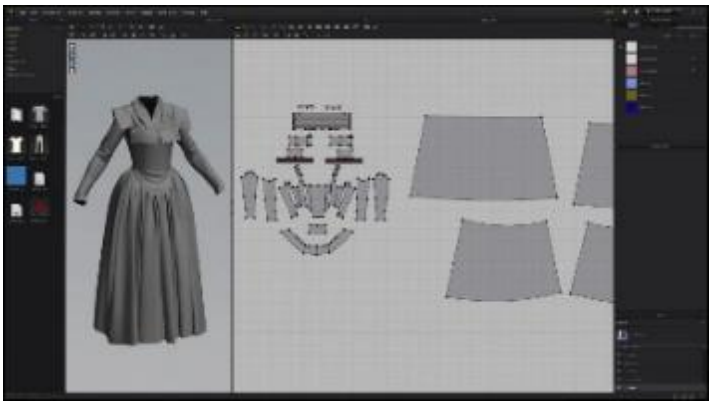


Figure 1 – Interface of the Marvelous Designer program [1]

And the most popular program used in creating 3D visualizations of clothes is CLO 3D. It helps to create and model clothes in three-dimensional space, to work out in detail every detail of the product, from the texture of the fabric to the folds and seams. CLO 3D allows you to automate the cutting and assembly of a product, achieve realistic fabrics, and animate avatar movements. Many leading brands are already actively using the program, for example, companies such as Adidas and Nike are using CLO 3D to develop sportswear (figure 2) [2, 4, 5].

Figure 2 – Interface of the CLO 3D program [4]

According to the results of the analysis, it was revealed that the programs are very similar to each other, but there are also differences. A table was compiled to compare Marvelous Designer and CLO 3D (table 1) [3, 5].

Table 1

Comparison of the programs Marvelous Designer and CLO 3D

Characteristics/ program	Marvelous Designer	CLO 3D
Scope of use (mainly)	Film industry, computer games	Clothes
Availability, price	From $39 to $199 monthly, or $280 to $2,000 per year The cost depends on the number of users and features	Regular subscription is $50 per month or $450 per year. Student subscription is $25 per month or $225 per year
Distinctive features	Realistic fabric physics (for example, with air flow)	More tools for working with patterns, intuitive interface
Number of avatar settings	35	35
The ability to download patterns in the DXF format	-	+

According to the results of the comparison, the CLO 3D program turned out to be the most suitable for the tasks. In it, a virtual fitting of the product for the final qualifying work will be performed.

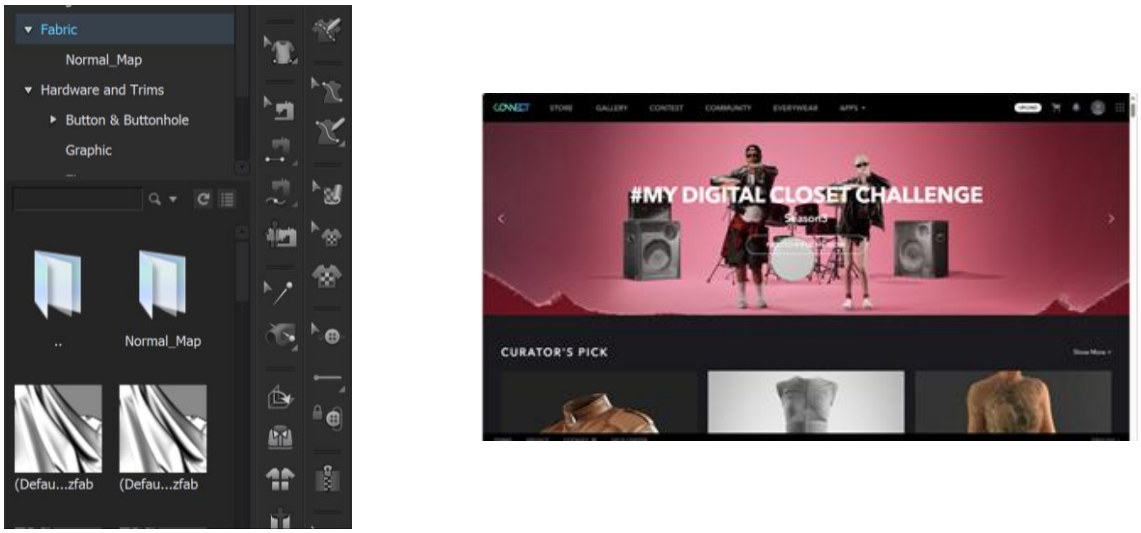
The first stage is the launch of the "CLO 3D" program. On the right is a library panel with various types of materials, accessories, and avatars. In the "Avatar" tab there are additional tabs "Female", "Male" and "Kid", which means female avatar, male and child respectively. Open the "Female" tab and upload the female avatar. Next, in the avatar editor, we change the size parameters for an individual shape (Figure 3).

a b

Figure 3 – Screenshot of the avatar from the program "CLO 3D" (a – basic avatar, b – avatar by individual standards)

Next, the patterns from the "AutoCAD" program were transferred [6]. Using the "Show location points", "Free stitching", and "Simulate" functions, we "put" the image on the avatar. If defects occur, we can correct them by changing the patterns in the 2d window.

Changing the material and its color will help add even more realism to our product during the virtual fitting. To select the product materials, the built-in CLO 3D library or third-party services can be used, for example, the connect close to website. To change the material into the program, go to the "Fabric" menu and select the fabric suitable for the product (figure 4 a). The CONNECT website is also used to add additional materials. On the website, go to the "Store" section. In the library we can find sections with ready-made clothes, fabrics, accessories and various accessories for the avatar. By going to any section, we can set up a search, for example, to select a product price, creator, or category (figure 4 b).



a b

Figure 4 – Selection of materials (a – CLO 3D program, b - CONNECT website)

To insert a print on a product, use the "Graphic (2D Pattern)" function, select the file from the computer, select the location of the print and its scale (then it can be changed using the "Transform Pattern" function). After editing the print, the following result is obtained (figure 5).

Figure 5 – Adding a print

The finished result of the virtual fitting is shown in figure 6.

a b c

Figure 6 – The finished result of fitting the graduation product (a – front view, b – side view, c – back view)

Conclusıon

Virtual fitting is a necessary and convenient tool for designers and designers in the modern world. The programs currently available on the market cover the needs of users. But despite the realism of the visualization obtained, it cannot completely replace sewing and fitting layouts. Virtual fitting software allows you to see the approximate final result of products for delivery to customers or online sales, but not to evaluate product defects.

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POTENTIAL RISKS OF FOSSIL FUELS ON HUMAN AND ENVIRONMENTAL HEALTH

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Abstract

Since the existence of mankind until today, energy has been an indispensable element for the continuation of life. The need for energy is increasing day by day due to factors such as industrialisation, urbanisation and rapidly increasing population. People prefer fossil fuels, which are non-renewable energy sources, because they are easily accessible and cheap to meet their energy needs. In this study, fossil energy sources and the negative effects on the environment and human health in the processes from production to consumption of these resources are mentioned. Various harmful substances such as sulphur oxides, nitric oxides, carbon dioxide and heavy metals are formed during the production, transport and use of fossil fuels. People exposed to these substances suffer from lung diseases, heart diseases, digestive system diseases, nervous system diseases and various cancers. In addition, they cause pollution when mixed with water, air and soil, causing acid rain, poisoning and climate change and disrupting environmental health. In order to reduce these effects, it is extremely important to reduce fossil fuel consumption, to dispose of the resulting harmful substances in accordance with the relevant legislation and to turn to environmentally friendly alternative energy sources.

Keywords: Energy sources, Fossil fuels, Human health, Environmental health, Potential risks

Introduction

Energy is an indispensable element necessary to meet the basic needs of people and to improve the quality of life. Energy, which is the main component of socioeconomic development, is the most important factor for the creation of national and international policies. Countries need energy resources for sustainability and create policies for access to these resources. Energy is one of the main factors that direct the security and future of mankind and states (Erdoğan 2020).

The energy needed to meet the basic needs of people is used in industry, buildings and transport. The energy demand caused by industrialisation and rapidly increasing population cannot be met with the limited fossil fuel resources in the world. Therefore, the difference between the energy produced and the energy consumed is increasing rapidly in the negative direction. However, fossil energy resources are likely to be depleted (Kumbur et al. 2005). Fossil fuels that meet a large part of the energy requirement are decreasing day by day and the intensive use of these resources causes the most important and complex environmental problems of our age (Arı 2023; Kumbur et al. 2005).

Environmental problems caused by the use of fossil fuels cause the death of many living things, especially humans. Fossil fuels used to meet the increasing energy demand at the global level are the main cause of environmental problems such as water pollution, air pollution and climate change (Arı 2023).

In this study, fossil energy sources are examined and the negative effects on the environment and human health in the processes from production to consumption of these resources are mentioned.

Energy Sources

Today, energy sources are considered in three groups: fossil fuels, renewable energy sources and nuclear energy. Although renewable energy sources have been used in the past among these three energy sources, fossil fuels now constitute the majority of energy sources. However, due to the decreasing reserves of fossil fuels and their negative effects on the environment, the search for alternative energy sources has started due to the increasing global energy demand. These searches have led people to nuclear and renewable energy sources to protect and improve environmental health. These two alternative energy sources have advantages and disadvantages like fossil fuels (Arı 2023). The main energy sources are shown in Figure 1.

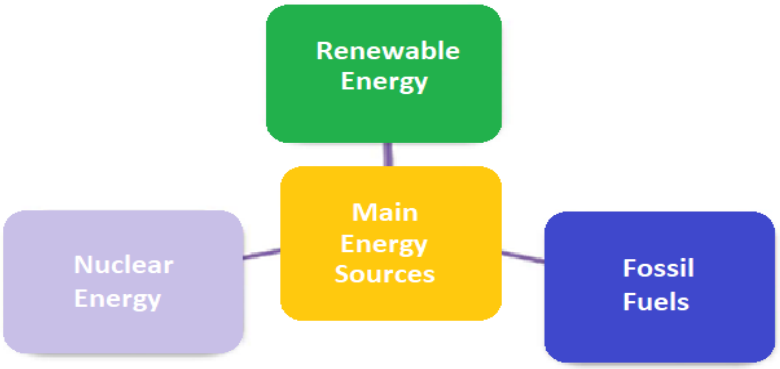

Figure 1. The Main Energy Sources (Arı 2023).

Fossil Energy Sources

Fossil energy sources, in other words non-renewable energy sources, are coal, oil, natural gas and the products of their processing. Fossil fuels meet more than half of the energy needed globally (Torunoğlu Gedik 2015; Yalçın 2022). Fossil energy sources in the world in solid, liquid and gaseous forms release the energy they contain as a result of some reactions. This energy consists of animal and plant residues fossilised by the effect of high pressure and high temperatures exposed under the soil over millions of years (Torunoğlu Gedik 2015). People have turned to sources that are easy to access and transform in order to meet their energy needs and therefore fossil fuels have been prioritised (Savrul 2010; Shahbaz et al. 2021).

Coal

Coal is a heterogeneous sedimentary rock rich in carbon and combustible gases formed by the effect of various biochemical and physical changes and high temperatures over time in suitable environments of organic and inorganic plant residues (Arı 2023; Uzunalp 2022). Among fossil fuels, coal is the most abundant energy source in the world (Ertürk, Akkoyunlu, and Varınca 2006).

The organic structure of coal consists of carbon, hydrogen and oxygen as well as sulphur and nitrogen. There are various ash-forming substances in the inorganic structure of coal. On the other hand, the chemical and physical effects caused by the decay of plant residues have varieties such as lignite, anthracite peat and bituminous coal (Miller 2005).

Coal is used both in production and heating as an energy source. As a result of industrialisation, urbanisation and increasing population, the demand for coal is increasing in order to meet the energy demand. Although the increased use of coal in countries positively affects economic growth, it has negative effects on human and environmental health (Yalçın 2022).

Petroleum

Petroleum energy found in the 1800s has made a significant contribution to the global economy. Initially used in residential lighting, petroleum has been used in different places with the industrial revolution. The use of petroleum in the production sector has created significant advantages in the socioeconomic field (Yalçın 2022).

Petroleum is a substance containing hydrocarbon mixture including gases such as methane, ethane, propane and various oils, sulphur, nitrogen and salt compounds (Bulkin 2003; Gürün 2024). Crude oil contains 84% carbon, 14% hydrogen, 1-3% sulphur, 1% oxygen, various metals and salt compounds (Gürün 2024). Crude oil is extracted from the subsoil by drilling and processed in refineries to make it suitable for use. Oil processed in refineries is separated into products such as diesel, petrol, jet fuel, heating oil, asphalt, wax and liquid petroleum gas (Çıtlak 2019).

Although petroleum offers various commercial and socioeconomic advantages, the wastes generated as a result of its consumption cause negative effects on both the environment and human health (Çıtlak 2019).

Natural Gas

Natural gas is an odourless, colourless, hydrocarbon gas consisting mostly of methane. Like other fossil energy sources, it is formed as a result of chemical reactions occurring under the influence of high temperature and high pressure under the soil of plant and animal residues. While natural gas was a waste gas formed during the production phase of petroleum in the past and seen as useless, today it is a source of energy of great importance (Umutlu and Bayraç 2020).

Natural gas is an important clean and cheap energy source used in different areas such as electricity generation, heating and cooling. The fact that it causes less damage to the environment compared to other fossil energy sources and that it comes after oil in terms of importance in the energy market increases the economic value of natural gas considerably. The use of natural gas in different areas contributes positively to economic growth (Umutlu and Bayraç 2020; Yalçın 2022).

Potential Risks of Fossil Fuels

During the production and consumption of fossil energy resources, the environment and ecosystem can be damaged. During the production of fossil fuels, soil structure and vegetation deteriorate, causing groundwater pollution. On the other hand, particles, dust and gases generated during the production phase cause air pollution. Ash, smoke, carbon dioxide and radioactive substances formed as a result of the use of fossil energy sources disrupt their structures by interacting with soil, air and water (Kaya, Aydın, and Karakurt 2019).

During coal mining, acidic mine drainage may occur when the coal containing pyrite is exposed to rain in storage areas or in the working area. As a result of the interaction of pyrite with air and water, sulphuric acid is formed due to its sulphurous structure. In addition, Acidic Mine Drainage may also contain environmentally harmful heavy metals such as nickel, zinc, lead and mercury. The contamination of these substances by contaminating nearby water resources damages aquatic products and biodiversity (Kaya, Aydın, and Karakurt 2019). In addition, exposure to toxic substances produced by coal combustion can cause various cancers, heart diseases, lung diseases, reproductive problems and problems such as deterioration in bone structure in children (Sönmez and Işık 2020).

Harmful metals, radioactive substances and other compounds produced during oil production can cause soil and water pollution. These substances, which contaminate marine and drinking water sources by contaminating them, damage the ecosystem they harbour by covering them. Oil has a toxic effect on aquatic organisms, causing poisoning and even death. In addition, oil covers water resources and prevents the passage of oxygen and daylight into the water (Kaya, Aydın, and Karakurt 2019).

During the production of natural gas, a large amount of water is used and therefore it creates various problems in places where water resources are scarce. On the other hand, some harmful substances are formed during the production and consumption of natural gas, and the contamination of these substances into water resources poses a risk to human and environmental health. In case of the end of natural gas extraction process, toxic substances can leak into water resources from wells that are not closed (Colborn et al. 2011).

Air pollutants formed during the consumption of fossil fuels are sulphur oxides, nitric oxides, particulate matter, carbon dioxide and heavy metals. These air pollutants combine with the water vapour in the atmosphere and cause acid rain, mixing with water, air and soil and causing negative effects on the environment and human health. It causes various respiratory diseases such as asthma and lung cancer in people exposed to air pollutants. Methane gas produced during the production of coal and carbon dioxide produced by the combustion of fossil fuels are greenhouse gases that are among the main causes of climate change (Kaya, Aydın, and Karakurt 2019).

Natural gas, another fossil energy source, is the source with the least environmental damage compared to other fossil fuels. As a result of its use, toxic substances such as particulate matter, greenhouse gases and sulphur dioxide are formed less than other sources. In the processes from production to consumption of natural gas, methane gas, which is a greenhouse gas, is released into the atmosphere. Natural gas has explosive and suffocating properties in enclosed spaces (Alarko Carrier Sanayi ve Ticaret A.Ş. 2003).

Conclusions and Recommendations

- As a result of industrialisation and technological advances, energy requirements are increasing day by day. The majority of the increasing energy need is provided from fossil energy sources.
- As a result of the production and consumption of fossil fuels, substances harmful to human and environmental health are formed and these substances are mixed into water, air and soil.
- In order to reduce the effects of fossil fuels on the environment and human health, it is necessary to comply with the relevant laws and regulations, to ensure proper disposal of the resulting wastes, and most importantly, to switch to environmentally friendly renewable energy in order to meet the majority of global energy needs by reducing the carbon footprint.

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EFFECT OF NI AND CU ADDITION TO COCRMO ALLOY ON MECHANICAL PROPERTIES AND CORROSION RESISTANCE

COCRMO ALAŞIMINA NI VE CU EKLENMESİNİN MEKANİK ÖZELLİKLER VE KOROZYON DİRENCİNE ETKİSİ

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ÖZET

Biyomedikal implant endüstrisinde uzun bir geçmişe sahip CoCrMo alaşımları, özellikle kalça ve diz implantlarında mükemmel aşınma direnci, gelişmiş mekanik özellikleri ve gösterdikleri yüksek yük taşıma profilleri sebebiyle yaygın olarak kullanılmaktadır. Alaşım sistemleri ve geliştirilen farklı üretim yöntemleriyle CoCrMo alaşımlarına farklı katkı maddelerinin etkilerinin değerlendirilmesi yeni implant malzemelerinin geliştirilmesi açısından büyük önem taşımaktadır. Toz Metalurjisi (T/M) ileri teknoloji alaşımların üretilmesinde kullanılan en modern yöntemlerden biridir. T/M'de metal tozlarına basınç, deformasyon ve ısı uygulanarak geliştirilmiş özelliklere sahip son şekle en yakın ve en net şekilli bileşenler elde edilmektedir. Bu çalışmada, CoCrMo alaşımına Ni ve Cu eklenmesinin korozyon direnci ve mekanik özellikler üzerindeki etkisinin araştırılması amacıyla CoCrMo, CoCrMo-6Ni ve CoCrMo-12Cu alaşımları toz metalurjisi yöntemiyle üretilmiştir. Alaşımların sertlikleri Vickers yöntemiyle ve aşınma davranışları pin-on disk yöntemiyle belirlenmiştir. Alaşımların elastisite modülü tahribatsız ultrasonik muayene kullanılarak hesaplanmıştır. Elektrokimyasal korozyon testleri simüle edilmiş vücut sıvısında (SBF) gerçekleştirilmiştir. CoCrMo alaşımına Ni ve Cu ilavesi alaşımların sertliğini ve elastisite modülünü düşürmüştür. Cu eklenmesiyle en yüksek aşınma yüzdesi görülürken Ni eklenmesi CoCrMo göre daha yüksek aşınmaya neden olmuştur. Alaşıma Ni eklenmesi korozyon direncini yükseltmiştir. Cu ilaveli alaşım ise CoCrMo alaşımı kadar iyi korozyon direnci göstermiştir. Sonuç olarak, CoCrMo alaşımına Cu ve Ni eklenmesi yenilikçi biyomedikal metal alaşımların ve implantların geliştirilmesinde önemli rol oynayabilecek potansiyel oluşturmaktadır.

Anahtar Kelimeler: CoCrMo, CoCrMo-6Ni, CoCrMo-12Cu, Toz metalurjisi.

ABSTRACT

CoCrMo alloys, which have a long history in the biomedical implant industry, are widely used especially in hip and knee implants due to their excellent wear resistance, improved mechanical properties and high load carrying profiles. Evaluation of the effects of different additives on CoCrMo alloys with alloy systems and different production methods developed is of great importance for the development of new implant materials. Powder Metallurgy (P/M) is one of the most modern methods used in the production of high-tech alloys. In P/M, components with the closest and clearest shape to the final shape with improved properties are obtained by applying pressure, deformation and heat to

metal powders. In this study, CoCrMo, CoCrMo-6Ni and CoCrMo-12Cu alloys were produced by powder metallurgy method in order to investigate the effect of Ni and Cu addition to CoCrMo alloy on corrosion resistance and mechanical properties. Hardness of the alloys was determined by Vickers method and wear behaviors were determined by pin-on disc method. Elasticity modulus of the alloys was calculated by non-destructive ultrasonic examination. Electrochemical corrosion tests were performed in simulated body fluid (SBF). Addition of Ni and Cu to CoCrMo alloy decreased the hardness and elasticity modulus of the alloys. While the highest wear percentage was observed with the addition of Cu, the addition of Ni caused higher wear than CoCrMo. Addition of Ni to the alloy increased the corrosion resistance. The alloy with Cu added showed as good corrosion resistance as CoCrMo alloy. In conclusion, addition of Cu and Ni to CoCrMo alloy has the potential to play an important role in the development of innovative biomedical metal alloys and implants.

Keywords: CoCrMo, CoCrMo-6Ni, CoCrMo-12Cu, Powder metallurgy.

GİRİŞ

Kobalt (Co) esaslı alaşımlar, yüksek sıcaklıklardaki endüstriyel uygulamalar için aşınmaya dayanıklı malzemeler olarak veya yüksek korozyon dirençleri sebebiyle biyolojik malzemeler olarak yaygın şekilde kullanılmaktadır (Liu vd., 2010). Üstün özellikleri sayesinde son yıllarda farklı alanlarda yoğun ilgi gören Co bazlı alaşımlar, titanyum alaşımı ve paslanmaz çelik gibi diğer metalik biyomalzemelere göre daha yüksek elastikiyet modülüne sahip olduklarından tercih edilmektedir (Cai vd., 2018; Mori vd., 2010). CoCrMo alaşımının havacılık ve biyomedikal implant endüstrilerinde uzun bir geçmişi bulunmaktadır (Davis, 2003). Korozif ortamlardaki mükemmel aşınma direnci ve mekanik özellikleri nedeniyle biyomedikal uygulamalarda özellikle total kalça veya diz protezlerinde yük taşıma profilleri yüksek olan CoCrMo alaşımları yaygın olarak kullanılmaktadır (Gümüşderelioğlu, 2002; Davis, 2003).

Toz Metalurjisi (T/M) ileri teknoloji alaşımların üretilmesinde kullanılan en modern yöntemlerden biridir. T/M'de metal tozlarına basınç, deformasyon ve ısı uygulanarak geliştirilmiş özelliklerde net şekle sahip bileşenler elde edilir (Jung vd., 2015). CoCrMo, CoCrMoNi ve CoCrMoCu alaşımlarını hazırlamada önemli bir yöntem olan T/M, diğer üretim yöntemlerine kıyasla daha geniş uygulama alanı ve daha büyük bir ekonomiye sahiptir. T/M daha yüksek akış kararlılığı, daha ince bir mikro yapı ve daha az çökelti sağlamaktadır (Wu vd., 2023).

Korozyon direnci malzemeler için en önemli konulardan biridir. Alaşımın elementel yapısı korozyon direnci üzerinde etkili bir faktördür (O'Brien ve Carroll, 2009). Cui vd. (2020) toz metalurjisi yöntemiyle ürettikleri CoCrNi, CoCrW ve CoCrMo alaşımlarına alaşım elementlerinin etkisini incelediler. Aşınma ve sürtünme davranışları oda sıcaklığından 1000°C'ye kadar incelenmiştir. CoCrNi, CoCrW ve CoCrMo'nun baskın aşınma mekanizmasının düşük sıcaklıkta plastik deformasyon ve aşındırıcı aşınma olduğu görülmüştür. Üç alaşım yüksek sıcaklıklarda oksidatif aşınma özellikleri göstermiştir. CoCr matris alaşımlarının sürtünme ve aşınma davranışları sertliğe, mikro yapıya, fazlara, alaşım elementlerine ve sıcaklığa bağlıdır (Cui vd., 2020).

Ni eklendiği alaşımların mikroyapılarında sünekliği ve yorulma direncini artıran daha yüksek tokluk matrisi olarak kabul edilen fcc ikizlerinin oluşumunu artırmaktadır. Shi vd. (2019) toz metalurjisi yöntemi ile değiştirilmiş Cr/Ni oranlarına sahip iki tip CoCrMoNi alaşımını hazırladılar. Ni içeriğinin öğütme işlemi üzerindeki etkisiyle sinterlenmiş alaşımların mikro yapı evrimi ve mekanik özelliklerini incelediler. Ni'nin artması ürün tozlarının iş sertleşmesini teşvik etmiş ve sinterlenmiş numunelerin gözenekli kusurlarını azaltmıştır. Ni içeriğinin artmasıyla çekme mukavemetinde ve düzgün plastik uzamada belirgin iyileşmeler elde edilmiştir. Li vd. (2020) ağırlıkça %5~55 Ni içeriklerine sahip Co-Ni-19Cr-9Mo alaşımlarının faz kararlılığını araştırdılar. Ni içerikleri ve 15Ni~55Ni alaşımlarının faz bileşeninin tek fazlı olduğunu buldular. Çekme kırılmasından sonra, gerilim kaynaklı martensit yalnızca 5Ni ve 15Ni alaşımında bulunabilmektedir. Yüksek Ni içerikli numunelerde gerilim kaynaklı martensit tespit edilmemiştir.

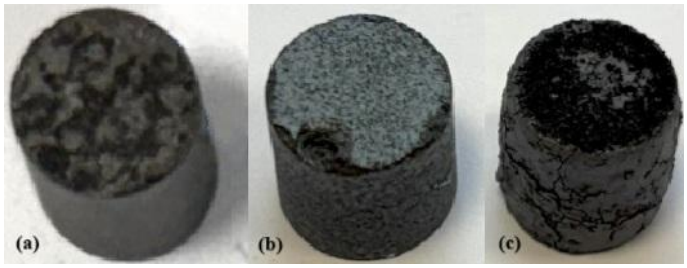
Cu, son yıllarda yeni metal bazlı antibakteriyel biyomalzemelerin tasarımında ve geliştirilmesinde alaşım elementi olarak yaygın şekilde kullanılmaktadır (Zhang vd., 2019). Zhang ve Liu (2016) CoCrMoCu alaşımının antibakteriyel özelliklerini araştırdılar. Cu ilavesinin Co bazlı alaşıma güçlü bir antibakteriyel özellik sağladığını ve antibakteriyel yeteneğin Cu içeriğindeki artışla artığını buldular. Cu ilaveli alaşım Co bazlı alaşım kadar iyi korozyon direnci göstermiştir. Ancak, Cu ilavesi sertliği azaltmıştır. Cu ilavesi Co alaşımlarının aşınma direncini azaltmakta ancak fiziksel özellikleri üzerinde bir etki göstermemektedir (Zhang ve Liu, 2016; Zhang vd., 2019). Wang vd. (2020) biyomedikal uygulamalar için Ni içermeyen sünek Co bazlı alaşımı üretmek amacıyla ağırlıkça %0, 1.5, 2, 4 Cu içeren Co-29Cr-6Mo-Cu alaşımlarının martensit dönüşümü incelediler. Cu elementinin, Co bazlı alaşımda martensit dönüşümünü engelleme yeteneğine sahip olduğunu gösterdiler. Cu atomuyla alaşımlama yük birikimlerini azaltıp atomik bağları artırabilmekte ve bunun sonucunda istifleme hatası enerjisini artırabilmektedir. Cu ilavesi, Co bazlı alaşımlarda östenit oluşumunu teşvik edebilmektedir (Wang vd., 2020).

Alaşım sistemlerine ve farklı üretim yöntemlerine gösterilen yüksek ilgiye rağmen, gelişmiş CoCrMo alaşımlarının üretilmesi için farklı ilavelerin etkilerinin değerlendirilmesine halen ihtiyaç duyulmaktadır. Yeni implant malzemelerinin geliştirilmesi açısından bu ihtiyaç büyük önem taşımaktadır. Bu çalışmada, CoCrMo alaşımına toz metalurjisi yöntemiyle Ni ve Cu ilavesinin alaşımın korozyon direnci ve mekanik özellikleri üzerindeki etkisinin araştırılması amaçlanmıştır. Bu araştırmanın biyomedikal uygulamalar için yeni CoCrMo alaşımlarının geliştirilmesinde yararlı bilgiler sağlayabileceği umulmaktadır.

MATERYAL VE YÖNTEM

Numunelerin Hazırlanması

CoCrMo alaşımı ile ağırlıkça %6 Ni ve %12 Cu içeren CoCrMo alaşımları toz metalurjisi yöntemiyle üretilmiştir. %99.5 saflıkta Kobalt (Co) tozu Alfa Aesar'den, %99.5~99.9 saflık oranlarında ve 44 µm tane boyutuna sahip Krom (Cr), Molibden (Mo), Nikel (Ni) ve Bakır (Cu) tozları Nanokar Nanotechnology'den temin edilmiştir. Metal tozlarının birbiriyle bağlanması için ağırlıkça %1-3 polivinilalkol (PVA) çözeltisi (%0.6'lık) kullanılmıştır. Metal toz karışımı 3 mm çapında zirkonya bilyeler kullanılarak bilyeli değirmende (MSE Teknik, Türkiye) 20 saat 400 rpm devirde mekanik olarak karıştırılmıştır. Tek eksenli hidrolik pres (MSE Teknik, Türkiye) ile tozlar sıkıştırılarak ham numuneler üretilmiştir. 1200 °C sıcaklıkta 60 dakika süreyle vakum ortamında yatay sinterleme fırını (MTI, GLS-1500X, ABD) kullanılarak numuneler sinterlenmiştir. Şekil 1'de geleneksel toz metalurjisi yöntemiyle hazırlanan CoCrMo ve ağırlıkça %6 Ni ve %12 Cu içeren CoCrMo alaşımlarının görüntüleri verilmiştir.



Şekil 1. Hazırlanan numuneler (a) CoCrMo (b) CoCrMo-6Ni (c) CoCrMo-12Cu

Sertlik ve Aşınma Testleri

CoCrMo alaşımları esas olarak aşınma ve korozyon ortamlarında kullanılmaktadır. Sertlik, bir malzemenin aşınma direncini karakterize eden önemli faktörlerden biridir. Üretilen numunelerin sertlikleri Vickers sertlik yöntemiyle sertlik test cihazında (Zwick/Roell, ZHU 187,5 LKV, ABD)

belirlenmiştir. Numunelerin aşınma davranışı pin-on disk yöntemiyle 20 m aşınma uzunluğunda aşınma test cihazı (Devotrans, Türkiye) kullanılarak belirlenmiştir.

Tahribatsız Ultrasonik Muayene

Sinterlenmiş numunelerin elastisite modülleri (E) ultrasonik hız darbe-yankı yöntemiyle çift kristalli normal prob kullanılarak 4 MHz frekansta (General Electric, USM Go+, ABD) ile ölçülerek denklem (1) ile hesaplanmıştır. Denklemde VT ve VL enine ve boyuna dalga ultrasonik hızları, (ρ) ise yoğunluktur (Krautkrämer ve Krautkrämer, 1977).

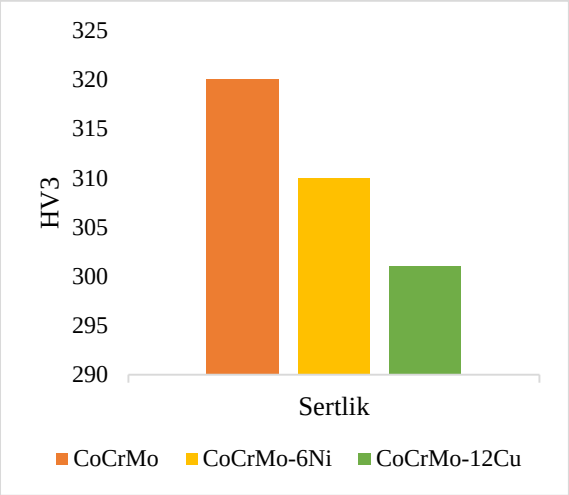
$$E = \rho V_T^2 \frac{3V_L^2 - 4V_T^2}{V_L^2 - V_T^2} \quad (1)$$

Elektrokimyasal Korozyon Testleri

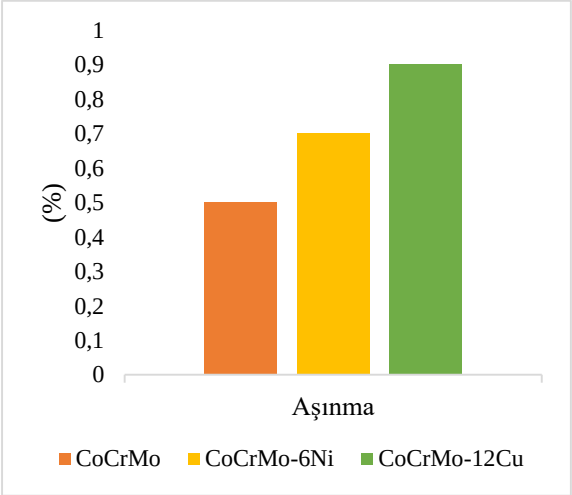
6.6 pH değerine sahip yapay vücut sıvısı çözeltisinde (SBF) potansiyostat (Gamry, Interface 1000, ABD) ile oda sıcaklığında gerçekleştirilmiştir. 3-elektrotlu elektrokimyasal korozyon ölçüm hücresi kullanılmıştır. Korozyon verilerinin elde edilmesi sistemin bilgisayar programı (Framework, Gamry, ABD) ile gerçekleştirilmiştir.

BULGULAR VE TARTIŞMA

Hazırlanan CoCrMo, CoCrMo-6Ni ve CoCrMo-12Cu alaşımlarının sertlik değerleri Şekil 2'de ve aşınma yüzdeleri Şekil 3'te gösterilmiştir. En düşük sertlik değeri, bakır ilaveli CoCrMo alaşımında görülmüştür. Bakır ilavesi sertlikte, nikel ilavesine göre daha fazla düşüşe neden olmuştur. CoCrMo alaşımına nikel ve bakır ilavesi sertliği düşürürken aşınma yüzdelerini artırmıştır. Bakır ilaveli CoCrMo alaşımı en yüksek aşınma yüzdesine sahiptir. Alaşımların aşınma yüzdeleri açısından nikel ilaveli CoCrMo alaşımı daha iyi bir sonuç ortaya koymuştur.



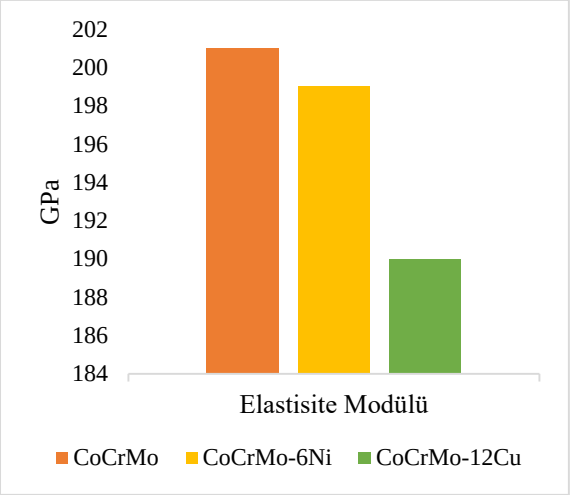
Şekil 2. Alaşımların sertlik değerleri



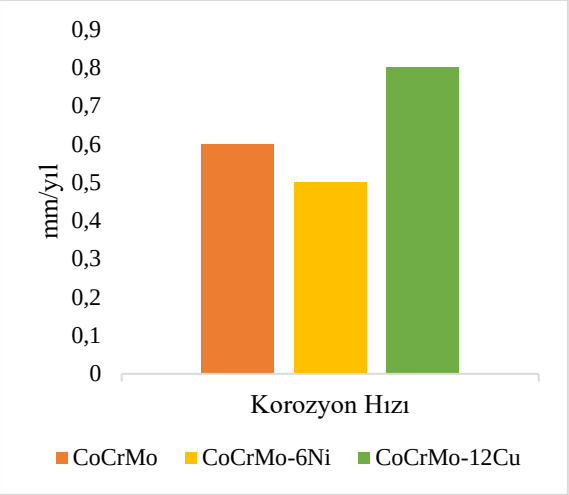
Şekil 3. Alaşımların aşınma yüzdeleri

Denklem (1)'den hareketle hesaplanan alaşımların elastisite modülleri Şekil 4'te gösterilmiştir. CoCrMo alaşımına nikel ve bakır ilavesi elastisite modülünü düşürmüştür. En düşük elastisite modülü, bakır ilaveli CoCrMo alaşımında görülmüştür. Bakır ilavesi, nikel ilavesine göre daha fazla elastisite modülü düşüşüne neden olmuştur. Alaşımların korozyon hızları Şekil 5'te verilmiştir. En yüksek korozyon hızı bakır ilaveli CoCrMo alaşımında görülmüştür. CoCrMo alaşımına nikel ilavesi korozyon hızını düşürürken bakır ilavesi korozyon hızını artırmıştır. CoCrMo, CoCrMo-6Ni ve CoCrMo-12Cu alaşımlarının yüzey oksit film korozyon direnci değerleri Şekil 6'da verilmiştir. En yüksek korozyon direnci CoCrMo-6Ni alaşımında görülürken CoCrMo ve CoCrMo-12Cu alaşımları benzer korozyon dirençleri göstermiştir. Nikel ilavesi, korozyon hızını azaltıcı etki gösterirken yüzey oksit korozyon direncini yükselten sonuçlar da ortaya koymuştur. Bakır ilavesi, CoCrMo alaşımının

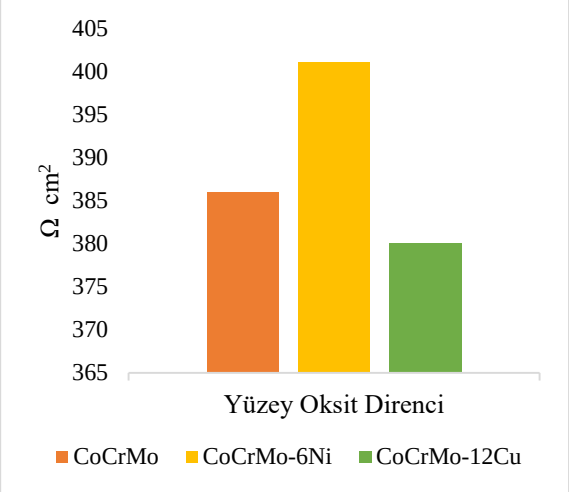
korozyon hızını yükseltmekte ancak katkısız CoCrMo alaşımına benzer düzeyde iyi korozyon direnci ortaya koymaktadır.



Şekil 4. Alaşımların elastisite modülleri



Şekil 5. Alaşımların korozyon hızları



Şekil 6. Alaşımların yüzey oksit film korozyon dirençleri

SONUÇ VE ÖNERİLER

CoCrMo alaşımının biyomedikal uygulamalarda ve farklı pek çok farklı alanda kullanımı bulunmaktadır. Bu çalışmada özellikle total kalça veya diz protezlerinde yaygın olarak kullanılan CoCrMo alaşımına Ni ve Cu ilavelerinin mekanik özellikler ve korozyon direncine etkisi incelenmiştir. CoCrMo alaşımına Ni ve Cu eklenmesi alaşımların sertliğini düşürmüş ve aşınma yüzdelerini artırmıştır. Sertlik düşüşü Cu ilavesiyle daha fazla gerçekleşmiştir. Cu eklenen alaşımda en yüksek aşınma yüzdesi görülmüştür. Ni ve Cu ilavesi CoCrMo alaşımının elastisite modülünü düşürmüştür. Cu ilavesi Ni ilavesine göre elastisite modülünde daha fazla düşüşe sebep olmuştur. CoCrMo alaşımına Ni ilavesi korozyon hızını düşürürken korozyon direncini yükseltmiştir. Cu ilavesi CoCrMo alaşımının korozyon hızını yükseltmiştir. Ancak Cu ilaveli CoCrMo alaşımı CoCrMo alaşımına benzer şekilde iyi korozyon direnci göstermiştir. Her iki elementel katkı da farklı uygulamalar için farklı avantajlar oluşturmaktadır. CoCrMo alaşımına Ni ve Cu eklenmesi yenilikçi biyomedikal metal alaşımların ve implantların geliştirilmesinde önemli rol oynayabilecek potansiyel oluşturmaktadır. Sonuç olarak, yüksek sertlik, düşük aşınma, uygun elastisite modülü ile düşük korozyon hızı ve yüksek korozyon direnci gösteren CoCrMo-6Ni alaşımı, biyomedikal implant uygulamalarında özellikle kalça ve diz implantlarında kullanılabilecek bir biyomalzeme olarak karşımıza çıkmaktadır. Çalışmanın ilerleyen aşamalarında bu doğrultuda kalça ve diz

implantlarındaki uygulamaların geliştirilmesiyle ve dental açıdan değerlendirilmesiyle alaşımın kullanımı mümkün olabilecektir. Biyouyumluluk testleriyle de canlı dokular ve insan sağlığı üzerine etkilerinin değerlendirilmesi hedeflenmektedir.

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DEVELOPMENT OF BORON AND GRAPHENE ADDITIVE PACKAGING MATERIAL

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Abstract

In this study, poly (vinyl alcohol) (PVA) was reinforced with graphene oxide (GO), reduced graphene oxide (rGO) and boron doped reduced graphene oxide (B-rGO) to develop high performance, environmentally friendly films for food packaging applications. In the literature, there are very limited studies on packaging materials in which boron and graphene are co-doped. The primary objective was to improve the barrier properties of PVA against UV radiation, gas and moisture and to increase its mechanical strength. Although previous studies have examined the doping of graphene oxide (GO) and reduced graphene oxide (rGO) in PVA films in various application areas, our approach is to examine the performance effect of GO, rGO, B-rGO doping in PVA films in packaging applications and especially to make the first systematic comparison of boron doped rGO.

Initially, GO was synthesized by a modified Hummers method, while rGO and B-rGO were obtained by hydrothermal reduction. The successful syntheses were confirmed by X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) analysis. Then, the chemical, optical and mechanical properties of the composite films prepared by incorporating GO, rGO and B-rGO into the PVA matrix at five different concentrations ranging from 0.05% to 1.5% were systematically evaluated using FTIR, UV-Vis spectroscopy, X-ray photoelectron spectroscopy (XPS) and mechanical tests.

The findings show that PVA-/GO/rGO/B-rGO nanocomposites show promise in extending food shelf life by reducing oxygen, moisture and UV light penetration while maintaining an environmentally friendly, biodegradable matrix. The results of this study will guide the design of a new generation of sustainable food packaging materials that balance performance, safety and ecological impact.

Keywords: Polyvinyl Alcohol, Graphene Oxide, Boron, Nanocomposite, Food Packaging, Sustainability.

EVALUATION AND OPTIMIZATION OF TREATMENT PROCESSES FOR INDUSTRIAL WASTEWATER

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Abstract

Industrial water pollution is a major environmental concern due to the presence of heavy metals, organic compounds, and inorganic contaminants. To mitigate its impact, optimizing wastewater treatment processes is essential for sustainable water management. Various techniques, including coagulation-flocculation, adsorption, advanced oxidation processes (AOPs), and membrane technologies, have shown efficiency in pollutant removal. Evaluating these methods requires considering key factors such as removal efficiency, cost-effectiveness, and environmental sustainability. Hybrid treatment systems and the optimization of operational parameters (pH, temperature, contact time) further enhance performance. Advanced analytical techniques, including UV-Visible spectroscopy, Fourier transform infrared spectroscopy (FTIR), and energy-dispersive X-ray spectroscopy (EDX), will be employed to assess pollutant degradation and adsorbent properties. This research aims to develop an optimized and sustainable treatment approach that aligns with environmental regulations and promotes water reuse within a circular economy framework. Combining technological innovation with sustainable practices is essential for efficient industrial wastewater treatment.

Keywords: Effluent treatment; Process optimization; Spectroscopic analysis; Water pollution

Main references of the study: https://www.sciencedirect.com/science/article/pii/S2213343721006655

https://books.rsc.org/books/edited-volume/937/chapter/741366/Industrial-Wastewater-and-Its-Toxic-Effects

https://www.tandfonline.com/doi/abs/10.1080/01919512.1997.10382859

https://hal.science/hal-04572490v1/document

PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES OF LEGUMES UNDER DROUGHT AND SALINITY STRESS

KURAKLIK VE TUZLULUK STRESİ ALTINDA BAKLAGİLLERİN FİZYOLOJİK VE BİYOKİMYASAL TEPKİLERİ

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ÖZET

Kuraklık ve tuzluluk stresi, baklagil bitkilerinin büyümesi ve verimi üzerinde ciddi sınırlayıcı etkilere sahip iki temel abiyotik stres faktörüdür. Bu stres koşulları, bitkilerin su alımını azaltarak ozmotik dengenin bozulmasına, hücresel iyon toksisitesine ve oksidatif stresin artmasına neden olmaktadır. Baklagiller, bu zorluklara karşı çeşitli fizyolojik ve biyokimyasal adaptasyon mekanizmaları geliştirerek hayatta kalma şanslarını artırmaktadır. Bu çalışmada, kuraklık ve tuzluluk stresi altındaki baklagillerin gösterdiği fizyolojik ve biyokimyasal yanıtlar ele alınmıştır. Kuraklık stresine maruz kalan baklagiller, su kaybını minimize etmek için stomatal kapanma mekanizmasını devreye sokmakta, antioksidan enzim aktivitelerini artırarak oksidatif hasarı azaltmaktadır. Ayrıca, prolin ve poliaminler gibi osmotik düzenleyici bileşiklerin sentezi, bitkilerin hücresel su potansiyelini koruyarak stres koşullarına uyum sağlamasına yardımcı olmaktadır. Tuzluluk stresine maruz kalan baklagillerde ise iyon dengesizliğini düzenlemek amacıyla Na^+ ve Cl^- iyonlarının taşınmasını kontrol eden mekanizmalar devreye girmektedir. Özellikle kök bölgesinde iyon sekestrasyonu ve seçici iyon taşınımı sağlayan proteinler, bitkinin iyon toksisitesine karşı direncini artırmaktadır. Tuz stresi ayrıca fotosentez mekanizmasını olumsuz etkileyerek bitki büyümesini kısıtlamakta, ancak bazı baklagiller kök simbiyozları aracılığıyla azot fiksasyonu yaparak bu olumsuz etkileri hafifletebilmektedir.

Sonuç olarak, baklagillerin kuraklık ve tuzluluk stresine karşı geliştirdiği fizyolojik ve biyokimyasal yanıtların anlaşılması, stres toleransı yüksek çeşitlerin geliştirilmesi açısından kritik öneme sahiptir. Gelecekte, ileri biyoteknolojik yaklaşımlar ve genomik seleksiyon teknikleriyle bu tolerans mekanizmalarının daha etkin şekilde değerlendirilmesi hedeflenmektedir.

Anahtar Kelimeler: Baklagiller, kuraklık stresi, tuzluluk stresi, antioksidan enzimler, ozmotik düzenleyiciler, iyon dengesizliği, stres toleransı.

ABSTRACT

Drought and salinity stress are two major abiotic constraints that significantly limit the growth and productivity of legume crops. These stress conditions disrupt water uptake, induce osmotic imbalance, cause cellular ion toxicity, and increase oxidative stress. To survive under such adverse conditions, legumes employ various physiological and biochemical adaptation mechanisms. This study examines the physiological and biochemical responses of legumes to drought and salinity stress. Under drought conditions, legumes minimize water loss by inducing stomatal closure and enhance

antioxidant enzyme activity to mitigate oxidative damage. Furthermore, the accumulation of osmoprotectants such as proline and polyamines helps maintain cellular water potential and supports stress adaptation. In response to salinity stress, legumes regulate ion homeostasis by controlling Na^+ and Cl^- transport, with root sequestration and selective ion transport mechanisms playing a critical role in mitigating ion toxicity. Salinity also adversely affects photosynthesis, limiting plant growth; however, some legumes counteract these negative effects through symbiotic nitrogen fixation, improving stress resilience.

In conclusion, understanding the physiological and biochemical responses of legumes to drought and salinity stress is crucial for developing stress-tolerant varieties. Future research should focus on leveraging advanced biotechnological approaches and genomic selection techniques to enhance stress tolerance mechanisms.

Keywords: Legumes, drought stress, salinity stress, antioxidant enzymes, osmoprotectants, ion homeostasis, stress tolerance.

Introduction

Drought and salinity stress are among the most significant environmental factors limiting agricultural productivity worldwide. In particular, the effects of climate change, diminishing water resources, and increasing soil salinization negatively impact plant growth and yield (Farooq et al., 2009). This situation becomes even more critical for legumes, which are widely cultivated in marginal areas with low input use. Legumes (Fabaceae) are strategic crops due to their ability to fix atmospheric nitrogen, improving soil fertility not only for themselves but also for subsequent crops. Additionally, their role as a key source of protein and micronutrients in human nutrition makes them indispensable both economically and ecologically (Graham & Vance, 2003). However, many legume species are sensitive to drought and salinity stresses, particularly during critical developmental stages such as flowering and grain filling. These stresses limit plant performance through multifaceted effects such as disruption of water and ion balance, reduced photosynthetic rate, damage to cellular structures, and metabolic imbalance (Ashraf & Harris, 2004). Recent studies have shown that certain legume species and genotypes have developed specific adaptation strategies to cope with these stresses. These adaptations include physiological mechanisms such as improved water use efficiency, osmotic adjustment, and stomatal regulation, as well as biochemical responses such as activation of antioxidant defense systems, accumulation of osmoprotectants, and enzymatic regulations (Naya et al., 2007; Zahran, 1999).

The aim of this study is to identify the main physiological and biochemical responses of legumes under drought and salinity stress, to discuss how these mechanisms can be utilized in developing stress-tolerant cultivars, and to emphasize their importance for sustainable agricultural practices.

Physiological and Biochemical Responses to Drought Stress

Drought stress is an abiotic factor that severely affects plant physiology and metabolism, arising when soil moisture is insufficient or when plants are unable to access available water. Under drought conditions, legume plants develop a wide range of physiological and biochemical adaptation mechanisms to survive and maintain productivity.

Physiological Responses

Legumes first employ strategies to reduce water loss under drought stress. These strategies include stomatal closure, reduced leaf surface area, early senescence, and deep root system development (Turner et al., 2001). While stomatal closure helps limit water loss through transpiration, it also restricts CO_2 uptake, leading to a reduction in the photosynthetic rate. This negatively affects energy production and carbon metabolism, resulting in growth retardation.

Furthermore, some legume genotypes with higher water use efficiency (WUE) have been observed to perform better under drought stress. Particularly, deep root development facilitates access to water in deeper soil layers, enhancing drought resilience (Zaman-Allah et al., 2011).

Biochemical Responses

Drought stress leads to the accumulation of reactive oxygen species (ROS) in plant cells, causing oxidative stress. This condition results in lipid peroxidation in membranes, DNA damage, and protein denaturation. Therefore, legumes activate antioxidant defense systems to mitigate these harmful effects (Hasanuzzaman et al., 2012). One of the most commonly observed biochemical responses to drought stress is the accumulation of osmoprotectants. Compounds such as proline, glycine betaine, mannitol, and trehalose help regulate osmotic balance and scavenge free radicals, thereby preserving cell integrity (Kaur & Asthir, 2015). Additionally, the expression of various stress-related proteins (e.g., dehydration-associated proteins, LEA proteins) increases to enhance stress tolerance. Among antioxidant enzymes, systems such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), and glutathione reductase (GR) are particularly prominent. The activity of these enzymes is typically higher in drought-tolerant genotypes, providing a significant advantage in coping with stress (Naya et al., 2007).

Genotypic Variation and Molecular Indicators in Stress Tolerance

Legume species exhibit a wide range of genetic variation in response to abiotic stresses such as drought and salinity. These genotypic differences are among the key determinants of survival and productivity under stress conditions. Therefore, determining the stress tolerance levels among genotypes requires evaluation at both physiological and molecular levels.

Phenotypic Indicators of Genotypic Tolerance

Genotypes with higher stress tolerance typically exhibit better performance in terms of water use efficiency (WUE), osmotic adjustment capacity, stomatal conductance regulation, chlorophyll preservation, and photosynthetic stability. For example, drought-tolerant genotypes often show adaptive traits such as deeper root systems, lower transpiration rates, and higher proline accumulation (Toker et al., 2007). Similarly, salt-tolerant genotypes are characterized by traits such as excluding Na^+ ions from leaves, selective ion uptake, and cellular modifications that preserve membrane integrity. High-throughput phenotyping (HTP) tools such as NDVI, SPAD, thermal imaging, LAI, and biomass analysis are commonly used to objectively evaluate genotype performance under stress conditions.

Molecular Markers and Genetic Basis

Stress tolerance is a complex trait often controlled by multiple gene regions. Therefore, QTL mapping, transcriptomic analysis, and gene expression studies are essential for identifying molecular markers associated with tolerance. For instance, gene families such as LEA (Late Embryogenesis Abundant) proteins, DREB (Dehydration Responsive Element Binding) transcription factors, and aquaporins are known to be upregulated under drought and salinity stress (Varshney et al., 2009). Transcriptome analyses using microarrays, RNA-Seq, and real-time PCR allow comparisons of gene expression profiles in different genotypes under stress, providing a solid foundation for molecular breeding. Furthermore, molecular markers such as SSRs (Simple Sequence Repeats), SNPs (Single Nucleotide Polymorphisms), and DArTs are valuable for identifying stress-related genomic regions and facilitating marker-assisted selection (MAS).

Use of Wild Genetic Resources

Wild relatives of legumes are considered important genetic reservoirs due to their survival capabilities under natural stress conditions. Species such as *Cicer reticulatum*, *Lens ervoides*, and *Vigna marina* have potential sources of genes conferring high salt and drought tolerance. Transferring these genetic

traits to cultivated species can broaden the genetic base and enhance adaptation to stress (Dwivedi et al., 2016). However, challenges such as linkage drag, genetic incompatibility, and loss of agronomic traits may arise during this process. Thus, introgression lines, genomic selection, and precise gene-editing tools such as CRISPR play crucial roles in overcoming these barriers.

Conclusion and Sustainability Perspective

Drought and salinity stress are two major abiotic stressors that increasingly threaten agricultural lands due to global climate change. These stress conditions significantly reduce both biomass production and seed yield in strategic legume species such as chickpea, lentil, bean, and faba bean, thereby directly jeopardizing food security. In this context, understanding the physiological and biochemical responses of legumes to such stresses is crucial for developing climate-resilient cultivars. Mechanisms such as osmotic adjustment, activation of antioxidant systems, protection against ion toxicity, and hormonal regulation are among the primary strategies enabling legumes to survive under stress. The effective use of molecular markers and genetic resources allows for the identification and utilization of stress-related gene regions in breeding programs.

In building sustainable agricultural systems, enhancing abiotic stress tolerance is not only a scientific objective but also a socio-economic necessity. Accordingly, the following recommendations are highlighted:

- Widespread use of high-throughput phenotyping and genotyping platforms will accelerate genetic progress.
- Collections of wild relatives should be systematically evaluated, and genetic variation should be integrated into agricultural production.
- New-generation breeding techniques such as genomic selection, marker-assisted selection, and CRISPR should be adopted to precisely control stress tolerance traits.
- Participatory field trials and the integration of local knowledge into breeding processes will enhance the acceptance of developed varieties.
- Public policies and support systems should be revised to promote the development of stress-tolerant cultivars.

In conclusion, understanding the physiological and biochemical responses of legumes to drought and salinity stress provides a solid foundation for developing more resilient, productive, and sustainable cultivars in the future. Achieving this goal will require the integration of multidisciplinary approaches, genomic technologies, and field-level practical strategies.

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MACHINE LEARNING-BASED YIELD AND QUALITY PREDICTION MODELS

MAKİNE ÖĞRENMESİ DESTEKLİ VERİM VE KALİTE TAHMİNİ MODELLERİ

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ÖZET

Tarım sektöründe verim ve kalite tahmininin doğruluğu, gıda güvenliği, ekonomik sürdürülebilirlik ve kaynak yönetimi açısından kritik bir öneme sahiptir. Geleneksel tahmin yöntemleri, iklim değişkenliği, toprak özellikleri ve tarımsal yönetim uygulamaları gibi çok boyutlu faktörleri tam olarak değerlendirmekte yetersiz kalmaktadır. Bu noktada, makine öğrenmesi (MÖ) tabanlı modeller, tarımsal üretim süreçlerinde veri analitiğini güçlendirerek daha doğru ve ölçeklenebilir tahminler sağlamaktadır.Bu çalışmada, MÖ destekli verim ve kalite tahmin modellerinin temel bileşenleri ve uygulama alanları ele alınmıştır. Çalışmada kullanılan veri setleri, uzaktan algılama, meteorolojik gözlemler, toprak verileri ve mahsul fenotip analizlerinden elde edilen çok boyutlu bilgileri içermektedir. Destek vektör regresyonu (SVR), rastgele ormanlar (RF), yapay sinir ağları (ANN) ve derin öğrenme tabanlı modeller, mahsul verimi ve kalite tahmini açısından karşılaştırılmıştır. Yapılan analizler, RF ve XGBoost modellerinin tahmin doğruluğu açısından üstün performans gösterdiğini ve daha düşük hata oranları ile çalıştığını ortaya koymuştur.Özellikle insansız hava araçları (İHA) ve multispektral görüntüleme teknolojileri ile desteklenen makine öğrenmesi modelleri, tarımsal alanlardaki bitki büyümesini gerçek zamanlı olarak izleyerek, verim ve kalite değişkenliklerini yüksek doğrulukla tahmin edebilmektedir. Derin öğrenme tabanlı konvolüsyonel sinir ağları (CNN) ile yapılan çalışmalar, geleneksel özellik mühendisliği tekniklerine dayalı modellere kıyasla daha üstün tahmin kabiliyeti sergilemiştir.

Sonuç olarak, makine öğrenmesi tabanlı tahmin modelleri, tarımda daha isabetli karar alma süreçleri sağlayarak sürdürülebilir üretimi desteklemektedir. Gelecekte, bu modellerin daha fazla tarımsal veri kaynağıyla entegre edilmesi, iklim değişikliği ve çevresel stres faktörlerine karşı daha dayanıklı mahsul geliştirilmesine önemli katkılar sunacaktır.

Anahtar Kelimeler: Makine öğrenmesi, verim tahmini, kalite analizi, derin öğrenme, uzaktan algılama, hassas tarım.

ABSTRACT

Accurate yield and quality prediction in agriculture is crucial for food security, economic sustainability, and resource management. Traditional forecasting methods often fail to fully account for multidimensional factors such as climate variability, soil properties, and agronomic practices. In this context, machine learning (ML)-based models enhance data analytics in agricultural production, providing more accurate and scalable predictions.This study examines the core components and applications of ML-supported yield and quality prediction models. The datasets used include

multidimensional information derived from remote sensing, meteorological observations, soil data, and crop phenotypic analyses. Support Vector Regression (SVR), Random Forest (RF), Artificial Neural Networks (ANN), and deep learning-based models were compared for yield and quality estimation. Analysis revealed that RF and XGBoost models demonstrated superior accuracy with lower error rates.Particularly, ML models supported by Unmanned Aerial Vehicles (UAVs) and multispectral imaging technologies enable real-time monitoring of plant growth, facilitating highly accurate yield and quality predictions. Studies utilizing deep learning-based Convolutional Neural Networks (CNNs) exhibited superior predictive capabilities compared to traditional feature engineering-based models.

In conclusion, ML-based predictive models enhance agricultural decision-making processes, fostering sustainable production. The future integration of these models with broader agricultural data sources is expected to contribute significantly to the development of climate-resilient crops and improved resource efficiency.

Keywords: Machine learning, yield prediction, quality analysis, deep learning, remote sensing, precision agriculture.

Introduction

Today, the agricultural sector faces multifaceted challenges such as increasing global population, climate change, depletion of natural resources, and rising input costs. These issues necessitate the management of agricultural production in a more precise, efficient, and sustainable manner. Yield and quality prediction, in particular, has strategic importance in both agricultural planning and the management of the food supply chain. Traditional forecasting methods often rely on limited datasets and fail to adequately account for environmental variables, making them insufficient in dynamic agricultural systems. At this point, machine learning (ML) techniques stand out as powerful tools that can be integrated into agricultural decision support systems due to their capabilities in analyzing large multivariate datasets, recognizing patterns, and modeling non-linear relationships (Kamilaris & Prenafeta-Boldú, 2018). ML algorithms can provide more accurate and scalable predictions by considering both environmental (climate, soil, irrigation) and plant-based (phenotypic traits, sensor data) factors.

The aim of this study is to examine machine learning-based yield and quality prediction models in both theoretical and applied contexts; to explore the main algorithms, data sources, model evaluation criteria, and their contributions to agricultural sustainability. Furthermore, the potential future applications of these models will be discussed in the context of their integration with remote sensing technologies, sensor systems, and digital agriculture platforms.

Fundamentals of Machine Learning and Agricultural Applications

Machine learning (ML) is a sub-discipline of artificial intelligence that enables computers to learn from experience without being explicitly programmed. Essentially, it aims to perform predictions and classifications by learning patterns and relationships from large datasets. ML algorithms are classified into different categories such as supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning (Jordan & Mitchell, 2015). Supervised Learning is the most commonly used approach in agricultural yield and quality prediction studies. In this method, the model learns from input-output pairs in historical data (e.g., temperature, soil moisture, NDVI as inputs; yield or protein content as outputs) to make predictions for new data. Regression and classification problems fall under this category. Among supervised algorithms, Random Forest (RF), Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Gradient Boosting Machines (GBM) are prominent models. Unsupervised Learning is used primarily for data exploration, dimensionality reduction, and pattern recognition. Clustering methods (e.g., Fuzzy C-

Means, K-Means) are valuable in defining homogeneity zones in agricultural data or grouping different stress responses. The application areas of ML in agriculture are increasingly diverse. In this context, ML techniques are used in the following key domains:

- Yield Prediction: Using multiple variables such as climate data, soil properties, NDVI, SPAD, and plant height, it is possible to estimate yield per plant or per unit area (Jeong et al., 2016).
- Quality Prediction: Quality parameters such as protein, gluten, and starch content can be predicted based on spectral data and laboratory analyses. Especially hyperspectral imaging and ANN models have yielded successful results in this area (Sharma et al., 2020).
- Disease and Stress Detection: ML systems based on image processing are increasingly used in identifying diseases through leaf symptoms and determining stress levels.
- Irrigation and Fertilization Optimization: ML-based models provide decision support regarding irrigation scheduling and fertilizer dosage using data such as soil moisture, EC, pH, and plant condition (Li et al., 2021).
- Remote Sensing Integration: With data from drones, satellites, and ground-based sensors, ML models can analyze within-field heterogeneity, support regional planning, and enable real-time intervention strategies.

Beyond decision support, the advantages of ML in these domains include sustainability, cost reduction, and environmental impact mitigation. Developing data-driven agricultural management models will support the broader adoption and integration of these technologies in farming systems.

Algorithms and Modeling Approaches in Yield and Quality Prediction

In machine learning applications for yield and quality prediction, algorithm selection depends on factors such as data structure, the type of target variable, and the intended use of the model. Below are some commonly used algorithms in agricultural modeling and their key characteristics:

Random Forest (RF): Random Forest is an ensemble learning method that combines the outputs of multiple decision trees through voting or averaging. It performs well even with noisy data, is resistant to overfitting, and provides variable importance metrics—making it a popular choice in agricultural datasets. It enables highly accurate yield predictions using multisource sensor data such as SPAD, NDVI, and plant height (Jeong et al., 2016).

Artificial Neural Networks (ANN): Inspired by the human brain, ANNs can model complex nonlinear relationships through multilayer architectures. They are especially successful in predicting quality attributes (e.g., protein or gluten content) from spectral reflectance data, performing multivariate time-series analyses, and stress classification (Sharma et al., 2020). However, ANNs require large volumes of data and careful training.

Support Vector Machines (SVM): SVM is a powerful algorithm that performs classification and regression by separating data with a hyperplane. It provides high accuracy in small to medium datasets and is particularly effective for classification-based quality analysis (e.g., high/low protein content). Due to its sensitivity to parameter tuning, careful optimization is necessary (Cortes & Vapnik, 1995).

Gradient Boosting Machines (GBM and XGBoost): Boosting algorithms offer a sophisticated learning strategy by minimizing the errors of successive models. Variants such as XGBoost show strong predictive performance, especially for large datasets and multivariate regression problems. Model accuracy can be further improved through hyperparameter tuning (Chen & Guestrin, 2016).

K-Nearest Neighbors (KNN): The KNN algorithm makes decisions based on the “k” nearest neighbors of a new data point. It is a fast and feasible method for small datasets, homogeneous regions, or intuitive estimations. However, its performance decreases in high-dimensional datasets.

Modeling Approaches

- **Data Preprocessing:** Agricultural datasets are often incomplete, noisy, and imbalanced. Therefore, preprocessing steps such as normalization, missing data imputation, dimensionality reduction (e.g., PCA), and outlier removal are essential.
- **Model Training and Testing:** Typically, 70–80% of the data is used for training, and the remaining 20–30% for testing or validation. K-Fold Cross Validation is employed to assess generalizability.
- **Performance Metrics:** Prediction performance is evaluated using metrics such as R^2, RMSE, MAE, and MAPE. These metrics are crucial for objectively comparing model accuracy.
- **Model Interpretability:** In practical domains like agriculture, techniques such as feature importance, SHAP values, and parsimonious models help provide understandable recommendations to producers.

Conclusion and Future Perspectives

Machine learning-based yield and quality prediction models have become a cornerstone of decision support systems in agricultural production. These technologies offer integrated solutions not only in yield forecasting and quality analysis, but also in stress detection, nitrogen management, soil classification, and harvest timing. Models that utilize multi-source datasets such as NDVI, SPAD, LAI, spectral reflectance, and meteorological data have demonstrated higher accuracy and generalizability than traditional methods. Improving prediction accuracy in yield and quality estimation depends not only on algorithm selection but also on the quality of data, model training processes, field validation, and interpretability. In this context, AI systems integrated with sensor-supported precision agriculture applications have great potential to enhance the environmental sustainability and economic efficiency of agricultural production. Prominent future perspectives include:

- **Integrated Data Infrastructures:** Centralized platforms that integrate remote sensing, drone data, soil analyses, and farmer records will enable models to generate more comprehensive and consistent predictions.
- **Real-Time Prediction Systems:** With the development of IoT-based sensor networks, models can be dynamically updated to provide field-specific, real-time recommendations.
- **Explainable Artificial Intelligence (XAI):** Presenting model outputs in an interpretable manner for farmers and agricultural advisors will enhance field-level adoption.
- **Local and Small-Scale Adaptation:** Adapting large-scale models to local conditions and retraining them with regional data will enable more sensitive solutions to local agricultural problems.
- **Policy and Incentive Mechanisms:** Expanding public-funded projects and R&D incentives to support the dissemination of digital agriculture solutions will accelerate the adoption of model-based decision-making.

In conclusion, machine learning-supported models play a strategic role in enhancing productivity, sustainability, and digitalization in future agricultural management systems. The rationalization, data-driven optimization, and environmental sensitivity of agricultural production are directly linked to the availability and field-level integration of these models. Therefore, interdisciplinary collaboration, open data sharing, and the development of user-friendly platforms are of critical importance in maximizing the effectiveness of these technologies.

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OPTIMAL CONCENTRATION EFFECT ON PHOTOLUMINESCENCE OF Mo^{3+} ACTIVATED SOFT GLASSES NEAR IR EXCITATION FOR PHOTONIC APPLICATIONS

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Abstract

In this study Mo^{3+} doped optical glass materials were prepared by conventional melt-quenching method. As a result of ongoing intensive research on the use of luminescent based photonic devices in today's lighting technologies, sensor applications, and fiber optic which attracts attention due to its environmental friendliness, high luminescence efficiency and brightness, long-term durability level, low energy consumption and structural stability. The use of xMo^{3+} ion (x=0.2, 0.5, 1.0, 2.0, 3.0 and 4.0 mol%) doped glass network shows significantly high absorption in the visible region (400-800nm) and play an indispensable role providing a wide spectral range including the UV, VIS, and IR regions as a luminescent glass material. These advantages include the Mo^{3+} doping seems to be the most successful and promising due to its smaller ionic radius and higher covalent radius of 0.65 (0.74 Å) and 1.54 (1.25 Å).

Within the scope of this research, Mo^{3+} based P_2O_5-ZnO-MoO_3 optical glass networks were prepared. Optical properties and photoluminescence of glass materials were investigated at different Mo^{3+} ion concentrations. Briefly, because of the different Mo^{3+} ion concentrations by excitation at a wavelength of 808nm it was observed that the luminescence intensity of the optimum optical glass material for 1.0mol% Mo^{3+} was at its highest value at the emission wavelength of 1100nm.

Keywords: optical glass, photonic, absorption, photoluminescence

NUMERICAL INVESTIGATION OF HYDRODYNAMIC BEHAVIOR OF FLOATING AGRICULTURAL APPLICATIONS PLATFORMS

YÜZER TARIM UYGULAMALARI PLATFORMLARININ HİDRODİNAMİK DAVRANIŞININ SAYISAL OLARAK İNCELENMESİ

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ÖZET

Küresel ölçekte iklim değişikliği, doğal afetler, nüfus artışı, tarım arazilerinin azalması ve su kaynaklarının tükenmesi, tarımsal üretim üzerinde ciddi baskılar oluşturmaktadır. Bu gelişmeler, gıda güvenliğini tehdit ederken, tarımın daha verimli, üretken ve iklim koşullarına dayanıklı hale getirilmesini zorunlu kılmaktadır. Ayrıca, üretimden tüketime uzanan süreçte yaşanan yüksek fire oranları, hem ekonomik kayıplara yol açmakta hem de tarım ürünleri fiyatlarını küresel düzeyde artırmaktadır. Bu sorunlara karşı geliştirilen yeni nesil tarım teknolojileri, özellikle üretimin yerinde yapılmasını ve su kaynaklarının daha etkin kullanılmasını ön plana çıkarmaktadır. Bu kapsamda, su kültürüne dayalı modern tarım uygulamaları, sınırlı alanlarda dikey üretime olanak sağlayarak daha kontrollü sulama ve besleme imkânı sunmakta; böylece tarımsal sürdürülebilirliğe katkı sağlamaktadır.

Tarımda su kadar önemli bir diğer temel girdi de enerjidir. Özellikle sulama suyunun kaynaktan tarım alanlarına taşınması süreci, ciddi bir enerji tüketimini beraberinde getirmektedir. Bu nedenle, geleneksel vahşi sulama yöntemlerinden akıllı sulama sistemlerine geçiş, hem suyu daha verimli kullanmakta hem de enerji ihtiyacını azaltmaktadır. Son yıllarda, suyun bulunduğu kaynaklara yakın alanlarda tarım yapılması yaklaşımı, su ve enerji tasarrufu açısından dikkat çeken bir çözüm olarak ön plana çıkmıştır. Bu bağlamda, sulama ihtiyacını karşılamak için çoğunlukla akarsular üzerine inşa edilen sulama barajları, hem suyun depolanmasını hem de tarımsal üretime yakınlaştırılmasını sağlayarak kaynakların daha etkin kullanılmasına katkı sunmaktadır.

Bu çalışmada, sulama barajları üzerine yerleştirilecek yüzer tarım platformları aracılığıyla, sulama için gereken enerji maliyetlerinin düşürülmesi ve sınırlı alanlarda yüksek verim elde edilmesi hedeflenmiştir. Bu doğrultuda, yenilikçi bir ada yapısı tasarlanmış ve bu yapıya etki eden rüzgar yükleri, Hesaplamalı Akışkanlar Dinamiği (CFD) yöntemleri kullanılarak analiz edilmiştir. Yapının üzerine gelen farklı rüzgar hızlarının ve hâkim rüzgar yönlerinin, platformun yerleşim kararları üzerinde belirleyici olduğu; yerleşim düzenine bağlı olarak yapı üzerindeki kuvvetlerin doğru biçimde belirlenmesinin büyük önem taşıdığı görülmüştür. Ayrıca, rüzgar kaynaklı girdapların yapı üzerinde zamana bağlı değişken yükler oluşturduğu tespit edilmiş, bu değişkenliklerin yapı stabilitesi açısından dikkate alınması gerektiği anlaşılmıştır. Bu kapsamda, platformun karaya güvenli biçimde

sabitlenebilmesi için kullanılacak tutturma ekipmanlarının taşıma kapasiteleri de detaylı biçimde değerlendirilmiştir.

Anahtar Kelimeler: Yüzer tarım, suda tarım, hesaplamalı akışkanlar dinamiği, CFD

ABSTRACT

On a global scale, climate change, natural disasters, population growth, diminishing agricultural land and depleting water resources are putting serious pressures on agricultural production. These developments threaten food security and make it imperative to make agriculture more efficient, productive and resilient to climatic conditions. In addition, high wastage rates from production to consumption cause economic losses and increase the prices of agricultural products globally. The new generation of agricultural technologies developed to address these problems emphasize on-site production and more efficient use of water resources. In this context, modern agricultural practices based on water culture enable vertical production in limited areas and provide more controlled irrigation and feeding, thus contributing to agricultural sustainability.

Energy is another basic input as important as water in agriculture. In particular, the process of transporting irrigation water from the source to the agricultural fields brings with it a significant energy consumption. Therefore, the transition from traditional wild irrigation methods to smart irrigation systems both uses water more efficiently and reduces the need for energy. In recent years, the approach of farming in areas close to water sources has come to the forefront as a remarkable solution in terms of water and energy savings. In this context, irrigation dams, which are mostly built on rivers to meet irrigation needs, contribute to more efficient use of resources by both storing water and bringing it closer to agricultural production.

In this study, it is aimed to reduce the energy costs required for irrigation and to achieve high yields in limited areas through floating agricultural platforms to be placed on irrigation dams. To this end, an innovative island structure was designed and the wind loads acting on this structure were analyzed using Computational Fluid Dynamics (CFD) methods. It has been observed that different wind speeds and prevailing wind directions are decisive on the layout decisions of the platform and it is of great importance to accurately determine the forces on the structure depending on the layout. In addition, it was determined that wind-induced vortices create time-dependent variable loads on the structure, and it was understood that these variations should be taken into account in terms of structural stability. In this context, the carrying capacities of the anchoring equipment to be used for the safe anchoring of the platform to the land were also evaluated in detail.

Keywords: Floating agriculture, hydroponics, computational fluid dynamics, CFD

GİRİŞ

Dünya genelinde hızla artan nüfus, enerji, su ve besin kaynaklarına olan talebi önemli ölçüde artırmaktadır (Sayed vd., 2022). Özellikle nüfusun yarısından fazlasının yaşadığı ve 2050 yılına kadar bu oranın %70'i aşmasının beklendiği kentlerde, bu artış ciddi bir kaynak yönetimi sorununa dönüşmektedir (*World Urbanization Prospects*, 2019). Artan kentleşme ve kaynak üzerindeki baskı göz önüne alındığında, tarımın sürdürülebilirliği günümüzün en kritik meselelerinden biri hâline gelmiştir.

Küresel ölçekte değerlendirildiğinde, çekilen tatlı suyun yaklaşık %70'inin tarımsal sulama amacıyla kullanıldığı, toplam su tüketiminin ise %80 ila %90 gibi büyük bir kısmının doğrudan bu süreçlerde gerçekleştiği görülmektedir (Gleick, 2009). Bu durum, tarımın su kaynakları üzerindeki baskısını açıkça ortaya koymakta ve mevcut kaynakların daha verimli kullanımını zorunlu kılmaktadır.

İklim değişikliğinin etkileri de bu sorunu daha karmaşık hâle getirmektedir. Özellikle su ve gıda gibi yaşamsal kaynaklar üzerindeki baskının artması, tarımsal sistemlerin bu değişime uyum sağlama

kapasitesini küresel gıda güvenliğinin sürdürülebilirliği açısından hayati bir konu hâline getirmiştir. Zira tarımsal üretim sistemleri; iklim, toprak ve yönetim uygulamalarıyla doğrudan etkileşim içinde olan, karmaşık ve çok yönlü yapılar sergilemektedir (Walthall & et al. [+55, 2013).

Bu kapsamda, tarım sektörü hem iklim değişikliğinin etkileri hem de artan nüfus baskısı nedeniyle su kaynaklarına erişimde ciddi zorluklarla karşı karşıyadır. Küresel tatlı su kaynaklarının yaklaşık %70'ini tüketen tarım faaliyetlerinde, azalan arazi ve su olanaklarına rağmen üretkenliğin sürdürülmesi için yenilikçi su yönetimi stratejileri ile hassas tarım teknolojilerinin entegrasyonu kaçınılmaz hâle gelmiştir (FAO, 2020).

Bu doğrultuda geliştirilen hassas tarım ve akıllı sulama teknolojileri, toprak nemi, iklim verileri ve bitki ihtiyaçlarını esas alan izleme ve kontrol sistemleri ile suyun doğru zamanda ve doğru miktarda uygulanmasını sağlamaktadır. Bu sayede, geleneksel sulama yöntemlerinde sıkça karşılaşılan su israfı, besin kaybı ve verim düşüklüğü gibi sorunların önüne geçilebilmekte, hem kaynak kullanımı optimize edilmekte hem de sürdürülebilir tarıma katkı sağlanmaktadır (Bwambale vd., 2022).

Yüzen yataklı tarım, sel baskınlarının mahsuller üzerindeki zararlarını azaltma, su kaynaklarının korunmasına katkı sağlama ve toprak bozulmasını önleme gibi çok yönlü çevresel ve tarımsal faydalar sunan yenilikçi bir üretim yöntemidir (Chowdhury & Moore, 2017). Yüzen yataklı tarım, ürünlerin göller, nehirler veya göletler gibi su kütleleri üzerinde konumlanan yüzer platformlar ya da sal yapılar üzerinde yetiştirildiği yenilikçi bir tarım uygulamasıdır (Ghosh vd., 2024) .

Yüzen yapılar; yerçekimi, dalga kuvvetleri, seviye değişimleri gibi çeşitli etkilere maruz kalsa da, bu kuvvetlerin tüm dinamik benzerliklerini sağlayacak ölçekli ve tam anlamıyla gerçek bir model mevcut değildir; ancak bu da zorunlu değildir, çünkü bu kuvvetlerden yalnızca birkaçı yüzer yapıların dinamik davranışlarını belirleyici şekilde etkiler (Steven A. Hughes, t.y.).

Son yıllarda yapılan araştırmalar, girdap kopmasının düşük hızlarda oluşmadığını ve yüksek türbülans seviyelerinde türbülansın bu kopmayı bastırdığını ortaya koymuştur; bu nedenle, zamana bağlı olmayan sürekli bir akış ancak cismin doğal frekansıyla rezonansa girdiğinde, yani kritik hız ve periyodik frekansta, akış yönüne dik büyük kuvvetler oluşturur ve eğer yapı bu kuvvetlere karşı yeterince dayanıklı değilse, yapısal hasarlar veya kırılmalar meydana gelebilir (Dexter & Ricker, 2002).

Bu çalışmada, sulama barajlarına yerleştirilecek yüzer tarım platformları ile sulama enerjisi maliyetlerini azaltmak ve sınırlı alanlarda yüksek verim sağlamak amaçlanmıştır. Bu kapsamda tasarlanan ada yapısına etki eden rüzgar yükleri CFD yöntemleriyle analiz edilmiş; rüzgar hızları ve yönlerinin yerleşim kararları ile yapı üzerindeki kuvvetleri önemli ölçüde etkilediği görülmüştür. Rüzgar kaynaklı girdapların zamana bağlı değişken yükler oluşturduğu ve bu yüklerin yapı stabilitesi açısından kritik olduğu belirlenmiş, platformun güvenli sabitlenmesi için tutturma ekipmanlarının taşıma kapasiteleri detaylı şekilde incelenmiştir.

YÖNTEM

Yöntem bölümünde; matematik model ve sayısal model hakkında bilgi verilmiştir. Analizlerde ticari bir kod olan Simcenter STAR-CCM+ programından yararlanılmıştır.

Matematik Model

Çalışmada kullanılan üç boyutlu, zamana bağlı, sıkıştırılamaz ve türbülanslı akış için kullanılan yönetici denklemler aşağıdaki gibidir;

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (1)$$

Akış hacminde çözülen problem kütle korunumu için süreklilik denklemine verilir.

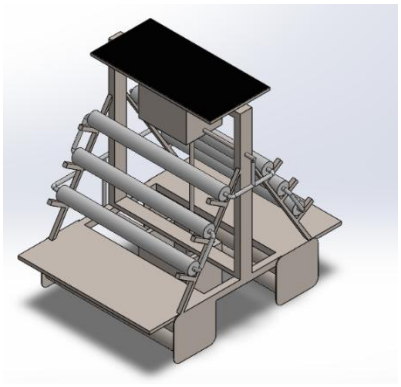
$$\frac{\partial \rho u}{\partial t}+\frac{\partial}{\partial x}\left(\rho u^2+p-\tau_{xx}\right)+\frac{\partial}{\partial y}\left(\rho uv-\tau_{xy}\right)+\frac{\partial}{\partial z}\left(\rho uw-\tau_{xz}\right)=\rho f_x \qquad (2a)$$

$$\frac{\partial \rho v}{\partial t}+\frac{\partial}{\partial x}\left(\rho uv-\tau_{xy}\right)+\frac{\partial}{\partial y}\left(\rho v^2+p-\tau_{yy}\right)+\frac{\partial}{\partial z}\left(\rho vw-\tau_{yz}\right)=\rho f_y \qquad (2b)$$

$$\frac{\partial \rho w}{\partial t}+\frac{\partial}{\partial x}\left(\rho uw-\tau_{xz}\right)+\frac{\partial}{\partial y}\left(\rho vw-\tau_{yz}\right)+\frac{\partial}{\partial z}\left(\rho w^2+p-\tau_{zz}\right)=\rho f_z \qquad (2c)$$

Sayısal Model

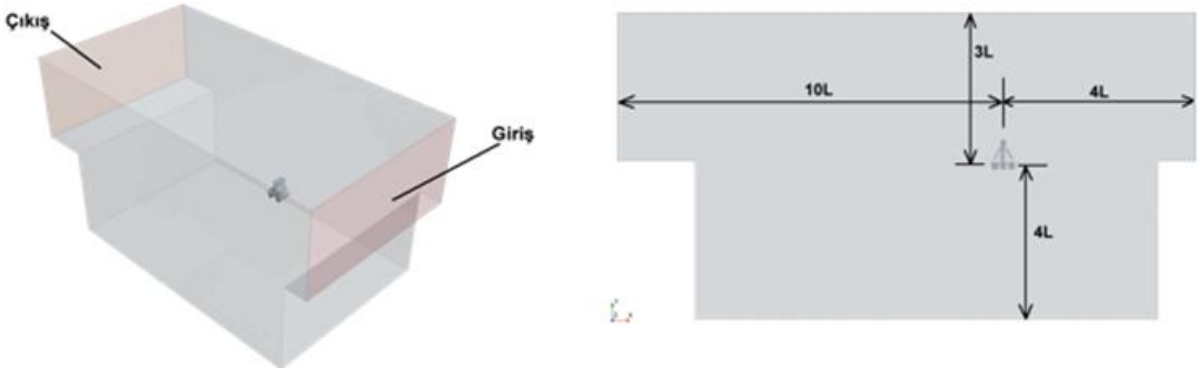
Geometri ve Çözüm Hacmi



Şekil 1: Tekil yüzer platform tasarımı

Şekil 1'de yüzer tarım için tasarlanan tekil olarak ada yapısında kullanılacak modülün bilgisayar destekli tasarımı gösterilmiştir. İki adet boyuna yüzdürücü üzerine inşa edilen yapıda sancak ve iskele olmak üzere iki cephede üçer tarım kolonu yerleştirilmiştir. Yüzdürücüler ortasında tarım kolonlarına su beslenmesi için kullanılacak ana su tankı, merkez düzlemde üst noktada sıvı gübre ile temiz suyun

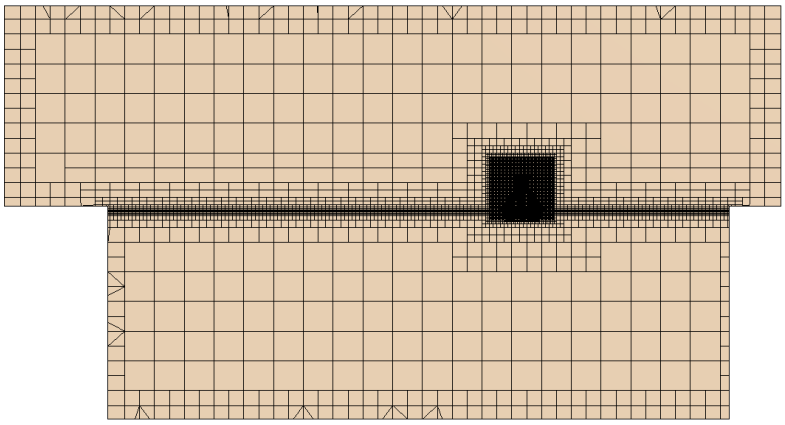
karıştırıldığı karışım tankı yer almaktadır. Yine yüzdürücüler arasında ana tanktan besin tankına su sirküle edecek bir sirkülasyon pompası kullanılmıştır. Modül üst kısmına sirkülasyon pompasının güç ihtiyacını karşılamak üzere PV panel eklenmiştir. Besin tankından tarım kolonlarına besleyici sıvı transferi yerçekimi kullanılarak aktarılmaktadır.



Şekil 2 : Çözüm hacminin boyutları ve Giriş-Çıkış sınır yüzeyleri

Çözümün gerçekleştirilmesi için Şekil 2'de boyut ve sınır ayrıntılarının verildiği çözüm hacmi tasarlanmıştır. Modülün yukarı akım bölümü 4 cisim boyu, aşağı akım bölümü 10 cisim boyu, derinlik yönü 4 cisim boyu yükseklik yönü 3 cisim boyu olacak şekilde boyutlandırılmıştır.

Çözüm Ağı



Şekil 3:Mesh yapısı 2 boyutlu düzlem

Şekil 3'de, analize ait yapısal 3 boyutlu çözüm ağının merkez kesit üzerindeki görünüşü verilmiştir.

Analiz edilen yapının yakın çevresi daha hassas çözüm ağı ile modellenirken, serbest su yüzeyinin oluşacağı bölge de yoğunluk değişimi ve dalga deformasyonunu doğru şekilde çözebilmek için hassas çözünürlükte örülmüştür. Cisim üzerinde oluşan hız gradyanlarını hesaplayabilmek için kalınlaşan çözünürlüklü sınır tabaka (boundary layer) çözüm elemanları tercih edilmiştir.

Çözüm Ağı Yakınsama İndeksi (GCI)

GCI, farklı ağ (mesh/grid) çözünürlüklerinde yapılan sayısal simülasyon sonuçlarının birbirine ne kadar yakın olduğunu ölçen bir yöntemdir; bir sayısal çözümün mesh bağımsızlığına ulaşıp ulaşmadığını kontrol etmek için kullanılır. Yani çözüm, ağ inceldikçe (grid küçüldükçe) değişmiyorsa, çözüm güvenilirdir; eğer sonuçlar ağ değişimiyle çok fazla değişiyorsa, çözüm henüz tam doğruya yakın değildir.

```
GCI Hesaplama için girişleri girin:
Eleman sayısı (N) - Kaba ağ: 881520
Eleman sayısı (N) - Orta ağ: 1797455
Eleman sayısı (N) - İnce ağ: 3582052
Numerik Çözüm (f) - Kaba ağ: 3.3175
Numerik Çözüm (f) - Orta ağ: 1.9902
Numerik Çözüm (f) - İnce ağ: 1.97082

GCI Hesaplama Sonuçları:
  Çözüm Ağı  Eleman Sayısı (N)  Numerik Çözüm (f)  GCI 21 (%)  GCI 32 (%)  Yakınsama Oranı (p)
Ağ 1 (Kaba)             881520            3.31750    2.458395         NaN            17.796981
Ağ 2 (Orta)            1797455            1.99020         NaN    0.041211                  NaN
Ağ 3 (İnce)            3582052            1.97082         NaN         NaN                  NaN

Sonuçlar ağ bağımsızlığına ulaşmıştır, çünkü GCI < %5.
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Bu analizde, Mesh 02 (orta çözünürlükte ağ) seçilmiştir çünkü GCI 32 değeri %0.05'in altındadır. Bu, çözümün ağdan bağımsız olduğunu ve daha ince ağla çözüm alınmasının anlamlı bir katkı sağlamadığını göstermektedir. Böylece daha kısa sürede ve yeterli doğrulukta hesaplama yapılabilir.

Sınır Şartları

Yapılan CFD analizinde yüzer platformun etrafındaki akış hacmini modellemek üzere hız girişi sınırından 1 m/s rüzgar hızı tanımlanmıştır; giriş kısmından herhangi bir akıntı hızı verilmemiş, giriş sınır yüzeyinde su hacimsel fraksiyonu (Volume Fraction of water) "0" olarak alınmıştır. Çıkış sınır yüzeyinde "dP/dx = 0" sınır şartı kullanılarak açık hava basıncında bir akış çıkışı elde edilmiştir; cisim harici kalan tüm yüzeyler "kaymama koşulu olmayan" duvar sınır şartı ile kullanılmıştır. Serbest su yüzeyinin yüzer platform kaidesinden 0.5 m yükseklikte olduğu başlangıç koşulu ile belirlenmiştir ve cisim tam boylu (Full Body) olarak analiz edilmiştir.

SONUÇLAR

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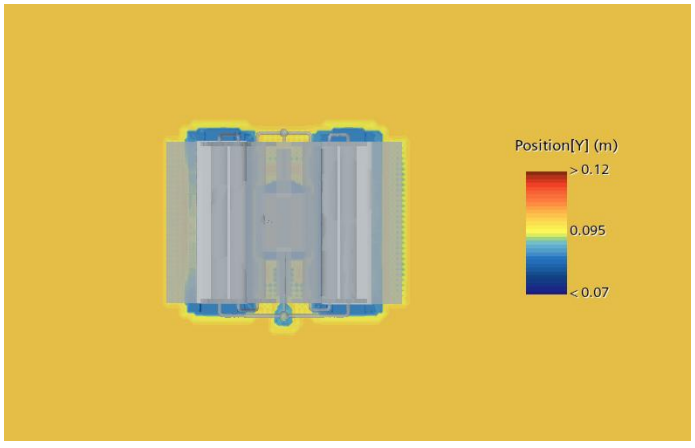
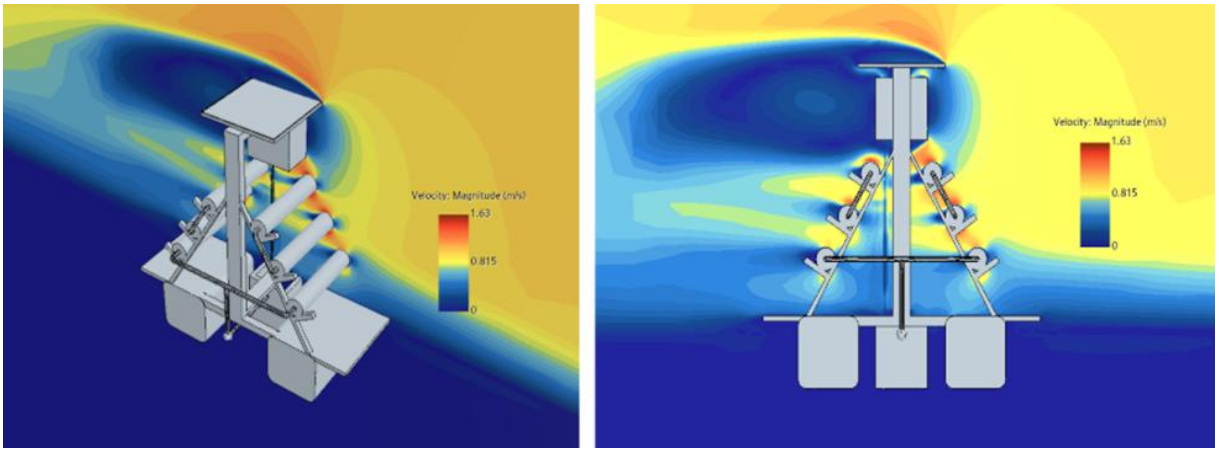


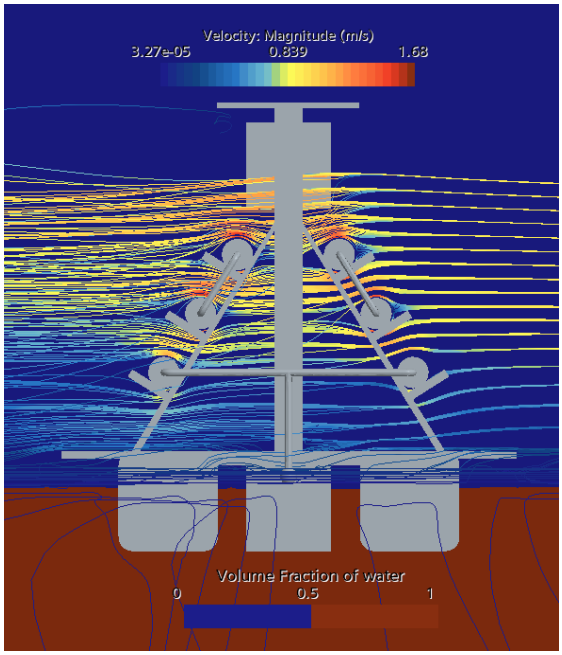
Şekil 4: Serbest yüzey deformasyonu görünümü

Şekil 4'de yüzer platforma üstten bakılarak serbest su yüzeyi deformasyonu gösterilmektedir. Önceki yansıda da bahsedildiği üzere herhangi bir akıntı sınır şartı verilmediği ve cismin sabit kabul edildiği bu modelde serbest su yüzeyinde bir dalga deformasyonuna rastlanmamıştır.



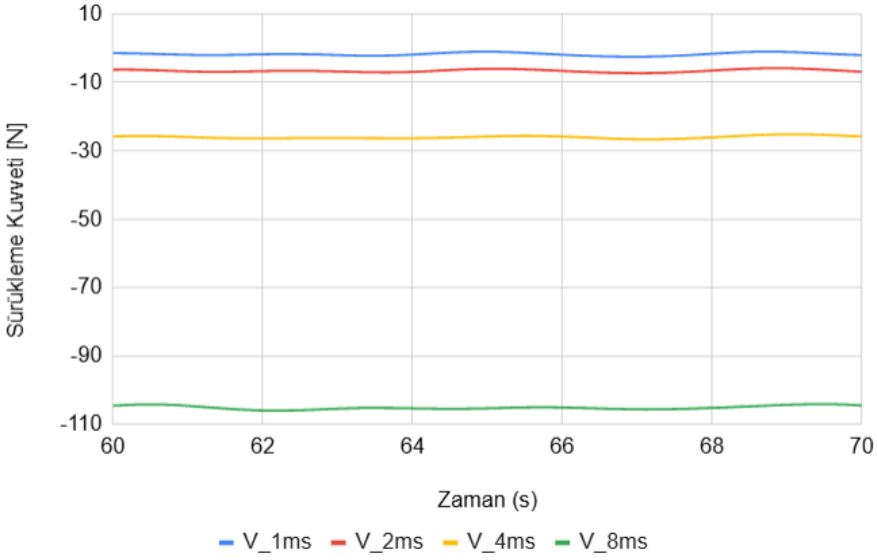
Şekil 5 :Orta kesit üzerindeki hız dağılımı

Şekil 5'de orta kesit üzerinde hız dağılımları gösterilmektedir. Problemin geometri özellikleri nedeniyle tarım ürünlerinin yetiştirildiği silindirik yapıların etrafında oluşan karmaşık akış ortamı ve silindirler arasındaki etkileşim, hız dağılımlarının karmaşık bir ortam oluşmasına neden olmaktadır. Akışın gelen akış yönündeki silindirler arası hız dağılımlarına bakıldığında hızların giden akış yönündeki silindirler arası hıza göre daha yüksek olduğu görülebilir. Bu durum da cismin gelen akış ve giden akış yönlerine göre farklı dirençler ortaya koyacağı anlamını taşır.



Şekil 6:Platform etrafındaki akım hatları

Şekil 6'da orta kesit üzerindeki faz dağılımı ve akım hatları görülmektedir; akım hatları incelendiğinde silindirler üzerinde hava hızlarının arttığı ve silindirler arasında akımın daha yüksek düşey kuvvetler üreteceği yönde gerçekleştiği görülmektedir. Serbest su yüzeyine yaklaşıldığında ise serbest akım hızının azaldığı gözlemlenmektedir.



Şekil 7: Farklı rüzgar hızlarında zamana bağlı sürüklenme kuvvetleri

Şekil 7'de platform üzerine gelen farklı rüzgar hızlarına göre tekil modülün sürüklenme kuvveti değerleri verilmiştir. Hızın artışı ile toplam sürüklenme kuvvetleri de artmaktadır. Her hızda kuvvet değerlerinde salınım miktarları benzer görüntüler göstermiştir. İleriki çalışmalarda bu yapının etrafında oluşan girdap alanlarının daha iyi çözülmesi için uyarlanabilir çözüm ağı iyileştirme metotları kullanılarak çözüm ağı kalitesi yerel olarak artırılması önerilir.

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ENERGY CONSUMPTION AND LIFE CYCLE EMISSION ANALYSIS BASED ON OUTDOOR METEOROLOGICAL PARAMETERS IN PUBLIC AND SERVICE BUILDINGS

KAMU İŞ VE HİZMET BİNALARINDA DIŞ ORTAM METEOROLOJİK PARAMETRELERİNE BAĞLI ENERJİ TÜKETİMİ ETÜDÜ VE YAŞAM ÇEVRİMİ EMİSYON ANALİZİ

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ÖZET

Çalışmada, ana bina ve matbaa ek binasından oluşan ve kamu iş-hizmet binası olan Balıkesir Üniversitesinin Rektörlük binası için sıcaklık, nem, güneş radyasyonu, güneşlenme, rüzgâr süresi, rüzgâr hızı, toprak sıcaklığı (1 m derinlik için), atmosfer basıncı, buhar basıncı, toplam güneşlenme süresi güneş-hava sıcaklığı ve yaş termometre sıcaklığı gibi dış ortam meteorolojik parametrelere bağlı, kış dönemi doğal gaz ve yaz dönemi elektrik tüketimi incelenmiştir. İnceleme yapılan kış döneminde mesai saatleri içinde olan sabah saat 08.30-17.00 arası ve yaz döneminde mesai saatleri içinde olan 10.45-15.45 arası dikkate alınmıştır. Kış döneminde aralık ayında ve yaz döneminde ise ağustos ayında beş günlük enerji tüketimi incelenmiştir. Meteorolojik veriler meteoroloji genel müdürlüğünden alınmıştır. Kış dönemi doğal gaz ve yaz dönemi elektrik kullanımına bağlı emisyon araştırması yapılmıştır. Enerji tüketimlerine bağlı doğal gaz ve elektrik için meydana gelen karbondioksit emisyon uzun yıllar için Yaşam Çevrimi Emisyon Değerlendirmesi (YCED) yapılmıştır. Çalışmada ilk olarak, binaların enerji analizlerinde kullanılan yapı kabuğu ısı transferi katsayıları ve alanlar tespit edilmiştir. Balıkesir Üniversitesinin Rektörlük binası, kuzey doğu yönünde 978 m^2 pencere ve 1946 m^2 duvar, güney doğu yönünde 166 m^2 pencere ve 980 m^2 duvar, güney yönünde 11 m^2 pencere ve 10 m^2 duvar, güney yönünde 945 m^2 pencere ve 1856 m^2 dış duvar, batı yönünde 18 m^2 pencere, kuzey batı yönünde 156 m^2 pencere ve 851 m^2 duvar alanı ve bodrum katı 266 m^2 yönsüz alan bulunmaktadır. Kış dönemi ölçüm alınan günlerde günlük ortalama değerler; sıcaklık 7.8 ^{0}C, bağıl nem % 89.6, güneş radyasyonu 4255.9 W/m^2, güneşlenme süresi 0.47 saat, rüzgâr hızı 4.2 m/s, toprak altı sıcaklığı 12.1 ^{0}C, atmosfer basıncı 1007.4 mb ve buhar basıncı 9.5 hPa olarak tespit edilmiştir. Yaz dönemi ölçüm alınan günler ortalama değerler, sıcaklık 32.2 ^{0}C, bağıl nem % 53.0, güneş radyasyonu 39079.3 W/m^2, güneşlenme süresi 8.08 saat, rüzgâr hızı 4.6 m/s, toprak altı sıcaklığı 25.8 ^{0}C, atmosfer basıncı 998.1 mb ve buhar basıncı 24.3 hPa olarak tespit edilmiştir.

Anahtar kelimeler: İş ve Hizmet Binaları, Meteorolojik Parametreler, Enerji Tüketimi, Yaşam Çevrimi Emisyon Analizi.

ABSTRACT

In this study, the natural gas consumption during winter and electricity consumption during summer were analysed for the Rectorate building of Balikesir University, a public business-service facility comprising the main building and the printing house annex. The analysis considered external

meteorological parameters, including temperature, humidity, solar radiation, sunshine duration, wind speed, wind duration, soil temperature (at a depth of 1 m), atmospheric pressure, vapor pressure, sun-air temperature and wet bulb temperature. The working hours were taken as 08:30–17:00 in winter and 10:45–15:45 in summer, with energy consumption examined over five days in December and August. Meteorological data were obtained from the General Directorate of Meteorology, and emissions were evaluated based on natural gas usage in winter and electricity consumption in summer. A Life Cycle carbon dioxide Emission Assessment (YCED) was conducted to assess emissions over an extended period. The building envelope's heat transfer coefficients and areas were determined to support the energy analysis. The Rectorate building includes 978 m² of windows and 1,946 m² of walls in the northeast, 166 m² of windows and 980 m² of walls in the southeast, 11 m² of windows and 10 m² of walls in the south, 945 m² of windows and 1,856 m² of external walls in the south, 18 m² of windows in the west, 156 m² of windows and 851 m² of walls in the northwest, and 266 m² of non-directional area in the basement. The meteorological data recorded during measurement days in winter showed an average temperature of 7.8°C, relative humidity of 89.6 %, solar radiation of 4,255.9 W/m², sunshine duration of 0.47 hours, wind speed of 4.2 m/s, soil temperature at 12.1°C, atmospheric pressure of 1,007.4 mb, and vapor pressure of 9.5 hPa. In summer, the recorded averages were 32.2°C for temperature, 53.0 % for relative humidity, 39,079.3 W/m² for solar radiation, 8.08 hours for sunshine duration, 4.6 m/s for wind speed, 25.8°C for soil temperature, 998.1 mb for atmospheric pressure, and 24.3 hPa for vapor pressure.

Keywords: Business and Service Buildings, Meteorological Parameters, Energy Consumption, Life Cycle Emission Analysis.

GİRİŞ

Binaların enerji tüketimi global ölçekte önemli bir konu haline gelmiştir ve birçok ülkede enerji tasarrufu için farklı politikalar geliştirilmektedir. Ayrıca günümüzde fosil yakıt kaynaklarının hızla azalması nedeniyle enerji tüketimi kontrol altına alınması gereken önemli bir faktördür. Buda standartlardan vazgeçmeden düşük yakıt tüketen ekipmanlar kullanmasına yol açmaktadır. Türkiye'de toplam enerji tüketiminin %35'ü konut ve hizmet binalarında gerçekleşmektedir. Ulaşım, sanayi ve tarım gibi diğer sektörlerle karşılaştırıldığında en büyük kısımlardan biridir. Konut ve hizmet binaları sektöründeki enerji talebindeki en büyük kısım ısı kayıplarından kaynaklanmaktadır. Binalardaki enerji tüketimi çoğunlukla ısıtma ve soğutma sistemlerinden kaynaklanmaktadır. Avrupa'daki toplam enerji tüketimin yaklaşık %60'ı mekanların ısıtmasında ve soğutmasında kullanılmaktadır. Bu ısıtma ve soğutma ekipmanlarındaki iyileştirmeler atık enerjinin azaltılmasıyla sonuçlanacaktır. Enerji harcadığımız paradır. Bu nedenle doğrudan ülke ekonomisini etkiler. Binalarda çok farklı amaçlar için enerji tüketir, buna göre yapı sektöründe enerji tüketiminin azaltılması, küresel iklim değişikliğiyle mücadelede ve sürdürülebilirliği iyileştirmede önemlidir. Karbondioksit emisyonu açısından ise binalar yaklaşık %36'sından sorumludur. Etkin enerji yönetimi için uygun yapı tasarımlarının seçilmesi yaşam döngüsü boyunca çevresel olarak karbondioksit gibi sera gazı emisyonlarının azaltılmasına ve küresel çapta iklim değişikliği ile mücadelede geleceğe dönük tahminde bulunmayı sağlar (Hua ve Yub, 2019, Rogeau ve diğerleri 2020, Yucer ve Hepbasli, 2011). Şekil 1 de Çalışmada temel alınan Balıkesir Üniversitesi Rektörlük binası ve ek matbaa binası görülmektedir.

Şekil 1. Örnek alınan Balıkesir Üniversitesi Rektörlük ve Matbaa ek Binalarının Görünüşleri (Kon, 2014)

Çalışmada amacı, ana bina ve matbaa ek binasından oluşan ve kamu iş-hizmet binası olan Balıkesir Üniversitesinin Rektörlük binası için dış ortam meteorolojik parametrelere bağlı (sıcaklık, nem, güneş radyasyonu, güneşlenme, rüzgâr süresi, rüzgâr hızı, toprak sıcaklığı (1 m derinlik için), atmosfer basıncı, buhar basıncı, toplam güneşlenme süresi güneş-hava sıcaklığı ve yaş termometre sıcaklığı) kış ve yaz dönemleri için enerji tüketimi değişimini araştırmaktır. Ek olarak yakıt tüketimine bağlı uzun dönemler için yaşam çevrimi karbondioksit emisyon değerlendirmesi yapılmıştır. Çalışmada, kış döneminde 27-31 Aralık arası (08.30-17.00) doğal gaz tüketimi ve yaz döneminde ise 9-13 Ağustos arası (10.45-15.45) elektrik tüketimi dikkate alınmıştır. Bu dönemler arası oluşacak karbon dioksit emisyonu için on yıllık süreye bağlı yaşam çevrimi incelenmiştir.

YÖNTEM

Çalışmada, kamu iş-hizmet binası olan ana bina ve matbaa ek binasından oluşan Balıkesir Üniversitesinin Rektörlük binası için sıcaklık, nem, güneş radyasyonu, güneşlenme, rüzgâr süresi, rüzgâr hızı, toprak sıcaklığı (1 m derinlik için), atmosfer basıncı, buhar basıncı, toplam güneşlenme süresi güneş-hava sıcaklığı ve yaş termometre sıcaklığı gibi dış ortam meteorolojik parametrelere bağlı, kış dönemi doğal gaz ve yaz dönemi elektrik tüketimi incelenmiştir. Bu incelemeler, kış döneminde 27-31 Aralık arası (08.30-17.00) doğal gaz tüketimi ve yaz döneminde ise 9-13 Ağustos arası (10.45-15.45) elektrik tüketimi dikkate alınmıştır. Bu dönemler arası bağlı doğal gaz ve elektrik tüketimine bağlı meydana gelen karbondioksit emisyon uzun yıllar için yaşam çevrimi emisyon Değerlendirmesi (YCED) yapılmıştır. Balıkesir Üniversitesinin Rektörlük binası, kuzey doğu yönünde 978 m^2 pencere ve 1946 m^2 duvar, güney doğu yönünde 166 m^2 pencere ve 980 m^2 duvar, güney yönünde 11 m^2 pencere ve 10 m^2 duvar, güney yönünde 945 m^2 pencere ve 1856 m^2 dış duvar, batı yönünde 18 m^2 pencere, kuzey batı yönünde 156 m^2 pencere ve 851 m^2 duvar alanı ve bodrum katı 266 m^2 yönsüz alan bulunmaktadır. Çalışmada, binaların enerji analizlerinde kullanılan yapı kabuğu ısı transferi katsayıları Tablo 1 de verilmiştir. alanlar tespit edilmiştir. Şekil 2 de Örnek binanın bodrum katttaki ısı merkezinde bulunan Kazan ve Chiller görünüşleri gösterilmiştir. Bu ekipmanların teknik özellikleri ise Tablo 2 de verilmiştir. Şekil 3 de yaz döenmi elektrik tüketinin ölçünde kullanılan elektrik sayacı gösterilmiştir. Şekil 4 de ise Balıkesir Üniversitesi Rektörlük binası için ısıtma ve soğutma sistemi ekipman şeması ve özellikleri verilmiştir.

Tablo 1. Örnek bina yapı kabuğu özellikleri ve ısı transfer katsayıları (Kon 2014, TS 825, 2013).

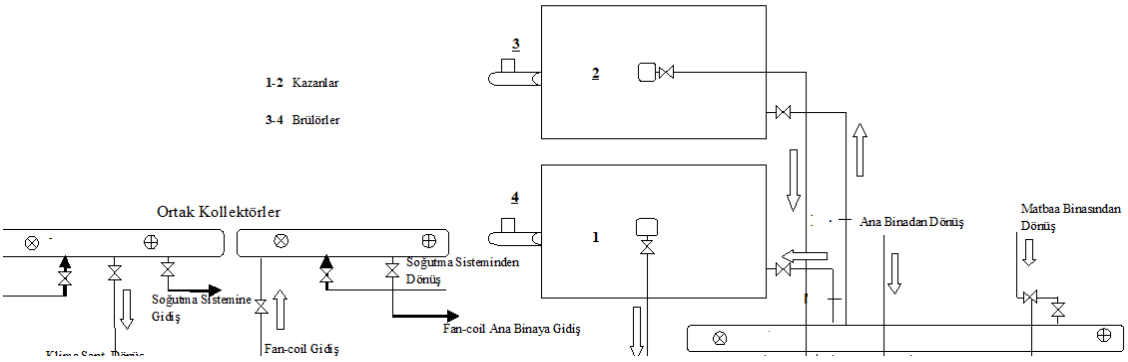
Parametre	Ana Bina	Matbaa Binası
Pencere ve Kapı Isı Transfer Katsayısı (W/m^2 K) (Pencere çift camlı, iki cam arası 12 mm, Al doğramalı)	2.908	2.908
Dış Duvar Isı Transfer Katsayısı (W/m^2 K)	0.494	0.555
Taban (Zemine Oturan Döşeme) Isı Transfer Katsayısı (W/m^2 K)	0.929	0.929
Geçitler Üzeri Döşeme (İki bina arası geçiş) Isı Transfer Katsayısı (W/m^2 K)	0.291	---
Betonarme Ara kat Döşeme Isı Transfer Katsayısı (W/m^2K)	2.733	---
Çatı (Üstü Teras Döşeme) Isı Transfer Katsayısı (W/m^2 K)	0.350	0.350
Betonperde Duvar-1 Isı Transfer Katsayısı (W/m^2 K)	1.221	---
Betonperde Duvar-2 Isı Transfer Katsayısı (W/m^2 K)	1.163	1.163
Pencere/Dış Duvar Oranı	0.440	0.385

Şekil 2. Örnek binanın ısıtılması için Kazan ve soğutulması için Chiller görünüşleri (Kon 2014).

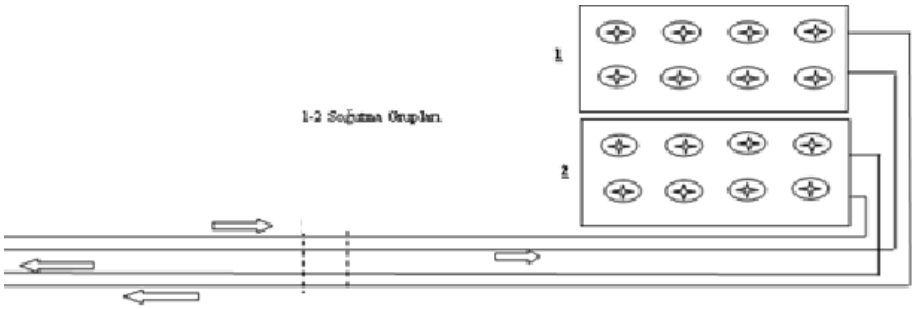
Tablo 2. Ekipman özellikleri (Etiket Değerleri) (Kon 2014).

Ekipman	Değer
Soğutma Sistemi	
Chiller Grubu Sayısı	2
Chiller Grubu Kapasitesi (kW) (1 adet)	539
Chiller COP	2.7
Chiller Grubu Tipi (Kondanser)	Hava soğutmalı
Soğutucu Akışkan	R-134a
Kompresör Sayısı ve Tipi	2-Vidalı
Evaperatör Su Sıcaklığı	7-12^{0}C
Isıtma Sistemi	
Kazan Sayısı	2
Kazan Kapasitesi (kW) (1 adeti)	698
Kazan Tipi	Çelik Gövdeli
Yakıt Tipi	Doğal Gaz
Kazan Verimi (%)	93
Kazan Su Kapasitesi (lt)	692
Gidiş-Dönüş Su Sıcaklıkları	70-90 ^{0}C
İşletme Basıncı	5 bar
Brülör	Min 200-Max1125 kW

Şekil 3. Elektrik Sayacı Görünüşü (Kon 2014).



(a)



(b)

Şekil 4. Örnek bina a) ısıtma ve b) soğutma sistemi ekipman şeması (Kon 2014).

Güneş-hava sıcaklığının hesaplanmasında,

$$T_{gh}=T_0+\frac{\alpha I_g}{h_d} \quad (1)$$

kullanılır. Burada T_0 dış ortam kuru termometre sıcaklığı, I_g güneş radyasyonu değeri ve α ise duvar yüzeyi soğurganlık değeridir. Çalışmada, alüminyum kaplamalı duvar için 0.15 alınmıştır (Meral 2013, Kon ve Arda, 2023). Yaş termometre sıcaklığı ise,

$$T_{o,i,yts} = T_0 \,.\, (\varphi) \quad (2)$$

Burada T_0 dış ortam kuru termometre sıcaklığı ve φ bağıl nemdir (Kon ve Arda, 2023).

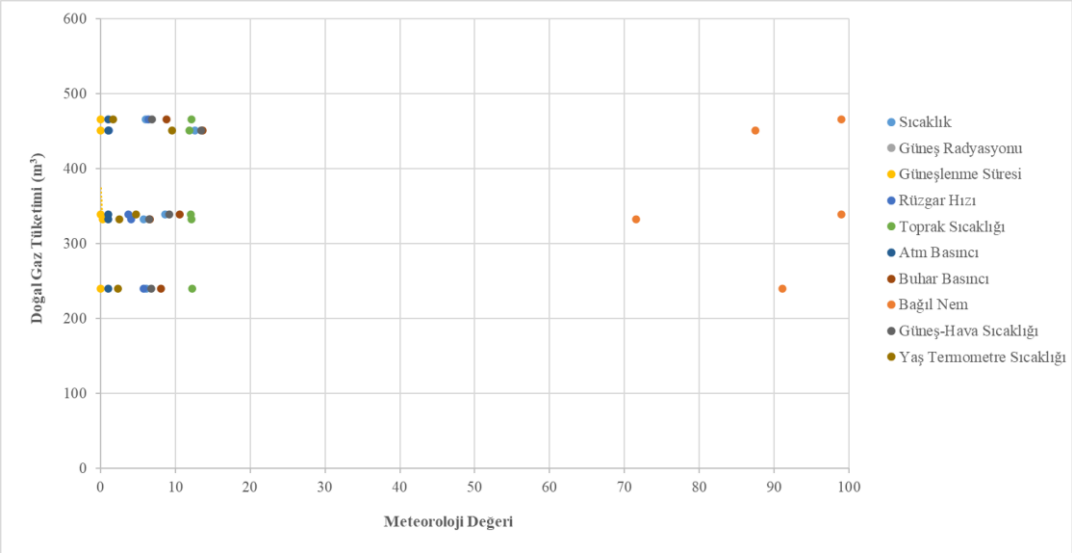
On yıllık ömürde karbon dioksit emisyonu için Yaşam Çevrimi Emisyon Değerlendirmesi (YCED) aşağıda verilmiştir.

$$YCED = C_{yakıt} \sum_{t=1}^{N} \frac{Q_{gün}}{(1+i_{yakıt})^t . \eta} \quad (3)$$

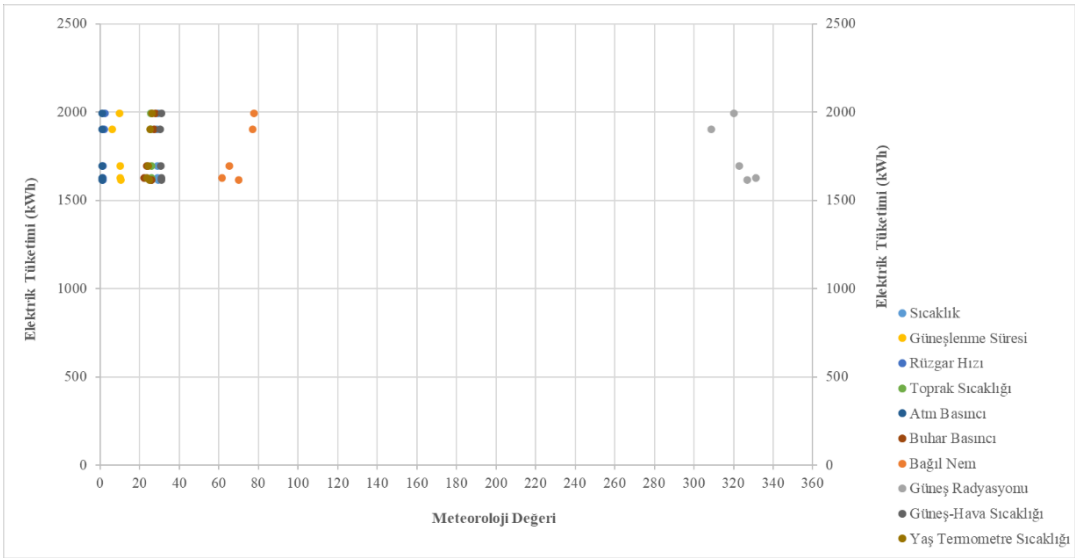
Burada, örnek Bina için $Q_{gün}$ ısıtma ve soğutma günün enerji tüketimini, $C_{yakıt}$ birim sera gazı emisyonu, Çalışmada, elektrik için 0.356 kg CO_2/kWh ve doğal gaz için 0.202 kg CO_2/kWh alınmıştır. $i_{yakıt}$ yakıtın faiz oranı (0.03 alındı), η (elektrik için 0.99 ve doğal gaz için 0.93 alındı) yanma verimi ve N bina ömrü (10 yıl alındı) (Molenbroek ve diğerleri, 2015, deLlano-Paz ve diğerleri 2018, Yılmaz ve Oral 2019, Shadram ve diğerleri 2020. Altun, Akgul ve Akcamete 2020, Rajulwar 2023, Tran ve diğerleri 2023).

BULGULAR

Çalışmada, kış dönemi ölçüm alınan 27-31 Aralık arası ortalama meteorolojik değerler; sıcaklık 7.8 ^{0}C, bağıl nem % 89.6, güneş radyasyonu 4255.9 W/m^2, güneşlenme süresi 0.47 saat, rüzgâr hızı 4.2 m/s, toprak altı sıcaklığı 12.1 ^{0}C, atmosfer basıncı 1007.4 mb, buhar basıncı 9.5 hPa, güneş hava sıcaklığı 8.6 ^{0}C ve yaş termometre sıcaklığı ise 4.13 ^{0}C olarak tespit edilmiştir. Yaz dönemi ölçüm alınan 9-13 Ağustos ortalama değerler, sıcaklık 32.2 ^{0}C, bağıl nem % 53.0, güneş radyasyonu 39079.3 W/m^2, güneşlenme süresi 8.08 saat, rüzgâr hızı 4.6 m/s, toprak altı sıcaklığı 25.8 ^{0}C, atmosfer basıncı 998.1 mb, buhar basıncı 24.3 hPa, güneş hava sıcaklığı 30.8 ^{0}C ve yaş termometre sıcaklığı 24.9 ^{0}C olarak tespit edilmiştir. Kış dönemi ortalama doğal gaz tüketimi 365.8 m3 ve yaz dönemi ortalama elektrik tüketimi ise 1766.5 kWh olarak tespit edilmiştir. Bu dğerelere bağlı olarak, Şekil 5 de meteorolojik parametrelere bağlı doğal gaz tüketimi ve Şekil 6 de ise meteorolojik parametrelere bağlı elektrik tüketimi verilmiştir. Tablo 3 de denklem (3) kullanılarak elde edilen günlük doğal gaz ve elektrik tüketimine bağlı Yaşam Çevrimi Karbondioksit Emisyonu Değerleri (YCED) gösterilmiştir. Buna göre kış dönemi doğal tüketimine bağlı YCED 371.4-721.1 kg arası karbon dioksit emisyonu tespit edilmiştir. Bu değer yaz dönemi elektrik tüketimine bağlı olarak 431.8-532.8 kg hesaplanmıştır.



Şekil 5. Meteorolojik Parametrelere Bağlı Doğal Gaz Tüketimi



Şekil 6. Meteorolojik Parametrelere Bağlı Elektrik Tüketimi

Tablo 3. Doğla gaz ve elektrik tüketimine bağlı Yaşam Çevrimi Karbondioksit Emisyonu Değerleri (YCED) (kg)

Kış Dönemi	
Tarih	
27 Aralık	697.9
28 Aralık	524.5
29 Aralık	721.1
30 Aralık	371.4
31 Aralık	515.3
Yaz Dönemi	
9 Ağustos	509.3
10 Ağustos	532.8
11 Ağustos	431.8
12 Ağustos	435.0
13 Ağustos	453.5

TARTIŞMA VE SONUÇ

Çalışmada, ana bina ve matbaa ek binasından oluşan ve kamu iş-hizmet binası olan Balıkesir Üniversitesinin Rektörlük binası için kış dönemi 27-31 Aralık arası doğal gaz tüketiminde dış ortam meteorolojik parametrelerden en etkili güneş radyasyonu ve rüzgâr hızı olduğu tespit edilmiştir. Dış ortam sıcaklığı daha az etkili olduğu görülmüştür. Yaz dönemi için ise 9-13 Ağustos arası (10.45-15.45) elektrik tüketimi dış ortam meteorolojik parametrelerden en etkili bağıl nem, güneş radyasyonu, güneşlenme süresi ve rüzgâr hızıdır.

Yakıt tüketimine bağlı on yıllık dönemde yaşam çevrimi karbondioksit emisyonu için değerlendirmede, kış dönemi doğal gaz tüketimine bağlı olarak 566.04 kg ve yaz dönemi elektrik tüketimine bağlı olarak ise 472.48 kg tespit edilmiştir. Enerji tüketimi etkili parametredir.

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ZERO-CARBON FUTURE IN MARITIME TRANSPORT: THE POTENTIAL AND CHALLENGES OF AMMONIA FUEL

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ABSTRACT

Global warming is widely regarded as one of the most pressing environmental challenges of our time, driven primarily by anthropogenic emissions. The shipping industry makes a significant contribution to global greenhouse gas (GHG) emissions, accounting for approximately 3% of global carbon dioxide (CO_2) emissions. This situation necessitates the sector's shift toward sustainable fuel alternatives. The International Maritime Organization (IMO) aims to reduce GHG emissions from shipping by at least 50% by 2050 compared to 2008 levels. In line with this goal, the adoption of low-carbon or zero-carbon fuels has become an inevitable requirement. Among alternative fuels, anhydrous ammonia (NH_3) stands out due to its potential for zero carbon emissions. Ammonia, with its high energy density and potential for large-scale production using renewable energy, emerges as a promising zero-carbon fuel. However, significant challenges remain regarding its production, storage, safety, and infrastructure for use in the maritime sector. This paper explores the feasibility of ammonia as a marine fuel, analyzing its environmental benefits, technological feasibility, economic implications, and regulatory considerations. While ammonia holds great potential in reducing shipping emissions, overcoming its associated technical and economic barriers is critical for its viability as an alternative marine fuel.

Keywords: Shipping, Ammonia Fuel, Maritime Emissions, Decarbonization, Alternative Fuels, Sustainable Shipping.

INTRODUCTION

Maritime transport is considered a more environmentally friendly mode of transportation compared to other types of international transportation. However, it is still estimated that this sector is responsible for approximately 3% of global carbon dioxide (CO_2) emissions (Buhaug et al. 2008). The emissions of CO_2, nitrogen oxides (NO_X), and sulfur oxides (SO_X) from ships account for approximately 2%, 11%, and 4% of global greenhouse gas emissions, respectively (Buhaug et al. 2008; Endresen et al. 2003). These significant percentages have prompted action from the International Maritime Organization (IMO). In April 2018, the IMO's Marine Environment Protection Committee (MEPC) took the first major step to align with the targets set by the United Nations' Paris Agreement and to reduce greenhouse gas (GHG) emissions from maritime transport. The committee presented a vision to phase out GHG emissions gradually (MEPC.342(77).pdf n.d.). This vision was updated in 2023 under the title "2023 IMO Strategy on Reduction of GHG Emissions from Ships". In line with this strategy, an approach has been adopted to transition to fuels that produce zero or near-zero GHG emissions by 2030-2040 (IMO, 2020; 2021).

Four key objectives have been set in the 2023 strategy. The first of these is to reduce carbon emissions from ships by increasing the energy efficiency of both existing and new vessels. The second objective is to reduce the CO_2 emission rate from international maritime transport by at least 40% by 2030 compared to 2008 levels. The third objective, aimed at achieving this reduction, is to ensure that fuels or energy sources producing zero or near-zero greenhouse gas emissions account for at least 5% of the fuel used by ships by 2030, with efforts to increase this share to 10%. The fourth and final

objective is to reduce greenhouse gas emissions from international maritime transport to “net zero” by 2050 or around that date (IMO, 2025).

The establishment of all these targets marks an international shift towards the use of zero-carbon or low-carbon fuels in the maritime industry. Among the zero-carbon or low-carbon fuel solutions, anhydrous ammonia is gaining recognition as an alternative marine fuel. Although NH_3 is not currently used as fuel on ships, findings from industries such as machinery technologies and petrochemicals indicate that this fuel could have significant potential as a marine fuel in the future.

MATERIALS AND METHODS

This study adopts a qualitative research methodology to evaluate the feasibility of anhydrous ammonia (NH_3) as an alternative marine fuel in the context of global efforts to reduce greenhouse gas (GHG) emissions from shipping. The research is structured around a comprehensive literature review, which serves as the primary data source. Peer-reviewed academic journals, policy reports from the International Maritime Organization (IMO), technical white papers, and industry publications were systematically reviewed to gather information on the environmental, technological, economic, and regulatory dimensions of ammonia as a marine fuel.

The literature review process involved the use of academic databases such as ScienceDirect, SpringerLink, and Google Scholar. Keywords including “ammonia as marine fuel,” “zero-carbon shipping,” “GHG emissions in maritime transport,” and “alternative fuels in shipping” were used to identify relevant sources published between 2000 and 2024. The selected literature was analyzed thematically to identify key challenges and opportunities related to ammonia usage in maritime applications.

In addition to the literature analysis, current regulatory frameworks and IMO strategies regarding decarbonization were examined to assess policy readiness and alignment with ammonia adoption. Technological feasibility was evaluated based on the availability of engine designs, fuel handling systems, and storage technologies compatible with ammonia. Economic implications were discussed using data from existing techno-economic assessments and cost-benefit analyses found in the literature.

FINDINGS

Properties of Ammonia and Ammonia Production

Ammonia (or anhydrous ammonia) is a compound composed of nitrogen and hydrogen, and it is primarily used as a building block for fertilizers in food production. Ammonia exists in two main forms: aqueous ammonia (typically containing 28% ammonia in water) and anhydrous ammonia. Under atmospheric conditions, ammonia is found in a gaseous form, but it becomes a liquid under high pressure (approximately 18 bar). Ammonia is a colorless gas with a characteristic sharp odor (EMSA 2022). The important combustion properties of ammonia are presented in Table 1.

Table 1. Combustion Properties of Ammonia (EMSA 2022)

Combustion Properties	Value
Melting point (ºC)	-77.7
Boiling point (ºC)	-33
Flash point (ºC)	132
Critical temperature (ºC)	132.25
Critical pressure (bar)	113
Flammable range in dry air (%)	15.15 to 27.35
Cetane number	0
Octane number	~130
Heat of vapourisation (kJ/kg)	1371
Autoignition temperature (ºC)	651
Energy density (MJ/L)	12.9(MJ/L)

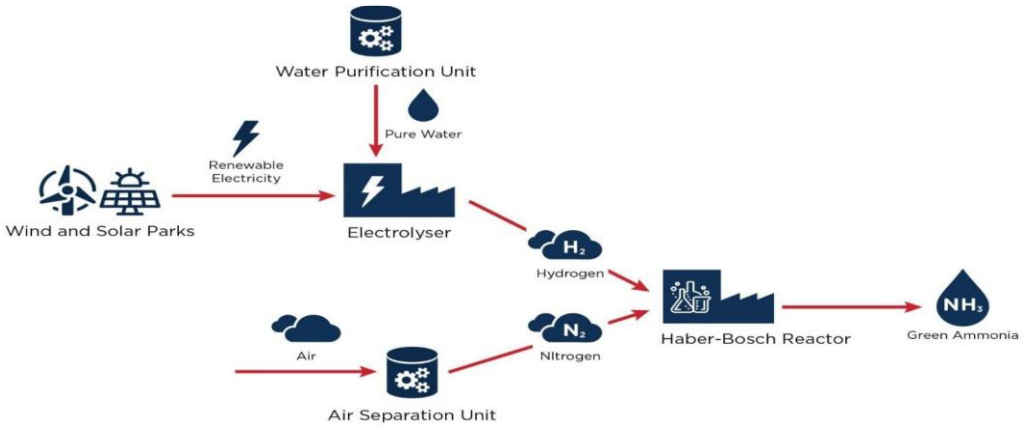

Figure 1. The production process of green ammonia (EMSA 2022)

Currently, ammonia production is primarily derived from methane, the gaseous form of natural gas. Ammonia produced in this way is referred to as “gray ammonia”. Ammonia obtained through the process of capturing and storing CO_2 emissions during the conversion of natural gas is called “blue ammonia” (Bicer et al. 2016, 2017; Bicer and Dincer 2018). The production of both gray and blue ammonia still relies on fossil fuels. As an alternative, there is a form of ammonia produced from hydrogen, a renewable energy source, through the Haber-Bosch synthesis process. Since this form is synthesized from green hydrogen, the produced ammonia is referred to as “green ammonia”, and the overall production process is presented in Figure 1 (Ghavam et al. 2021; Rouwenhorst et al. 2019, 2019, 2020; Rouwenhorst, Van der Ham, and Lefferts 2021; Sagel, Rouwenhorst, and Faria 2022; Smith, Hill, and Torrente-Murciano 2020). Other synthesis methods in ammonia production technology are also available, and they are presented in Table 2.

In 2019, global ammonia production reached 235 million tons (Mt) (Ghavam et al. 2021). However, there are currently numerous green ammonia projects underway, and it is reported in EMSA reports that approximately 133 Mt of additional production capacity is expected annually from these projects. While the current global ammonia production is around 235 Mt, the required amount is approximately 650 Mt (EMSA 2022). Therefore, the current production capacity meets only about half of the demand.

Table 2. Green ammonia production Technologies (EMSA 2022)

Production pathway	Technologies	Sources
Electrolysis and Haber-Bosch synthesis	Cryogenic air separation	(Rouwenhorst et al. 2019)
	Pressure swing adsorption	(Rouwenhorst et al. 2020)
	Membrane permeation	(Rouwenhorst, Van der Ham, and Lefferts 2021)
	Haber-Bosch synthesis reactor	(Cerulogy 2018)
	Alkaline electrolyser	(Rouwenhorst et al. 2019; Smith, Hill, and Torrente-Murciano 2020)
	PEM electrolyser	(Smith, Hill, and Torrente-Murciano 2020)
	SOEC electrolyser	(Rouwenhorst et al. 2020; Smith, Hill, and Torrente-Murciano 2020)
Direct solar hydrogen production	Direct solar conversion	(Smith, Hill, and Torrente-Murciano 2020)
Non-thermal plasma synthesis	Non-thermal plasma synthesis	(Smith, Hill, and Torrente-Murciano 2020)
Electrochemical ammonia synthesis	Electrochemical ammonia synthesis	(Bird et al. 2020; X. Liu, Elgowainy, and Wang 2020)

Advantages of Ammonia as A Marine Fuel

Ammonia emerges as a significant alternative fuel candidate in line with global goals for decarbonizing maritime transport. The advantages of this fuel encompass a wide range, from environmental benefits to its economic and technical potential. In this context, the benefits of ammonia as a fuel in maritime transport are detailed below.

Contribution of Ammonia to the Decarbonization Process

Ammonia is inherently a carbon-free compound, making it an ideal alternative fuel for the decarbonization of maritime transport. Ammonia is produced by converting hydrogen, derived from renewable electricity or fossil fuels (primarily natural gas), into ammonia through the Haber-Bosch synthesis reactor; as a result, nearly no GHG emissions occur during the production phase (EMSA 2022; Ghavam et al. 2021). In this context, the production of ammonia through green production techniques offers a promising solution aimed at reducing dependence on fossil fuels and significantly decreasing the carbon footprint of the maritime sector.

Low Emission Profile

When ammonia is used in marine internal combustion engines, it reduces emissions such as CO_2, SO_2, carbon monoxide (CO), heavy metals, hydrocarbons, and polycyclic aromatic hydrocarbons (PAH) to zero (C. Liu and Chen 2019; X. Liu, Elgowainy, and Wang 2020). Compared to other conventional fossil fuels, particulate matter (PM) emissions in ammonia-powered engines are also significantly lower (Ash and Scarbrough 2019). Additionally, in 2-stroke or 4-stroke engines powered by ammonia, combustion products do not form due to the use of fuel cell technology, which does not require a combustion process (Valera-Medina et al. 2018, 2021). However, this technology is still in the development stage and requires further research and development for widespread commercial use. Although there is a risk of NO_x formation during ammonia combustion, optimizing the combustion conditions can significantly reduce NO_x emissions (Cerulogy 2018).

Portability, Ease of Storage, and Industrial Experience

Ammonia offers a significant advantage in terms of transport and storage due to its ability to be liquefied. Ammonia can be stored in liquid form at approximately 18 bar pressure (or at -33°C), which makes its storage process much safer and more cost-effective compared to other gaseous fuels, such as liquefied natural gas (LNG). This characteristic stems from its ability to be stored using more economical materials, such as low-cost carbon manganese or low-nickel steels. Additionally, ammonia has been produced and used in large quantities for many years in other industries, providing substantial knowledge and experience in the transportation, storage, and operation of ammonia

(EMSA 2022). Furthermore, ammonia is a well-known product in the maritime industry and has been transported for many years in liquefied petroleum gas (LPG) carriers, which are subject to existing regulations such as the International Gas Carrier Code (IGC Code). Ammonia transport systems can be compatible with existing ship infrastructure, such as LPG carriers. As the use of ammonia as a fuel in maritime transport increases, the existing LPG storage infrastructure could also be utilized for ammonia, and vessels designed for LPG transport could be adapted to carry ammonia (EMSA 2022; EMSA Lisbon 2022). This would facilitate the establishment of an ammonia-powered fleet and significantly reduce the need for new infrastructure investments.

Advantages in Energy Density, Fire, and Explosion Safety

Ammonia offers a high energy density per volume (specific energy: 18.6 MJ/kg and energy density: 12.9 MJ/L), making it an efficient energy carrier. Table 2 provides a detailed comparison of NH_3 with other fuel types in terms of storage conditions and fuel properties. As shown in this table, increasing ammonia production using renewable energy could hold significant potential for long-term economic sustainability.

Table 2. Comparison of Storage and Fuel Properties of NH_3 and Other Fuels (EMSA 2022)

Fuel	Storage Conditions		Fuel Properties		
	T*	P*	Specific Energy (MJ/kg)	Energy Density (MJ/L)	Carbon Content
MGO**	atm	atm	42.7	38.4	0.8744
LNG	-162 °C	atm or (~5- 0 bar)	48	21.6	0.75
Ethane	-89 °C	atm or (~ 5 bar)	47.8	27.2	0.7989
Methanol	atm	atm	19.9	15.7	0.375
LPG	-48 °C (Propane)	atm or (up to 18 bar)	46.3 ropane) 45.7 Butane)	23.2 (Propane) 27.4 (Butane)	0.8182(Propane) 0.8264 (Butane)
Ammonia	-33 °C	atm or (to~ 18 bar)	18.6	12.9	N/A

* T: Temperature and P: Pressure, **MGO: Marine gas oil

Compared to other hydrocarbon fuels and gases, ammonia has a narrower flammability range; however, in open air, the flammability range of ammonia can increase from 15.2% to 27.4% compared to dry air (EMSA 2022). Although ammonia does not offer a high energy density per volume, its lower flammability and explosive characteristics make it less hazardous, reducing the fire and explosion risks compared to traditional fuels. This feature demonstrates that ammonia has a significant safety advantage, providing ship operators with a safer alternative fuel option.

Barriers to The Use of Ammonia As A Marine Fuel

The global maritime sector has shifted towards alternative and sustainable energy sources in line with carbon emission reduction targets. In this context, ammonia, with its zero-carbon content, stands out as a potential alternative fuel. However, the use of ammonia as a fuel in maritime transport presents various technical, safety, environmental, and regulatory challenges. This study addresses the key barriers and potential risks encountered in the use of ammonia as an alternative fuel from a holistic perspective.

Ammonia's Ignition Problem and Hybrid Fuel Requirements

Ammonia, due to its low cetane number, is not suitable for direct ignition. This characteristic complicates its use as an independent fuel in internal combustion engines and creates the need for an additional energy source to ignite the fuel. In this context, to effectively utilize ammonia in engines, pilot fuel support is necessary. Among the most suitable alternatives for pilot fuel are marine diesel oil (MDO), marine gas oil (MGO), and dimethyl ether (DME) (EMSA 2022; EMSA Lisbon 2022).

This requirement necessitates the development of hybrid or dual-fuel systems in systems where ammonia is used as an energy carrier.

Chemical Properties of Ammonia and Material Compatibility Issues

Ammonia's alkaline nature leads to chemical reactions with certain metal alloys, such as copper, zinc, and brass, especially in moist environments. Additionally, it tends to react with acids and oxidizing agents. This characteristic makes material selection a critical engineering issue in systems where ammonia is used as a fuel. In particular, it is essential that the materials used in the design of fuel systems, pipelines, and storage tanks be resistant to ammonia's chemical properties. Material incompatibility can increase the risk of corrosion, cause system failures, and lead to long-term operational problems (Jang et al. 2023). Therefore, selecting appropriate alloys in ship equipment and engine systems is necessary to ensure safety, durability, and longevity. This feature not only requires material engineering solutions but also demands innovative approaches in the design of fuel systems and engine technologies.

Currently, the most common method for ammonia production is through steam methane reforming (SMR) of natural gas. The product obtained through this process is known as gray ammonia due to the high level of carbon emissions it contains (Bicer et al. 2016; Bicer and Dincer 2018). If the carbon dioxide emissions resulting from this process are captured and stored, the product is referred to as blue ammonia. However, the CO_2 capture efficiency of SMR and similar alternative methods, such as Auto-Thermal Reforming (ATR), is typically below 95% (Rouwenhorst et al. 2019, 2020; Rouwenhorst, Van der Ham, and Lefferts 2021). This indicates that the production of blue ammonia continues to rely on fossil fuels, thus offering a limited solution in terms of long-term environmental sustainability (Ghavam et al. 2021; Smith, Hill, and Torrente-Murciano 2020). A truly sustainable alternative is green ammonia production. Green ammonia is produced using renewable energy sources, such as solar and wind, with green hydrogen being synthesized from atmospheric nitrogen. This method offers a production process that is not dependent on fossil fuels, minimizing the carbon footprint (Bird et al. 2020; Cerulogy 2018; X. Liu, Elgowainy, and Wang 2020; Smith, Hill, and Torrente-Murciano 2020). However, the production of green hydrogen requires a significant amount of renewable electricity. This makes the secure supply of green electricity a critical factor, not only for the maritime sector but also for energy-intensive industries such as steel, cement, and chemicals. Energy supply planning is of great importance in this context. Moreover, renewable energy production facilities, such as solar power plants and wind farms, require large areas, which poses significant challenges in terms of land use, particularly with potential conflicts over agricultural land. Therefore, utilizing desert areas or offshore wind farms presents itself as a sustainable solution.

Toxic Nature of Ammonia and Its Potential Impacts on Ecosystems

One of the major safety risks associated with the use of ammonia as a fuel in maritime applications is the exposure hazard due to its toxic nature. According to national and international regulations, the Permissible Exposure Limit (PEL) is set at 50 ppm, and the Recommended Exposure Limit (REL) is set at 25 ppm (EMSA 2022). These limits highlight the necessity for strict control and monitoring systems during the transportation, storage, and use of ammonia to ensure the safety of the crew. Even at low concentrations, ammonia can cause irritation to the eyes, skin, and respiratory system; while at higher concentrations, inhalation can lead to severe health issues or even death. In this context, it is mandatory to establish a comprehensive safety infrastructure on vessels planned to use ammonia as fuel. This infrastructure should include personal protective equipment (PPE), advanced gas detection systems, effective ventilation solutions, and emergency evacuation protocols.

Ammonia is a toxic compound to marine organisms and can cause long-term ecological damage in the case of direct exposure (J. Hansson, Fridell, and Brynolf 2020; Julia Hansson et al. 2020). When ammonia comes into contact with marine ecosystems, it can produce toxic effects on organisms, threatening the sustainability of biodiversity (Boardman et al. 2004). Moreover, ammonia's environmental impacts pose serious threats. When released into the atmosphere, ammonia can convert

into nitrogen oxides, indirectly contributing to the depletion of the ozone layer (Valera-Medina et al. 2018, 2021). While this effect is currently considered negligible, the widespread use of ammonia as a maritime fuel could alter this balance. Additionally, ammonia released into the atmosphere due to incomplete combustion or leaks can trigger processes such as acidification and eutrophication, negatively affecting soil and water quality (Ash and Scarbrough 2019). These types of emissions can lead to serious environmental issues that degrade environmental quality.

Ammonia can present a significant environmental threat. When released into the atmosphere, ammonia can convert to nitrogen oxides, indirectly contributing to the depletion of the ozone layer (Valera-Medina et al. 2018). Although scientists currently consider this contribution to ozone depletion as negligible, the growing use of ammonia as a maritime fuel may change this situation (Valera-Medina et al. 2018). Additionally, ammonia released into the atmosphere due to incomplete combustion or leaks can cause environmental issues such as acidification and eutrophication in soil and water resources (Ash and Scarbrough 2019).

Physical Properties of Ammonia and Fire Safety Requirements

Ammonia offers a high energy density per volume and has a high boiling point. Furthermore, compared to other hydrocarbon fuels, it has a lower risk of fire and explosion. The flammability range in dry air is 15.2%, but it can increase to 27.4% in open atmospheric conditions (EMSA 2022). This situation increases the risks of fire and explosion; thus, the design of fire protection, fire fighting systems, and effective ventilation solutions becomes critically important. Detailed regulations must be developed to address the risks of leaks, fires, and explosions that may occur during the transportation, storage, and use of ammonia. These regulations should include components such as the installation of specialized ventilation systems, increasing firefighting equipment, standardizing fuel refueling procedures, and defining safe methods for discharging contaminated water. Therefore, safety concepts must be designed in a way that considers both toxicity and fire risks together (Valera-Medina et al. 2018).

Regulatory Gaps Regarding the Use of Ammonia

In the maritime industry, the fuel standard encompassing all traditional fuel categories is ISO 8217, with the latest edition published on June 11, 2024. When comparing the ISO 8217:2024 standard to its 2017 version, significant updates in fuel categories and parameters can be observed (ISO, 2017). Particularly, the creation of new terminology for biofuels and the categorization of marine fuels represent important innovations. However, the 2024 ISO standard does not include a section covering specifications for anhydrous ammonia.

The International Maritime Organization regulates safety in international maritime transport through the International Convention for the Safety of Life at Sea (SOLAS, 1974). Under SOLAS, Chapter II-2 Regulation 4.2.1, the use of traditional fuels with a flashpoint lower than 60°C has been prohibited (Guidelines et al. 2024). To address the growing interest in the use of fuels with flashpoints below 60°C, IMO added a new section to SOLAS II-1 in 2015. This section, known as the International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels (IGF Code), allows for the use of alternative fuels and technologies, including the combustion of other alternative fuel types under the “Alternative fuels and technologies” section (EMSA 2022). This new regulation has removed barriers to the combustion of toxic loads. However, no regulation has yet been developed for the use of anhydrous ammonia as a fuel. The only regulation related to ammonia in the IGC Code pertains to the specific requirements for its transport. Similarly, the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code) only outlines the requirements for the transport of aqueous ammonia up to 28% (EMSA 2022; Vidmar and Perkovič 2018). Therefore, the applicability of the IGC Code to ammonia is still not established.

IMO’s International Safety Management (ISM) Code provides an international standard for the safe management and operation of ships and the prevention of pollution (EMSA 2022). Although this code is widely implemented based on general principles and objectives, it does not include direct

provisions for the use of ammonia as a fuel. However, the operational requirements under Section C-1 of the International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels (IGF Code), which are applicable to methane, could also be applicable to ammonia (EMSA Lisbon 2022).

The International Convention for the Prevention of Pollution from Ships (MARPOL) sets international requirements for the prevention of pollution from ships operating in international waters. This convention is divided into annexes containing specific pollution control measures. The latest annex, Annex VI, includes comprehensive regulations on the use and combustion of substances that contribute to air pollution and ozone layer depletion, such as NO_X, SO_X, and Volatile Organic Compounds (VOCs) (MARPOL, 2017). Annex VI of MARPOL mandates that all marine diesel engines over 130 kW (excluding engines used solely for emergency applications) comply with the applicable emission limits to reduce harmful effects of NO_X emissions on human health and the environment.
When examining this regulation in Annex VI, it is evident that the environmental impact of NH_3 emissions from exhaust gases, should ammonia be used as a marine fuel, is not yet addressed in terms of limits for water and air emissions. Therefore, uncertainties exist regarding how acceptable emission limits for NH_3 and N_2O from ship engines will comply with air emission limits.

DISCUSSION AND CONCLUSION

Ammonia is a prominent alternative fuel for the maritime transportation sector, aimed at decarbonization and reducing environmental impacts. Due to its lack of carbon content, no CO_2 emissions are produced during the combustion process, which provides a significant advantage in combating global climate change. Additionally, its low greenhouse gas emissions make ammonia one of the key factors driving the green transformation of the maritime sector. The high energy density of ammonia, its compatibility with existing fuel infrastructure, and its safe storage properties present great potential for its widespread use in maritime transport. Furthermore, the existing industrial knowledge and experience in ammonia production, transportation, and storage facilitate the integration of this fuel into the maritime industry. Ammonia's capability to act as a hydrogen carrier further enhances its role, making it not only an alternative maritime fuel but also a strategic resource for the development of the green hydrogen economy. With its versatile potential, ammonia is poised to play a crucial role in the transition to sustainable maritime transport.

However, the use of ammonia brings about a variety of challenges. From a technical perspective, its lower energy density limits engine performance and reduces efficiency. Advanced technological transformations are required to make existing ship engines compatible with ammonia. In terms of safety, ammonia's toxic, corrosive, and non-flammable but asphyxiating nature presents serious risks to both human health and the environment. This situation demands special equipment and procedures for transportation, storage, and use. Environmentally, it is known that ammonia can have toxic effects on aquatic life if it leaks into the marine environment. Furthermore, the lack of regulatory frameworks and the uncertainty surrounding international standards remain key factors limiting the widespread use of this fuel. Additionally, while the production process of green ammonia is not yet sufficiently mature at an economic scale, its reliance on renewable energy sources and high costs undermine its commercial viability.

In conclusion, ammonia has the potential to play a significant role in the low-carbon future of the maritime sector. However, realizing this potential requires overcoming numerous technical, safety, environmental, and regulatory challenges. To prepare for this transition, the sector will require extensive research and development activities, multi-stakeholder collaborations, and an integrated regulatory framework.

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MITIGATING GREENHOUSE GAS EMISSIONS IN CEMENT MANUFACTURING: A COMPREHENSIVE REVIEW OF SOLUTIONS AND STRATEGIES

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Abstract

The cement industry and its constituent activities is a significant contributor to greenhouse gas emissions (GHG), with approximately 8% of global CO_2 emissions attributed majorly to cement production. As the growing demand for cement continues to persist, it is imperative to explore green and sustainable solutions to mitigate these GHG emissions. This research study examines the current state of cement manufacturing and identifies key challenges and opportunities for GHG emission reduction. Numerous low-carbon solutions and strategies are assessed, which includes alternative fuels, carbon capture and storage, and green and novel cement formulation. The study also discusses the critical role of policy and regulation in driving the adoption of sustainable approach in the cement industry. For stakeholders and industry stakeholders looking to mitigate the environmental impact of cement production and advance a more sustainable and green future, the research study's conclusions offer a valuable insight. This research seeks to assist the shift to a low-carbon cement sector by emphasizing the best approaches and solutions.

Keywords: Cement industry, Greenhouse gas emissions, Low-carbon solutions, Environmental Sustainability.

Introduction

The production of cement, the main binder in concrete, the most popular building material, is essential to the growth of global infrastructure. But the industry also contributes significantly to greenhouse gas (GHG) emissions, making up around 7-8% of global CO_2 emissions, which is higher than the combined emissions from the shipping and aviation industries. The calcination of limestone, which produces CO_2 as a chemical byproduct, and the burning of fossil fuels to power high-temperature kilns are the two main processes that have an influence on the environment. Furthermore, producing cement uses a significant quantity of energy and raw materials, which exacerbates pollution and resource depletion (Barbhuiya et al.,2024; Griffiths et al.,2023; Habert et al.,2020). Emissions from cement production must be reduced in light of the pressing need to address climate change. Cement manufacturing confronts particular difficulties because of its intrinsic process emissions, in contrast to other industries where electrification and renewable energy can significantly reduce emissions. Cement-related CO_2 emissions might rise by 12–23% by 2050 if nothing is done, undermining international climate goals. In order to achieve the 1.5°C global warming target set forth in the Paris Agreement, this industry must decarbonise (Nehdi et al.,2024; Zhang,2024).

Given the urgent need to combat climate change, reducing emissions from cement production is critical. Unlike other sectors where electrification and renewable energy can drastically cut emissions, cement manufacturing faces unique challenges due to its inherent process emissions. Without intervention, cement-related CO_2 emissions could increase by 12-23% by 2050, undermining global climate targets. Decarbonizing this industry is essential for meeting the Paris Agreement's goal of limiting global warming to 1.5°C. With demand driven by China, India, and Southeast Asia, global cement production has tripled since 1990 to reach 4.3 billion metric tonnes yearly. The sector's total emissions could endanger carbon budgets if current practices continue. The challenge facing emerging economies in particular is striking a balance between the expansion of infrastructure and sustainable industrial practices (Favier et al.,2018; Adesina, 2020; Busch et al.,2022; Lippiatt et al.,2020).

This paper provides a comprehensive review of strategies to mitigate GHG emissions in cement manufacturing, analyzing technological innovations, alternative materials, carbon capture, and policy measures. By evaluating current solutions and future pathways, this study aims to guide stakeholders in transitioning toward a low-carbon cement industry.

Overview of the Cement Manufacturing Process

Devi et al. (2017) and Abdul-Wahab et al. (2021) highlighted the production process of cement involves several energy-intensive stages. The most common type, Portland cement, is made through the following key steps:

i. Raw Material Extraction: Limestone (calcium carbonate) and clay are mined and crushed into a fine powder.

ii. Raw Meal Preparation: The crushed materials are blended to achieve the correct chemical composition.

iii. Preheating & Calcination: The raw meal is heated in a preheater tower at 800-900°C, where limestone decomposes into lime (CaO) and CO_2—a process called calcination.

iv. Clinker Formation: The material is then fed into a rotary kiln heated to 1,450°C, forming clinker—small, hard nodules that are the basis of cement.

v. Cooling & Grinding: The clinker is cooled and mixed with gypsum and other additives before being ground into fine cement powder.

vi. Packaging & Distribution: The final product is stored in silos and shipped for use in construction.

Difficulties in Lowering GHG Emissions in the Cement Sector

The logistical, financial, regulatory, and technical challenges that the cement industry faces in reducing its greenhouse gas (GHG) emissions were emphasized by Barbhuiya et al. (2024) and Pisciotta et al. (2023). The sector's unique industrial processes and market dynamics impede efforts to cut emissions, despite the fact that decarbonization is crucial for reaching climate targets. This section looks at the primary barriers to the transition to low-carbon cement production.

i. High Temperature Process Requirements Clinker, the primary ingredient in Portland cement, is made in kilns that can reach temperatures of 1,450°C. Since fossil fuels are usually used to meet this heat requirement, complete decarbonization is difficult. While electrification and hydrogen-based kilns are gaining traction as alternatives, they still consume a lot of energy and require advancements in reasonably priced high-temperature heating (Abdul-Wahab et al., 2021).

ii. ii. Limestone Calcination Process Emissions

In contrast to other industries where emissions are mostly produced by fuel burning, the chemical breakdown of limestone ($CaCO_3$) during calcination accounts for about 60% of cement's CO_2

emissions. Even if all energy came from renewable sources, process emissions would still occur because this reaction is a natural consequence of conventional cement chemistry. Solutions like carbon capture and storage (CCS) or alternative cement formulations (such geopolymers) are crucial even though they are not yet widely scaled (Jiang et al., 2019).

iii. Various Carbon Pricing Mechanisms: Although some regions (such as the EU) have implemented carbon taxes or cap-and-trade programs, global policy are largely fragmented. Many large cement-producing countries, including China and India, lack rigorous carbon pricing, which leads to an unfair playing field where high-emission producers disadvantage greener competitors (Barbhuiya et al., 2024; Andrew, 2018).

iv. Absence of Innovation Incentives: Government initiatives to promote the use of low-carbon cement, such as tax breaks or subsidies, frequently fall short of providing sufficient support for decarbonization. This strategy calls for funding for pilot projects in carbon capture and alternative cement chemistries, as well as the use of green public procurement in infrastructure projects (Jiang et al.,2019).

v. Limited Access to Alternative Raw Materials Supplementary cementitious materials (SCMs), such as fly ash and slag, can reduce the amount of clinker, but their supply is limited: fly ash, a byproduct of coal production, is diminishing as coal facilities phase out, and new mining and processing facilities are required for calcined clays and natural pozzolans (Abdul-Wahab et al., 2021; Yi et al., 2021).

vi. The Challenges of Growing Alternative Fuels Although waste-derived fuels and biomass can replace fossil fuels in kilns, there are barriers to their widespread use: Supply chains for industrial and municipal trash are irregular and more costly to process than coal or pet-coke, which results in regulations restricting the use of specific waste items as fuel (Jiang et al., 2021).

Strategies and Solutions

An organized, multi-stakeholder strategy that incorporates technology, policy, and market mechanisms is needed to make the switch to low-carbon cement manufacturing. Actionable methods to speed up decarbonization while preserving industry competitiveness are outlined in this implementation framework.

Phase 1: Immediate Measures (2023–2030): Scaling established solutions with shown efficacy should be the primary priority right now. Energy efficiency improvements like waste heat recovery systems, which can cut emissions by 10% to 15% with comparatively little expenditure, must be given top priority by cement makers. By streamlining supply chains for biomass and waste-derived fuels, the sector should simultaneously raise the percentage of alternative fuel replacement to at least 30%. By enacting green procurement laws and carbon pricing, governments play a critical role in generating market incentives for low-carbon cement (IEA,2021; GCCA,2022).

Phase 2: Transformation in the Medium Term (2030–2040): Carbon capture and storage (CCS) must be implemented extensively throughout this phase. To increase viability, governments and business must work together to build CCS hubs close to cement clusters, splitting infrastructure expenses. It will be crucial to implement policy measures like tax rebates and subsidized storage facilities. At the same time, production processes should be completely digitalized, utilizing blockchain for transparent carbon monitoring and AI for real-time optimization. To ensure that novel goods have access to the market, standards organizations must revise building codes to allow for the wider usage of alternate cement formulas (IEA,2021; Scrivener et al.,2018).

Phase 3: Prolonged Upheaval (2040–2050); Biocementation and electrochemical cement manufacturing are examples of radical inventions that need to move from laboratory to industrial use. Pilot plants to reduce the risk of these technologies should be funded by public-private partnerships.

A circular economy strategy will be crucial, with cement factories acting as centers for the recycling of industrial waste and the use of CO2. In order to maintain global equity, policymakers must assist developing countries by providing funding and technology transfer (Davis et al.,2018; Bataille, 2020).

This paradigm balances short-term measures with long-term systemic change, offering a clear roadmap for cement decarbonization. Coordination is essential for success; manufacturers must make investments, legislators must provide incentives, and inventors must produce. The cement sector can attain net-zero emissions and support world development by carrying out this plan. Only bold, group action will ensure a sustainable future; the time for gradual transformation is over (Gassner & Maréchal,2022; Lehne & Preston, 2018).

Conclusion

A combination of technological innovation, material substitution, policy intervention, and industry collaboration are necessary to fully decarbonize cement production. First, alternative cement formulations like geopolymers, LC2, and carbon-cured concrete offer promising pathways to reduce clinker dependence, but adoption among consumers requires standardization, performance validation, and market acceptance. The government and research institutions must accelerate funding for large-scale pilot projects to demonstrate feasibility. The cement industry is at a critical juncture in the global effort to combat climate change, and it must undergo a rapid and radical transformation to align with net-zero targets. In the meanwhile, using more recycled concrete and industrial wastes (such as fly ash and slag) can reduce emissions right away and support a circular economy. Secondly, two crucial short-term tactics are fuel switching and energy efficiency. Reliance on fossil fuels can be reduced by updating kiln systems, implementing waste heat recovery, and switching to green hydrogen or biomass-based fuels. Scalability, however, is contingent upon investments in enabling infrastructure and cost reductions in renewable energy. Thirdly, in order to address process emissions from limestone calcination, carbon capture (CCUS) is still an unavoidable solution. Even while early-stage CCUS initiatives have promise, obstacles including high costs and energy requirements still exist. Policymakers must prioritize financial incentives, CO_2 storage networks, and cross-industry cooperation to make CCUS commercially viable.

Ultimately, the industry's decarbonization rests on collaboration throughout value chains—from raw material suppliers to construction firms. Investors, governments, and manufacturers must jointly commit to R&D, pilot deployments, and long-term policy frameworks. The technology and strategic tools for decarbonization are now in place, despite ongoing hurdles, especially in the areas of cost, scalability, and behavioural resistance. Delays will only raise the transition's financial and environmental costs. Climate action must be implemented immediately. The cement industry may become a leader in sustainable industrial practices and move from being a climate laggard by embracing innovation and policy-driven change.

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THE ROLE OF FUMES/SMOKE EXTRACTION SYSTEMS IN FIRE OUTBREAK FROM DOMESTIC AND INDUSTRIAL SECTORS

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Abstract

The increasing frequency and severity of fire outbreaks in both domestic and industrial sectors necessitate a critical examination of the role of fumes and smoke extraction systems in mitigating these incidents. Fire outbreaks pose significant threats to life, property, and the environment, prompting a need for effective preventive measures. This study argues that the implementation of advanced smoke extraction systems is not merely a regulatory requirement but a fundamental necessity for enhancing fire safety and minimizing damage during fire incidents. The methodology employed in this study involved a comprehensive review of existing literature, case studies, and empirical data regarding fire incidents in various settings. The analysis focused on the effectiveness of different smoke extraction technologies, including mechanical and natural ventilation systems, in controlling smoke spread and improving visibility during evacuations. Additionally, the study examined the integration of these systems with fire detection and suppression technologies to provide a holistic approach to fire safety management. The results indicate that effective smoke extraction systems significantly reduce the concentration of toxic fumes, thereby enhancing the survivability of occupants and facilitating the work of emergency responders. Case studies reveal that buildings equipped with advanced smoke control systems experienced lower casualty rates and property damage compared to those without such systems. Furthermore, the findings suggest that the design and maintenance of these systems are critical factors influencing their effectiveness, underscoring the importance of adherence to established safety standards and regular inspections. This study advocates for a paradigm shift in fire safety management, emphasizing the need for proactive measures that integrate smoke control technologies as a core component of fire prevention strategies.

Keywords: Fumes/Smoke extraction, fire outbreak, industrial sectors, ventilation systems.

Introduction

Fire outbreaks pose significant risks to life, property, and the environment, particularly in domestic and industrial settings. They are a leading cause of loss in both domestic and industrial environments, resulting in devastating consequences. The increasing frequency and severity of fire outbreaks in urban environments necessitate the implementation of effective fire safety measures (Masoumi et al., 2019; Kodur et al., 2020). Among these, Fumes/Smoke Extraction Systems (FSES) play a pivotal role in mitigating the detrimental effects of smoke and toxic fumes during fire incidents. FSES are

engineered solutions designed to remove smoke, heat, and toxic gases from a building during a fire outbreak (Węgrzyński & Lipecki, 2022). Fire outbreaks produce a myriad of hazardous byproducts, including smoke, which poses immediate and long-term health risks to occupants and first responders. FSES are also designed to mitigate the detrimental effects of smoke and toxic fumes during a fire, thereby safeguarding human life and minimizing property damage. Smoke inhalation is a leading cause of fatalities in fire incidents, often surpassing injuries caused by flames. The World Health Organization has identified smoke as a critical factor in fire-related deaths, emphasizing the need for effective smoke control measures (Stefanidou et al., 2008; Gill & Martin, 2015). Fumes and smoke extraction systems serve as a frontline defense against these dangers, facilitating the safe evacuation of individuals and the efficient operation of firefighting efforts. These systems typically comprise a network of ducts, fans, and smoke detectors that work in tandem to identify smoke presence and facilitate its expulsion from the affected area. The primary objective of FSES is to enhance visibility, reduce toxic exposure, and maintain tenable conditions for occupants and first responders. The National Fire Protection Association (NFPA) reports that thousands of fires occur annually, leading to fatalities, injuries, and substantial economic losses (Perry, 2009). In response to these alarming statistics, the integration of fumes and smoke extraction systems has emerged as a critical component of fire safety protocols. Fumes and smoke extraction systems operate through a combination of mechanical and passive strategies designed to remove hazardous smoke and gases from the environment. In domestic settings, these systems often include kitchen hoods, bathroom exhaust fans, and whole-house ventilation systems. In industrial contexts, more complex systems such as smoke control systems, fume hoods, and industrial ventilation systems are employed (Huang et al., 2016; Udoh et al., 2024). These systems function by creating a negative pressure that draws smoke and toxic fumes away from occupied spaces, thereby reducing the risk of smoke inhalation and fire spread. The effectiveness of these systems is contingent upon their design, installation, and maintenance. For instance, the placement of extraction units must be strategically determined to ensure optimal airflow and coverage. Furthermore, regular maintenance is essential to prevent system failures during critical moments. Thus, the technical specifications and operational protocols surrounding these systems are vital for their efficacy in fire outbreak scenarios.

Historical Evolution of Fumes and Smoke Extraction Systems

The origins of smoke extraction systems can be traced back to ancient civilizations, where rudimentary methods were employed to manage smoke in enclosed spaces. The Romans, for instance, utilized flues in their baths and kitchens to vent smoke, demonstrating an early understanding of the need for smoke management. However, it was not until the Industrial Revolution that the need for systematic smoke extraction became pronounced (Akatsu, 2015). The rapid urbanization and the proliferation of factories led to increased fire risks, necessitating more sophisticated smoke control measures. The Great Fire of London in 1666 serves as a pivotal moment in the history of fire safety. The devastation wrought by this disaster prompted legislative changes and the establishment of fire codes, which laid the groundwork for modern fire safety practices. The introduction of the first fire insurance companies further incentivized the development of smoke extraction technologies, as property owners sought to minimize their risks (Mills, 2003). The 19th century witnessed significant technological advancements that transformed smoke extraction systems. The invention of the steam engine and the subsequent rise of mechanical ventilation systems marked a turning point (Ikpe et al., 2024a). These innovations allowed for the development of more effective smoke control systems, such as the use of fans and blowers to facilitate smoke removal. The introduction of the first smoke control regulations in the early 20th century, particularly in the United States and Europe, underscored the growing recognition of the importance of smoke management in fire safety. The mid-20th century brought about further advancements with the advent of electronic control systems and the integration of smoke detection technologies. The development of smoke extraction systems became increasingly sophisticated, incorporating sensors and automated controls that could respond to fire conditions in

real-time. This evolution reflects a broader trend in fire safety that prioritizes proactive measures over reactive responses (Gaur et al., 2019). The evolution of smoke extraction systems is also indicative of changing societal values regarding safety and health. As urban populations grew and industrial activities intensified, public awareness of the dangers posed by smoke inhalation increased. This shift in perception led to the establishment of regulatory frameworks aimed at protecting public health and safety. The introduction of building codes and fire safety regulations in the late 20th century mandated the incorporation of smoke extraction systems in commercial and residential buildings (Meacham, 2022). Moreover, the increasing emphasis on sustainability and environmental protection has influenced the design and implementation of smoke extraction systems. Modern systems are now required not only to manage smoke effectively but also to minimize their environmental impact. This dual focus on safety and sustainability reflects a broader societal commitment to protecting both human life and the environment (Meacham, 2023).

Recent Advancements and Key Milestones in Fumes/Smoke Extraction Systems in Fire Outbreaks

Recent advancements in smoke extraction technology have the potential to revolutionize fire safety protocols, through the following:

i. One of the most significant advancements in smoke extraction systems is the integration of smart sensor technology. Modern systems utilize a network of sensors that can detect smoke and heat in real-time, allowing for immediate activation of extraction mechanisms. This capability is crucial in minimizing smoke inhalation risks, which are responsible for a substantial percentage of fire-related fatalities (Sulthana et al., 2023;Medewar et al., 2024). The argument here is that the adoption of smart technologies not only enhances the effectiveness of smoke extraction but also contributes to a more proactive approach to fire safety.
ii. Automated smoke extraction systems have emerged as a critical milestone in fire management. These systems can operate independently, adjusting their functionality based on real-time data. For instance, advancements in artificial intelligence (AI) enable systems to analyze fire behaviour and predict smoke movement, thereby optimizing extraction efforts. This level of automation reduces the reliance on human intervention, which can often be hindered by panic or disorientation during a fire outbreak.(Zhang et al., 2022) Thus, the argument posits that automation in smoke extraction systems is a vital advancement that enhances both efficiency and safety.
iii. There is a growing emphasis on sustainability within the design and operation of smoke extraction systems. Recent innovations have focused on using eco-friendly materials and energy-efficient designs. For example, systems that utilize natural ventilation principles not only reduce energy consumption but also improve air quality during and after a fire (Itiat et al., 2024; Ahmadizadeh et al., 2024). The argument here is that integrating sustainability into smoke extraction systems is not merely a trend but a necessity in the context of global environmental challenges.
iv. The development of hybrid systems that combine mechanical and natural smoke extraction methods represents a significant milestone. These systems can adapt to various fire scenarios, providing flexibility and efficiency (Salami et al., 2023). The argument is that such adaptability is crucial in urban environments where building designs and fire risks are increasingly complex.
v. The evolution of smoke extraction systems has also been influenced by changes in regulatory frameworks and standardization efforts. Recent years have seen the introduction of stricter building codes and fire safety regulations that mandate the installation of advanced smoke extraction systems in new constructions. This regulatory push is essential for ensuring that safety measures keep pace with technological advancements (Spinardi et al., 2017). Without a robust regulatory framework, the benefits of technological innovations may not be fully realized, as compliance and enforcement are critical to effective fire safety.

Technological Trends in Fumes and Smoke Extraction Systems

The increasing frequency and severity of fire outbreaks in urban and industrial settings necessitate the development of advanced fumes and smoke extraction systems. The key technological trends in this area, includes the use of smart sensors, automated extraction systems, advanced filtration technologies, and the application of artificial intelligence (AI) in smoke detection and management which are discussed as follows:

i. Smart Sensors and IoT Integration: One of the most significant technological trends in smoke extraction systems is the incorporation of smart sensors and the Internet of Things (IoT) (Ekanem et al., 2024). Smart sensors can detect smoke and heat with high precision, providing real-time data that can be transmitted to central monitoring systems. This capability allows for quicker response times and more effective evacuation strategies. Adopting smart sensor technology is compelling; it not only enhances situational awareness but also facilitates predictive analytics, enabling preemptive actions before a fire escalates (Negi et al., 2024). Furthermore, IoT integration allows for seamless communication between various building systems, ensuring that smoke extraction systems activate automatically upon detection of smoke, thereby reducing human error.

ii. Automated Extraction Systems: Automated smoke extraction systems represent another critical advancement in fire safety technology. These systems are designed to operate autonomously, deploying smoke extraction mechanisms without the need for manual intervention (Ekunke et al., 2024). Automation is rooted in the inherent unpredictability of fire outbreaks. Human response times can vary significantly, and in high-stress situations, the likelihood of error increases. Automated systems, equipped with advanced algorithms, can assess the situation and activate extraction protocols instantaneously. This capability not only enhances safety but also minimizes property damage by controlling smoke spread more effectively.

iii. Advanced Filtration Technologies: The development of advanced filtration technologies is another pivotal trend in smoke extraction systems. Traditional smoke extraction methods often fail to adequately filter harmful particulates and toxic gases produced during a fire. Recent advancements in filtration technology, such as HEPA (High-Efficiency Particulate Air) filters and activated carbon filters, have shown promise in capturing a broader range of pollutants (Ikpe et al., 2024b). The argument for implementing these advanced filtration systems is twofold: they not only improve air quality during and after a fire but also contribute to the overall health and safety of occupants in the vicinity. By reducing the concentration of harmful substances, these technologies can significantly lower the risk of long-term health issues associated with smoke exposure.

iv. Artificial Intelligence in Smoke Detection and Management: The application of artificial intelligence (AI) in smoke detection and management is perhaps the most transformative trend in the field. AI algorithms can analyze vast amounts of data from various sensors to identify patterns indicative of fire outbreaks (Aspragathos et al., 2019). This capability allows for more accurate predictions and faster responses. AI integration is particularly strong when considering the potential for machine learning to improve over time; as systems gather more data, their predictive accuracy increases, leading to more effective fire prevention strategies. Moreover, AI can facilitate the optimization of smoke extraction systems by dynamically adjusting their operation based on real-time conditions, thereby enhancing overall efficiency.

Design Considerations for Fumes and Smoke Extraction Systems

The efficacy of fumes and smoke extraction systems (FSES) during fire outbreaks is critical in mitigating the detrimental effects of smoke inhalation and enhancing the safety of occupants. The design of effective FSES is paramount in ensuring the safety of occupants and facilitating the safe evacuation of buildings. This section delineates the following critical design considerations which must be addressed to enhance the effectiveness of FSES:

i. System Capacity and Performance Metrics: One of the foremost considerations in the design of FSES is the system's capacity to handle smoke and fumes generated during a fire. The design must account for the volume of smoke produced, which can vary significantly based on the materials involved in the fire (Gehandler, 2015). Research indicates that the rate of smoke production can be influenced by factors such as the combustion process and the nature of the fuel. Therefore, designers must employ performance metrics that accurately predict smoke generation rates and ensure that the FSES can effectively manage these volumes. Failure to do so can result in system overload, rendering the extraction system ineffective and jeopardizing occupant safety.

ii. Airflow Dynamics and Ventilation Strategies: The dynamics of airflow within a building during a fire are complex and can significantly impact the effectiveness of smoke extraction systems. The design must incorporate an understanding of the principles of fluid dynamics, including the behaviour of smoke as it rises and spreads. Effective ventilation strategies, such as the use of natural and mechanical ventilation, must be integrated into the FSES design to facilitate the rapid removal of smoke from the environment (Short et al., 2006). This study argues that a failure to consider airflow dynamics can lead to the entrapment of smoke in certain areas, exacerbating the dangers posed to occupants and emergency responders.

iii. Material Selection and Durability: The materials used in the construction of FSES must be carefully selected to withstand the extreme conditions associated with fire outbreaks. High temperatures, corrosive gases, and potential structural damage necessitate the use of durable, fire-resistant materials. The selection of appropriate materials is not merely a technical consideration but a critical factor that influences the overall reliability and longevity of the system (Li et al., 2018). Inadequate material selection can lead to system failure during a fire, thereby compromising safety and increasing the risk of injury or loss of life.

iv. Integration with Fire Detection Systems: The integration of FSES with fire detection and alarm systems is another crucial design consideration. Effective communication between these systems can enhance the overall response to a fire outbreak, allowing for timely activation of smoke extraction measures (Birajdar et al., 2020). A holistic approach to system design, which includes the synchronization of FSES with fire detection systems, is essential for maximizing the effectiveness of smoke control strategies. Neglecting this integration can result in delayed responses and increased risks to occupants.

v. Regulatory Compliance and Standards: Compliance with relevant building codes and fire safety regulations is a fundamental aspect of FSES design. These regulations are established to ensure that systems meet minimum safety standards and are capable of performing effectively in the event of a fire (Brinson et al., 2019). Adherence to regulatory frameworks is not only a legal obligation but also a moral imperative to protect human life. Designers must remain abreast of evolving standards and incorporate them into their designs to ensure that FSES are both compliant and effective.

Installation Steps for Effective Fumes/Smoke Extraction Systems

The increasing prevalence of industrial activities and urbanization has heightened the risk of fire outbreaks due to the accumulation of flammable fumes and smoke. Effective fumes and smoke extraction systems are essential for mitigating these risks. However, the effectiveness of these systems is contingent upon proper installation steps which are highlighted as follows:

i. Site Assessment: The first step in the installation of an effective fumes/smoke extraction system is a thorough site assessment. This involves evaluating the specific characteristics of the environment where the system will be installed. Factors such as the type of activities conducted, the nature of the materials used, and the layout of the facility must be considered (Avazov et al., 2023). A comprehensive risk assessment should be conducted to identify potential sources of fumes and smoke, as well as the specific fire hazards associated with them. This foundational step is crucial, as it informs subsequent decisions regarding system design and equipment selection.

ii. System Design: Following the site assessment, the next step is to develop a tailored system design. This design must align with the identified risks and comply with relevant safety regulations and standards. The design process should involve the calculation of airflow requirements, the selection of appropriate extraction points, and the determination of ductwork configurations. An effective design will ensure that the system can adequately capture and remove fumes and smoke before they reach hazardous concentrations (Maluk et al., 2017). Additionally, considerations for redundancy and scalability should be integrated into the design to accommodate future changes in facility operations.
iii. Equipment Selection: The selection of appropriate equipment is a critical step in the installation process. This includes choosing fans, filters, and ducting materials that are suitable for the specific application. The equipment must be capable of handling the anticipated volume and type of fumes and smoke, as well as being resistant to corrosion and other forms of degradation (Bromwich et al., 2020). Furthermore, energy efficiency should be a key consideration, as it not only impacts operational costs but also aligns with sustainability goals. Engaging with manufacturers and suppliers who specialize in fumes and smoke extraction systems can provide valuable insights into the latest technologies and best practices.
iv. Installation Procedures: Once the design and equipment have been finalized, the installation process can commence. This phase should be executed by qualified personnel who are familiar with the technical requirements and safety protocols associated with fumes and smoke extraction systems. The installation should adhere to the specifications outlined in the design phase, ensuring that all components are correctly positioned and securely connected (Kuusisto, 2000). It is imperative to conduct regular inspections during installation to identify and rectify any potential issues before the system becomes operational.
v. Post-Installation Evaluation: The final step in the installation process is a comprehensive post-installation evaluation. This involves testing the system to ensure it operates as intended and meets all regulatory requirements. Performance metrics such as airflow rates, pressure differentials, and filtration efficiency should be measured and documented. Additionally, training for personnel on the operation and maintenance of the system is essential to ensure long-term effectiveness (Yit et al., 2020). Regular maintenance schedules should be established to monitor system performance and address any emerging issues proactively.

Regulatory Frameworks for Fumes and Smoke Extraction Systems

As industries expand and urban centers grow, the emissions from various processes pose significant risks, necessitating the establishment of the following regulatory frameworks that govern the design, implementation, and maintenance of these systems:

i. Occupational Safety and Health Administration (OSHA) Standards: OSHA regulations primarily focus on workplace safety and health, establishing permissible exposure limits (PELs) for various airborne contaminants. However, these standards often lack specificity regarding the design and operational efficiency of smoke extraction systems, leading to potential gaps in worker protection (Komis & Scott, 2018;Finkel et al., 2022).
ii. Environmental Protection Agency (EPA) Regulations: The EPA enforces regulations aimed at controlling air pollution from stationary and mobile sources. While these regulations set limits on emissions, they do not universally mandate the implementation of smoke extraction systems, resulting in inconsistencies across industries (Kumar & Gupta, 2016). The Clean Air Act serves as a cornerstone for air quality management, yet its effectiveness is contingent upon rigorous enforcement and compliance monitoring.
iii. European Union Directives: The EU has established comprehensive directives, such as the Ambient Air Quality Directive and the Industrial Emissions Directive, which emphasize the need for effective emission control technologies (Tankosić, 2023). However, the transposition of these directives into national laws often varies, leading to disparities in implementation and enforcement across member states.

iv. National Fire Protection Association (NFPA): has developed a series of codes and standards that address fire safety, including those related to smoke and fume extraction. NFPA 91, for instance, provides guidelines for the design and installation of smoke control systems, emphasizing the importance of preventing smoke migration during a fire event. The NFPA standards advocate for a proactive approach to fire safety, which is essential in industries where flammable materials are present (Miranda et al., 2015). By integrating NFPA standards into regulatory frameworks, organizations can ensure that their smoke extraction systems are not only compliant but also effective in mitigating fire hazards.

v. American National Standards Institute (ANSI): plays a pivotal role in establishing consensus standards that enhance safety and performance across various industries. ANSI/ASHRAE Standard 62.1, which pertains to ventilation for acceptable indoor air quality, is particularly relevant for fumes and smoke extraction systems. This standard outlines the minimum ventilation requirements necessary to maintain healthy indoor environments, thereby addressing the health implications of inadequate fume extraction (Makhija et al., 2022). By adhering to ANSI standards, organizations can ensure that their systems are designed to meet both safety and health requirements, thus fostering a holistic approach to workplace safety.

vi. International Organization for Standardization (ISO): provides a global framework for standardization that transcends national boundaries. ISO 14001, which focuses on environmental management systems, encourages organizations to minimize their environmental impact, including emissions from fumes and smoke. The integration of ISO standards into regulatory practices promotes consistency and accountability across international operations. As industries increasingly operate on a global scale, adherence to ISO standards becomes imperative for ensuring that fumes and smoke extraction systems are effective and compliant with international best practices (Delmas& Montes-Sancho, 2011; Orcos & Palomas, 2019).

Types of Smoke Extraction Systems

Smoke extraction systems play a vital role in enhancing visibility, reducing toxic gas accumulation, and facilitating safe evacuation. The primary types of smoke extraction systems include natural, mechanical, and hybrid systems which are discussed as follows:

i. Natural Smoke Extraction Systems: Natural smoke extraction systems leverage the principles of buoyancy and thermal dynamics to facilitate the removal of smoke from a building. These systems typically include smoke vents, which are strategically placed to allow hot smoke to rise and escape, thereby creating a negative pressure that draws in cooler air (see Figure 1) (Ivanov et al., 2021). While natural systems are often lauded for their simplicity and low energy requirements, their effectiveness is contingent upon environmental conditions such as wind and temperature differentials. This reliance on external factors can render them less effective in certain scenarios, particularly in large or complex structures where smoke may become trapped.

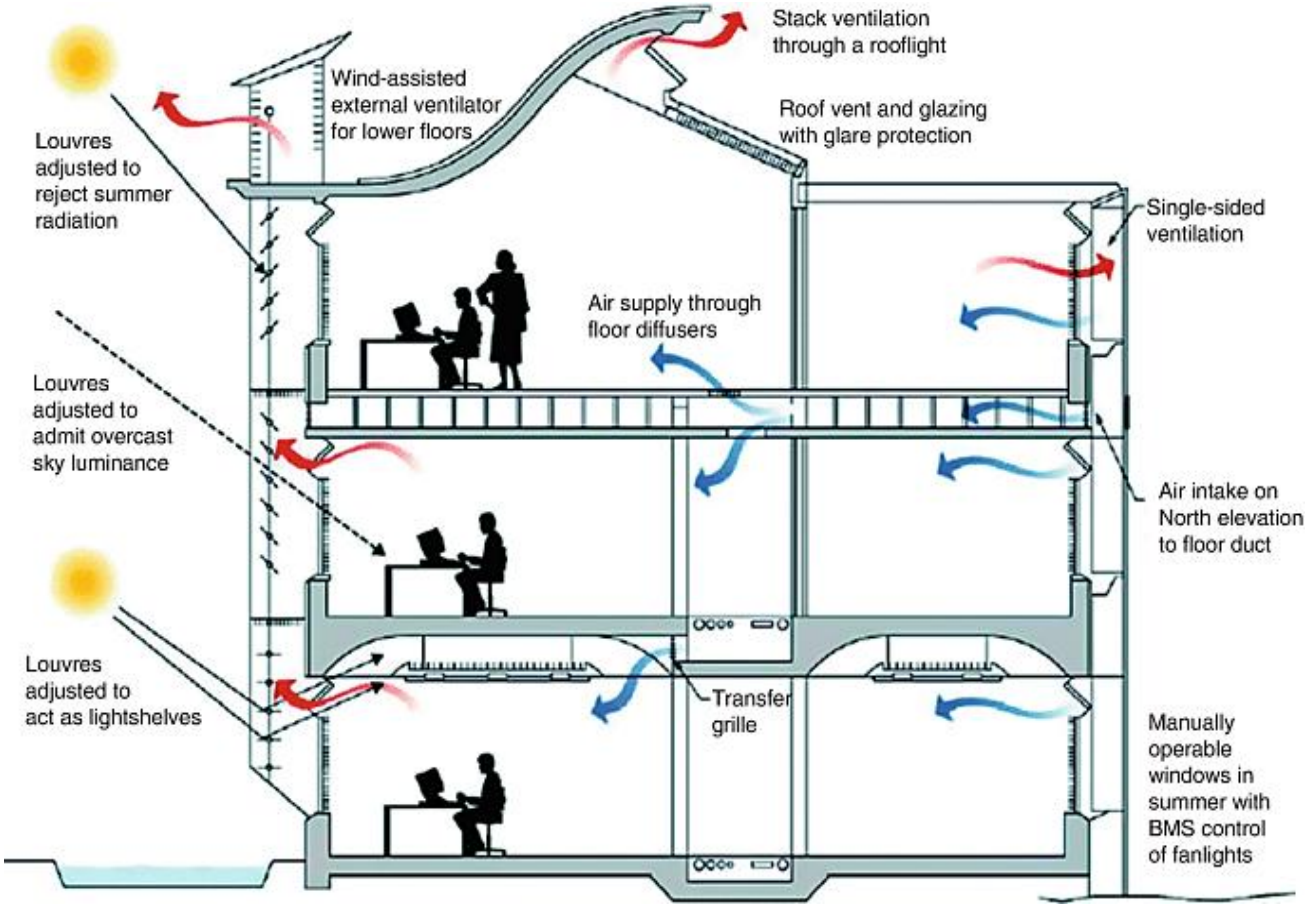

Figure 1: Natural smoke extraction systems (Yang and Clements-Croome, 2018)

ii. Mechanical Smoke Extraction Systems: Mechanical smoke extraction systems utilize powered fans to actively remove smoke and fumes from a building as shown in Figure 2. These systems can be designed to operate independently or in conjunction with fire alarm systems, providing a more controlled and reliable means of smoke management. The primary advantage of mechanical systems lies in their ability to function regardless of external conditions, offering a consistent and efficient means of smoke extraction (Su & Yao, 2016; Abdel Aziz et al., 2023). However, they also present challenges, including higher energy consumption and the potential for mechanical failure. Moreover, the design and placement of these systems must be meticulously planned to ensure optimal performance, which can complicate the installation process.

Figure 2: Mechanical smoke extraction systems (Khalid et al., 2023)

iii. Hybrid Smoke Extraction Systems: Hybrid systems combine elements of both natural and mechanical extraction methods, aiming to capitalize on the strengths of each while mitigating their weaknesses (see Figure 3). These systems may employ mechanical fans to enhance the natural buoyancy effect or utilize natural vents to supplement mechanical extraction during peak smoke conditions. Hybrid systems represent a progressive approach to smoke management, offering flexibility and adaptability in various fire scenarios (Khalid et al., 2023; Bhadange et al., 2024). However, their complexity can lead to increased costs and maintenance requirements. Furthermore, the integration of both systems necessitates careful engineering to ensure that they operate synergistically, which can be a significant challenge in practice.

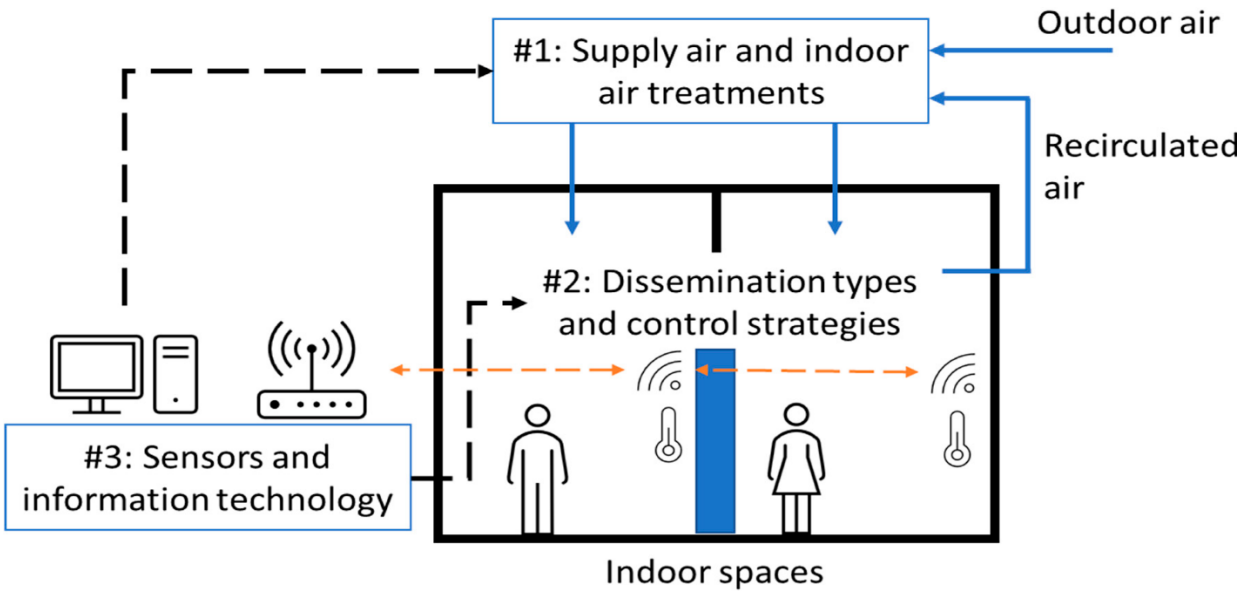

Figure 3: Hybrid Smoke Extraction Systems (Zhou et al., 2025)

Operational Mechanisms in Smoke Extraction Systems

The efficacy of fumes and smoke extraction systems is contingent upon their operational mechanisms which are discussed as follows:

i. Ventilation Principles: At the core of any smoke extraction system lies the principle of ventilation. The mechanisms employed can be categorized into natural and mechanical ventilation. Natural ventilation relies on buoyancy and wind effects to facilitate air movement, while mechanical systems utilize fans and blowers to actively remove smoke and fumes (Milke, 2016).While natural ventilation can be effective in certain scenarios, mechanical systems offer greater control and efficiency, particularly in high-density environments where smoke accumulation poses significant risks (Wen et al., 2020).

ii. Filtration Technologies: Filtration is another critical operational mechanism in smoke extraction systems. Various filtration technologies, including electrostatic precipitators, HEPA filters, and activated carbon filters, play a pivotal role in capturing particulate matter and gaseous pollutants. The effectiveness of these filters is contingent upon their design, material composition, and maintenance protocols (Gadgil et al., 2024). Investing in advanced filtration technologies is essential for enhancing the overall performance of smoke extraction systems, particularly in industries with high levels of airborne contaminants.

iii. Ductwork Design and Configuration: The design and configuration of ductwork significantly influence the efficiency of smoke extraction systems. Factors such as duct size, shape, and layout can affect airflow dynamics and pressure differentials. A well-engineered duct system is crucial for minimizing resistance and ensuring optimal airflow (Huat, 2022). Moreover, the integration of variable air volume (VAV) systems can enhance adaptability, allowing for real-time adjustments based on smoke concentration levels.

iv. Control Systems and Automation: Modern smoke extraction systems increasingly incorporate advanced control systems and automation technologies. These systems utilize sensors and data analytics to monitor air quality and adjust extraction rates accordingly. Automation not only enhances the responsiveness of smoke extraction systems but also reduces human error, thereby improving overall safety (Seesaard et al., 2024). Furthermore, the integration of smart technologies can facilitate predictive maintenance, ensuring that systems operate at peak efficiency.

Applications of Smoke Extraction Systems

FSES serve as a pivotal technology in this regard, designed to capture and filter harmful emissions before they can adversely affect human health and the environment. The applications of FSES extend beyond mere compliance with health and safety regulations; they are integral to sustainable industrial practices, public health, and environmental stewardship. The different applications of smoke extraction systems are as follows:

i. Manufacturing Industries: In manufacturing environments, particularly those involving welding, soldering, and machining processes, FSES are employed to extract harmful fumes and particulate matter. The presence of volatile organic compounds (VOCs) and metal particulates poses significant health risks to workers (Balasubramanian et al., 2024; Udoh et al., 2024). By implementing FSES, manufacturers not only comply with occupational safety standards but also enhance worker productivity and morale, as a cleaner work environment fosters better health outcomes.
ii. Food Processing: The food processing industry utilizes FSES to manage smoke and vapors generated during cooking and processing operations. The extraction of these emissions is crucial for maintaining air quality and preventing contamination of food products (Pereira & Vicente, 2010). Furthermore, effective smoke extraction systems can help in preserving the sensory qualities of food, thereby enhancing consumer satisfaction and product quality.
iii. Automotive Industry: In automotive manufacturing and repair, FSES play a vital role in controlling emissions from paint booths, exhaust systems, and other processes that generate harmful fumes. The implementation of these systems is essential not only for worker safety but also for compliance with stringent environmental regulations aimed at reducing air pollution (Rosenman, 2010). The automotive sector's commitment to sustainability is further reinforced through the adoption of advanced FSES technologies.
iv. Laboratories and Research Facilities: Laboratories, particularly those engaged in chemical research and development, are environments where FSES are indispensable. The extraction of toxic fumes and vapors is critical to ensuring the safety of personnel and the integrity of experimental results (Freese et al., 2024). Moreover, the presence of FSES in laboratories demonstrates a commitment to best practices in safety and environmental responsibility, which is increasingly important in securing funding and partnerships.
v. Construction Sites: Construction activities often generate significant amounts of dust and fumes, particularly during demolition and renovation projects. FSES can be employed to mitigate these emissions, thereby protecting workers and nearby residents from exposure to harmful pollutants (Cook et al., 2022). The integration of smoke extraction systems in construction practices not only enhances safety but also aligns with sustainable development goals by minimizing the environmental impact of construction activities.
vi. Waste Management Facilities: Waste management operations, including incineration and recycling processes, produce a variety of harmful emissions. FSES are crucial in these settings to capture and filter out toxic fumes, thereby reducing the environmental footprint of waste management activitiesv (Van Caneghem et al., 2019; Jakhar et al., 2023). The adoption of advanced FSES technologies in waste facilities is indicative of a broader trend towards sustainable waste management practices.

Conclusion

The study of fumes and smoke extraction systems in the context of fire outbreaks has emerged as a critical area of research, particularly given the increasing frequency and intensity of fire incidents in urban environments. This study has argued that effective smoke extraction systems are not merely supplementary components of fire safety protocols but are essential to mitigating the adverse effects of smoke inhalation and improving survival rates during fire emergencies. The findings reveal the necessity for a paradigm shift in how fire safety is conceptualized and implemented, emphasizing the integration of advanced smoke extraction technologies into building designs and emergency response strategies. One of the primary conclusions drawn from this study is that the efficacy of smoke

extraction systems significantly influences the overall safety of occupants during a fire outbreak. For example, buildings equipped with effective smoke control systems experience lower casualty rates and reduced property damage compared to those lacking such systems. This correlation highlights the imperative for policymakers and building designers to prioritize the incorporation of these systems in both new constructions and retrofitting existing structures. Moreover, this study reveals that the effectiveness of smoke extraction systems is contingent upon several factors, including system design, operational protocols, and the specific characteristics of the fire environment. For instance, passive smoke control measures, such as smoke barriers and vents, can be highly effective when combined with active systems like mechanical smoke extraction fans. This multifaceted approach not only enhances the immediate response to fire outbreaks but also contributes to long-term resilience in urban planning.

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A TECHNICAL SURVEY ON MECHANICAL PLUMBING AND RETICULATION SYSTEMS IN CONVENTIONAL ENGINEERING APPLICATIONS

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Abstract

The integration of mechanical plumbing and reticulation systems within conventional engineering applications is a critical area of study, particularly as urbanization and industrialization continue to escalate. This study presents a comprehensive technical review of these systems, focusing on their design, implementation, and operational efficiency. The problem statement centres on the inadequacies and inefficiencies often observed in existing plumbing and reticulation systems, which can lead to significant resource wastage, increased operational costs, and environmental degradation. The methodology employed in this review encompasses a systematic analysis of existing literature, case studies, and empirical data related to mechanical plumbing and reticulation systems. A comparative analysis of various systems was conducted, focusing on their design principles, material selection, installation techniques, and maintenance protocols. The results indicated that many conventional plumbing systems are plagued by inefficiencies, including inadequate flow rates, poor pressure management, and susceptibility to leaks and blockages. These issues not only compromise the functionality of the systems but also contribute to increased energy consumption and operational costs. Furthermore, the findings reveal that the adoption of advanced materials and technologies, such as smart sensors and automated control systems, can significantly enhance the performance and reliability of plumbing and reticulation systems. The study also highlights the importance of regular maintenance and the implementation of best practices in system design to mitigate common issues.

Keywords: Mechanical Plumbing, Reticulation Systems, Engineering Applications, energy consumption, operational costs.

Introduction

Mechanical plumbing and reticulation systems are integral components of modern infrastructure, facilitating the efficient distribution of water and the removal of waste. The advent of urbanization has necessitated the development of sophisticated mechanical plumbing and reticulation systems. These systems are not merely functional; they embody a complex interplay of engineering principles, regulatory frameworks, and societal norms. Mechanical plumbing refers to the network of pipes, valves, fixtures, and other apparatuses that facilitate the transport of water and waste within a building

or infrastructure (Gupta &Thawari, 2016; Gurmu & Mudiyanselage, 2023). Reticulation systems, on the other hand, specifically denote the distribution networks that deliver potable water and manage wastewater. Together, these systems form the backbone of urban sanitation and water supply, impacting public health, environmental sustainability, and economic efficiency. The operation of mechanical plumbing and reticulation systems is grounded in several fundamental principles including:

i. Hydraulic Principles: The movement of fluids through pipes is governed by principles of fluid dynamics, including pressure differentials, flow rates, and resistance. Understanding these principles is essential for designing systems that can efficiently transport water and waste(Ibrahim, 2010).
ii. Gravity and Pressure Systems: Plumbing systems can operate under gravity or pressure. Gravity systems rely on sloped pipes to facilitate drainage, while pressure systems utilize pumps to move fluids against gravitational forces (Pozos et al., 2010). The choice between these systems depends on the specific requirements of the infrastructure.
iii. Material Science: The selection of materials for pipes and fixtures is critical, as it affects durability, corrosion resistance, and overall system performance. Common materials include PVC, copper, and galvanized steel, each with distinct properties that influence their suitability for various applications (Giovanardi et al., 2020).
iv. Thermal Expansion and Contraction: Materials used in plumbing systems expand and contract with temperature changes. Engineers must account for these variations to prevent structural failures or leaks, employing expansion joints and appropriate material selection(King & King, 2013).
v. Water Quality Management: Ensuring the quality of water within reticulation systems is paramount. This involves the implementation of filtration, disinfection, and regular monitoring to prevent contamination and ensure compliance with health standards(Bandh & Mushtaq, 2025).

A simple rule that governs the design and operation of mechanical plumbing and reticulation systems is the principle of "minimum resistance." This principle posits that systems should be designed to minimize friction and turbulence, thereby enhancing efficiency and reducing energy consumption. Normative practices in the field are guided by local building codes, health regulations, and environmental standards (Theodossiou et al., 2014). These regulations ensure that systems are designed and maintained to prevent contamination, promote water conservation, and protect public health. Compliance with these norms is not merely a legal obligation; it is a moral imperative that underscores the responsibility of engineers and planners to safeguard community well-being. The complexity of mechanical plumbing and reticulation systems necessitates a comprehensive understanding of their definitions, principles, and normative practices. Failure to appreciate these aspects can lead to inadequate system design, resulting in inefficiencies, increased costs, and potential public health crises. For instance, poorly designed plumbing systems can lead to water contamination, which poses significant health risks to populations (Lee & Schwab, 2005; Julien et al., 2020). Moreover, as urban areas continue to expand, the demand for efficient water management systems will only increase. A robust understanding of mechanical plumbing and reticulation systems is essential for developing innovative solutions that address these challenges. This includes the integration of smart technologies, sustainable materials, and practices that promote water conservation. As society grapples with the challenges of urbanization and environmental sustainability, the importance of well-designed plumbing and reticulation systems cannot be overstated.

Key Milestones on Mechanical plumbing and reticulation systems

Mechanical plumbing and reticulation systems have undergone substantial transformations, driven by technological innovations and changing societal needs. Key Milestones recorded are as follows:

i. Standardization of Materials and Practices: The early 20th century marked a significant milestone with the standardization of plumbing materials, such as copper and PVC. This standardization not

only improved the reliability of plumbing systems but also facilitated the widespread adoption of plumbing codes, ensuring safety and efficiency in installations (Cowles 1941; Agbasi et al., 2025).

ii. Introduction of Pressure Systems: The development of pressurized plumbing systems in the mid-20th century revolutionized water distribution. These systems allowed for greater efficiency in water delivery and reduced the risk of contamination, thereby enhancing public health outcomes (Locicero, 2017).

iii. Automation and Smart Technologies: The late 20th and early 21st centuries witnessed the integration of automation and smart technologies into plumbing systems. The advent of sensors, IoT devices, and automated controls has enabled real-time monitoring and management of water usage, leading to significant reductions in waste and improved system performance (Lorinc, 2022Ekanem et al., 2024a).

iv. Sustainability Initiatives: The growing emphasis on sustainability in engineering practices has led to the adoption of eco-friendly materials and water-saving technologies. The introduction of grey water recycling systems and rainwater harvesting has become increasingly prevalent, reflecting a shift towards more sustainable plumbing solutions (Ekanem, et al., 2024b; Abdelhak, 2024).

Recent Trends on Mechanical Plumbing and Reticulation Systems

The evolution of mechanical plumbing and reticulation systems has been pivotal in shaping modern engineering applications, in facilitating the distribution of fluids in residential, commercial, and industrial settings. Recent trends in mechanical plumbing and reticulation systems include the following:

i. Digital Twin Technology: One of the most significant recent trends is the application of digital twin technology in plumbing systems. By creating virtual replicas of physical systems, engineers can simulate performance, predict failures, and optimize maintenance schedules (Qian et al 2022; Mihai et al., 2022). This trend not only enhances operational efficiency but also reduces costs associated with system downtime.

ii. Resilience and Adaptability: As climate change poses new challenges, the resilience of plumbing systems has become a focal point in engineering design. Recent trends emphasize the need for adaptable systems that can withstand extreme weather events, thereby ensuring continuity of service in the face of environmental disruptions (Ali, 2023).

iii. Regulatory Compliance and Health Standards: The increasing complexity of regulatory frameworks surrounding plumbing systems necessitates a proactive approach to compliance. Recent trends indicate a shift towards more stringent health and safety standards, compelling engineers to adopt innovative solutions that meet these requirements while maintaining system efficiency (Umeokafor et al., 2022).

iv. Integration of Renewable Energy Sources: The incorporation of renewable energy sources, such as solar heating systems for water supply, represents a significant trend in plumbing design. This integration not only reduces reliance on fossil fuels but also aligns with global sustainability goals, showcasing the potential for plumbing systems to contribute to broader environmental objectives (Islam et al., 2013).

Design Considerations for Mechanical Plumbing and Reticulation Systems

Mechanical plumbing and reticulation systems serve as the backbone of water supply and waste management in residential, commercial, and industrial buildings. The complexity of these systems necessitates a thorough understanding of various design considerations that influence their performance and sustainability which are as follows:

I. Hydraulic Performance: The hydraulic performance of plumbing systems is paramount, as it directly affects water delivery and waste removal efficiency. Key considerations include:

i. Flow Rate and Pressure: Designers must calculate the required flow rates and pressures to ensure adequate service delivery. This involves understanding the demand patterns and peak usage times to prevent system failures.
ii. Pipe Sizing: Proper pipe sizing is critical to minimize friction losses and ensure efficient flow. Oversized pipes can lead to increased costs and potential stagnation, while undersized pipes can cause pressure drops and inadequate service (Kamel et al., 2015).
iii. System Layout: The configuration of the plumbing system should minimize bends and fittings, which can introduce turbulence and pressure losses. A well-planned layout enhances flow efficiency and reduces maintenance needs (Gupta & Thawari, 2016).

II. Material Selection: The choice of materials for plumbing systems significantly impacts their durability, maintenance, and environmental footprint. Considerations include:

i. Corrosion Resistance: Materials must be selected based on their resistance to corrosion, particularly in environments with aggressive water chemistry. Common materials include copper, PVC, and PEX, each with distinct advantages and limitations (Arthur et al., 2020).
ii. Thermal Conductivity: The thermal properties of materials influence energy efficiency, particularly in hot water systems. Insulation materials should be considered to minimize heat loss.
iii. Sustainability: The environmental impact of materials should be assessed, favouring those that are recyclable or have lower embodied energy. This consideration aligns with global sustainability goals and regulatory frameworks (Bribián et al., 2011).

III. Environmental Impact: The design of plumbing systems must account for their environmental implications, particularly in the context of water conservation and energy efficiency. Key points include:

i. Water Efficiency: Incorporating fixtures and appliances that promote water conservation is essential. Low-flow faucets, dual-flush toilets, and grey water recycling systems can significantly reduce water consumption (Friedman& Friedman, 2012; Varma, 2022).
ii. Energy Efficiency: The design should consider the energy required for heating water and transporting it through the system. Utilizing energy-efficient pumps and heaters can reduce operational costs and environmental impact.
iii. Pollution Prevention: Systems must be designed to prevent cross-contamination and backflow, ensuring that potable water supplies remain uncontaminated. This involves the use of appropriate backflow prevention devices and regular system maintenance.

IV. Regulatory Compliance: Adherence to local, national, and international codes and standards is a fundamental aspect of plumbing system design. Considerations include:

i. Building Codes: Designers must ensure that plumbing systems comply with relevant building codes, which dictate minimum standards for safety, performance, and accessibility (Foliente, 2000).
ii. Health and Safety Regulations: Compliance with health regulations is critical to protect public health. This includes ensuring that materials used are safe for potable water and that systems are designed to prevent health hazards.
iii. Sustainability Standards: Increasingly, regulatory frameworks are incorporating sustainability criteria. Designers must stay abreast of these evolving standards to ensure compliance and promote environmentally responsible practices.

V. Maintenance and Accessibility: The long-term performance of plumbing systems is heavily influenced by their design in terms of maintenance and accessibility. Key considerations include:

i. Access Points: Adequate access points for maintenance and inspection should be integrated into the design. This facilitates routine checks and repairs, reducing downtime and extending system lifespan.
ii. Modular Design: Implementing a modular design approach can simplify repairs and upgrades, allowing for easier replacement of components without extensive system overhauls.

iii. Documentation and Training: Comprehensive documentation of the plumbing system design and operation is essential for maintenance personnel. Additionally, training staff on system operation and maintenance can enhance performance and longevity (Wirag, 2014).

Sustainable Plumbing and Reticulation Solutions in Modern Engineering Practices

The plumbing and reticulation systems of buildings and infrastructure are critical to public health, environmental sustainability, and economic viability. Traditional plumbing practices often prioritize immediate functionality and cost-effectiveness, frequently neglecting long-term environmental impacts. In contrast, sustainable plumbing solutions advocate for a holistic approach that considers the lifecycle of materials, water conservation, and energy efficiency (Hauashdh, et al., 2022). The various sustainable plumbing and reticulation practices in modern engineering which aligns with global sustainability goals are as follows:

i. Rainwater Harvesting Systems: Rainwater harvesting (RWH) systems are a cornerstone of sustainable plumbing practices. By capturing and utilizing rainwater, these systems reduce dependency on municipal water supplies, thereby conserving potable water. The implementation of RWH systems can significantly mitigate urban flooding, decrease storm-water runoff, and lower water treatment costs (Lepcha et al., 2024). Furthermore, the integration of RWH into building designs exemplifies a proactive approach to resource management, aligning with principles of sustainable development.

ii. Grey water Recycling: Grey water recycling systems offer a viable solution for reducing freshwater consumption. By treating and reusing water from sinks, showers, and laundry, these systems can substantially decrease the demand for potable water in residential and commercial settings. The argument for grey water recycling is strengthened by its potential to alleviate pressure on wastewater treatment facilities and reduce the environmental impact of effluent discharge. However, the successful implementation of grey water systems requires robust regulatory frameworks and public education to ensure safety and efficacy (Al-Jayyousi, 2003).

iii. Low-Flow Fixtures and Fittings: The installation of low-flow fixtures and fittings is a straightforward yet effective strategy for enhancing water efficiency in plumbing systems. These devices, which include low-flow toilets, faucets, and showerheads, significantly reduce water consumption without compromising performance (Schück et al., 2023). The argument for their widespread adoption is bolstered by empirical evidence demonstrating substantial water savings and reduced energy costs associated with heating water. Moreover, the economic benefits of low-flow fixtures can lead to a rapid return on investment, making them an attractive option for both consumers and developers.

iv. Sustainable Materials: The choice of materials in plumbing systems plays a crucial role in sustainability. Traditional materials, such as PVC and copper, often have significant environmental footprints due to resource extraction and manufacturing processes. In contrast, sustainable alternatives, such as cross-linked polyethylene (PEX) and recycled materials, offer lower environmental impacts and enhanced durability. The argument for adopting sustainable materials is further supported by the increasing availability of eco-friendly options and the growing consumer demand for sustainable products (Asadi et al., 2016).

v. Smart Water Management Systems: The integration of smart technology into plumbing and reticulation systems represents a transformative approach to water management. Smart meters and sensors can provide real-time data on water usage, enabling more efficient consumption patterns and early detection of leaks (Mounce, 2021;Palermo et al., 2022). This technology not only enhances operational efficiency but also empowers consumers to make informed decisions about their water usage. The argument for smart water management systems is compelling, as they align with the broader trend of digital transformation in engineering and contribute to the overarching goals of sustainability.

Risk Management Solutions Associated With Plumbing and Reticulation Systems

Despite the importance of plumbing and reticulation systems to public health, environmental sustainability, and economic efficiency, these systems face numerous risks that can lead to significant operational failures and adverse consequences. Conventional engineering practices often overlook the integration of robust risk management solutions, leading to vulnerabilities that can compromise system integrity and public safety. The adoption of systematic risk management strategies is not merely beneficial but essential for the effective functioning of plumbing and reticulation systems. They include the following:

i. Identification of Risks: The first step in effective risk management is the identification of potential risks. In plumbing and reticulation systems, risks can be categorized into several domains: operational, environmental, regulatory, and financial. Operational risks include pipe failures, leaks, and blockages, which can result from material degradation, poor installation practices, or inadequate design. Environmental risks encompass contamination of water sources and the impact of climate change on water availability and quality (Taiwo et al., 2023). Regulatory risks arise from non-compliance with local, national, and international standards, which can lead to legal repercussions and financial penalties. Financial risks are associated with the costs of repairs, legal liabilities, and potential loss of revenue due to service disruptions.

ii. Proactive Design Strategies: One of the most effective risk management solutions is the implementation of proactive design strategies. Engineers must prioritize the selection of durable materials and innovative design techniques that enhance system resilience. For instance, the use of corrosion-resistant materials can significantly reduce the likelihood of pipe failures. Additionally, incorporating redundancy in critical components of the system can provide backup options in the event of a primary system failure (Yazdi, 2024). Furthermore, the application of advanced modelling techniques during the design phase can help predict potential failure points and inform the development of mitigation strategies.

iii. Regular Maintenance Protocols: Regular maintenance is a cornerstone of effective risk management in plumbing and reticulation systems. Scheduled inspections and preventive maintenance can identify and rectify issues before they escalate into major failures. This proactive approach not only extends the lifespan of the infrastructure but also minimizes the risk of service interruptions (Thabane, 2016). The implementation of a comprehensive maintenance management system, which includes detailed records of inspections, repairs, and replacements, is essential for tracking the condition of the system and ensuring compliance with regulatory standards.

iv. Advanced Monitoring Technologies: The integration of advanced monitoring technologies represents a significant advancement in risk management for plumbing and reticulation systems. Real-time monitoring systems, equipped with sensors and data analytics capabilities, can provide valuable insights into system performance and detect anomalies indicative of potential failures. For example, pressure sensors can alert operators to leaks or blockages, allowing for immediate intervention. Moreover, the use of Geographic Information Systems (GIS) can enhance the management of reticulation networks by providing spatial analysis and visualization tools that aid in decision-making processes (Nanruksa & Dhanasin, 2024).

v. Regulatory Compliance and Stakeholder Engagement: Ensuring compliance with regulatory standards is a critical aspect of risk management. Engineers must stay abreast of evolving regulations and incorporate them into their design and operational practices. Furthermore, engaging stakeholders-including local communities, regulatory bodies, and environmental organizations can foster a collaborative approach to risk management (Nandan Prasad, 2024). Stakeholder engagement not only enhances transparency but also builds trust and facilitates the identification of potential risks that may not be immediately apparent to engineers.

Integration of Plumbing and Reticulation Systems with Smart Technologies

As urban populations increase and climate change exacerbates water scarcity, the limitations of traditional systems become increasingly apparent. The integration of smart technologies such as the Internet of Things (IoT), artificial intelligence (AI), and advanced data analytics offers a promising avenue for addressing these challenges. The solutions for the integrating these technologies are as follows:

i. Enhancing Efficiency through Real-Time Monitoring: One of the primary advantages of integrating smart technologies into plumbing systems is the ability to implement real-time monitoring. Smart sensors can be deployed throughout the reticulation network to collect data on water flow, pressure, and quality. This data can be analyzed using AI algorithms to identify inefficiencies, such as leaks or blockages, in real time. The implementation of this technology not only reduces water wastage but also minimizes the costs associated with emergency repairs and system downtime (Romano & Kapelan, 2014). Therefore, investing in smart monitoring systems is a critical solution for enhancing the efficiency of plumbing and reticulation systems.

ii. Predictive Maintenance and Asset Management: Another significant benefit of integrating smart technologies is the potential for predictive maintenance. Traditional maintenance practices often rely on scheduled inspections, which can lead to unnecessary expenditures and system failures. By utilizing data analytics and machine learning, engineers can predict when components of the plumbing system are likely to fail and schedule maintenance accordingly. This proactive approach not only extends the lifespan of infrastructure but also ensures that resources are allocated efficiently (Achouch et al., 2022). Consequently, the adoption of predictive maintenance technologies is a vital solution for modernizing plumbing and reticulation systems.

iii. Water Quality Management: The integration of smart technologies also enhances water quality management. IoT devices can continuously monitor water quality parameters, such as pH levels, turbidity, and microbial contamination. This real-time data allows for immediate responses to potential health hazards, ensuring that the water supply remains safe for consumption. Furthermore, the use of blockchain technology can enhance transparency in water quality reporting, fostering public trust and accountability (Park et al., 2020; Jan et al., 2021). Therefore, the implementation of smart water quality management systems is essential for safeguarding public health and ensuring compliance with regulatory standards.

iv. Consumer Engagement and Behavioural Change: Smart technologies can also play a pivotal role in engaging consumers and promoting water conservation behaviours. Smart meters provide consumers with real-time feedback on their water usage, empowering them to make informed decisions about their consumption patterns (Zainurin et al., 2022;Silva et al., 2022). Educational applications can further enhance this engagement by providing tips and insights on water-saving practices. By fostering a culture of conservation, the integration of smart technologies can lead to significant reductions in water demand, thereby alleviating pressure on existing plumbing and reticulation systems.

Standardization in Plumbing and Reticulation Systems

The complexities of plumbing and reticulation systems necessitate a robust framework of standards to govern their design, installation, and maintenance. The argument is structured around three pivotal points: the enhancement of public health and safety, the promotion of environmental sustainability, and the facilitation of economic efficiency which are detailed as follows:

i. Public Health and Safety: The foremost argument for the standardization of plumbing systems is the imperative of public health and safety. Standards such as those set forth by the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) provide guidelines that mitigate risks associated with waterborne diseases and contamination. For instance, the Uniform Plumbing Code (UPC) outlines specifications for materials, installation practices, and system designs that prevent cross-contamination and ensure the safe delivery of potable water (Binz

et al., 2018; Bailey et al., 2021). Without these standards, the likelihood of system failures increases, potentially resulting in catastrophic public health crises. The Flint water crisis serves as a poignant reminder of the consequences of neglecting standardized practices, where the absence of rigorous standards led to widespread lead contamination and public outcry.

ii. Environmental Sustainability: In addition to safeguarding public health, standardized plumbing and reticulation systems play a crucial role in promoting environmental sustainability. Standards such as the Water Efficiency Labelling and Standards (WELS) scheme encourage the adoption of water-efficient fixtures and fittings, thereby reducing water consumption and minimizing the strain on natural resources (Fane et al., 2020;Fane et al., 2024). The implementation of standardized practices in storm-water management, as outlined in the Australian Rainfall and Runoff guidelines, further exemplifies how engineering standards can mitigate the impacts of urbanization on local ecosystems. By fostering a culture of sustainability through standardization, engineers can contribute to the preservation of water resources and the protection of biodiversity.

iii. Economic Efficiency: The economic implications of standardized plumbing and reticulation systems are profound. Standardization facilitates interoperability among components, reducing costs associated with design, procurement, and installation. Furthermore, adherence to established standards can lead to decreased maintenance costs and extended system lifespan. For instance, the adoption of standardized pipe sizes and materials can streamline the supply chain, resulting in lower prices for consumers and increased competition among manufacturers (Rane, 2023). Conversely, the lack of standardization can lead to inefficiencies, as disparate systems may require specialized components and expertise, ultimately driving up costs for both consumers and service providers.

Standardized Plumbing Codes

Plumbing is a fundamental aspect of modern infrastructure, directly impacting public health, environmental sustainability, and economic development. As globalization continues to shape the construction and engineering sectors, the need for standardized plumbing codes has become increasingly apparent. To ensure a sustainable plumbing and reticulation systems in conventional infrastructures, the following plumbing codes are necessary:

i. International Plumbing Code (IPC): The IPC, developed by the International Code Council (ICC), is designed to provide a comprehensive set of regulations for plumbing systems. It emphasizes water conservation, health and safety, and the efficient use of resources. Key features of the IPC include provisions for water supply systems, drainage systems, and venting requirements. The IPC also incorporates advanced technologies and sustainable practices, such as rainwater harvesting and grey water recycling, thereby promoting environmental stewardship (Johnson & Kalkowski, 2017; Saravanos et al., 2024).

ii. Uniform Plumbing Code (UPC): The UPC, established by the International Association of Plumbing and Mechanical Officials (IAPMO), is widely adopted in the United States. It focuses on ensuring public health and safety through rigorous standards for plumbing installations. The UPC is notable for its detailed requirements regarding materials, fixtures, and installation practices(Devine et al., 2024). Furthermore, it emphasizes the importance of backflow prevention and cross-connection control, which are critical for safeguarding potable water supplies.

iii. National Plumbing Code of Canada (NPC): The NPC serves as a model code for plumbing systems in Canada, providing guidelines that reflect the unique climatic and geographical conditions of the country. It addresses issues such as frost protection, drainage, and venting, while also promoting water conservation and energy efficiency (Abdeen et al., 2020). The NPC is particularly significant in its approach to harmonizing plumbing practices across provinces and territories, thereby facilitating interprovincial trade and collaboration.

iv. National Standard Plumbing Code (NSPC): This code is primarily used in the north-eastern United States and is developed by the National Association of Plumbing-Heating-Cooling Contractors (NAPHCC). The NSPC emphasizes practical installation methods and the use of innovative technologies (Armstrong et al., 2017).

v. British Standards (BS): In the United Kingdom, plumbing practices are governed by British Standards, which provide specifications for materials, design, and installation. The BS 6700, for instance, outlines the design of plumbing systems for buildings (Vagtholm et al., 2023).
vi. European Norms (EN): In Europe, plumbing codes are often governed by European Norms, which establish standards for plumbing materials and practices across member states. These norms aim to facilitate trade and ensure safety across borders (Sheridan et al., 2003).

Components for Plumbing and Reticulation Systems

The complexity of plumbing and reticulation systems is often underestimated, yet these systems are foundational to public health and urban functionality. A thorough understanding of the components involved is essential for professionals in the field, as it informs design, maintenance, and innovation. The various components of plumbing and reticulation systems are highlighted as follows:

i. Pipes and Fittings: The backbone of any plumbing system, pipes are responsible for transporting water and wastewater. Common materials include PVC, copper, and PEX, each with distinct advantages and limitations. Fittings, such as elbows, tees, and couplings, facilitate the connection and direction of flow within the system as shown in Figure 1 (Asadi et al., 2016).

Figure 1: Different types of pipes and fittings used in plumbing (Petty & Knepper, 2021)

ii. Valves: Valves control the flow and pressure within plumbing systems. Types include gate valves, ball valves, and check valves, each serving specific functions (see Figure 2). The strategic placement of valves is crucial for maintenance and emergency situations, underscoring the need for careful planning in system design (Paul, 1954).

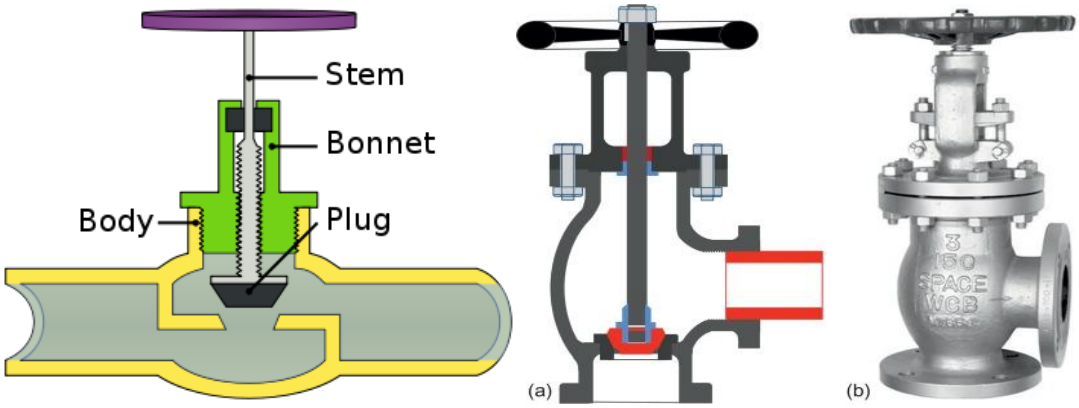

Figure 2: Types of Valves in plumbing system (Creswell & Creswell, 1993)

iii. Fixtures: Fixtures, including sinks, toilets, and showers, are the endpoints of plumbing systems where water is utilized (see Figure 3). The design and efficiency of fixtures have evolved significantly, with modern innovations focusing on water conservation and user comfort.

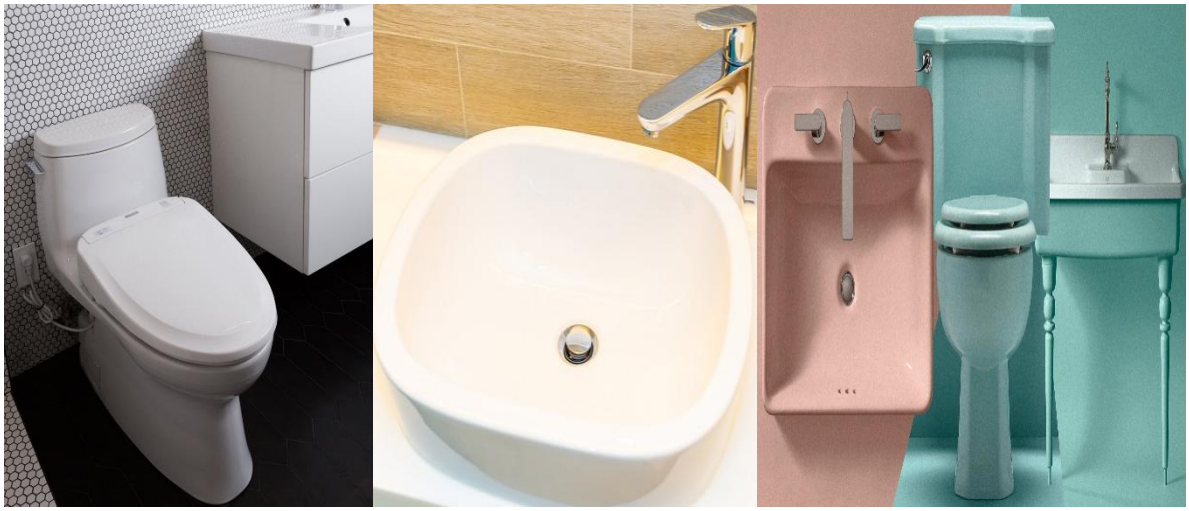

Figure 3: Types of fixtures in plumbing system (Murphy, 2016)

iv. Pumps: In systems where gravity alone cannot facilitate water movement, pumps are essential. They are particularly important in high-rise buildings and in situations where water must be moved over long distances. The selection of appropriate pumps is critical for energy efficiency and system reliability (Müller et al., 2021).

v. Water Heaters: These components are vital for providing hot water for domestic use (see Figure 4). Traditional tank heaters and modern tank less systems each have their advantages, and the choice between them can significantly impact energy consumption and user satisfaction (Ibrahim et al., 2014).

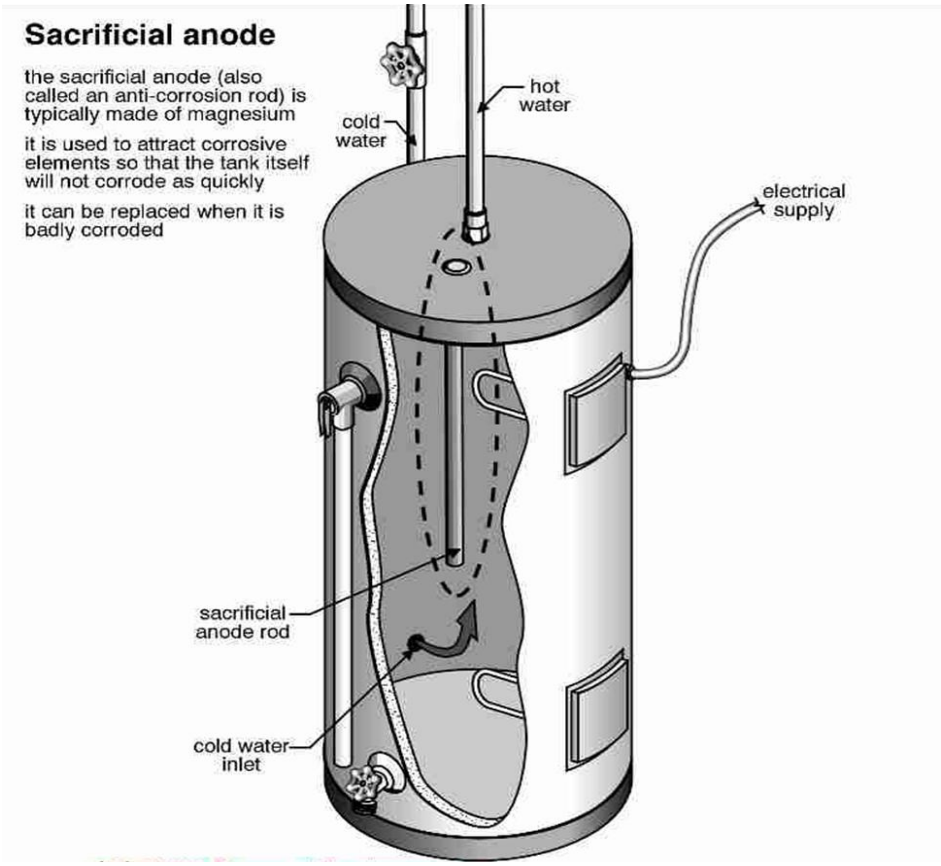

Figure 4: An electric water heater in a plumbing system (Buse et al., 2024)

vi. Backflow Prevention Devices: To protect potable water supplies from contamination, backflow prevention devices are essential. These components prevent the reverse flow of water, ensuring that drinking water remains uncontaminated by wastewater or other pollutants (see Figure 5).

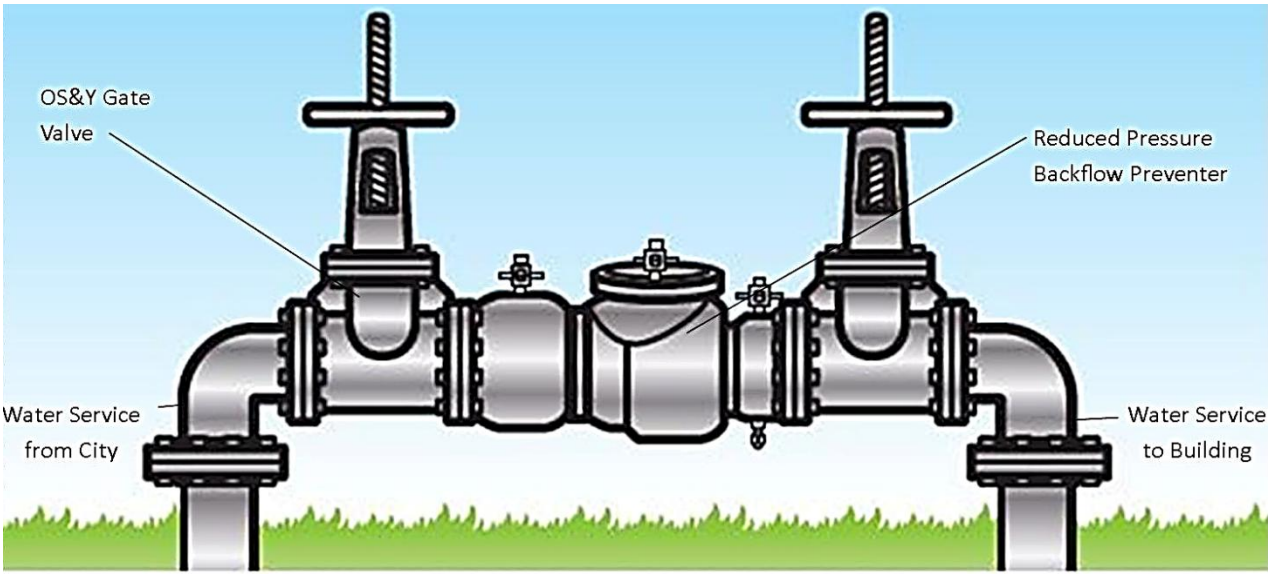

Figure 5: Backflow Prevention Devices (Walski, 1996)

vii. Drainage Systems: Effective drainage systems are crucial for the removal of wastewater. Components include drain pipes, traps, and cleanouts, each playing a role in preventing clogs and ensuring proper flow. The design of drainage systems must consider local regulations and environmental impacts (Blom, 2015).

viii. Sewage Systems: These systems are responsible for the safe disposal of human waste. Components include sewer pipes, manholes, and lift stations (as shown in Figure 6). The integration of sewage systems with municipal infrastructure is vital for public health and environmental protection (Mokhtar et al., 2022).

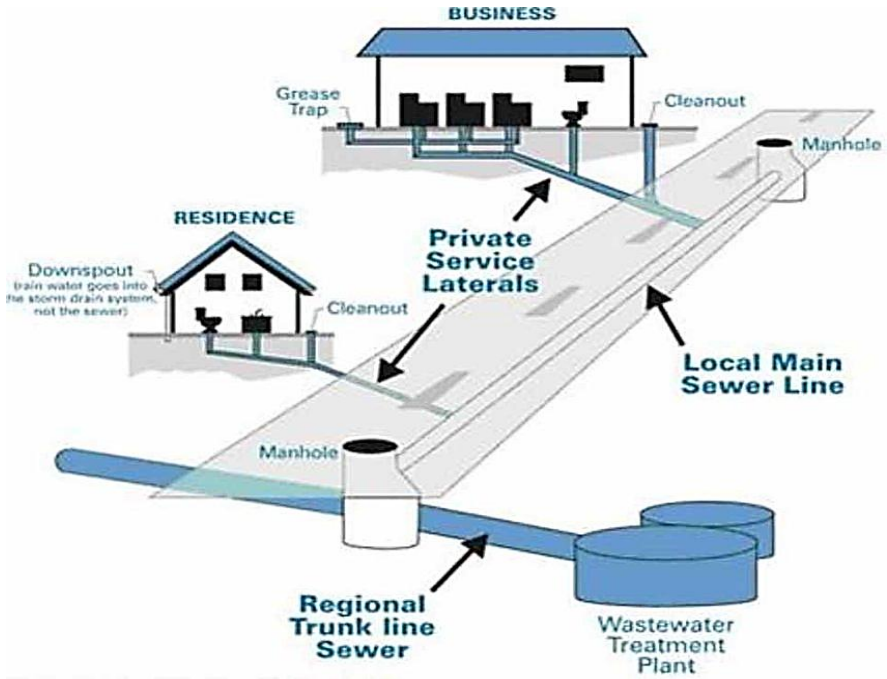

Figure 6: Sewerage Systems (Merchán-Sanmartín et al., 2022)

ix. Water Quality Treatment Systems: As concerns about water quality increase, treatment systems such as filtration and disinfection units are becoming more prevalent (see Figure 7). These components are essential for ensuring that water meets health standards before reaching consumers (Gitis & Hankins, 2018).

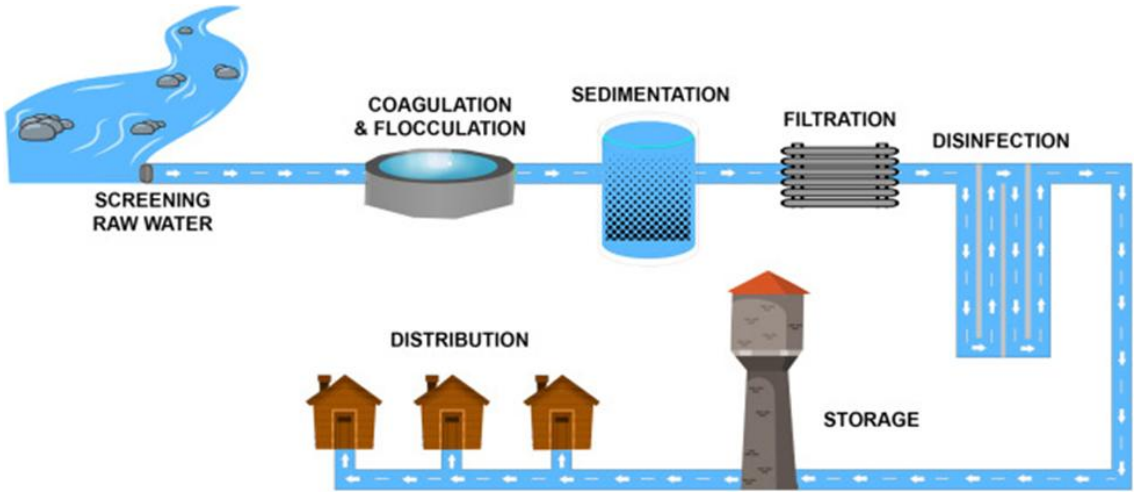

Figure 7:Water Quality Treatment Systems (Garcia et al., 2013)

Types of Plumbing and Reticulation Systems

Plumbing and reticulation systems serve as the backbone of modern sanitation and water supply networks. The evolution of these systems has been influenced by technological advancements, environmental considerations, and public health imperatives, leading to the following types of plumbing and reticulation systems:

i. Traditional Gravity-Flow Systems: Traditional gravity-flow systems rely on the natural force of gravity to transport water and waste. These systems are characterized by their simplicity and low operational costs (Karmakar et al., 2022). However, they are limited by topographical constraints and may not be suitable for all geographical locations. The argument for gravity-flow systems lies in their low energy consumption and minimal maintenance requirements, making them a viable option for rural areas.

ii. Pressurized Systems: Pressurized plumbing systems utilize pumps to distribute water throughout a network. These systems are particularly advantageous in high-rise buildings and urban environments where gravity-flow systems may be ineffective. The ability to maintain consistent water pressure is a significant benefit; however, the reliance on mechanical components introduces potential points of failure and increased energy consumption (Koike, 2014). While pressurized systems offer enhanced functionality, their environmental impact must be carefully considered.

iii. Dual-Pipe Systems: Dual-pipe systems separate potable water from non-potable water, allowing for the reuse of grey water in irrigation and other non-potable applications. This system promotes water conservation and sustainability, addressing the growing concern of water scarcity. However, the initial installation costs and the complexity of maintenance pose challenges. The argument for dual-pipe systems is strengthened by the increasing need for sustainable practices in urban planning.

iv. Rainwater Harvesting Systems: Rainwater harvesting systems collect and store rainwater for various uses, including irrigation and toilet flushing. These systems are particularly relevant in regions facing water shortages. The argument for rainwater harvesting is compelling, as it reduces reliance on municipal water supplies and mitigates storm-water runoff (Fernandes et al., 2015). However, the effectiveness of these systems is contingent upon local climate conditions and regulatory frameworks.

v. Sustainable Plumbing Systems: Sustainable plumbing systems incorporate eco-friendly materials and technologies, such as low-flow fixtures and solar water heaters. These systems aim to minimize environmental impact while maximizing efficiency. The argument for sustainable plumbing is underscored by the urgent need to address climate change and resource depletion (Abdel Hay bin Omera, 2024). However, the higher upfront costs and the need for consumer education present barriers to widespread adoption.

Applications of Plumbing and Reticulation Systems

While the primary function of plumbing and reticulation systems is to ensure the safe and efficient delivery of potable water and the disposal of wastewater, their applications extend far beyond these basic utilities, towards the following areas:

i. Public Health and Sanitation: One of the most critical applications of plumbing and reticulation systems is their role in public health and sanitation. Access to clean water and adequate sanitation facilities is a fundamental human right and a cornerstone of public health. The World Health Organization has consistently highlighted the correlation between improved water supply and sanitation systems and the reduction of waterborne diseases (Roaf et al., 2018). Plumbing systems facilitate the safe transport of water to households, schools, and healthcare facilities, thereby reducing the incidence of diseases such as cholera, dysentery, and typhoid fever. Furthermore, effective wastewater management through reticulation systems prevents the contamination of water sources, safeguarding community health (Macfarlane 2003; Brown et al., 2013). Thus, the argument stands that the advancement and maintenance of plumbing systems are essential for public health initiatives globally.

ii. Environmental Sustainability: In an era marked by climate change and environmental degradation, plumbing and reticulation systems are increasingly recognized for their role in promoting sustainability. Modern plumbing technologies, such as grey water recycling and rainwater harvesting systems, exemplify how plumbing can contribute to resource conservation (Landman et al., 2024). These systems not only reduce the demand for freshwater but also mitigate the impact of storm-water runoff, which can lead to flooding and water pollution. Moreover, the integration of smart technologies in plumbing systems allows for real-time monitoring of water usage, enabling more efficient management of resources(Palermo et al., 2022). This argument posits that plumbing and reticulation systems are not merely infrastructural necessities but are also pivotal in advancing environmental sustainability goals.

iii. Economic Development: The economic implications of plumbing and reticulation systems are profound. Access to reliable water supply and sanitation is a prerequisite for economic development, particularly in developing regions (Lee & Schwab, 2005). Industries such as agriculture, manufacturing, and tourism rely heavily on efficient plumbing systems to operate effectively. For instance, agricultural productivity is directly linked to irrigation systems that depend on well-designed plumbing networks. Furthermore, the construction and maintenance of plumbing infrastructure create jobs and stimulate local economies (Noll et al., 2000). The argument here is that investment in plumbing and reticulation systems is not only a matter of public health but also a strategic economic initiative that can drive growth and development.

iv. Technological Advancement: The evolution of plumbing and reticulation systems has been significantly influenced by technological advancements. Innovations such as smart meters, automated leak detection systems, and advanced materials have transformed traditional plumbing practices (Wu et al., 2019). These technologies enhance the efficiency and reliability of water distribution and wastewater management, thereby improving overall system performance. The argument posits that the continuous integration of technology into plumbing systems is essential for addressing the challenges posed by urbanization, population growth, and climate change. As such, plumbing and reticulation systems serve as a platform for technological innovation, fostering advancements that can lead to more resilient and sustainable urban environments (Lahmar, 2025).

Conclusion

The technical survey of mechanical plumbing and reticulation systems highlights several key arguments that underscore their indispensable role in contemporary engineering practices. Firstly, the evolution of plumbing technologies, driven by innovations in materials and design methodologies, has significantly enhanced system efficiency and durability. The transition from traditional materials to advanced composites and smart technologies has not only improved performance but also reduced

maintenance costs and environmental impact. This shift is particularly relevant in the context of increasing regulatory pressures aimed at promoting sustainability and resource conservation. Secondly, the integration of automation and smart monitoring systems within plumbing and reticulation frameworks represents a transformative advancement that warrants further exploration. These technologies facilitate real-time data collection and analysis, enabling proactive maintenance and optimization of system performance. The argument here is that the adoption of such technologies is not merely a trend but a necessity in the face of growing urbanization and the corresponding demand for efficient resource management.

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THE AGEING PHENOMENON AND THE POSSIBILITY OF LEARNING FROM THIS TYPE OF ACCIDENTS

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ABSTRACT

The ageing phenomenon of equipment, organisations and information is still a problem for safety of our society and represents a significant risk factor in the prevention of major accidents.

This paper tries to verify how the ageing phenomenon is a significant factor in the root causes of major accidents in the Czech Republic.

The aim of this article is to describe and analyse the approach to learning from major accidents using the example of accidents in the Czech Republic caused by the phenomenon of ageing in individual companies that occurred and were reported in the period 2000 - 2024.

Keywords: accidents, ageing, lessons learned

INTRODUCTION

This document focuses on the reported accidents in the Czech Republic caused by the ageing phenomenon in the companies in the period 2000 - 2024.

For a closer look into types of ageing and risk factors, we can use the breakdown according to (OECD 2017)

- The engagement of third party personnel to work at the facility with insufficient knowledge of the facility's history, insufficient information about equipment
- Missing or incomplete documentation on the design, operation and history of the facility
- Availability of information (transition from paper to electronic systems or other changes)
- Loss of knowledge about the design and operation of the plant: (many or all of the original design and operating team will have moved on or retired)
- Inspection plans that do not sufficiently provide for the monitoring of critical pieces of equipment particularly subject to ageing
- The absence of risk assessments, before changing the way in which a piece of equipment is to be used

The phenomenon of ageing in the industry has received attention for a long time. A considerable number of studies in recent years have dealt with the ageing of employees and the necessary organizational steps in this area (Aisa et al. 2023, Ranasinghe et al. 2023) , as well as the aging of facilities or companies (Fischer et al. 2024, Bravo et al. 2024, Zhang et al. 2025). Different countries have taken different approaches to the safe ageing of companies, which may even be beyond their original life expectancy (Kotek et al. 2022, Bragatto et al. 2020). However, it is not the aim of this paper to analyse the many methods and approaches available to this phenomenon or its evolution. Due to the highest relative number of accidents in the Czech Republic among the selected EU countries (Kotek et al. 2024), it is necessary to try to look for the context of their occurrence in the Czech Republic. I can also address the question of whether and how the ageing phenomenon is a statistically significant problem in the Czech Republic in the period under study.

Because of the specific and brief form of the data available from the publicly available database of major accidents eMars [6] and from the reports or final reports on major accidents in the Czech Republic, it is very complicated to find and divide the accidents to those that were caused by degradation of the used material, due to ageing of employees (longer reaction time, worse visual angle, hearing, ability to work at heights, etc. ..) the departure of the original founding employees (who knew the company to the last screw) to another company, retirement, or obsolescence of the production processes used in relation to the used equipment, the impact of ageing IT equipment, incompatibility of older software, etc.

Between the lines of the individual event records, it is sometimes possible to read the context of the evolution of security legislation since the date of introduction of the equipment in use and the need for revisions and modifications to the operation. In addition, alongside the development of computer technology, paper documentation is logically being replaced by electronic documentation, etc. However, relying on computer technology brings new risks, for example, the possible total loss of the necessary documentation or its current form.

METHODS

The data were drawn from the publicly available database eMARS - Major Accident Reporting System and from accident reports in the Czech Republic.

By sorting the not always complete available data according to the ISAAC methodology, ESIA criteria and other additional factors, even from such limited sources, an overview of 35 accidents with undeniable ageing effects can be obtained from investigated accidents in the Czech Republic.

According to predetermined indexes and monitored values such as, for example, accident location, type of work activity, work operation, manufacturing means, accident process, amount of hazardous chemical substances, human consequences, environmental consequences, economic losses, etc., the data of accidents in the Czech Republic could be further structured and processed.

Selected accidents can therefore be further investigated and classified more easily.

RESULTS FROM AGEING ACCIDENTS IN THE CZECH REPUBLIC

Accidents according to the type of aging

In the Czech Republic, a significant number of entities have been in operation for several decades. In conjunction with the often aggressive environment of the used substances, vibrations or the occurrence of non-standard situations, problems with the degradation of the properties of the used materials occur most frequently in accidents. Various leaks at connections, valves, or problems due to wear and tear and lower efficiency or performance of the equipment arise. In more than half of the recorded cases (20 times), this type of ageing was involved in the occurrence of the accident. The next two most significant types of ageing (in 6 occurrences each) are corrosion and complete destruction of equipment (rupture, loss of integrity, etc.).

Unwillingness or inability to inspect the condition of equipment (or underestimation of the condition found) and possible lack of available funds to replace identified damaged components (or to provide for planned replacement) lead to a significant proportion of all recorded accidents.

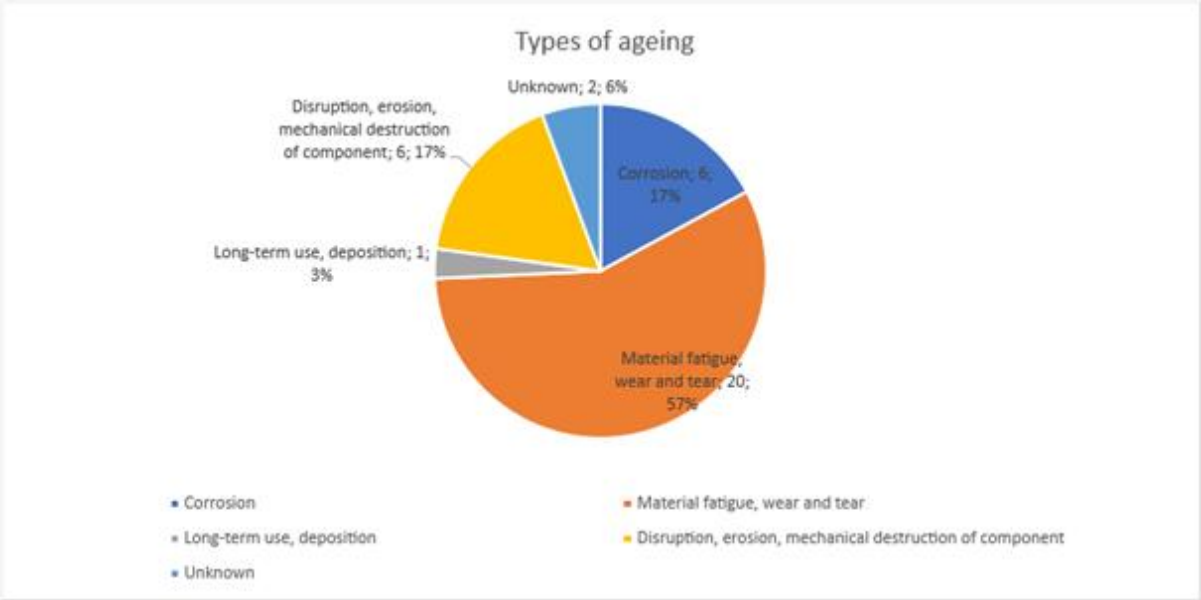

Figure 1: Types of ageing

According to the consequences of accidents caused by ageing

The most frequent consequence in the Czech Republic is the release of a hazardous substance (24 cases) outside the plant environment. In the context of barriers created within the company, these are usually leaks into catch pits, etc. In a few cases, there are also spills outside the company premises, either into the surrounding air or water. The company's infrastructure and old sewage connections or pipes from previous years, which are no longer in use and often not registered, often in a state of disrepair, have several times played a role here.

The second most frequent consequence (6 occurrences) is the occurrence of high equipment damage or losses due to stopped production. Due to the frequent partial communication of the accident, a significant number of events (in general, and outside of the observed section dedicated to ageing) cannot be classified at all. Deaths and human casualties are not as frequent in the period under review and there is a qualitative shift in the equipment and measures set up for the types of operation. In the monitoring of ageing-related accidents, there are only two accidents involving the death of a staff member.

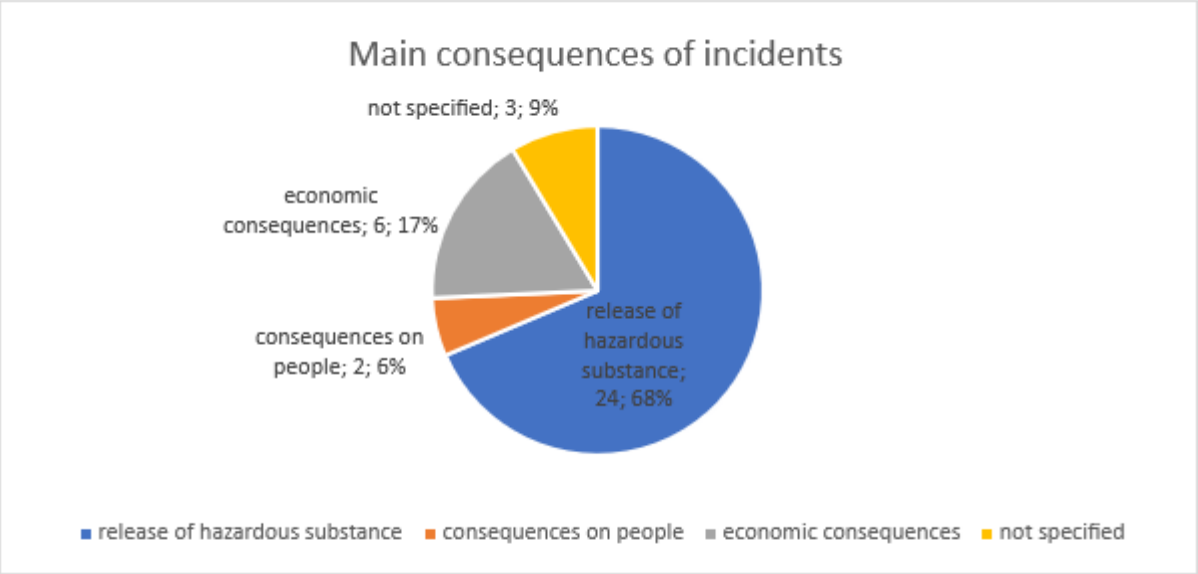

Figure 2: Main consequences of accidents

Accidents according to the type of device

The most vulnerable parts are the various types of pipes and their flanges and valves. Together with various tanks and reservoirs, they account for two-thirds of all recorded accidents related to ageing. The remaining third of accidents are associated with other imaginable equipment without an increased frequency of the different types represented.

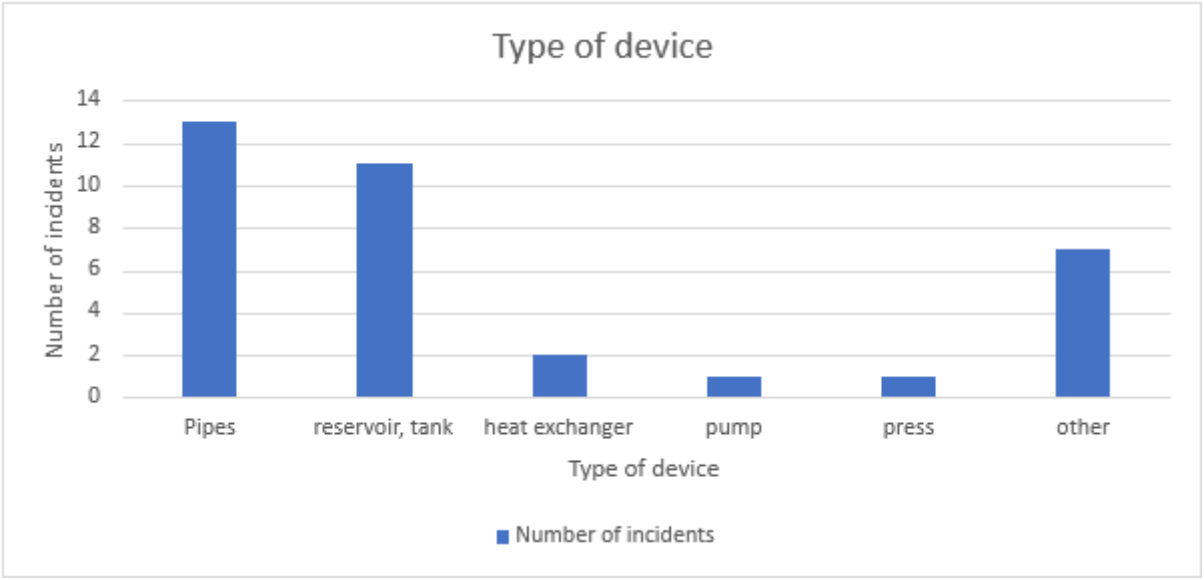

Figure 3 Type of equipment associated with ageing accidents

Typical examples of accidents

8.2.2016 eMARS Accident ID 001073

At night., the steel casing was ruptured/destroyed in the lower part of wet scrubber, resulting in a circular hole with a diameter of approximately 80 cm. As a result of this event, approx. 30 000 m3 of furnace gas was released into the air and 8 employees of the plant were intoxicated.

Wet scrubber was manufactured according to the drawing documentation dated 25 March 1958. It is a cylindrical vessel, of self-supporting steel construction, 33 300 mm in height and 5 500 mm in diameter up to 23 400 mm and 7000 mm in diameter thereafter. The wet scrubber is made of 12 mm thick steel plate. It is equipped with water sprayers and a water cap at the bottom. It is an outdoor version. The last overhaul of this wet scrubber took place at the end of 2008. The explosion occurred downstream of the blast furnace gas inlet pipe into the wet scrubber at the 7000 mm level at the bottom of the wet scrubber. At the time of the accident, blast furnace was in normal production and wet scrubber was cleaning the produced blast furnace gas.

The destruction of the steel casing of wet scrubber was caused by severe local degradation of the steel casing on the inside of the scrubber, reducing the thickness of the steel casing from the original 12 mm to 1,5 mm, at an operating blast furnace gas pressure of 125 kPa.

Accident 24.10.2013:

The reason for the accident was a failure of the integrity of the plastic holding tank of a steam cleaning plant for railway tankers. The inspection revealed a bulging of the plastic tank wall, probably caused by the collapse of the concrete tank containment due to increased rail tanker traffic. A pipe was discovered in the original concrete tank, through which the pollutants had entered the rain drainage system and consequently the nearest brook. This was a mixture of aviation kerosene, diesel fuel and water, which is produced during the steam cleaning of railway tankers after these products.

The last cleaning of the rail tankers was carried out on 23 October 2013. The residue after cleaning was discharged continuously into the holding tank. The entire volume of the tank was pumped to the chemical treatment plant for cleaning after the cleaning was completed. The leakage of pollutants was detected on 24 October 2013 at approximately 16:30. Immediately after the leak was detected, the sewer was plugged and a barrier wall was erected on the brook and collection of pollutants started. A survey of the extent of the contamination on brook was then carried out. It was found that the pollutants had reached 400m beyond the site boundary. Two more barrier walls were erected on the stream by the intervening firefighters. The most distant contamination of this brook water was detected within 5km on 25.10.2013 at 0,15 mg/l C10 - C40. Further sampling in this profile in the following days did not show the presence of contaminants. No damage occurred due to the small amount of pollutants leaked, the early detection of the leak and the immediate action taken by the warehouse staff.

DISCUSSION

I compared the data of accidents in the Czech Republic with accidents from analysis of the Major Accident Bureau of the Joint Research Centre of the European Commission, Organisation for Economic Cooperation and Development, Working Group on Chemical Accidents (OECD, 2017). They had processed data from: Australia, France, Germany, Italy, Sweden, the Netherlands, and the United Kingdom.

In OECD analysis was the most commonly cited ageing phenomena corrosion, in 45 % of the cases. The second most common factor was due to either fatigue/wear and vibration or the combination of these, almost 20% of all reported accidents. The same two most frequently represented factors of ageing can also be found in accidents in the Czech Republic, but their representation is reversed. Corrosion is reported in 17%, fatigue, wear and tear in 57%. But in both datasets, these two types of ageing are making the most significant part.

Main consequences of the reported accidents are similar too. Dangerous substances release is the most problematic phenomena in both analysis (68% in CZ analysis, 50% in OECD analysis). The remaining part is divided among many other consequences with a small percentage.

When we mention types of equipment affected by ageing phenomena, the situation is almost the same. Pipes and various tanks and reservoirs make up the largest share of equipment. (Pipes 37%, Tanks 31% in CZ analysis, pipes 45%, tanks 33% in OECD analysis) Despite the fact, that for this classification in OECD analysis was obtained data from only half of all surveyed accidents.

I can conclude, that the consequences of ageing are manifested almost in the same way across selected countries.

The initial idea after presenting this data is whether inspection intervals or scheduled maintenance for the apparently most critical pieces of plant equipment (pipelines, storage tanks) tend to be set correctly and how they are carried out.

On the basis of the collected data, another question arises as to how the companies have actually developed their own safety policy in general, because much has been presented in the past about the problematic nature of these types of equipment.

Although a significant amount of information related to ageing cannot be found from the final reports, the frequency of repetitions for selected indicators points to their importance in the development of new safety policies or their revision and to the lack of a learning process from previous events.

The very limited information on the condition or update of security policies as a result of individual events indicates the perception settings of individual enterprises in this area.

The setting of a fixed lifetime for some equipment was not mentioned in a single document. However, the replacement of some equipment once the enterprise has exceeded an acceptable risk (which is clearly not often set) is often a minor expense compared to the potential consequences. In comparison, from the results of multiple studies, the estimated global annual spending on corrosion control alone was $2.5 trillion, which is equivalent to 3.4% of the global GDP (2013) (Impact.NACE 2025). These costs typically do not include individual safety or environmental consequences.

We see the following data in terms of the percentage of ageing events to all emergencies in a given year.

From this data we calculate the trend of the total number of accidents and events associated with ageing, using linear regression analysis.

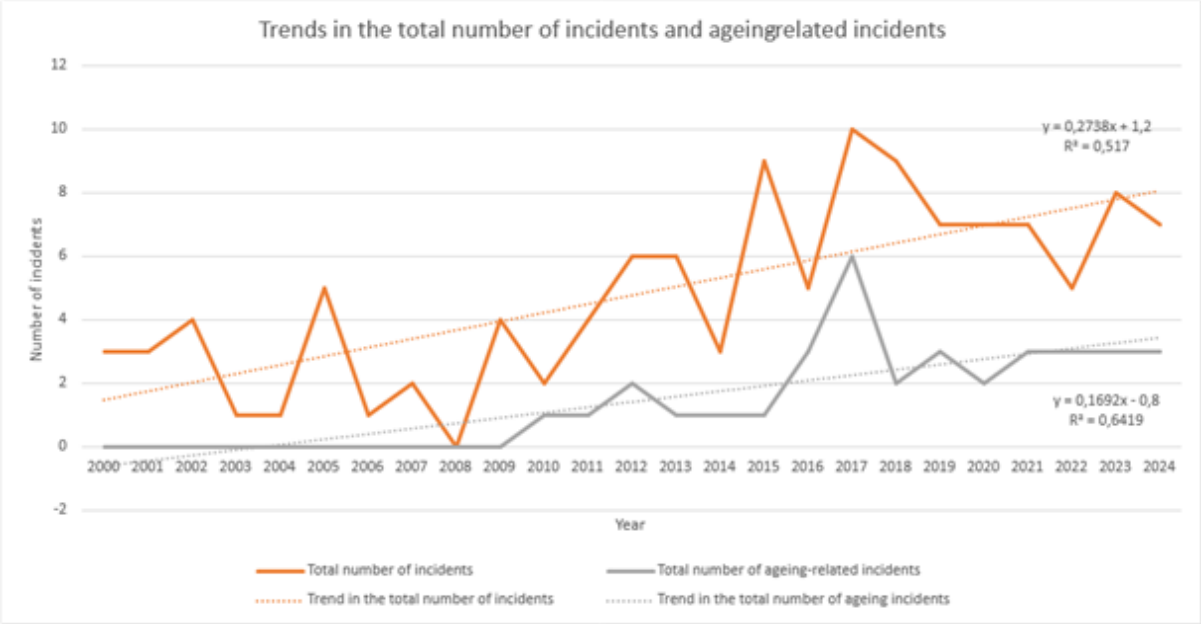

Figure 5: Trends in the total number of emergencies and ageing events

Trends in the total number of reported accidents and the selection of accidents due to ageing show an increase over time using linear regression analysis. The data for all reported accidents show a moderate direct linear relationship (R=0.52) and the correlation coefficient is statistically significant at the α=5% significance level. Using this method, the growth in the number of accidents comes out at a rate of 0.27 for each year.

The data of all recorded ageing accidents also show a medium direct linear relationship (R=0.64) and the correlation coefficient is statistically significant at the α=5% significance level. Here the increase in the number of accidents is 0.17 for each year.

CONCLUSION

Overall, it can be concluded that the number of accidents as well as the number of ageing accidents in the Czech Republic is slowly increasing over the years despite all made interventions. Considering the number of companies in operation and the generally lower number of newly commissioned companies, this is a clear message where to focus our attention. Both for the owners of these companies and for the inspection authorities.

From the review of the data obtained, specific priorities emerge, in particular to address ageing in pipelines and storage tanks, but also to ensure and control maintenance and diagnostics in the companies. At the level of the public administration, to carry out a higher number of inspections using the Hungarian or Italian methods.

Given the combination of the findings of the high relative number of accidents from selected countries and the evidence of a gradual increase in the number of such events, including the impact of ageing in the Czech Republic, this data will be forwarded to the supervisory authorities and relevant ministries to ensure possible corrective action.

ACKNOWLEDGEMENT

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INVESTIGATION OF NITROGEN OXIDE EMISSIONS IN A HYDROGEN/DIESEL DUAL-FUEL INTERNAL COMBUSTION ENGINE

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Abstract

Diesel engines play an important role in transportation, industrial applications and electricity generation due to their high torque capacity and long durability. However, emissions such as carbon dioxide, nitrogen oxides (NOx) and particulate matter resulting from combustion pose serious threats to the environment and human health. The importance of using diesel/hydrogen dual fuels to make diesel engine emissions cleaner is emphasized in the literature. Hydrogen offers approximately three times the energy of diesel (42.6 MJ/kg) with its mass energy density (120 MJ/kg) and is notable for not containing carbon. However, due to the high temperatures during the combustion of hydrogen, oxygen reacts with nitrogen in the air and produces a high amount of NOx. The low volumetric energy density (Hydrogen: 0.0107 MJ/L, Diesel: 34.6 MJ/L) makes it difficult to use hydrogen in internal combustion engines (ICE). In methods such as sending hydrogen from the intake port in the gas phase into the cylinder, hydrogen replaces air, which reduces combustion efficiency and negatively affects engine performance. This study aims to optimize engine performance and NOX emissions by simulating hydrogen/diesel dual fuel in a diesel-fueled ICE, which is generally used for electricity generation. Using the technical specifications of an engine previously tested with diesel and different fuels, it was modeled as one-dimensional (1D) in the AVLBOOST program and verified with experimental test results. Since the engine used in generator drive usually operates at a fixed speed of 1500 rpm, it was operated at a fixed speed of 1550 rpm in the simulation. Extremely lean mixture conditions were tested by gradually increasing the air inlet pressure from 1 bar to 4 bar. Hydrogen was proportioned as 0% (100D) and 20% (80D20H) in the total fuel energy. The aim of this study is to reduce NOx emissions obtained at 1 bar atmospheric pressure in the verified simulation with extremely lean mixture conditions while preserving power as much as possible. Simulation showed that NOx emissions were reduced with hydrogen addition and increased air pressure. Also, the loss of power was compensated by increasing the air pressure. In this simulation study, power and NOX emissions were optimized under different air inlet conditions with constant speed and 20% hydrogen energy ratio.

Keywords: Nitrous oxide, Hydrogen, Diesel, Port Injection.

Introduction

Electric generators continue to be used and produced to meet production or domestic electricity needs. Due to the abundance and ubiquity of fossil fuels such as gasoline, diesel or natural gas, internal combustion engines (ICE) are generally preferred for generators. Diesel engines are more advantageous for generators due to their fuel economy and long-term durability (Mustayen, Rasul, Wang, Negnevitsky, & Hamilton, 2022). Diesel pollutes the environment with high amounts of exhaust emissions due to end-of-combustion emissions, and it is emphasized in the literature that these pollutants are generally CO, CO2, HC, SOX, NOX and particulate matter. When complete combustion occurs, CO2 is released, and when incomplete combustion does not occur, CO, HC and particulate matter are released. Nitrogen oxide (NOX) emissions generally occur under conditions where the combustion temperature is high. Nitrogen (N2) in the air combines with oxygen (O2) at high temperatures to form NO and NO2 groups, also known as NOx emissions. When combustion reaches a temperature of 1800 K, NOX emissions begin to form, and as the temperature increases, the reaction rate increases, which causes more NOX formation (Ni et al., 2020).

Hydrogen is a colorless, odorless gas that only releases water (H2O) at the end of combustion. Since this gas does not contain carbon, it is often emphasized in the literature as a clean energy carrier and a clean fuel. Since its flammability limit has a wide range of 4%-75%, it can burn in extremely lean mixtures or in highly rich mixtures. This wide combustion range has a direct effect on temperature and heat release, allowing for emission and power control. Since its auto-ignition temperature is high, it prevents its direct use in compression ignition (CI) engines. Table 1.1 provides a comparison of hydrogen and diesel fuel (Mekonnin et al., 2025).

Table 1. Hydrogen and diesel fuel properties (Karagöz et al., 2016) (Ramsay & Dinesh, 2024)

Fuel Properties	**Hydrogen**	**Diesel**
Auto-ignition temperature (K)	858	473
İgnition Energy (mj)	0.02	0.24
Adiabatic flame temperature (K)	2390	2327
Lower Heating Value (Mj/kg)	119.93	42.5
Stoichiometric Air Fuel Ratio (Air (kg)/Fuel (kg))	34.3	14.6
Flame Propagation Speed (cm/s)	270	2-8
Flammability Limit (% Volume İn Air)	4-75	0.6-7.5
Minimum Extinction Distance (mm)	0.64	2
Cetane Number		45-55
Octane Number	≥120	

Hydrogen is usually sent to the cylinder with two different strategies in ICE. In the literature, these strategies are defined as direct injection (DI) or port injection (PI). In DI, high-pressure hydrogen gas is directly sprayed into the cylinder with the help of an injector and ignition is usually provided with the help of a spark plug. The biggest disadvantage of the DI strategy is that hydrogen injectors operating at high pressures and temperatures are rare. The high and rapid corrosion effect and the need for a system that will constantly lubricate the injector make the use of this injector difficult. In PI, an injector is placed on the intake port and the air-hydrogen mixture is sent to the cylinder by spraying hydrogen. Ignition energy is provided by spraying a certain amount of diesel fuel with a spark plug or injector (Saravanan et al., 2007).

In the PI method, hydrogen gas is sent into the port as an additional fuel, but this sent fuel replaces a significant volume of air. This is one of the important disadvantages of the PI strategy. In order for combustion to occur ideally, the amount of air must be at least stoichiometric. Although the lower calorific value of hydrogen has 3 times the energy of diesel, this value is 10.7 Mj/m3 in hydrogen at 1 bar 273 K conditions, while it is approximately 35,000 Mj/m3 in diesel. It is emphasized in the literature that hydrogen has much more energy in terms of volumetric energy in diesel (Mekonnin et al., 2025). This causes the hydrogen to take up more space volumetrically and reduce the volumetric amount of combustion air (Pinto et al., 2023).

In the literature, there are fewer studies on reducing NOx emissions, while there are more studies on hydrogen-diesel dual fuel.

In their study, Gültekin and Ciniviz (2023) sent hydrogen fuel to the cylinder with the PI strategy in a single-cylinder four-stroke direct injection Common Rail diesel engine. Two different pistons were designed to be used in this engine and the combustion chamber volume and shape were changed. These pistons were named as NG1 and NG2. In addition, experiments were carried out at different rates of hydrogen energy content, fixed 1850 rpm engine speed and different engine loads in the study. The NG1 design increased the maximum in-cylinder pressure by 1.41%, reduced specific energy consumption by 2.29% and reduced particle emissions by 8.82% at 9 Nm load and 12% hydrogen energy rate. In general, increasing the hydrogen energy rate above 14% negatively affected engine performance and emissions. The reason for this was explained as the sudden combustion of hydrogen and causing early ignition. The ignition advance needs to be optimized according to operating conditions. In addition, increasing the hydrogen energy ratio up to 20% significantly increased the combustion speed and thus increased the in-cylinder temperatures. This situation caused a significant increase in NOx emissions (Gültekin & Ciniviz, 2023).

In the study conducted by Liu et al. (2022), a direct injection, single-cylinder diesel engine with a volume of 497.8 cm^3, a cylinder diameter of 83 mm and a stroke length of 92 mm, a compression ratio of 17.7 was converted into a direct hydrogen-diesel dual fuel injection engine by adding an electronically controlled hydrogen injector. The engine was operated naturally aspirated at a constant speed of 2000 rpm with hydrogen as the main fuel and diesel as the pilot fuel. The injection timing of hydrogen was decisive on NOx missions. In delayed hydrogen injections, engine efficiency and in-cylinder pressure increased, while NOx emissions exceeded the reference value of 6.4 g/kWh h. For example, in the hydrogen injection experiment conducted at 90o before reaching top dead center (bTDC) when the hydrogen energy ratio was 90%, the average effective pressure was 943 kPa and 57.5% engine efficiency was obtained. However, in this experiment, NOx emissions increased almost threefold and were determined as 23 g/kWh. At the same hydrogen energy rate, when the injection timing was 40o bTDC, the diesel efficiency was 43.9%, while this rate was 49.7% in hydrogen, and the average in-cylinder pressure was 843 kPa. NOx emissions decreased significantly and fell to 10.3 g/kWh. In this study, it was reported that injection timing had a significant effect on NOx emissions (Liu et al., 2022).

In the compilation study conducted by Wan Mahdi et al. (2025), they examined the effects of hydrogen enrichment on engine performance and emissions in diesel engines based on data obtained from different experimental studies. The engines used in these studies are generally single-cylinder, four-stroke and have a compression ratio of 17.5:1, and are mostly tested at a constant speed of 1500 rpm. Hydrogen addition, especially when applied in the range of 10–15 LPM (gas passing per minute), significantly increased the brake thermal efficiency (BTE) of the engine to 33.6% and reduced the specific fuel consumption (BSFC). However, an increase in NOx emissions was observed; in some studies, NOx emissions increased significantly with hydrogen addition compared to the diesel reference. This is due to the high combustion temperature of hydrogen. Studies have shown that both high efficiency and controlled emission levels can be achieved in hydrogen-added diesel engines with appropriate fuel-air mixture and injection strategies (Wan Mahdi et al., 2025).

Materials and Methods

In our one-dimensional simulation study, data from a single-cylinder diesel engine manufactured by Erin Motor, used in applications such as generators, marine applications, agricultural irrigation and motor pumps, were used. The technical specifications of the engine are given in Table 2.

Table 2. Diesel engine technical specifications (Erin Motor, 2025)

Number of Cylinders	1
Bore x Stroke	108 mm x 127 mm
Total Engine Capacity	1.16 L
Number of Valves Per Cylinder	4
Compression Ratio	14.6:1
DIN Maximum Power	18 kW-25 HP/ 2400 rpm
Maximum Torque	80 Nm / 1800 rpm
Maximum No Load Speed	2900 rpm
Minimum Yüksüz Devir (Rolanti Devri)	600 rpm
Specific Fuel Consumption	187 g/Hph
Fuel Pump	Bosch 1,050 Bar High Pressure Mechanical Pump

Based on the technical specifications in Table 2, the one-dimensional engine in Figure 1. was modeled in the AVL BOOST program. Here, SB (System Boundary) indicates the system boundaries, PL (Pleum) indicates the intake and exhaust ports, C1 (Cylinder) indicates the cylinder, E1 (Engine) indicates the engine, MP (Meesuring Point) indicates the measurement points, and I1 (Injector) indicates the hydrogen injector. SB1 determines the system inlet boundary where the intake air conditions are introduced to the system. From this section, the air pressure was changed separately for each experimental simulation as 1, 1.5, 2, 3, 4 bar. The mass amount calculated to have a hydrogen energy ratio of 20% was sprayed into the port from the I1 injector.

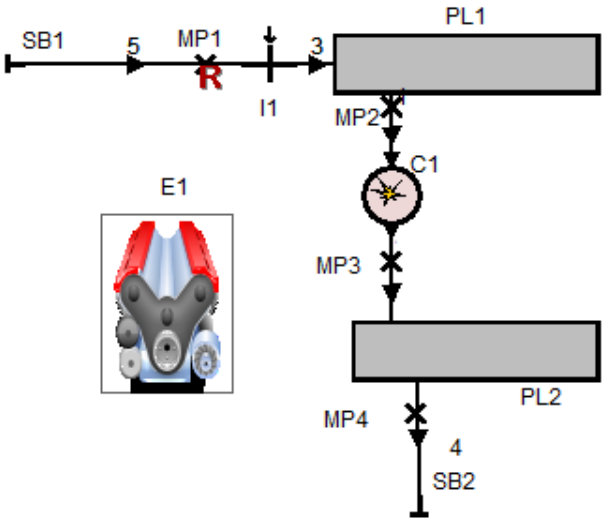

Figure 1. One-dimensional engine model

In the experimental study conducted by Karagöz, Y. with the same engine, experiments were conducted with only diesel fuel at nearly full load and as a result, the power graph in Figure 2 was

obtained. In this graph, the engine speed was measured starting from 1150 rpm and increasing by 200 rpm up to 2750 rpm. This graph constituted the validation of our study (Karagöz, 2017).

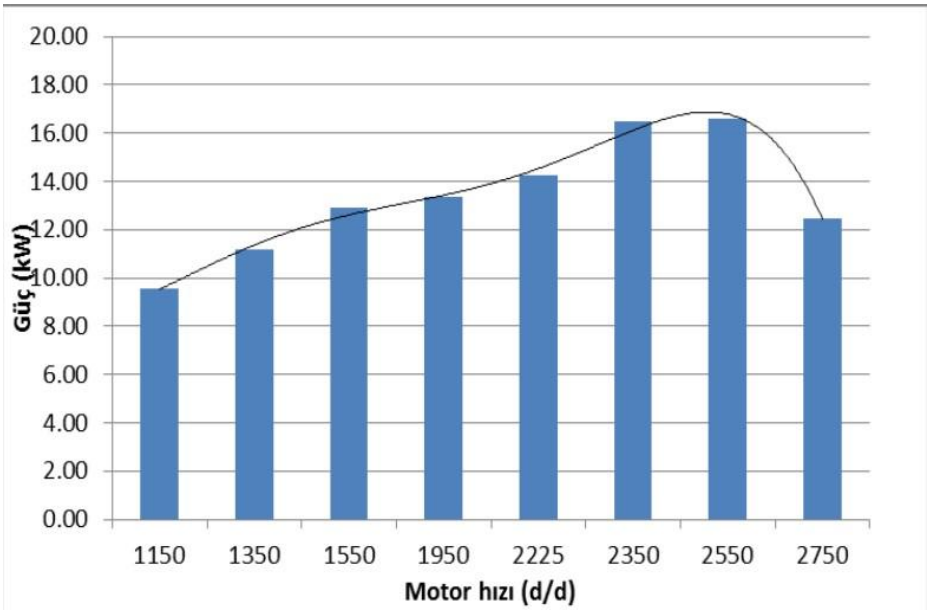

Figure 2. Power graph at certain engine speeds with only diesel fuel (Karagöz, 2017)

After creating the one-dimensional model, the engine speeds in the experimental study with 100% diesel fuel were run in the simulation. The power curve graph between the simulation tests and the experimental tests was created as in Figure 3. In this graph, the highest difference between the two curves was at 2225 rpm. Here, the power difference in the simulation compared to the experimental power is approximately 2.82%.

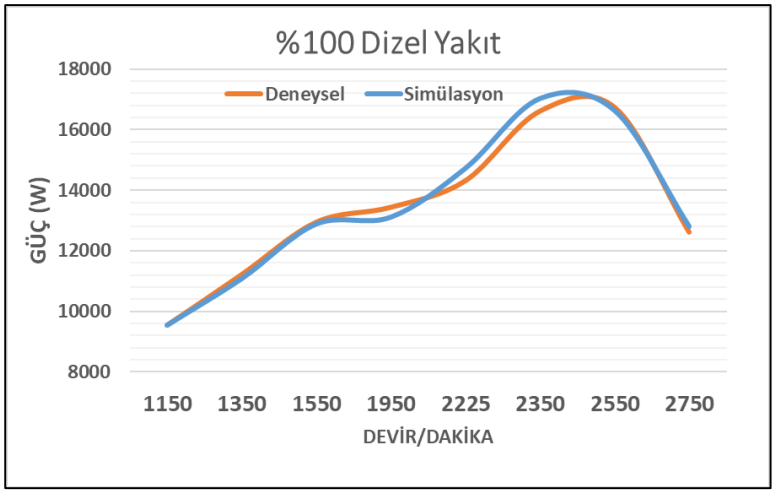

Figure 3. Comparison of experimental and simulation test results

After the simulation was verified with power, hydrogen was injected into the intake port with an injector so that 20% of the fuel energy was hydrogen without changing the amount of energy entering the cylinder. At the same time, the air inlet pressure was changed to 1, 1.5, 2, 3 and 4 bar, respectively. Different air inlet pressures were tested with both 100% diesel fuel (100D) and 20% hydrogen (80D20H).

Findings and Discussion

The change in power with different air pressures is shown in Figure 4 with a bar graph. According to this graph, as the air inlet pressure increases, power increases for both fuels. It was observed that there was a greater increase in power in diesel fuel. Since hydrogen replaces the combustion air and dilutes the amount of oxygen, a slight decrease in power is observed in all weather conditions in the use of

hydrogen compared to 100D fuel. However, as the air inlet pressure increases compared to 1 bar atmospheric pressure, an increase in power was also observed in the tests conducted with 80D20H fuel. When 80D20H fuel is used at 1.5 bar air pressure, it almost compensates for the power obtained in the test conducted with diesel fuel at atmospheric pressure (1 bar), while approximately 18% more power is obtained at 4 bar. When the inlet air is increased from atmospheric pressure to 4 bar in 100D fuel, an increase of approximately 43% is observed, while when 80D20H is used, this is approximately 18% compared to 1 bar 100D fuel. The reason for this is shown in the literature as the dilution of the amount of oxygen with the use of hydrogen.

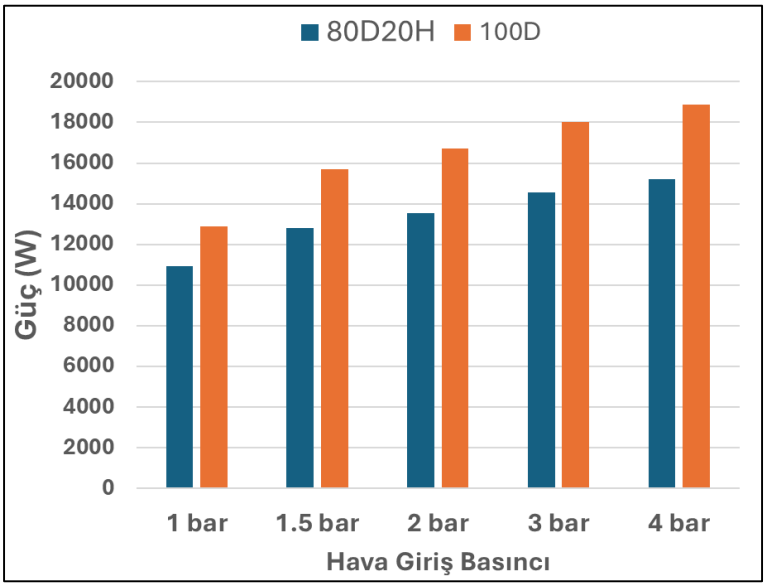

Figure 4. Power change according to changing air inlet pressures

Figure 5 shows the heat release rate depending on the crankshaft angle. In this graph, it is seen that the heat release rate decreases as the air inlet pressure increases. The increase in the mass of the air increases the amount of oxygen, which shortens the ignition delay. Since the fuel is diluted in the air, the heat release rate decreases (Heywood, 2018).

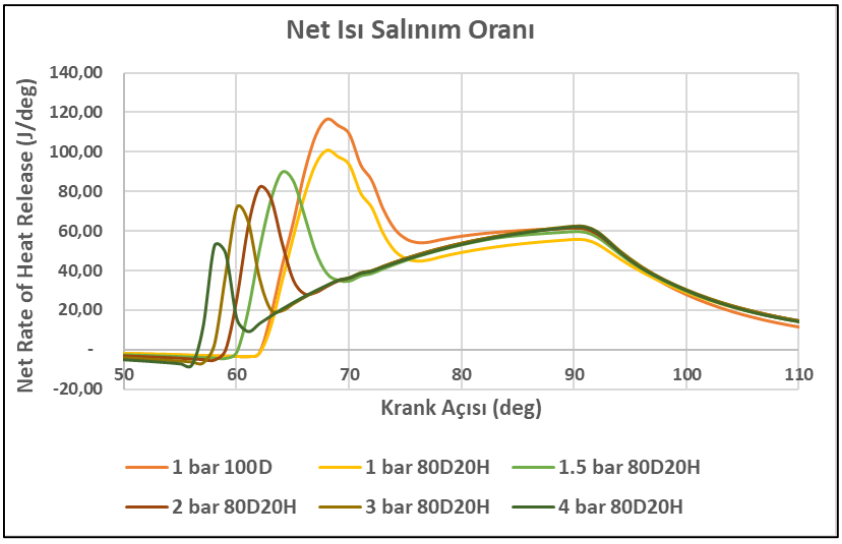

Figure 5 Heat release depending on crankshaft angle

In general, the temperature decreases with the dilution of the fuel in the cylinder. Figure 6 shows the in-cylinder temperature graph according to the crank angle. Since the addition of hydrogen reduces the amount of air, it decreases the combustion temperature. The hydrogen added at atmospheric pressure replaced the air in the cylinder, creating a rich mixture, decreasing the oxygen required for combustion and decreasing the temperature compared to 100D. With the increase in intake pressure,

the 80D20H fuel was burned by diluting in the air, and the heat produced was absorbed in the excess air and thrown out of the exhaust. The excess air caused the combustion temperature to decrease as it increased.

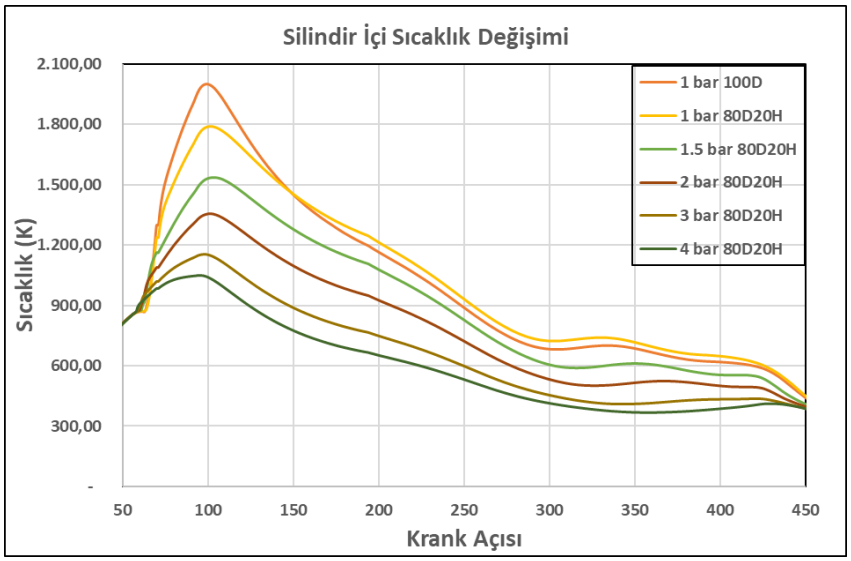

Figure 6. In-cylinder temperature graph according to crank angle

According to the Zeldovich thermal mechanism, nitrogen (N2) and oxygen (O2) molecules react at high temperatures above approximately 1800 K to form NOx emissions. This emission is much more common in ICEs, especially in diesel engines. When the temperature rises above 2400 K, the NOx formation rate begins to increase and much more NOx emissions are seen. Since the adiabatic temperatures of diesel and hydrogen are around 2300 K, they form excessive NOx during combustion. The decreases in in-cylinder heat release rate and temperature directly affected NOx emissions, and a decrease was observed in NOx emissions as the air inlet pressure increased. Figure 7. shows the change in NOx emissions with the change in air inlet pressure as a bar graph. With the use of hydrogen at 1 bar, the temperature fell below 1800 K, which reduced NOx emissions by approximately 75% compared to 100D fuel. A decrease of approximately 85% was observed in the use of 80D20H fuel at 4 bar compared to 100D fuel at 1 bar.

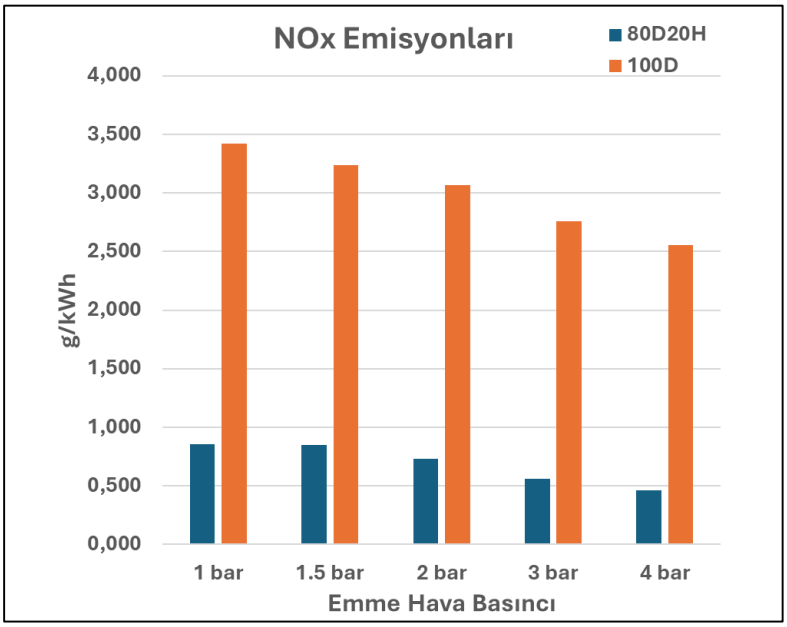

Figure 7. Change in NOx emissions with change in air inlet pressure

Conclusion and Recommendations

NOx emissions are a significant obstacle for hydrogen and diesel. Since the combustion temperature is high for both fuels, optimizing these emissions within the engine is seen as more cost-effective than exhaust after-treatment systems.

When hydrogen-diesel dual fuel is used, there is a significant decrease in power. This power can be compensated by increasing the air inlet pressure.

The fuel diluted in the air both reduces NOx emissions and provides a significant increase in power.

Since generator engines generally operate at low and fixed speeds, systems that work with exhaust gas, such as turbochargers, may not be sufficient to increase the intake pressure in these engines. Compressors such as superchargers, which provide the air flow required for the engine at 4 bar pressure, also put additional load on the engine since they work with the engine's output shaft. Although increasing the intake pressure reduces NOx emissions, it also brings additional cost depending on the compressor to be used.

In later studies, an exergy analysis can be performed to examine the energy efficiency and losses of the system by including a compressor that increases the suction pressure.

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HYDROGEN-BASED PEM FUEL CELLS AND BATTERIES IN SUSTAINABLE ENERGY SYSTEMS: A COMPARISON IN TERMS OF PERFORMANCE, ENERGY DENSITY, AND APPLICATION AREAS

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Abstract

Humanity has largely met its growing energy needs through fossil fuels and technological advancements. However, the depletion of these resources and their environmental impacts have made it necessary to seek alternative solutions. In this context, there has been a growing interest in renewable energy sources such as solar, wind, and hydrogen. As an energy carrier, hydrogen stands out as a promising alternative due to its sustainable and environmentally friendly nature. In recent years, interest in hydrogen energy has increased significantly, and research and development in this field have highlighted hydrogen's potential in energy systems. Technologies that utilize hydrogen directly have become critical components, particularly in energy conversion systems. In this process, not only energy conversion but also the efficient storage and production of energy have become increasingly important. Especially in portable systems, electric transportation, and mobile power applications, there is a growing demand for efficient and reliable energy solutions. In this regard, Proton Exchange Membrane (PEM) fuel cells and batteries have emerged as key technologies attracting attention in both academic and industrial applications. Due to their high energy efficiency, environmentally friendly operation, compact structures, and ease of integration with renewable energy systems, these two technologies have become fundamental components of sustainable energy systems. This study compares hydrogen-based Proton Exchange Membrane (PEM) fuel cells and batteries within the scope of sustainable energy systems in terms of performance, energy density, and application areas. The advantages and limitations of both energy storage and conversion technologies are analysed in detail by considering key parameters such as efficiency and environmental impact. Furthermore, the potential of hydrogen-based PEM fuel cells and batteries in various applications—including electric vehicles, portable devices, and stationary energy systems—is evaluated, and their roles in the transition to sustainable energy are presented from a comprehensive perspective.

Keywords: Energy, Hydrogen, PEM Fuel Cells, Battery.

Introduction

As one of the world’s six largest emitters of greenhouse gases, the European Union (EU) bears significant responsibility for the emergence of climate change. In this context, to combat climate change, the EU has implemented the ambitious European Green Deal—a policy aiming to achieve carbon neutrality by 2050, ensure economic growth decoupled from resource use, and leave no individual or region behind (Gramc et al., 2025). Interim targets for 2030 have been set within the framework of the EU’s 2030 Climate and Energy Framework. The key goals to be achieved by 2030 are as follows:

(i) reducing greenhouse gas emissions by at least 55% compared to 1990 levels,

(ii) increasing the share of renewable energy sources in energy production to at least 32%,

(iii) improving energy efficiency by at least 32.5%.

Achieving these targets necessitates a transition to a decarbonized energy system free from fossil fuels (Commission, 2020).

In this context, the shift toward renewable energy sources is of great importance to meet the growing global energy demand in an environmentally friendly and sustainable manner. These sources represent clean energy alternatives with significantly lower environmental impacts compared to conventional energy production methods, and they produce near-zero carbon emissions. Among renewable energy sources, hydrogen stands out as one of the most promising energy carriers for future energy systems due to its carbon-free nature and the ability to be produced from renewable resources. With its high calorific value per unit mass, hydrogen is an extremely suitable and attractive energy source for use across various sectors (Daş & Öner, 2025). The combustion of hydrogen results in the release of only water vapor, with no harmful emissions to the environment. When compared to other hydrocarbon-based fuels, hydrogen possesses a higher specific energy (Emeksiz & Kara, 2022). Hydrogen is a colorless, odorless, and tasteless element with no toxic properties. Classified as a non-metal on the periodic table, hydrogen is an extremely flammable gas. It becomes liquid at a temperature of -252.77 °C under 1 atmosphere of pressure. In its liquid phase, hydrogen occupies approximately 1/700th the volume of its gaseous phase under the same conditions, offering volumetric advantages in storage and transportation. From a chemical standpoint, hydrogen undergoes a highly exothermic combustion reaction, especially when reacting with oxygen, producing water (H_2O) in the process. In addition, hydrogen typically forms covalent bonds with other non-metals and is most commonly found in nature in a diatomic molecular form (H_2). This molecular structure allows hydrogen to attain stability and defines its typical behavior in chemical reactions (Mutlubaş & Özdemir, 2023). Energy systems that utilize hydrogen as a fuel—particularly fuel cells—are among the innovative technologies of strategic importance in the transition to a sustainable and environmentally friendly energy infrastructure (Le et al., 2024). One of the most notable examples among these technologies is the Proton Exchange Membrane (PEM) fuel cell, which stands out as an innovative breakthrough in the field of sustainable energy production (Türkoğlu & Semiz, 2025). PEM fuel cells are energy conversion devices that generate electrical energy through an electrochemical reaction between hydrogen and oxygen (İlbeyoğlu & Gürbüz, 2024). Thanks to their low operating temperatures, ranging between 60 and 90 °C, PEM fuel cells are capable of rapid start-up and can respond quickly and effectively to sudden changes in power demand. Another significant advantage of these fuel cells is their high power density, despite their low weight and compact size. These features position PEM fuel cells as a potentially transformative technology for applications in the transportation sector, portable devices, and small-scale stationary energy systems (Karanfil, 2020).

PEM fuel cells essentially consist of a sandwich-like structure composed of a membrane electrode assembly (MEA), bipolar plates, and sealing gaskets. A fuel cell stack is formed by assembling multiple MEAs, with each MEA positioned between two bipolar plates. These plates provide mechanical support to the fuel cell and also act as protective shields. Gaskets placed along the edges of the MEA are used to prevent gas leakage. The electrochemical reaction takes place in the MEA, which consists of two electrodes: an anode and a cathode. Each electrode includes a gas diffusion layer and an active catalyst layer, and between these two layers lies a proton exchange membrane (PEM) (Madhav et al., 2024). Hydrogen is supplied as fuel to the anode side, where it passes through the gas diffusion layer and reaches the surface of the anode catalyst. The catalyst facilitates the oxidation of hydrogen, resulting in the formation of protons (H^+) and electrons (e^-). The protons travel through the PEM to the catalyst surface on the cathode side, while the electrons are transferred to the cathode via an external circuit. On the cathode side, air is injected, which passes through the gas diffusion layer and reaches the surface of the cathode catalyst. The catalyst on the cathode side enables

the reduction of oxygen by reacting with the protons from the membrane and the electrons from the external circuit. In this process, hydrogen (H_2) and oxygen (O_2) are used to generate water and heat as part of the overall reaction (Di Maria, 2022; Madhav et al., 2024). Figure 1 illustrates the schematic of the operating mechanism of a PEM fuel cell.

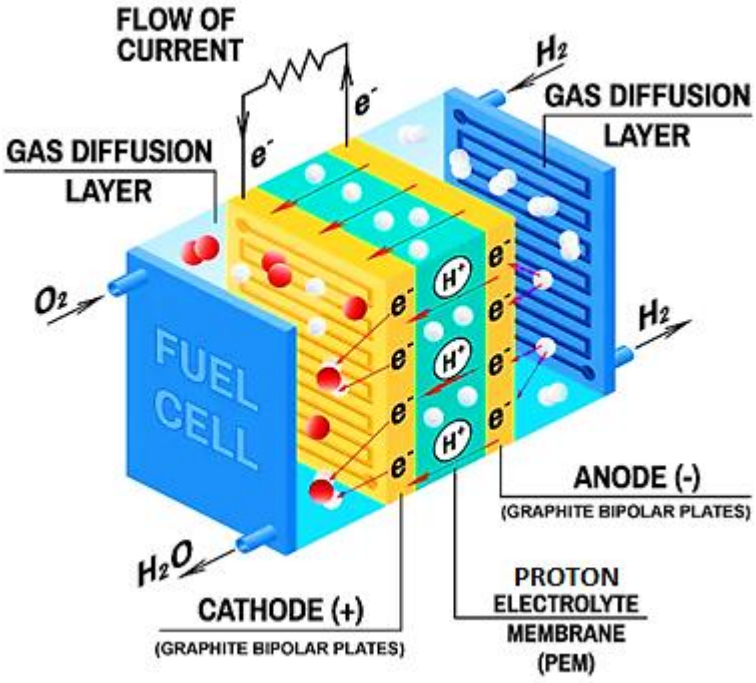

Figure 1. PEM fuel cell working mechanism diagram (Griffin, 2024).

The reactions that occur at the anode and cathode sides of the fuel cell are presented in Equations 1, 2, and 3 (Silaa et al., 2020).

At the anode: (Hydrogen oxidation reaction)

$$H_2 \rightarrow 2H^+ + 2e^- \quad (1)$$

At the cathode: (Oxygen reduction reaction)

$$1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad (2)$$

Overall reaction:

$$H_2 + 1/2O_2 \rightarrow H_2O + \text{Enerji} \quad (3)$$

PEM Fuel Cells and Batteries

Today, energy storage and conversion technologies have gained significant importance, especially in portable and transportation applications. In this context, PEM fuel cells and battery systems are among the most prominent solutions (Ehsani et al., 2018). These two technologies offer distinct advantages and limitations in terms of energy density, response time, refueling/charging durations, and overall system efficiency. Due to positive developments in battery technology worldwide, the adoption of electric vehicles (EVs) has accelerated significantly in recent years. With this growing interest, the number of electric vehicles, which has surpassed 5.2 million in recent years, is expected to reach 15 million globally by 2030 (Gürbüz, 2023).

Although PEM fuel cell technology holds significant potential for meeting increasing energy demands and reducing the carbon footprint, its widespread adoption remains limited. The primary challenges include the lack of a widespread hydrogen infrastructure, high costs, and insufficient durability. Durability requirements for PEM fuel cells vary considerably depending on the

application; expected lifespans can range from several thousand to tens of thousands of hours (Waseem et al., 2023). PEM fuel cells, especially in fuel cell electric vehicles (FCEVs), are widely recognized as a critical technology in the transition to sustainable transportation systems. These fuel cells significantly reduce greenhouse gas emissions and greatly decrease dependence on non-renewable energy sources (De Abreu et al., 2024). Electric vehicles are generally classified into three main categories: battery electric vehicles, hybrid electric vehicles, and fuel cell electric vehicles. As shown in Figure 2a, battery electric vehicles (BEVs) are systems equipped with a large-capacity battery pack and an electric motor. In these vehicles, movement is achieved through motors powered by electrical energy supplied from the battery. An important advantage of BEVs is regenerative braking, which enables the conversion of kinetic energy into electrical energy, allowing the battery to be recharged during operation. However, battery electric vehicles have some disadvantages, such as heavier battery systems compared to hybrid vehicles, more limited driving range compared to internal combustion engine vehicles, and longer full charging times (Kaba et al., 2021). As shown in Figure 2b, hybrid vehicles consist of a small battery, an electric motor, an internal combustion engine, and a fuel tank. While they offer advantages such as high efficiency and low emissions, they also have drawbacks including limited range and high cost. Fuel cell vehicles, as shown in Figure 2c, are powered by fuel cells that operate based on the electrochemical reaction between fuel and air. Although they are quiet, efficient, and environmentally friendly, challenges related to hydrogen production and storage, as well as high costs, pose significant disadvantages (Kaba et al., 2021).

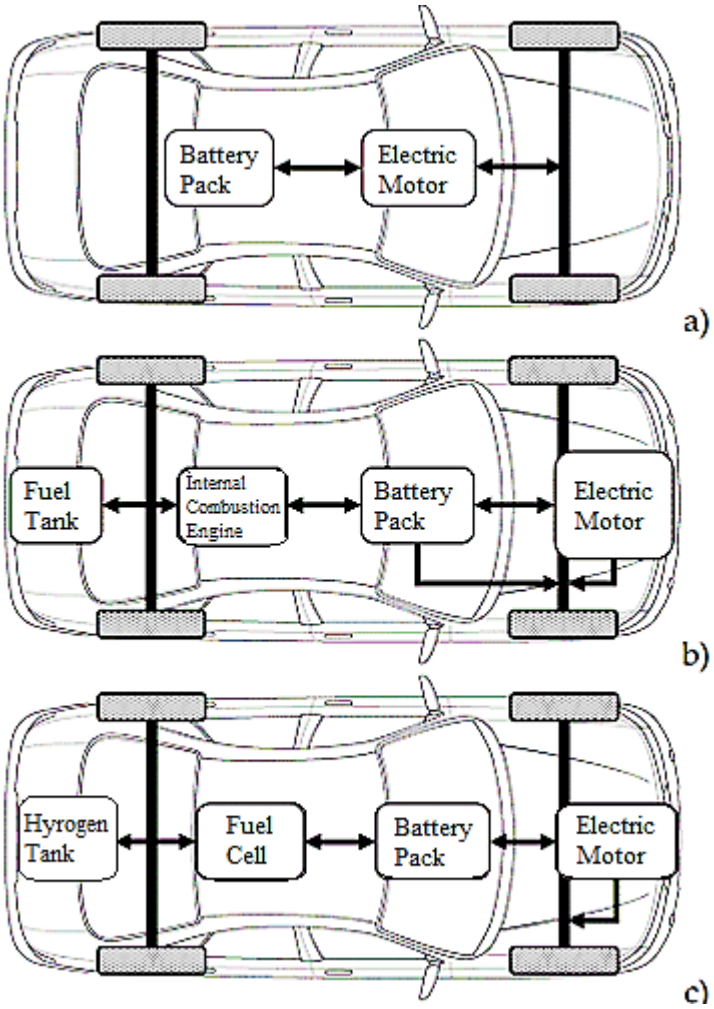

Figure 2. Basic components of electric vehicles: a) 100% battery electric vehicles, b) hybrid vehicles, and c) fuel cell vehicles (Kaba et al., 2021).

The fundamental component of an electric vehicle battery is the individual battery cell, which represents the smallest unit of power. These cells are connected in series or parallel to form different

battery modules, and multiple modules are then connected in series to form the high-power battery pack (Evpedıa, 2024). The battery market is categorically divided into consumer electronics, automotive, industrial, and specialized applications such as aerospace and military sectors. In consumer electronics, lithium-ion batteries have become the most common rechargeable power source due to their high energy density, lightweight design, and long cycle life. This battery chemistry is preferred for its ability to provide consistent and reliable performance in products such as smartphones, laptops, cameras, and portable electronic devices (Acedera, 2023). The performance of a lithium-ion battery pack in an electric vehicle (EV) is directly related to its sensitivity to thermal effects. These batteries operate most efficiently within a temperature range of 15°C to 35°C. When temperatures fall below 15°C, the battery's capacity decreases and internal resistance increases. Conversely, temperatures above 35°C can trigger irreversible reactions, increase the risk of thermal runaway, and accelerate capacity loss (Hwang et al., 2024).

Lithium-ion batteries consist of an electrolyte solution that allows positively charged ions to be transported between the cathode and anode terminals. Electrolytes enable the transfer of electrical charge between the terminals, enabling the conversion of stored energy into usable electrical energy. A thin layer called a separator in the electrolyte solution allows lithium ions to pass through while preventing electrons from passing through, maintaining the separation between the electrodes. During charging, lithium ions store energy by moving from the anode to the cathode through the electrolyte under the influence of an external voltage. During the discharge process, the stored energy is released and lithium ions move back from the cathode to the anode, enabling the electric vehicle to operate (Evpedıa, 2024). A schematic representation of a lithium-ion battery is given in Figure 3.

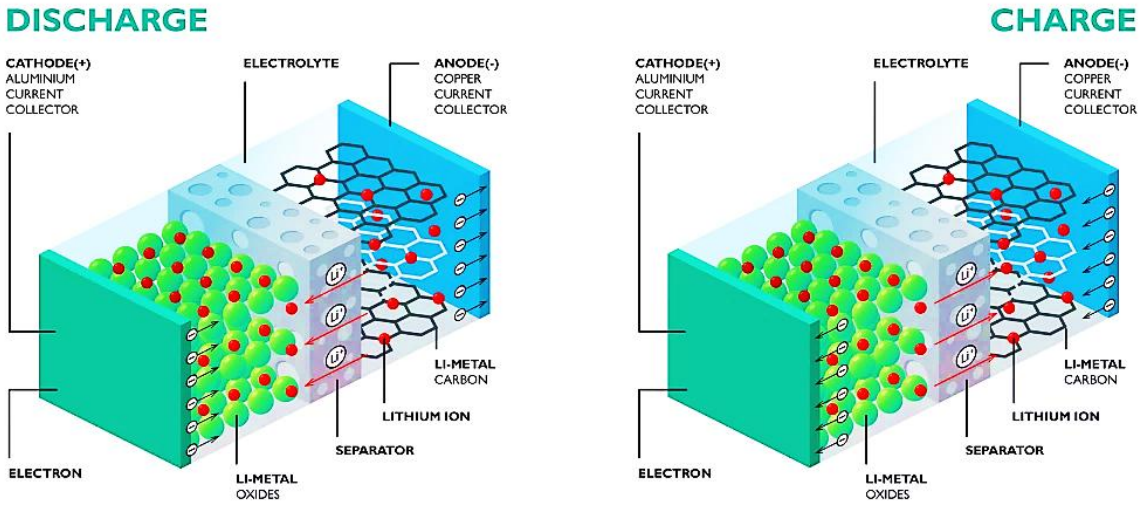

Figure 3. Schematic representation of a lithium-ion battery (Evpedıa, 2024).

Lithium-ion batteries play an important role in a wide range of applications, from electronic devices to large-scale electric transportation systems and grid-scale energy storage. However, these batteries can pose safety risks due to both progressive aging and unexpected failures, which can lead to disasters such as explosions or fires. Given their increasing use on a global scale, the safety of these batteries and the potential hazards that may arise from serious failures have now become a major public health concern (Zhao et al., 2024). PEM fuel cells and batteries are electrochemical systems used for electricity generation and differ in terms of energy production and storage methods. While PEM fuel cells directly convert an existing fuel, such as hydrogen, into electrical energy, batteries provide previously stored electrical energy for use when needed. While PEM fuel cells offer advantages such as high power output, long range capacity and short refueling time, batteries stand out with their higher energy efficiency and low operational emission levels. Choosing between these two technologies depends on many variables such as system weight, operational range, downtime, economic costs and infrastructure possibilities (Redway, 2023).

Figure 4 compares the variation in system mass with respect to energy storage capacity for a 500 W PEM fuel cell system and a Li-S battery system, based on the study by (Koku et al., 2021). The results indicate that the Li-S battery system consistently exhibits a significantly higher mass than the fuel cell system across all energy storage levels. Notably, as energy storage capacity increases, the impact of the Li-S battery on total system mass becomes even more pronounced. Some studies in the literature have also reported that while battery systems tend to be lighter than fuel cells at low energy capacities, fuel cells become more advantageous as energy storage requirements grow.

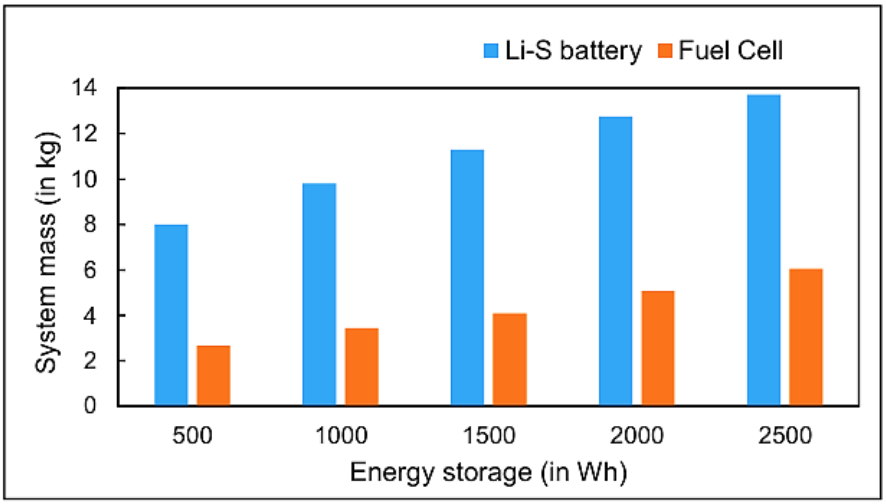

Figure 4. The variation in mass between the 500 W PEM fuel cell system and the Li-S battery system depending on energy storage capacity (Koku et al., 2021).

In the graph presented in Figure 5, from a study conducted by (Gürbüz, 2023), the variations in vehicle speed, fuel cell power, and battery power over time are analyzed throughout the NEDC (New European Driving Cycle) driving cycle for a PEM fuel cell electric vehicle. The sharp increase in battery power during sudden accelerations in vehicle speed indicates that the system primarily meets the power demand during rapid acceleration phases through the battery. In contrast, the power output of the fuel cell increases more slowly and steadily. This behavior is clearly observed in the areas highlighted with green circles, demonstrating that the fuel cell cannot respond as quickly as the battery to sudden load changes. When the vehicle travels at a constant speed, the fuel cell power remains stable, while the battery power drops below zero, indicating that the battery is being charged. These results show that the fuel cell and battery systems function as complementary components: the battery effectively meets sudden power demands, while the fuel cell plays a key role in providing continuous power.

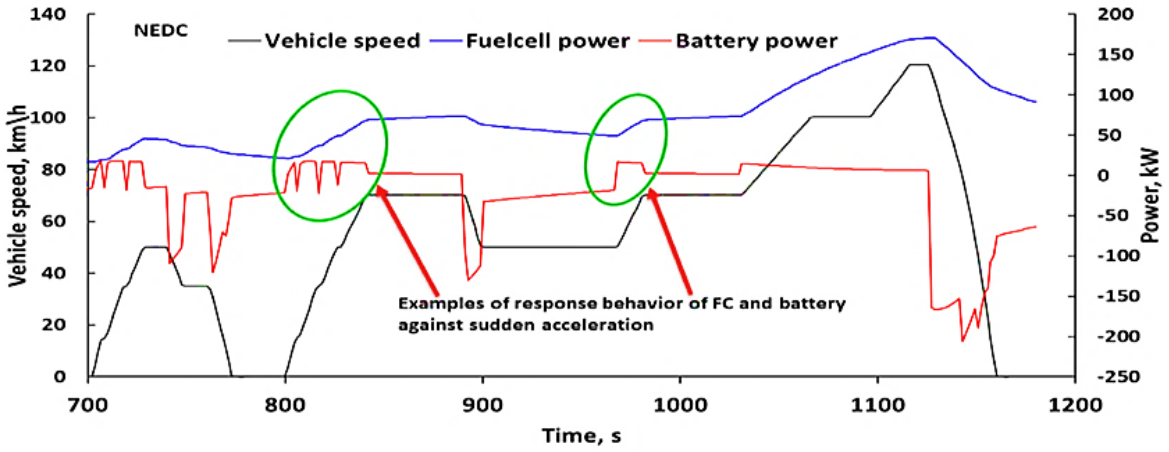

Figure 5. Changes in fuel cell power during 0–100 km/h acceleration of fuel cell-battery electric vehicles (Gürbüz, 2023).

Conclusion and Recommendations

In line with sustainability goals, the demand for renewable energy sources and carbon-neutral technologies is steadily increasing both within the European Union and globally. Hydrogen energy and PEM fuel cells offer a strategic alternative for clean energy production and environmentally friendly transportation solutions. Due to its high energy density and minimal environmental impact, hydrogen is expected to play a critical role in future energy systems.

- Advances in battery technologies are addressing the growing demand for energy storage, particularly in areas such as electric vehicles and portable electronic devices.
- Key challenges awaiting solutions include the high costs and infrastructure gaps in hydrogen production, storage, and transportation, as well as durability and cost issues in PEM fuel cells.
- In lithium-ion batteries, thermal management, safety risks, and lifespan limitations constitute the primary research areas for next-generation battery development.
- The future expansion of hydrogen technologies will depend on the development of more durable, efficient, and cost-effective PEM fuel cells.
- The progress of lithium-ion battery technology will be supported by the discovery of new battery chemistries that offer higher energy density and enhanced safety.
- Multidisciplinary research, innovative materials development, and international collaborations will play a critical role in the advancement of both technologies.
- Hydrogen energy and battery technologies will provide complementary strategic solutions for building a carbon-neutral future.

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FIR FILTER DESIGN AND IMPLEMENTATION IN RASPBERRY PI ENVIRONMENT

FIR FİLTRE TASARIMI VE RASPBERRY PI ORTAMINDA GERÇEKLENMESİ

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ÖZET

Bu seminer, özellikle biyomedikal sinyal işleme ve gürültü azaltma üzerine odaklanarak, FIR (Sonlu İmpuls Yanıtı) filtrelerinin tasarımı ve optimizasyonunu ele almaktadır. Genetik algoritmalar (GA) ve parçacık sürüsü optimizasyonu (PSO) gibi ileri düzey yöntemler, düşük geçiş FIR filtrelerinin performansını artırmak için kullanılmıştır. Ayrıca, gerçek zamanlı sinyal işleme ve veri analizi, düşük maliyetli sistemlerde uygulanabilirliği kolaylaştıran Raspberry Pi platformu üzerinde gerçekleştirilmiştir. Çalışma, FIR filtrelerinin IoT ve çevresel izleme gibi alanlarda nasıl verimli bir şekilde kullanılabileceğini göstermektedir. Araştırma sonuçları, FIR filtrelerinin pratik uygulamalarda etkin bir şekilde kullanılabileceğini ve düşük maliyetli sistemlerde yüksek performans sağlayabileceğini göstermektedir.

Anahtar Kelimeler: Filtre Tasarımı, FIR Filtre, Raspberry Pi.

ABSTRACT

This seminar focuses on the design and optimization of FIR (Finite Impulse Response) filters, with particular emphasis on biomedical signal processing and noise reduction. Advanced methods such as genetic algorithms (GA) and particle swarm optimization (PSO) have been used to enhance the performance of low-pass FIR filters. Additionally, real-time signal processing and data analysis have been conducted on the Raspberry Pi platform, which offers ease of application in low-cost systems. The study demonstrates how FIR filters can be efficiently utilized in areas such as IoT and environmental monitoring. The results of this research show that FIR filters can be effectively used in practical applications and can provide high performance in low-cost systems.

Keywords: Filter Design, FIR filter, Raspberry Pi

INTRODUCTION

Filters are fundamental components in signal processing systems, designed to suppress undesired frequency components or enhance desired ones. They are broadly categorized into analog and digital filters. Analog filters operate on continuous-time signals and are typically built using passive components, whereas digital filters process discrete-time signals using algorithmic methods. While analog filters offer a low-cost and fast solution, digital filters provide higher accuracy, flexibility, and adaptability through software-based implementation. These advantages make digital filters essential in contemporary signal processing applications (Mondal & Alagirisamy, 2023).

Unlike analog filters, digital filters are implemented via algorithms on digital platforms and form a cornerstone of digital signal processing (DSP) systems. They are widely employed in tasks such as noise reduction, signal attenuation, frequency component isolation, and waveform shaping. Their digital nature allows for greater flexibility in design, high accuracy, phase linearity, and consistent performance. Additionally, as they are based on mathematical algorithms rather than physical components, digital filters are immune to physical degradation and instability over time (Grobbelaar et al., 2022).

Digital filters are commonly implemented on platforms such as microcontrollers, FPGAs, and dedicated DSP processors, and are typically classified into two types: Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters. FIR filters use only present and past input values, without any feedback, which ensures inherent stability. This characteristic makes FIR filters highly reliable and predictable. In contrast, IIR filters incorporate feedback from previous outputs, enabling sharper frequency transitions with lower filter order. While this increases computational efficiency, it also introduces potential stability concerns, necessitating careful design analysis (Tekin & Güler, 2023).

Recent advancements in IIR filter design have focused on optimizing stability and performance. For instance, a study by Mondal and Alagirisamy (2023) explored the design of a graphical user interface (GUI) for simulating and analyzing EEG signals using IIR-FIR filters. This interface allows users to generate synthetic EEG signals, apply filters in real-time, and visualize the filtered signals, demonstrating the practical application of IIR filters in neuroscience and brain signal analysis.

This study focuses on the real-time implementation of a FIR filtering algorithm on a Raspberry Pi platform. The main objectives include denoising EEG signals, preserving low-frequency components, and attenuating high-frequency noise. Additionally, the system utilizes the Raspberry Pi's GPIO pins to acquire data from external sensors, process the data, and perform signal analysis. The design involves the derivation and application of the FIR filter's difference equation, which serves as the foundation for computing output signals based on filter coefficients and input samples.

FILTERS

A filter, in general, is a system designed to control the frequency components of a signal. An electrical or digital filter selectively transmits or attenuates specific frequency ranges of the signal applied to its input (Johnson & Smith, 2023). This characteristic allows signals to be processed in the desired form and plays a critical role in many areas, from communication to data analysis. For example, in radio and television communications, filters are used to select a specific channel, while in medical applications, they are used to clean biomedical signals contaminated with noise (Miller et al., 2023). The primary purpose of filters is to optimize system performance by analyzing the spectral content of a signal (Williams & Zhang, 2023)

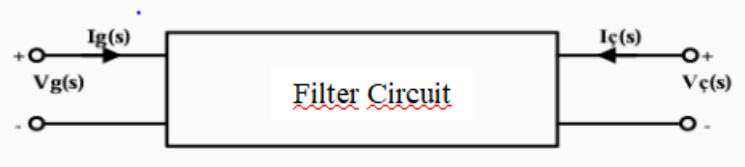

Figure 1.1 General Filter Circuit

Filter Types and Basic Filter Terms

Filters are categorized into various types based on their functional and structural characteristics. From a functional perspective, low-pass filters transmit signals below a certain cutoff frequency while attenuating higher frequencies. These filters are commonly used in applications such as audio processing, analog-to-digital conversion, and noise reduction (Lee & Choi, 2023). High-pass filters,

on the other hand, transmit signals above a certain cutoff frequency while suppressing lower frequencies, and are typically preferred in harmonic analysis and environmental noise removal (Sharma et al., 2023). Band-pass filters select a specific frequency range while blocking other frequencies. These filters provide an ideal solution for channel selection in radio and television communication (Nguyen & Tran, 2023). Band-stop filters, conversely, suppress a specific frequency range while allowing the transmission of other components (Kumar & Yadav, 2023).

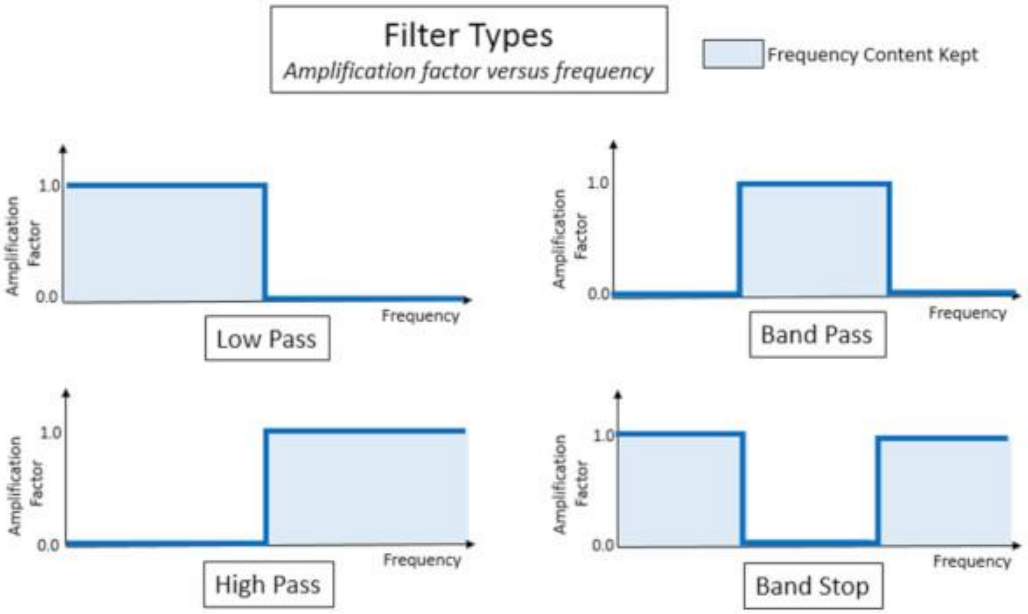

Figure 1.2. Filter Types

DIGITAL FILTER

Unlike analog filters, digital filters operate through algorithms implemented on digital platforms and form a fundamental building block of digital signal processing (DSP) systems. These filters are used for purposes such as noise reduction, signal attenuation, frequency component filtering, and signal shaping. Since they work with digital signals, the design and implementation of digital filters provide a more flexible and customizable structure. The main advantages of digital filters include high accuracy, phase fidelity, and repeatability. Furthermore, these filters do not degrade or lose stability over time because they rely on mathematical algorithms rather than physical components. Digital filters are typically implemented on microcontrollers, FPGAs, or dedicated DSP processors and are classified into two main structures: FIR and IIR.

The structural differences, advantages, and disadvantages of FIR and IIR filters play a critical role in determining the preferred filter type for signal processing applications. For instance, the linear phase characteristic of FIR filters provides a significant advantage in applications such as audio and image processing, while IIR filters offer higher frequency selectivity with lower resource consumption. Therefore, selecting the appropriate filter type based on the requirements of the application is an important step in digital filter design.

For a rational system function and a linear time-invariant system, the relationship between the input signal x(n) and the output signal y(n) is defined by the linear constant coefficient difference equation given in the equation. In such systems, the mathematical relationship between the input and output is expressed through difference equations based on constant coefficients.

$$y(n) = \sum_{k=0}^{\infty} a^k . x(n-k)$$

Equation 1.1

FIR Filter Structure

FIR filters provide a structure that processes only the input signal and do not contain feedback elements. This feature ensures one of the fundamental advantages of FIR filters: stability. FIR filters are always stable because, in the absence of feedback, the system cannot oscillate or become unstable. This stability is an important factor that increases the reliability of FIR filters.

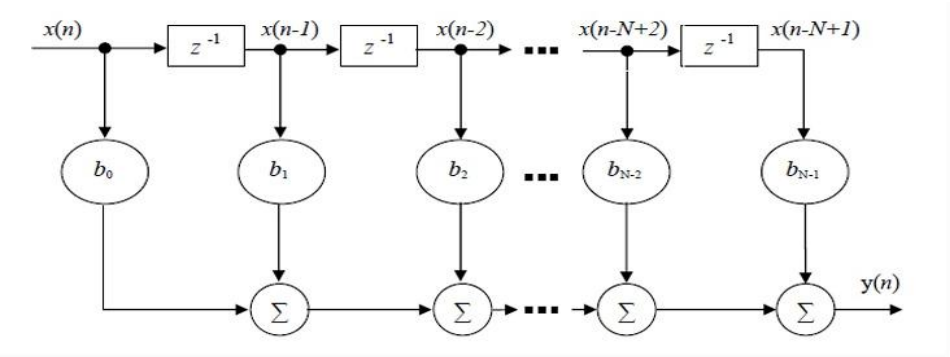

Figure 1.3. Feedforward FIR filter structure

$$y(n) = \sum_{k=0}^{N-1} a_k x(n-k)$$

Equation 1.2

Another significant advantage of FIR filters is their linear phase characteristic. This feature preserves the timing order of the signal's frequency components and prevents phase distortion. Linear phase plays a critical role, especially in audio and image processing applications, as it helps maintain the natural structure of the signal. For example, in a music signal processed with an FIR filter, the natural tone and phase relationships of the sound are preserved (Almeida & Chen, 2023).

One of the disadvantages of FIR filters, however, is their higher computational demand. To achieve the same frequency selectivity, FIR filters typically require a higher-order design compared to IIR filters. This leads to increased use of processing power and memory resources (Singh & Patel, 2024). Nevertheless, with advancements in modern processor technologies and optimization techniques, this disadvantage has largely been mitigated, and FIR filters are now widely used in many applications (Zhou & Ahmed, 2023).

RASPBERRY PI

Raspberry Pi is a microcomputer platform widely used in electronic projects due to its portability, low cost, and flexible programmability. Its GPIO (General Purpose Input/Output) pins, communication protocols, and software support through popular programming languages such as Python make it a powerful tool (Kumar & Lee, 2023). In this study, the programmable logic, interconnection features, digital input/output functions, relation to hardware description languages, and application areas of the Raspberry Pi are examined in detail (Ahmed & Silva, 2024).

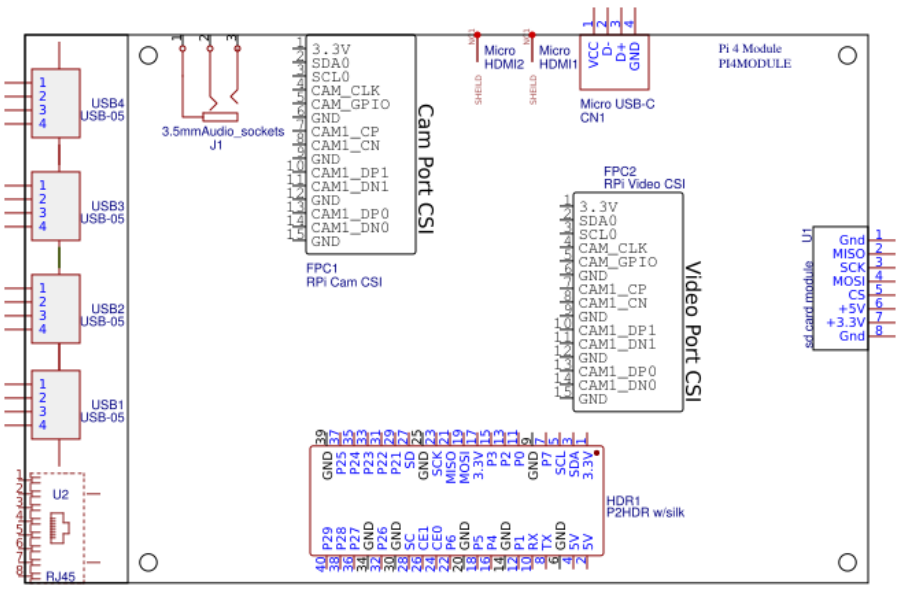

Figure 2.1. Schematic of the Raspberry Pi 4 Model B.

Programmable Logic of the Raspberry Pi

The programmable logic of the Raspberry Pi offers great flexibility at both software and hardware levels. It can interact with peripheral devices through GPIO pins, provide software-level control using programming languages such as Python, and facilitate data processing tasks. The open-source nature of the Raspberry Pi and its compatibility with high-level programming languages like Python allow users to implement complex projects using simple methods (Singh & Zhao, 2023; Martinez & Gupta, 2024).

Programmable Connectivity Features of the Raspberry Pi

The Raspberry Pi's connectivity features, which support protocols such as I²C, SPI, and UART, are used to receive data from sensors, control actuators, and transfer data between devices. I²C is preferred in applications that require low-speed data transmission, while SPI is used in situations that demand high-speed data transfer. UART enables serial communication for connecting with devices such as GPS modules or Bluetooth.

Programmable Input/Output Operations of the Raspberry Pi

Digital input and output operations are performed through the Raspberry Pi’s GPIO pins. Digital inputs are used to detect signals from external devices, while digital outputs are used to control devices. For example, detecting whether a button is pressed and controlling an LED accordingly is a common application.

Hardware Description Language of the Raspberry Pi

The Raspberry Pi does not offer hardware description support at the same level as traditional FPGA or ASIC-based systems. However, controlling GPIO pins using languages like Python significantly simplifies hardware description and control processes. This structure makes the Raspberry Pi a cost-effective and accessible solution for hardware design (Smith & Johnson, 2023).

Raspberry Pi Selection

In this study, the Raspberry Pi 4B model was chosen due to its powerful processing capacity and extensive software support. With an ARM Cortex-A72 processor, 4 GB of RAM, and USB 3.0 support, this model is an ideal platform for complex data processing projects. The micro HDMI

outputs provide high-definition display support, while the GPIO pins enable integration with a wide variety of peripheral devices (Brown & Green, 2023).

Raspberry Pi Applications

Raspberry Pi is used in a wide range of applications, from processing sensor data in IoT projects and transmitting it to cloud systems, to controlling devices in automation systems. Additionally, it is a popular tool for users who want to learn programming and electronic circuit design in the education sector. Furthermore, it is an effective platform for more technical projects, such as real-time implementation of FIR and IIR filters in digital signal processing (Gates & Allen, 2023).

FIR FILTER APPLICATION WITH RASPBERRY PI

The design of the FIR low-pass filter and its real-time implementation on Raspberry Pi provide a practical solution in the field of digital signal processing. This section will detail the general application, coding done using the Python programming language, and the graphical results obtained. The code and visuals used in the study demonstrate the accuracy of both theoretical and practical analyses. The main objective of this work is to design a FIR low-pass digital filter on Raspberry Pi and implement it in real time. This process involves generating square wave signals (100 Hz and 500 Hz), combining them, and then processing them with a low-pass filter. Python was preferred for algorithm design and hardware control, particularly due to its extensive library support, which greatly facilitated data analysis and signal processing tasks (Johnson & Lee, 2023).

GRAPHICAL RESULTS AND ANALYSIS

The graphs obtained during the study clearly demonstrate both the accuracy of the signal processing steps and the success of the filtering process. The project results have been analyzed as follows.

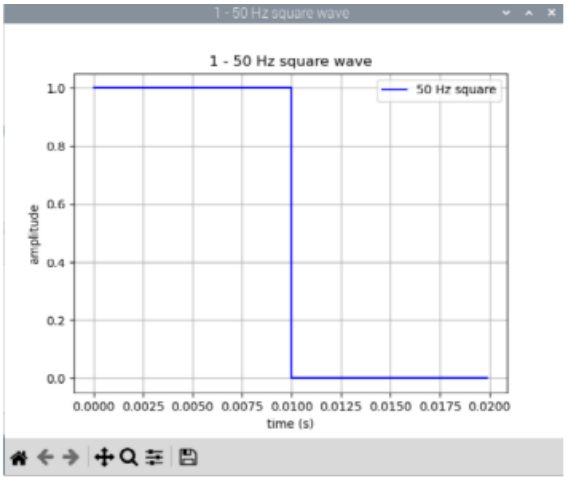

Figure 4.1 50 Hz Square Wave

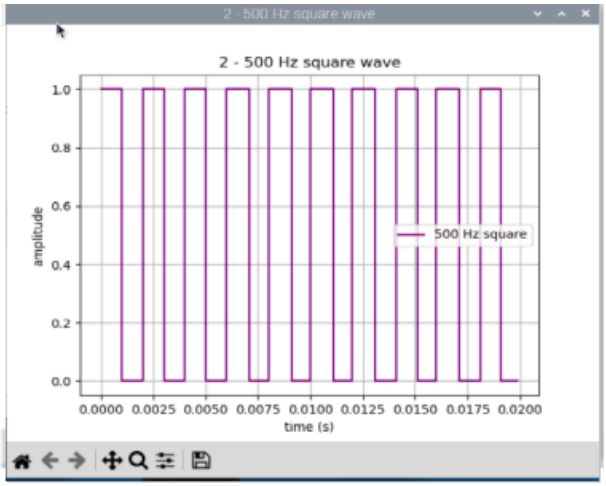

Figure 4.2 500 Hz Square Wave

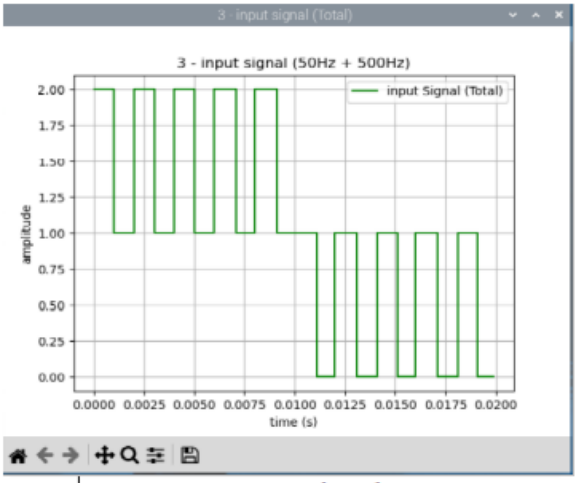

Figure 4.3.Input Signal

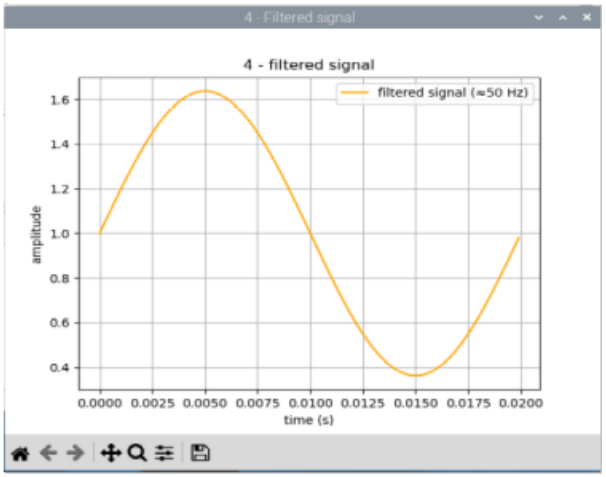

Figure 4.4. Filtered Signal

This study aims to evaluate the performance of a low-pass FIR filter design in the context of analog signal processing. The input signal consists of the superposition of two square waves with different frequencies (50 Hz and 500 Hz). This composite signal is then applied to a low-pass analog FIR filter with the goal of suppressing the high-frequency components.

Single-Frequency Square Waves (Figures 1 and 2)

The first two graphs show the 50 Hz and 500 Hz square wave signals individually.

Figure 4.1 (50 Hz Square Wave): This signal is a low-frequency component with relatively slow transitions.

Figure 4.2 (500 Hz Square Wave): This high-frequency signal features rapid transitions and contains more energy in the higher frequency spectrum, resulting in a broader spectral content.

Input Signal (Figure 4.3)

This graph shows the combined signal (50 Hz + 500 Hz). The input signal exhibits amplitude variations and includes both low and high-frequency components. Such signals are ideal test cases for evaluating the frequency selectivity of filters.

Filtered Signal (Figure 4.4)

After applying the low-pass FIR filter, the resulting signal appears noticeably smoother and resembles a sinusoidal waveform.

The high-frequency 500 Hz component is significantly attenuated.

The 50 Hz component is preserved, and the overall shape of the signal closely matches this low-frequency component.

This indicates that the low-pass filter has a passband centered around 50 Hz and effectively attenuates components at 500 Hz.

CONCLUSION AND ACADEMIC EVALUATION

This experimental implementation successfully demonstrates the frequency selectivity of an analog low-pass FIR filter. The filter effectively retains the signal within the passband (50 Hz) while attenuating the higher-frequency component (500 Hz).
Analog FIR filters may offer advantages over digital filters in terms of reduced latency, but it should be noted that their filter characteristics are limited by physical components (such as resistors and capacitors).

ACKNOWLEDGMENT

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NUMERICAL INVESTIGATION AND OPTIMIZATION OF CENTRIFUGAL FAN PERFORMANCE IN HOUSEHOLD HEAT PUMP TUMBLE DRYER

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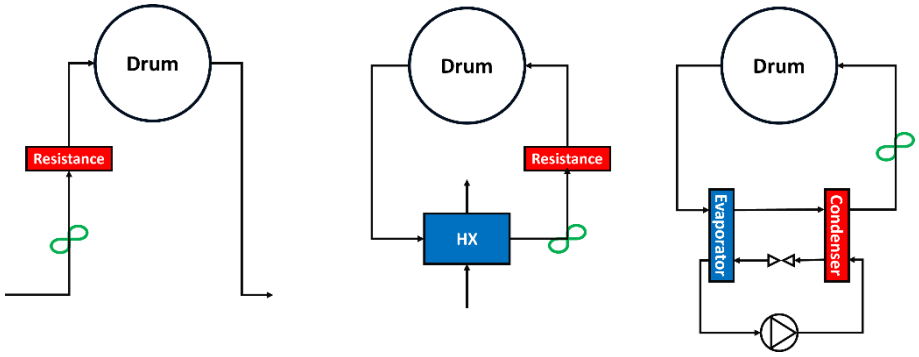
ABSTRACT

Centrifugal fans are widely used in household appliances which direct air from one place to another. Such as, ovens, dryers, refrigerators, boilers, etc. In tumble driers centrifugal fans directing the air from de-humidification process to the clothes where the air increases its' humidity. In this paper, performance of centrifugal fan is investigated. Different fan geometries created in the CAD (Computer Aided Design) environment and CFD (Computational Fluid Dynamics) methods have been used to comparison of the performance. In this paper, three different parameters were initially investigated, total investigation will be shared in another paper. The parameters that are investigated in this paper are blade shape (straight, curved), blade length or offset from center, and number of blades. In the comparison study, rpm value kept as constant, only differences during the studies were geometries of the blades. Performance investigations are conducted for different parameters such as torques, mass and volumetric flow rates. Torque comparison is conducted for comparison of the energy usage of the fan, because due to the rotation of the fan, blades are interacting with air and this effect causes the torque in the motor shaft which is directly proportional with the energy consumption, on the other hand, flow rate is crucial for the drying because the moisture extraction from the clothes directly proportional with the flow rate.

Keywords: Centrifugal fan, CFD, Design of Experiment, Optimization, Torque, Fan Efficiency.

INTRODUCTION

Household applications are evolving day by day and to be competitive in the sector, brands must find a way to improve their products by performing better, using less energy, consuming less water etc., due to the competitive environment, technological advancement can be considered as essential key to increase their market share. Household tumble dryers are one of the growing platforms in worldwide, because while houses getting smaller people can find less place to hang their clothes for drying, therefore, need of tumble dryer is increasing day by day. In this study, centrifugal fan of heat pump tumble dryer was investigated. Tumble dryers can be classified in three different categories, first and oldest ones are vented dryers which can be considered as hair dryers for working principle. Second, condenser tumbler dryers they still have the resistance like vented machines but in these machines, air is circulating in close cycle, and air-air heat exchangers implemented on the machines to increase their performance. Finally, heat pump tumble dryers can be considered state-of art solution for the tumble dryer sector, in these machines drying have occurred in the heat pump system, in these system instead of resistance condenser of the heat pump is heating the air to increase humidity absorption capacity, while evaporator of the heat pump trying to extract humidity from air. In Figure 1 sketch of three system be found.



a) Vented b) Condenser c) Heat Pump

Figure 1. Schematic representation of tumble dryers, a) Vented, b) Condenser, c) Heat Pump

In this study, centrifugal fan on the heat pump was investigated, this study can be considered as preliminary study to further development. Plenty of numerical and practical investigations have been conducted on centrifugal fans, one of the study, fan noise has been investigated with numerical methods, with the modifications that they represent, they achieve 15 dB reduction in the fan noise (Liu, et al., 2006).

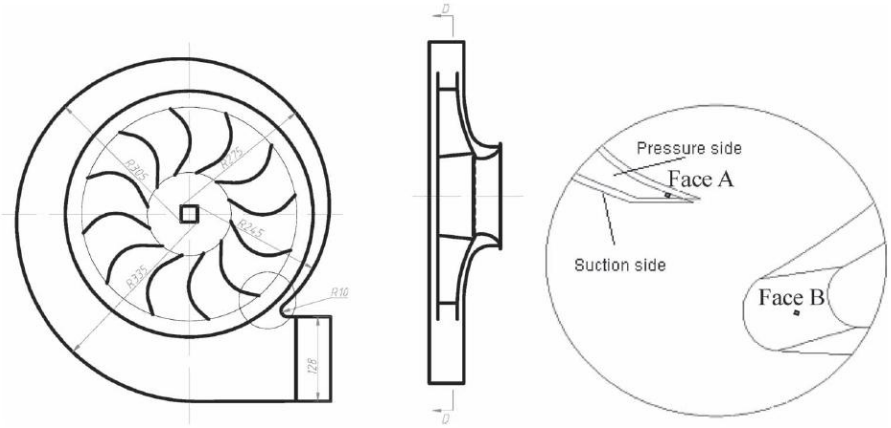


Figure 2. Centrifugal fan sketch and the location of face A and face B (Liu et al.,2006)

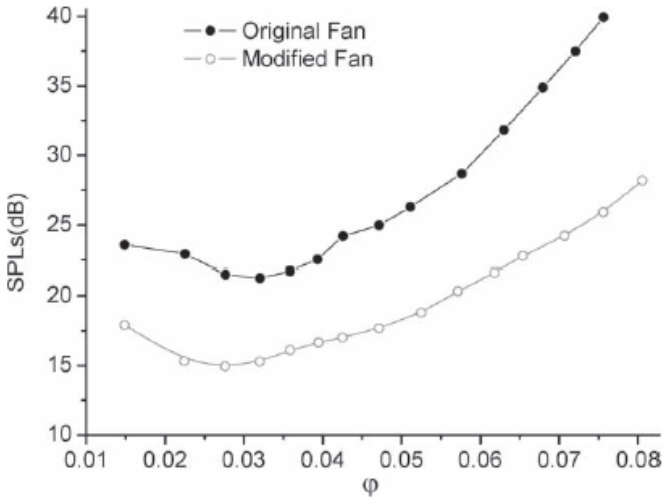


Figure 3. Comparisons of the measured specific A-weighted sound levels between the modified and the original fan (Liu et al.,2006)

In this study, beside the numerical methods, Design of Experiments (DoE) method is used, there is also plenty of study in the literature in this regard, with Computational Fluid Dynamics (CFD) and

DoE methods centrifugal fan is investigated for six different parameters, parameter list is shared in the Table 1 (Jung et al.,2016).

Table 1. Design parameters for the DOE (Jung, et al.,2016)

Parameter	Factor Description
A	Number of the $GV_{(rear)}$
B	Meridional plane length of the $GV_{(rear)}$
C	Cross-sectional area of the LE in the $GV_{(rear)}$
D	Beta angle of the TE in the $GV_{(rear)}$
E	Maximum thickness of airfoil in the $GV_{(rear)}$
F	Maximum thickness position of airfoil in the $GV_{(rear)}$

Another study has investigated the design parameters of a backward-inclined centrifugal fan using DoE method and CFD. Four different parameters have been investigated, base radius of the motor hub, the radius of the fan entry section, the deceleration factor throughout the entry zone and the solidity factor were investigated (Behzadmehr et al., 2006).

In this study, the main aim is differentiating to see if numerical methods can differ the good from the bad. In the future, additional studies will be conducted about this topic to explore the much efficient designs with the DoE method.

Method

In this study, centrifugal fan inside the heat pump tumble dryer were investigated, to make that investigation couple of software were used, to grab the CAD model of the machine Creo Parametric were used, to simplify the geometry for CFD Spaceclaim were used, CFD simulations were run on the ANSYS Fluent, for last optimization studies were conducted on Minitab Statistical software.

To simplify the problem, bottom part of the machine (basement) was cutted from the middle and reducing the complexity and enhancing the better solution time condenser module were deleted from the volume, then centrifugal fan is placed with the 1650rpm. Air exits from the centrifugal fan and enters to the air duct which directs air from heat exchangers and fan to the wet clothes. Again, to simplify the geometry drum were excluded from the volume and to reduce the numerical error on the outlet some extruded region is added. In Figure 4, isometric view, back view and solution geometry were presented.

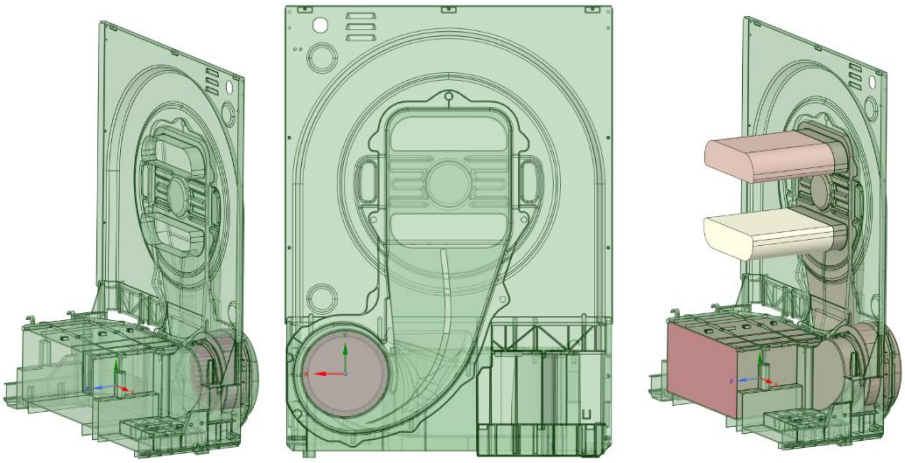


Figure 4. Geometrical representations that is used in the simulation environment

During this study three different parameters were investigated, and their listed in Table 2 below. Six different blade lengths, two different blade geometry, and four different number of blades at the

beginning. However, in this study number of simulation runs are restricted and further investigation will be shared in another comprehensive article.

Table 2. DoE Parameter Table

Factors	Number of Levels	Levels
Blade Length	6	0, 3, 6, 9, 12, 15
Blade Geometry	2	Straight, Curved
Number of Blades	4	5, 15, 25, 35

According to Table 2, forty-eight different run should be conducted. However, as explained before full study will not be included to the scope of this study. During the study, some quantities were observed fort the DoE, these quantities can be sorted as follows, speed, volumetric flow rate, mass flow rate, torque.

In the study, mesh independency is only investigated for first study, and the rest of the study mesh size are used according to these parameters. This behaviour is caused by if the mesh independency were run for every studies at least ninety or more study would be conducted which will extend the solution time and consume lots of computational power.

Boundary conditions of the simulation is shared in Figure 5. All outlets and inlets were defined as Pressure inlet or outlet which has atmospheric pressure. Fan is rotated with 1650rpm to create air flow inside the cavity.

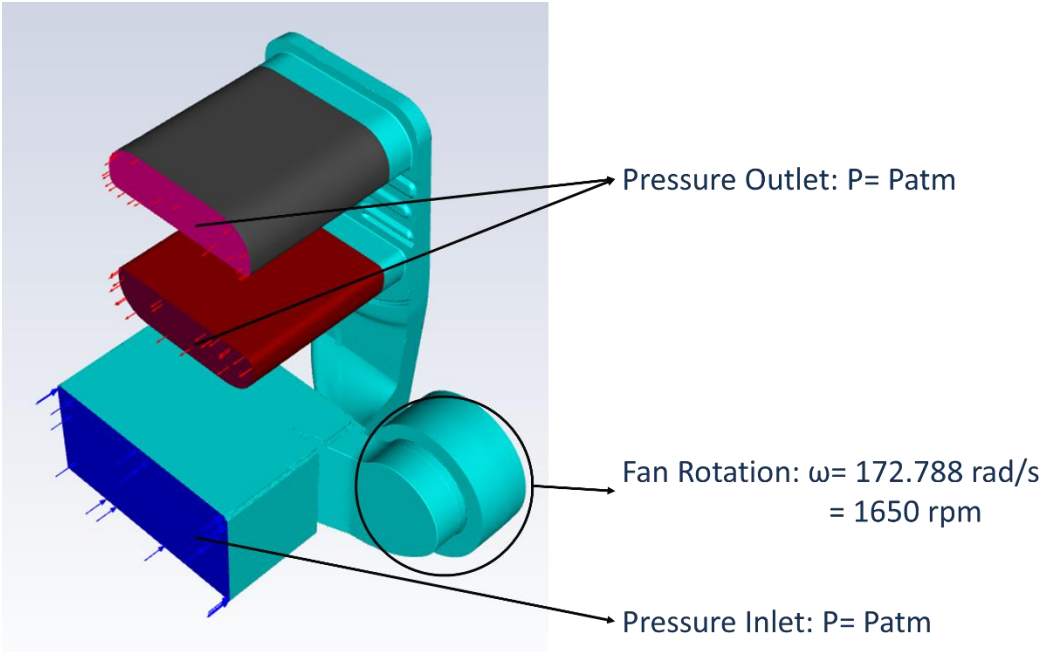


Figure 5. Boundary Conditions

Due to the turbulent flow inside the cavity k-ω SST turbulence model (Eq. 1,2) (Menter, 1994) is used. Continuity equations (Eq. 3-6) (Wilcox, 1998) and equations of k-ω SST turbulence model is shared in below.

$$\rho\frac{\partial k}{\partial t}+\rho u_i\frac{\partial k}{\partial x_j}=P-\beta^*\rho k\omega+\frac{\partial}{\partial x_j}\left[(\mu+\sigma_k\mu_T)\frac{\partial k}{\partial x_j}\right] \quad [1]$$

$$\rho\frac{\partial \omega}{\partial t}+\rho u_i\frac{\partial \omega}{\partial x_j}=\frac{\gamma\rho}{\mu_T}P-\beta\rho\omega^2+\frac{\partial}{\partial x_j}\left[(\mu+\sigma_\omega\mu_T)\frac{\partial \omega}{\partial x_j}\right]+2\rho(1-F_1)\frac{\sigma_{\omega 2}}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} \quad [2]$$

$$\left(\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}\right)=0 \quad [3]$$

$$\rho U\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial x}+\frac{\partial W}{\partial x}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}+\frac{\partial^2 U}{\partial z^2}\right)-\mu\left(\frac{\partial \overline{u\prime^2}}{\partial x^2}+\frac{\partial \overline{u\prime v\prime}}{\partial x\partial y}+\frac{\partial \overline{u\prime w\prime}}{\partial x\partial z}\right) \quad [4]$$

$$\rho V\left(\frac{\partial U}{\partial y}+\frac{\partial V}{\partial y}+\frac{\partial W}{\partial y}\right)=-\frac{\partial P}{\partial y}+\mu\left(\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}+\frac{\partial^2 V}{\partial z^2}\right)-\mu\left(\frac{\partial \overline{u\prime v\prime}}{\partial x\partial y}+\frac{\partial \overline{v\prime^2}}{\partial y^2}+\frac{\partial \overline{v\prime w\prime}}{\partial y\partial z}\right) \quad [5]$$

$$\rho W\left(\frac{\partial U}{\partial z}+\frac{\partial V}{\partial z}+\frac{\partial W}{\partial z}\right)=-\frac{\partial P}{\partial z}+\mu\left(\frac{\partial^2 W}{\partial x^2}+\frac{\partial^2 W}{\partial y^2}+\frac{\partial^2 W}{\partial z^2}\right)-\mu\left(\frac{\partial \overline{u\prime w\prime}}{\partial x\partial z}+\frac{\partial \overline{v\prime w\prime}}{\partial y\partial z}+\frac{\partial \overline{w\prime^2}}{\partial z^2}\right) \quad [6]$$

Results

As described in the Method section, during the optimization phase volumetric flow rate and torque values is compared but during the study some other contours or parameters is also investigated, in Figure 6 velocity contour is shared, according to that contour one can understand that, on that specification turbulence is highly effective and negatively affecting the flow pattern, also in Figure 7 pressure contour is shared and in that figure right hand side of the duct has higher pressures than the left side which is expected but to create more equal dissipation fan volute and dilute should be investigated and also seperator position should be re-established. Figure 8 shows the streamlines of the flow and it is clearly seen that upper section of the duct is more effective than the lower, which is also shown in the mass flow rate iteration graph in Figure 9.

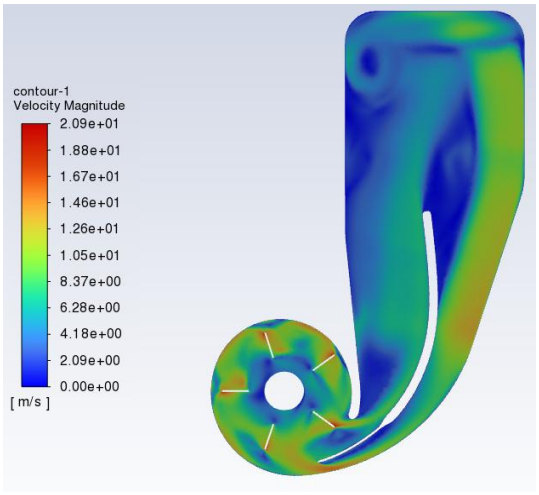


Figure 6. Velocity Contour

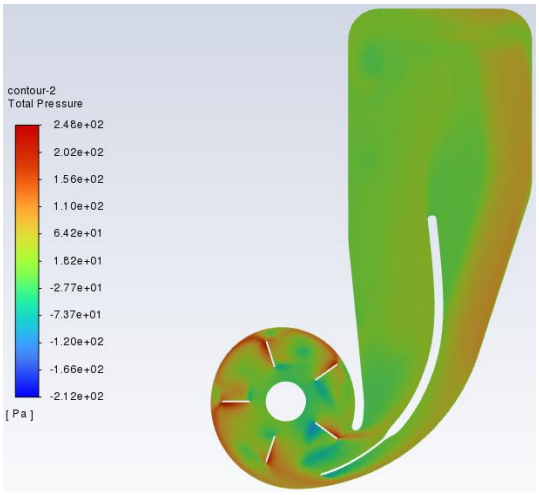


Figure 7. Pressure Contour

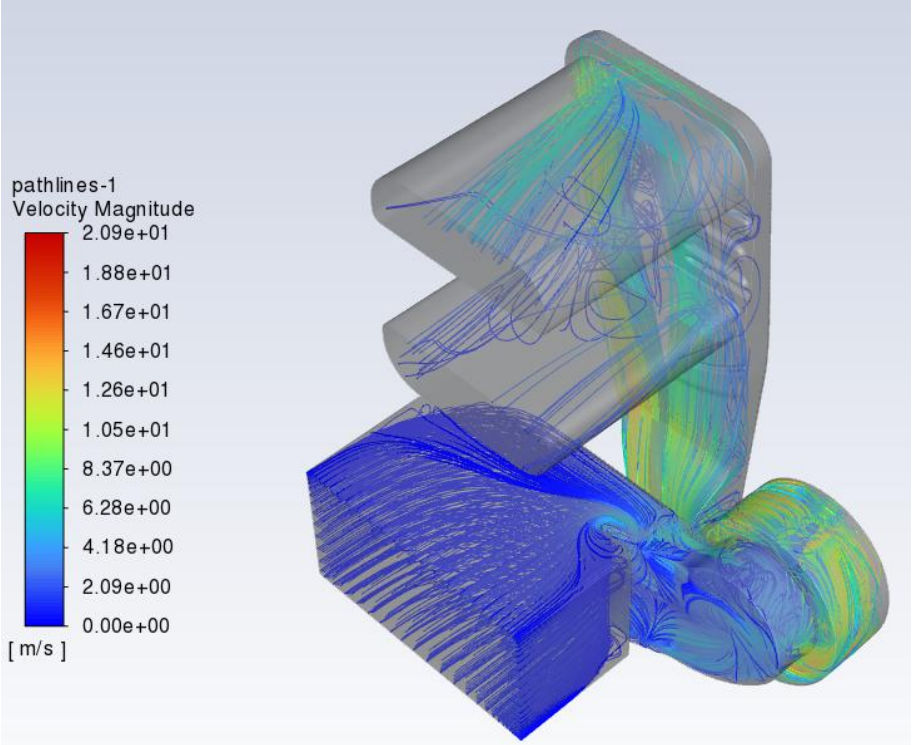


Figure 8. Streamlines of the flow

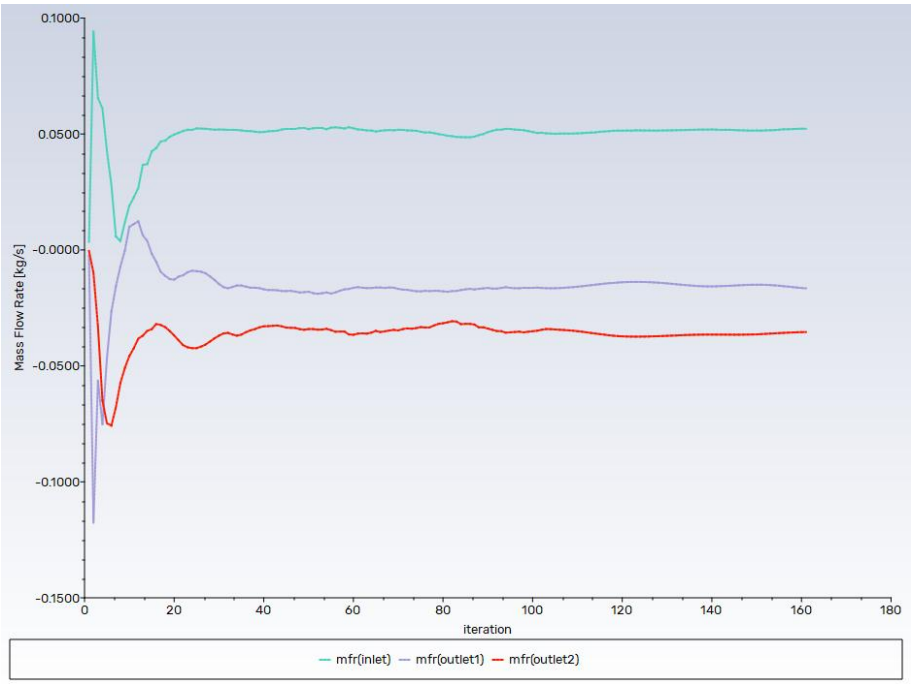


Figure 9. Mass flow rate / iteration graph

At the end of the simulation phase optimization study was started, for that study, sixteen different result were investigated, results are shared in Table 3.

Then, with the help of Minitab software, comparison/optimization study was conducted, in Figure 10 torque values in comparison with number of blades were investigated in the boxplot. It is clearly seen that with the increased number of blade number torque value is increased. In Figure 11, mass flow rate (MFR) values in comparison with the number blades were investigated, as Figure 10 with the increased number of blades MFR values is also increased. In Figure 12, and Figure 13 was compared but without clear deduction because number of blade has more impact then the offset values and therefore dissipation between results are vary.

Table 3. Result table

Number of Blades	Offset	Torque (Nm)	MFR (kg/s)
5	0	0.045227	0.040421
15	0	0.064533	0.050959
25	0	0.065159	0.050482
35	0	0.070601	0.051192
5	3	0.044295	0.039693
15	3	0.059873	0.04908
25	3	0.072802	0.050929
35	3	0.071473	0.051728
5	6	0.042877	0.036565
15	6	0.073984	0.051846
25	6	0.073897	0.05246
35	6	0.073265	0.05131
5	9	0.038188	0.035497
15	9	0.040266	0.03675
25	9	0.07137	0.052238
35	9	0.074696	0.051426

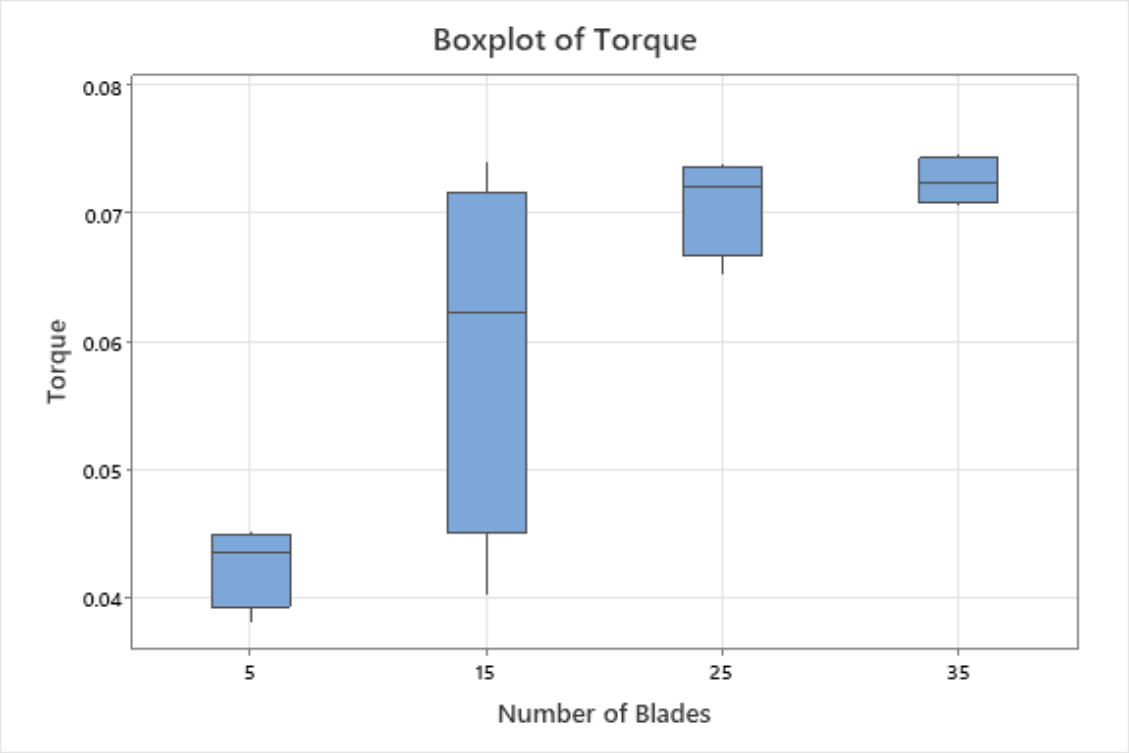


Figure 10. Torque values with the comparison of number of blades.

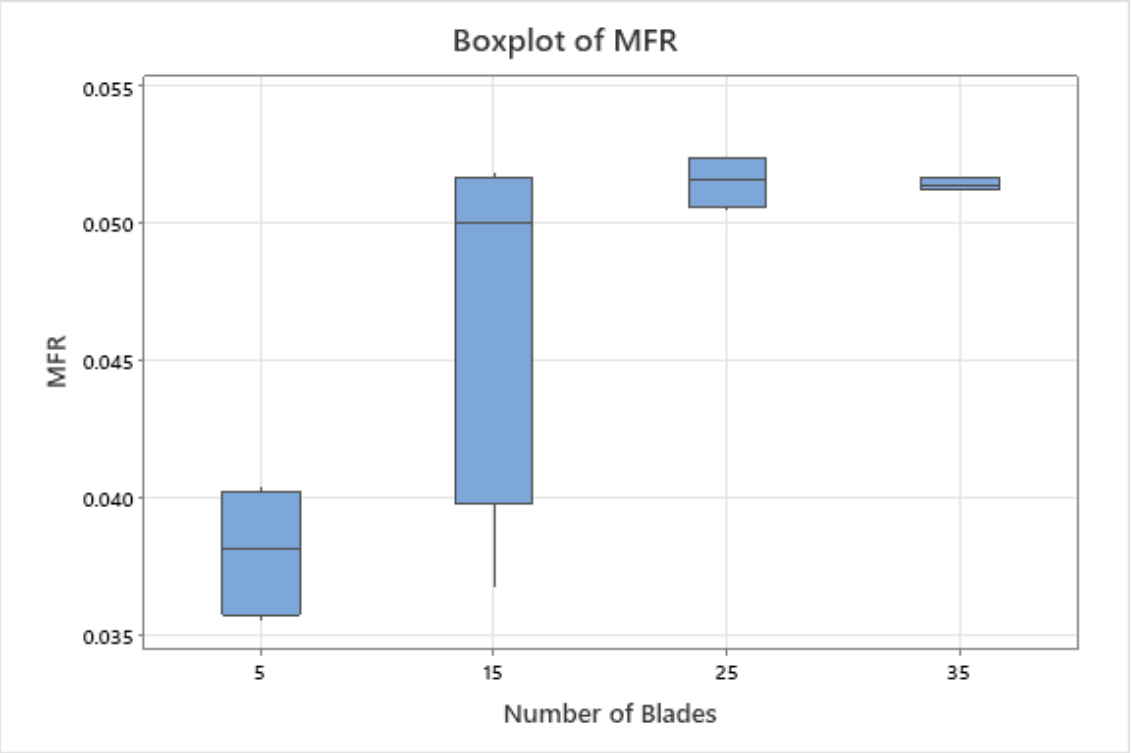


Figure 11. MFR values with the comparison of number of blades

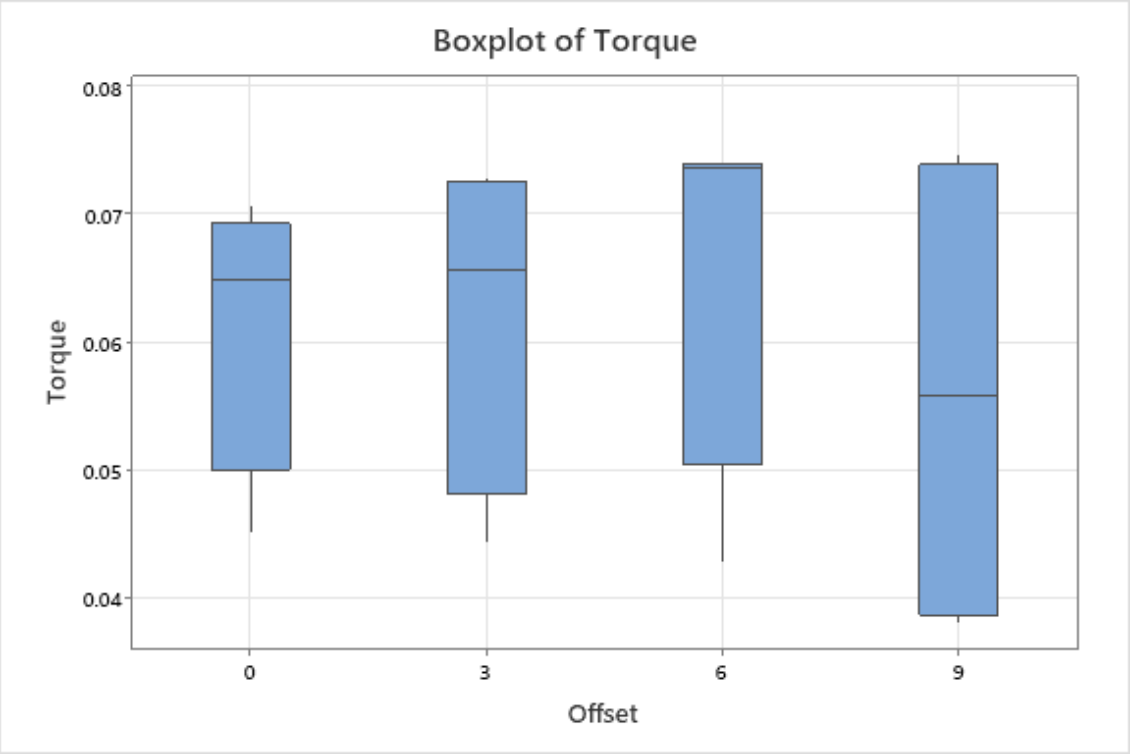


Figure 12. Torque values with the comparison of offset

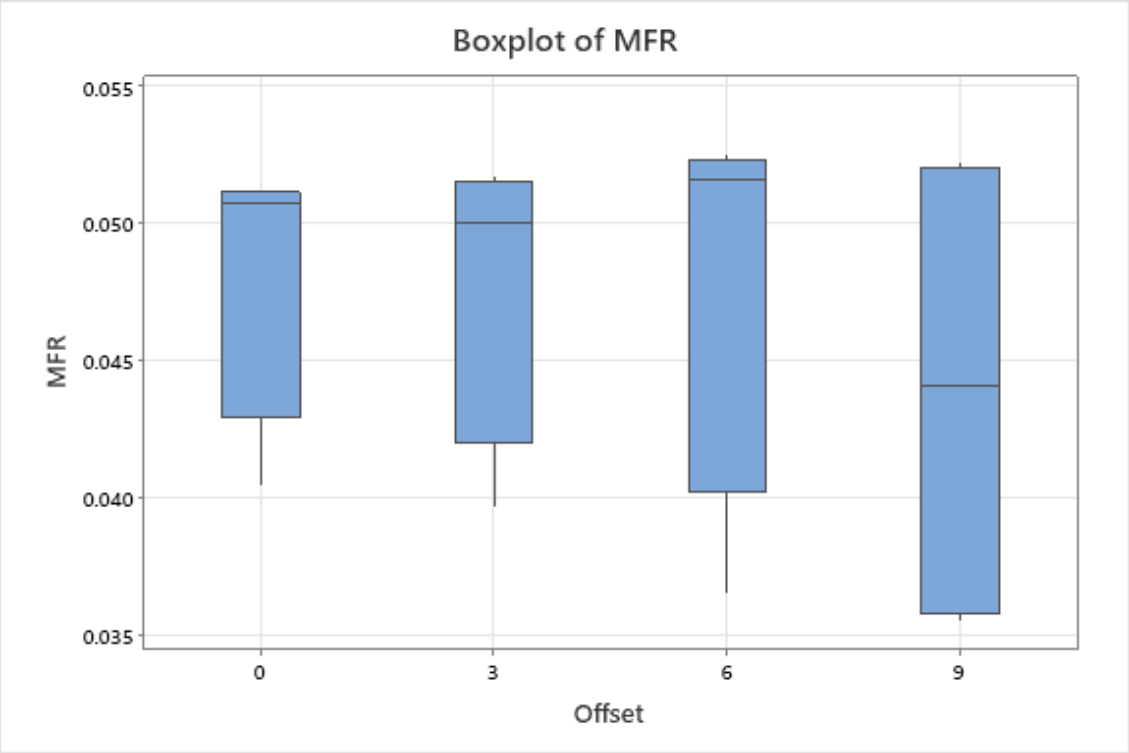


Figure 13. MFR values with the comparison of offset

Second optimization study were conducted between blade profile and number of blades, results are shared in Table 4. According to the results, curved blade profile has more torque than straight blade profile and this phrase can be copied for MFR either. Boxplots of these parameters is shown in Figure 14 and Figure 15.

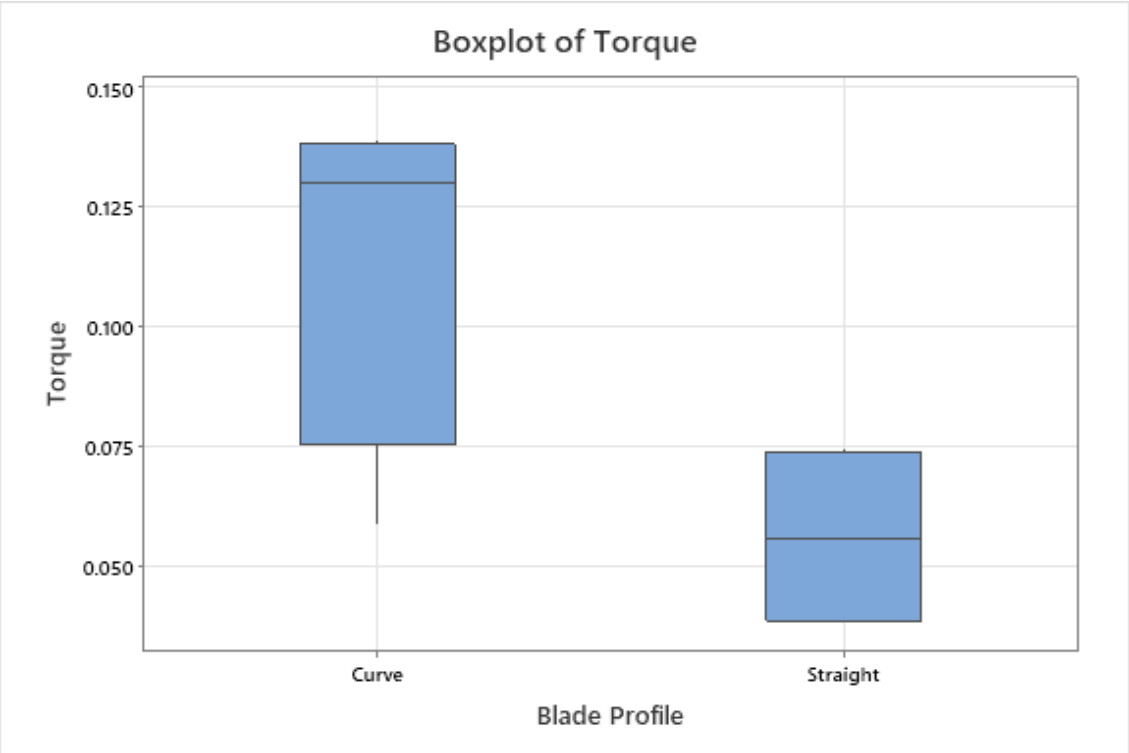


Figure 14. Blade profile and torque value comparison

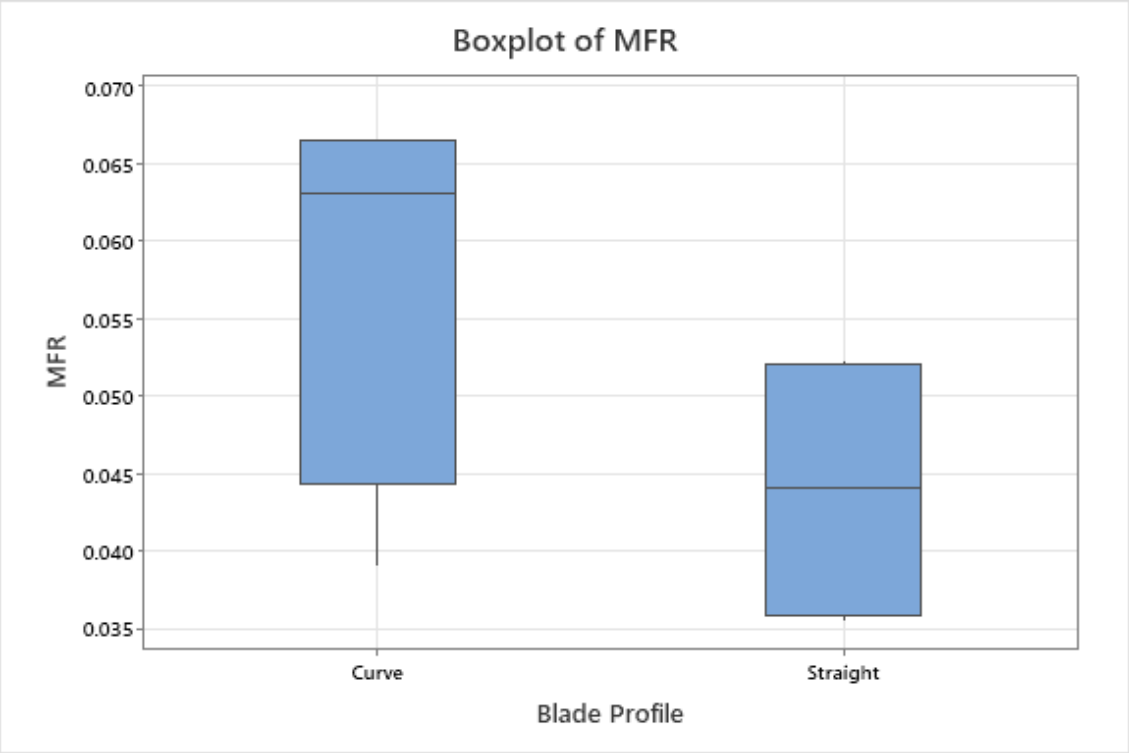


Figure 15. Blade profile and MFR value comparison

Conclusion & Future Studies

According to results, one can say that this study can distinguish good designs from the bad ones. Also it has been observed that fans with curved profile are more promising, and it is planned to proceed with this profile in future studies.

In the future, Full DoE (48 runs) will be finished and solution will be investigated deeply, definitive second DoE will be created according to results of current DoE. Further improvements, fine tuning, prototypin phase will be followed. After prototyping and tests, the appropriate model will be selected and will be homologated for the serial production.

Acknowledgement

We extend our gratitude to Renta Electric Home Appliances Industry and Foreign Trade Ltd. and our affiliated company, Haier Europe, for their contributions to our work.

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LONG-TERM BEHAVIOR OF ZEOLITE $NA_8AL_8SI_{12}O_{48}$ IN HEAT PUMP DRYER APPLICATIONS

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Abstract

In order to reduce our carbon footprint in appliances that we all use today and to leave a more clean world for the future, heat pump tumble dryers have been examined and Zeolite mineral used for absorbing humidity and possible impurities used in heat exchanger sets has been selected.The changes in the properties of $Na_8Al_8Si_{12}O_{48}$ (Zeolite XH 9) mineral, which is used in the molecular filters of heat pump tumble dryers, were examined after different cycle counts inside the machine through Scanning Electron Microscopy (SEM), X-ray Diffractometer (XRD), Brunauer-Emmett-Teller (BET), Thermogravimetric Analysis (TGA), and Fourier Transform Infrared Spectroscopy (FTIR). In these analyses, samples with virgin, 700 cycles, and 1600 cycles were used. Simulation has been conducted for 700 cycles of customer usage over 4 years and for 1600 cycles of customer usage over 10 years. These studies have been conducted to examine the ability of Zeolites to absorb potential contaminants from moisture and production processes after multiple cycles. The results revealed that the surface area decreased in proportion to the number of cycles. Additionally, blockages in the micro and mesopores were observed as the cycle count increased. Following these changes, nitrogen adsorption-desorption results showed that there was a change in capacity after the cycles. However, it was determined that this change in capacity did not affect the performance of the machine. The synthetic zeolite $Na_8Al_8Si_{12}O_{48}$ is produced by hydrothermal synthesis and hydrothermal crystallization methods. Considering this, we have determined that we can achieve the desired machine life-cycle by using less of this mineral in the heat pump tumble dryer heat exchanger sets. As a result, it has been concluded that the use of Zeolite mineral can be reduced by 35%, which would help in reducing the carbon footprint of the dryers.

Keywords: Zeolite, Scanning Electron Microscopy (SEM), X-ray Diffractometer (XRD), Brunauer-Emmett-Teller (BET), Thermogravimetric Analysis (TGA) Fourier Transform Infrared Spectroscopy (FTIR), Heat Pump Tumble Dryers.

Introduction

The need for more sustainable household appliances has become increasingly urgent as environmental concerns rise globally. Among the various household devices, tumble dryers are crucial in many households, with their primary function being the efficient drying of clothes. However, conventional dryers have high energy consumption, contributing significantly to the carbon footprint. In response to this, heat pump tumble dryers have gained significant attention as an energy-efficient alternative, as they operate by recycling the heat generated during the drying process.

Heat pump tumble dryers utilize a closed-loop system that includes key components such as the capillary, compressor, evaporator, and condenser. The heat exchanger is particularly important as it

facilitates the transfer of heat and moisture from the clothes to the air within the dryer. Zeolite, a naturally occurring mineral with a high surface area and excellent moisture-absorbing properties, has been incorporated into the heat exchangers of these machines to enhance efficiency. This mineral is especially useful in trapping humidity and impurities, improving the dryer's performance over time. However, the long-term effects of multiple drying cycles on the physical and chemical properties of zeolite within the heat exchanger system are not well understood.

This research aims to investigate the impact of extended usage cycles on the properties of Zeolite XH 9, a synthetic zeolite mineral, used in the molecular filters of heat pump tumble dryers. The study will analyze the structural and thermal changes in zeolite after 700 and 1600 cycles, simulating typical customer usage over 4 and 10 years, respectively. Various analytical techniques, including Scanning Electron Microscopy (SEM), X-ray Diffractometer (XRD), Brunauer-Emmett-Teller (BET), Thermogravimetric Analysis (TGA), and Fourier Transform Infrared Spectroscopy (FTIR), will be employed to evaluate changes in surface area, pore structure, and overall capacity.

The ultimate aim of this study is to determine whether zeolite usage in heat pump tumble dryers can be reduced without compromising machine performance, thereby contributing to the reduction of the appliance's environmental footprint.

Materials and Methods

Zeolite Material Description

In this study, the synthetic zeolite used is $Na_8Al_8Si_{12}O_{48}$, a form of Zeolite XH 9, which is hydrothermally synthesized through a controlled crystallization process. This zeolite is selected for its superior moisture adsorption properties and thermal stability, making it an ideal candidate for use in the heat exchangers of heat pump tumble dryers. Unlike natural zeolites, this synthetic variant offers a uniform pore distribution, allowing for more predictable performance in moisture adsorption across various conditions.

To assess the long-term effects of repeated cycles on zeolite, three distinct sample groups were analyzed:

Untreated Zeolite (Virgin): The base material, not subjected to any operational cycles.

Zeolite after 700 cycles: Simulating approximately four years of regular household use, this sample was exposed to typical drying conditions (temperature and humidity fluctuations, varied clothing types).

Zeolite after 1600 cycles: This group reflects a scenario of intense usage over ten years, with each cycle replicating the average conditions found in high-frequency domestic drying operations.

Each zeolite sample was sourced from heat pump tumble dryers that underwent accelerated life cycle testing. The testing conditions, including temperature, moisture content, and load weight, were precisely controlled to match typical consumer behavior as closely as possible.

Analytical Methods

The investigation of the physical and chemical changes in zeolite was carried out using several high-resolution analytical techniques, detailed as follows:

Scanning Electron Microscopy (SEM): SEM was employed to closely examine the surface morphology of the zeolite particles post-cycling. Images were captured at varying magnifications to reveal any physical damage, pore blockages, or particle agglomeration due to prolonged moisture exposure.

X-ray Diffraction (XRD): XRD was utilized to probe the crystalline structure of the zeolite. By comparing diffractograms before and after cycling, we identified any shifts in crystallinity or the formation of new phases that might indicate structural degradation after extensive use.

Brunauer-Emmett-Teller (BET) Surface Area Analysis: BET surface area measurements were conducted to assess any significant changes in the zeolite's porosity, particularly focusing on pore volume reduction or surface area collapse. Nitrogen adsorption-desorption isotherms were collected and analyzed, with a focus on identifying the impacts of moisture retention over prolonged cycles.

Thermogravimetric Analysis (TGA): TGA was performed to observe changes in the thermal stability and moisture holding capacity of zeolite after multiple cycles. Weight loss data, particularly in relation to moisture evaporation, were used to assess the retention of absorbed contaminants over time.

Fourier Transform Infrared Spectroscopy (FTIR): FTIR spectra were analyzed to detect chemical changes in the zeolite framework. This method helped to determine whether any additional impurities or contaminants were absorbed into the structure after several drying cycles, potentially affecting the zeolite's functionality.

Results and Conclusion

This study has systematically examined the aging effects on Zeolite XH 9 used in the molecular filters of heat pump tumble dryers. Through 0 (unused), 700, and 1600 drying cycles, a series of material characterization methods were applied to assess structural, morphological, and adsorption-related changes.

SEM-EDS Findings

SEM images revealed a clear evolution of surface morphology across usage cycles. The unused zeolite showed a uniform and porous structure, while after 700 cycles, minor surface irregularities emerged. After 1600 cycles, noticeable pore blockage, surface cracks, and carbon-based impurities were observed, indicating contamination and degradation of adsorption efficiency.

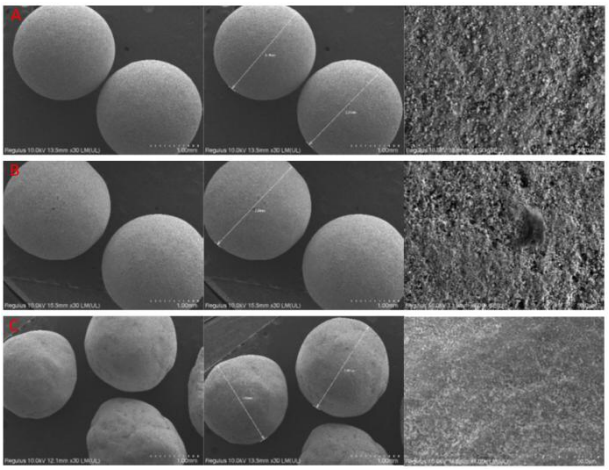

Figure 1. SEM images of zeolite samples: (a) Unused, (b) 700 cycles, (c) 1600 cycles.

XRD and FTIR Results

XRD patterns confirmed the persistence of the Zeolite-A crystalline structure across all usage levels, suggesting structural stability despite surface degradation.

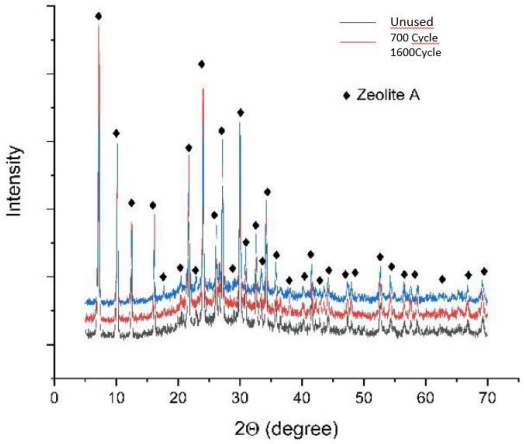

Figure 2. XRD diffractograms of zeolite samples showing no phase changes, confirming stability.

Similarly, FTIR spectra showed no significant changes in the functional groups, indicating that chemical bonding within the framework remained intact despite impurities.

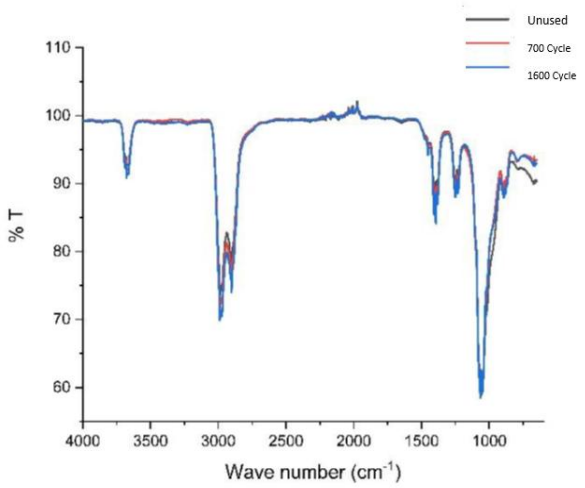

Figure 3. FTIR diffractograms of zeolite samples showing no phase changes, confirming stability.

BET Surface Area and Porosity Analysis

BET results displayed a substantial decline in surface area from 18.28 m²/g (unused) to 4.44 m²/g (1600 cycles), while average pore radius increased. These changes imply micropore filling and partial mesopore blockage.

Table-1. BET Analysis results of samples

Property	Unused	700 Cycles	1600 Cycles
Surface Area (m²/g)	18.28	8.66	4.44
Avg. Pore Radius (nm)	5.45	8.55	9.02
Pore Volume (cc/g)	0.056	0.036	0.025
Micro Pore Volume	1.85e-5	0	0

Nitrogen adsorption-desorption isotherms showed a consistent drop in adsorption capacity, further supporting surface area and pore structure degradation.

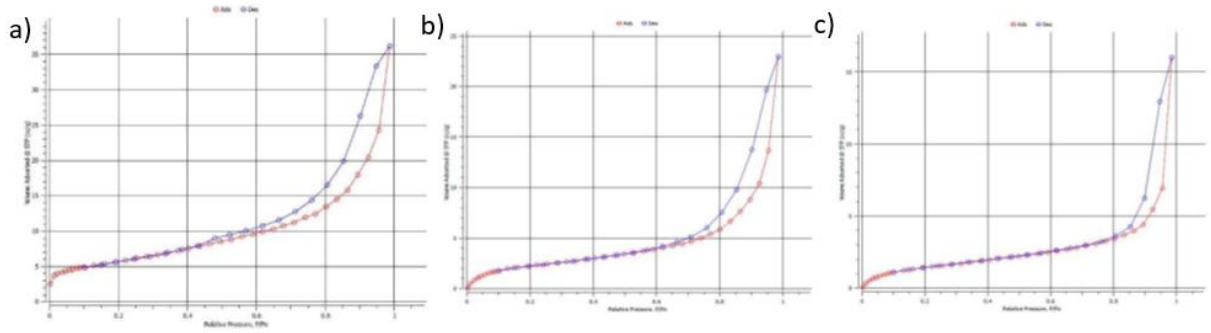

Figure 4. Nitrogen adsorption-desorption graphs of samples, (a) Unused, (b) 700 cycle, (c) 1600 cycle

TGA Analysis

Thermogravimetric analysis confirmed that moisture and contaminant retention increased with usage. The 1600-cycle sample exhibited the highest mass loss upon heating, indicating poor thermal desorption behavior.

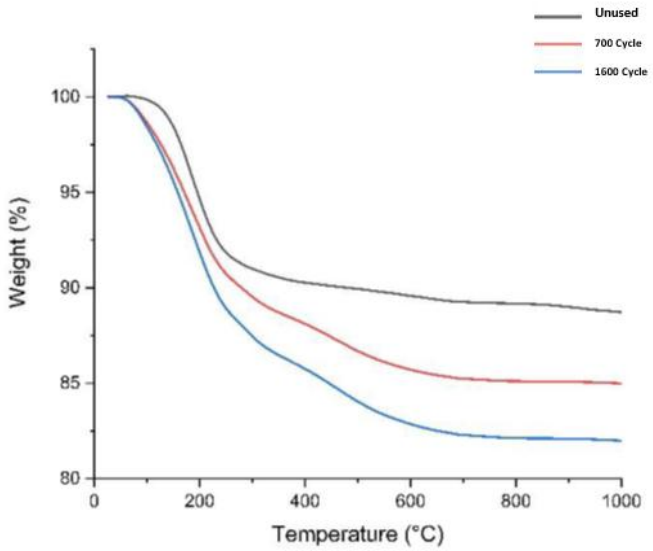

Figure 5. TGA graphs of zeolite samples.

Conclusion

The findings of this study indicate that it is possible to reduce zeolite content by up to 35% in the molecular filters of heat pump tumble dryers without impairing the device's drying efficiency or moisture adsorption performance. Such a reduction not only preserves the functional integrity of the system throughout its operational lifespan but also offers a tangible benefit in terms of environmental sustainability. By minimizing the consumption of synthetic zeolite—a material that requires energy-intensive production—this adjustment contributes directly to lowering the carbon footprint associated with manufacturing and disposal processes. Hence, this research highlights a promising avenue for optimizing material usage in consumer appliances while aligning with broader goals of eco-efficiency and circular resource management.

Acknowledgement

We extend our gratitude to Renta Electric Home Appliances Industry and Foreign Trade Ltd. and our affiliated company, Haier Europe, for their contributions to our work.

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ROBUST NON-LINEAR CONTROL OF A DOUBLY-FED INDUCTION GENERATOR

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Abstract

In this presentation the principle of direct vector control using oriented stator flux is presented, applied to a doubly-fed asynchronous machine. The decoupling of currents in a rotating reference frame is discussed, and a conventional PI regulator is implemented for control. To improve performance, fuzzy logic control is introduced and a fuzzy PI controller based on "Mamdani" technique is evaluated, showing superiority over the classical PI regulator in terms of dynamics and robustness against parameter variations. Furthermore, type-1 fuzzy logic is replaced with type-2 fuzzy logic to better handle uncertainties, with its effectiveness in maintaining speed regulation and stator flux orientation demonstrated under varying conditions. Finally, type-2 fuzzy control is shown to be robust against external disturbances and parameter changes.

Keywords – Double fed induction generator (DFIG), Proportional and integral controller, type-1 fuzzy logic controller, type-2 fuzzy logic controller.

OPTIMIZING HARMONIC REDUCTION AND VOLTAGE OUTPUT IN INDUCTION MOTORS USING SVPWM WITH VFD

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ABSTRACT

Induction motors are widely used in various applications due to their reliability, low cost, and durability. However, many of these motors are limited in their ability to operate at variable speeds. Recent advancements in motor speed regulation have addressed this limitation in electric drives. These advancements are achieved through Variable Frequency Drives (VFDs), which convert a DC input into a three-phase AC output signal with adjustable frequency and amplitude. This paper explores the application of the Space Vector Pulse Width Modulation (SVPWM) technique for controlling induction motor speed. A software model for this method was developed using MATLAB/Simulink, and a detailed description of the subsystems is provided. The simulation results for various voltage signals (line, phase, and pole voltages) and stator currents are presented. Simulations were carried out at different modulation indices and switching frequencies (2.5 kHz and 5 kHz), with additional tests at frequencies of 8 kHz, 13.5 kHz, and 20 kHz for the stator current. The results show that the SVPWM technique effectively reduces harmonic distortion (THD%) while improving the fundamental voltage output. In the linear modulation region, the technique yields an output of 90.7%. In the over-modulation region, two operational modes are observed: Mode I, with an output ranging from 90.7% to 95.2%, and Mode II, which provides an output from 95.2% to 100%.

Keywords: VFD, Modulation, SVPWM, Reference Vector over-modulation,

INTRODUCTION

Today most of the appliances and machines in the world work on AC power. In the absence of AC power, there should be some way to convert DC power to AC power. This conversion is done by the power electronic circuit called the Inverter. The basic function of a power inverter is to change DC input voltage to a symmetric AC output voltage of the desired magnitude and frequency. In Pulse Width Modulation (PWM) technique, pulses of constant amplitude but different duty cycles are generated by modulating the time periods (Gupta, 2017).

These output waveforms are desired for many applications, in adjustable speed drives (ASD), uninterruptible power supplies (UPS), active filters, and second generation of flexible AC transmission systems (FACTS). Space vector modulation is one of the most preferred PWM strategies

today, because of it is easier digital realization, best DC bus utilization and less THD in output voltages. With the development of microprocessors, SVPWM became one of the most important PWM techniques for three-phase inverter (Gussay Abdalrahman, 2018).

SVPWM FOR TWO-LEVEL VSI (VOLTAGE SCOURCE INVERTER)

In figure 1 it is shown the two-level VSI composes of DC input at the entry, inverter bridge, a switch driver and the motor at the output. The function of this inverter is to convert a DC input voltage into a Three-Phase AC output voltage, with desirable magnitude and frequency. This is achieved by switching these semiconductor devices (IGBTs) to create an AC waveform (Lan Dongdong, 2019). There are 2 switches (IGBTs) in one leg, there are six IGBTs in total. One phase in generated from one leg. With these six switches there can be eight switching combinations (Ranganathan, 1997). The principle operation of SVPWM technique is based on the 8 switching combinations of a three-phase inverter. When the upper switches (S_1, S_3, S_5) are turned ON, the lower switches (S_4, S_6, S_2) must be turned OFF, they have to work in a complementary manner to avoid the short circuit. The output voltage is determined by "ON" state of upper switches (Ayse KOCALMIS BILHAN).
Usually IGBT is employed as switches and can be turned ON and Off based from gate pulses. Three phases are shifted for 120-degree and conduction mode requires only two transistors to be turned-on at every 60-degree duration and performs the six mode of operation within one cycle. Thus, major advantage of using 120-degree conduction mode is less susceptible to short circuit. (Ayse KOCALMIS BILHAN).

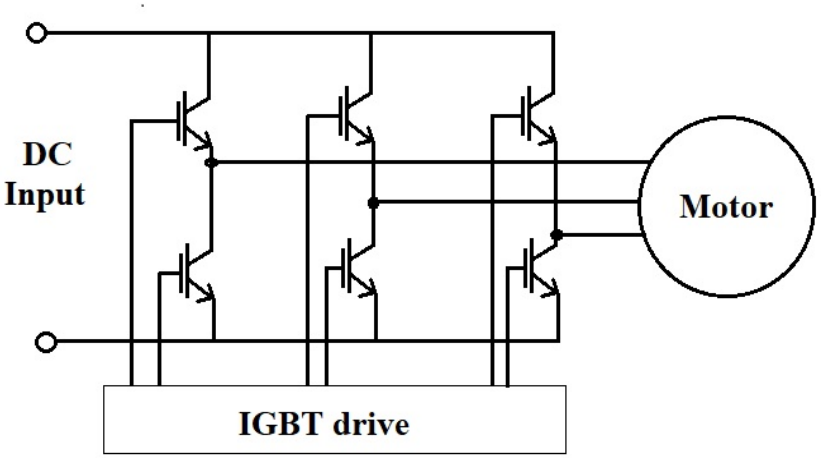

Figure 1 - Three-Phase Sinusoidal PWM Inverter.

Figure 2 shows the graphical representation of basic switching vectors and sectors. The main idea of SVPWM is to convert the eight switching combinations into αβ plane and then to divide the 2D plane into six equal areas, each of them is called sector. Sectors are determined by vectors. There are eight vectors $\vec{V}_0$ to $\vec{V}_7$ in which six of them are called active vectors and two vectors are called zero (inactive) vectors. Zero vectors are in coordinate $\vec{V}_0(000)$ and $\vec{V}_7(111)$. Six vectors are in $\vec{V}_1(100)$, $\vec{V}_2(110)$, $\vec{V}_3(010)$, $\vec{V}_4(011)$, $\vec{V}_5(001)$ and $\vec{V}_6(101)$ respectively. In Figure 2, $\vec{V}_{ref}$ is the reference voltage vector and here its magnitude and frequency are used to control the magnitude and frequency of fundamental voltage. The reference space vector is synthesized by switching two active vector and one or two zero vectors. The determination of switching pattern may be achieved by space vector modulation based on the representation of switching vector in αβ plane (ANUGU SARITHA, 2016).

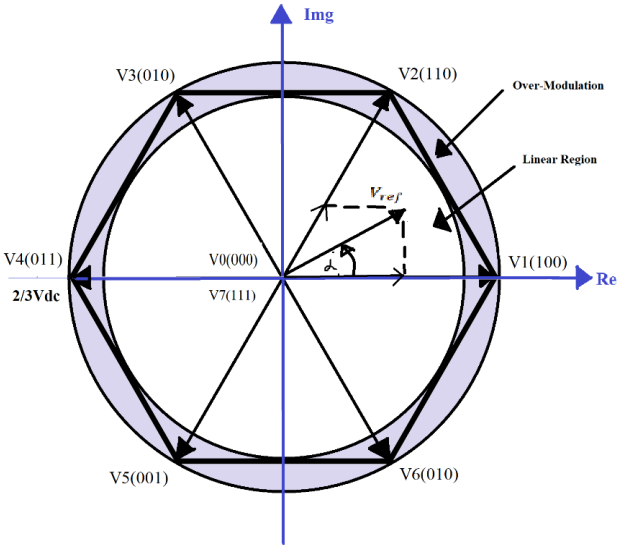

Figure 2 - Under-modulation and Over-modulation regions in Space Vector representation.

Three-phase to Two dimensional αβ-plane: The three-phase reference vector can be represented from a 3-dimensional plane onto a 2-dimensional plane known as the $\alpha\beta$ - plane. "α" corresponds to the vertical axis, while "β" corresponds to the horizontal axis (Avinash Mishra, 2014)**.**

In this 2-dimensional plane, the position of the reference vector can be determined. based on the switching combinations of the inverters, the phase voltages can be transformed into the $\alpha\beta$-plane coordinates (Mafasigodo, 2014).
The reference voltage can be expressed as:

$$\vec{V}_{ref} = \begin{pmatrix} V_\alpha \\ V_\beta \end{pmatrix} = \frac{2}{3}\begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{(3)}}{2} & -\frac{\sqrt{(3)}}{2} \end{pmatrix}\begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} (1)$$

Therefore, the modulation index is (WU, 2006)**:**

$$MI = \frac{\vec{V}_{ref}}{V_{\max\_sixstep}} = \frac{\frac{2}{3}V_{dc} * \cos 60°}{\frac{2}{\pi}V_{dc}} = \frac{\frac{2}{3}V_{dc} * \frac{\sqrt{3}}{2}}{\frac{2}{\pi}V_{dc}} = 0.907\,(2)$$

Over-modulation Mode I

Over-modulation occurs when the magnitude of the reference space vector is greater than the $Vdc/\sqrt{3}$ (at 30°) causing the end of the vector to be located outside of hexagon (M. Kubeitari, 2012).

Therefore, the trajectory of the reference voltage vector intersects the hexagon at two points for each sector as shown in figure 3. Operating in overmodulation area, the inverter cannot generate the output voltage as large as the voltage reference since the provided maximum output is limited up to the sides of the hexagon (Dong-Choon Lee, 1998).

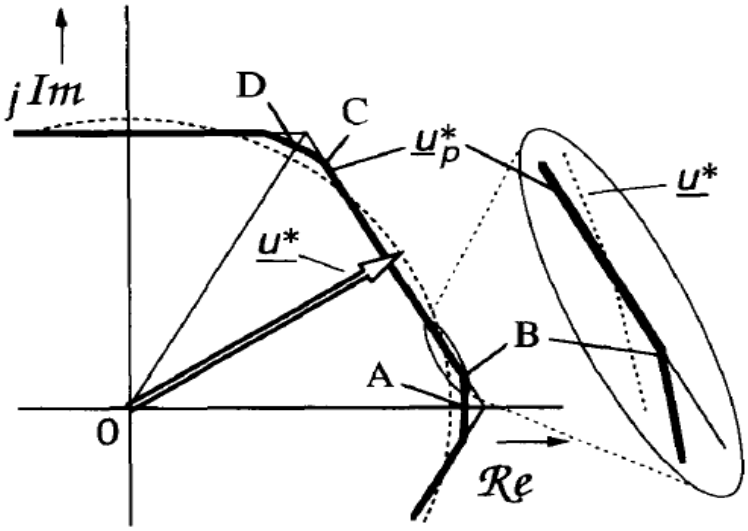

Figure 3 - Overmodulation mode I.

In this mode, the preprocessor changes the amplitude of the reference while the angle is transmitted without any change $(\alpha_h = \alpha)$. To illustrate this, Fig. 3 shows one of the $60°$-sectors of complex plane. The dashed circle is the required reference trajectory $\vec{V}_{ref}$ (u^*). The solid line u_p^* is the trajectory generated by the preprocessor, observing the physical constraints inherent to the inverter. Whenever the reference track is within the hexagon, near the outer comers of a sector on curve-length A-B in Fig. 3, the inverter control selects the adjacent active switching state vectors or the zero state. This corresponds to sinusoidal modulation, and the ON-durations are calculated using (Kumar, 2019):

$$T_a = \sqrt{3}T_s \frac{\vec{V}_{ref}}{V_{dc}} \sin\left(\frac{\pi}{3} - \theta\right)(2) T_b = \sqrt{3}T_s \frac{\vec{V}_{ref}}{V_{dc}} \sin(\theta)(3)$$

$$T_0 = T_s - T_a - T_b(4)$$

However, when the original reference trajectory passes outside the hexagon, the time average equation (2, 3 and 4) gives an unrealistic ON-duration for the zero vector. Hence, only the two adjacent active switching state vectors are switched alternately. During this process the average voltage trajectory moves along B-C which coincides with the hexagon. Finally, the trajectory of $\vec{V}_{ref}$ (u^*) reaches the point C near the other vertex. The reduced fundamental component in this region is compensated by a higher fundamental on the A-B path. The ON-durations for the B - C path are calculated by (Joachim Holtz, 1993):

$$T_a^` = T_z \frac{T_a}{T_a + T_b}(5)$$

$$T_b^` = T_z \frac{T_a}{T_a + T_b}(6)$$

$$T_0^` = 0(7)$$

Therefor the reference vector $\vec{V}_{ref}$ is (Dong-Choon Lee, 1998):

$$\vec{V}_{ref}T_z = \vec{V}_1T_a + \vec{V}_2T_b(8)$$

$$\vec{V}_{ref}^{`}T_z = \vec{V}_1T_a^{`} + \vec{V}_2T_b^{`}(9)$$

$$\vec{V}_{ref}^{`} = \left(\frac{T_z}{2(T_a+T_b)}\right)\vec{V}_{ref}^{`}(10)$$

Over-modulation Mode II:

In this range, the modulation index further increases from its initial value $m_i = 0.953$ to $m_i = 1$. While the trajectory of the reference signal $\vec{V}_{ref}$ (u^*) always remains a circle, the trajectory of u_p^* changes gradually from a continuous hexagon to the discrete six-step switching sequence. The demonstration of how this is achieved is easier understood if operation in the six-step mode. The demonstration of how this is achieved is easier understood if operation in the six-step mode is considered first, working then backwards to the continuous hexagonal trajectory of mode I. The six-step mode is characterized by holding that particular switching state vector which is closest to the reference vector for $1/6$ of the fundamental period. While the reference vector $\vec{V}_{ref}$ (u^*) moves along a circle with fundamental angular frequency, u_p^* remains fixed at the vertex. As the angle of the reference u_p^* reaches a value $\left(\alpha = \frac{k\pi}{6}, k = 0,1,2,3,4,5\right)$ U_p^* is switched to the next active switching state. This way, the modulator generates the six-step waveform and the maximum possible voltage of the inverter is available at $m_i = 1$. Such switching method is characterized by a hold angle, which controls the time interval the active switching state remains at the vertices, and the respective switching times of two active switching states controlling the motion along the hexagon (MANOJ KUMAR MODI, 2013)**.**

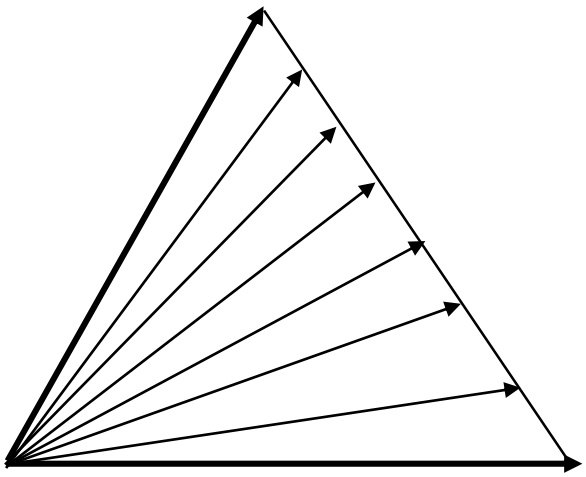

Figure 4 - Average voltage vectors produced by zone-I and zone-II.

The current distorsion can be reduced by increasing the switching frequency. The maximim switching frequency is dictated by the switching devices and can not be arbitrarily increased. In figure 5 we can

see that for a given switching frequency, the current distortion increases with the modulation index. (Joachim Holtz, 1993).

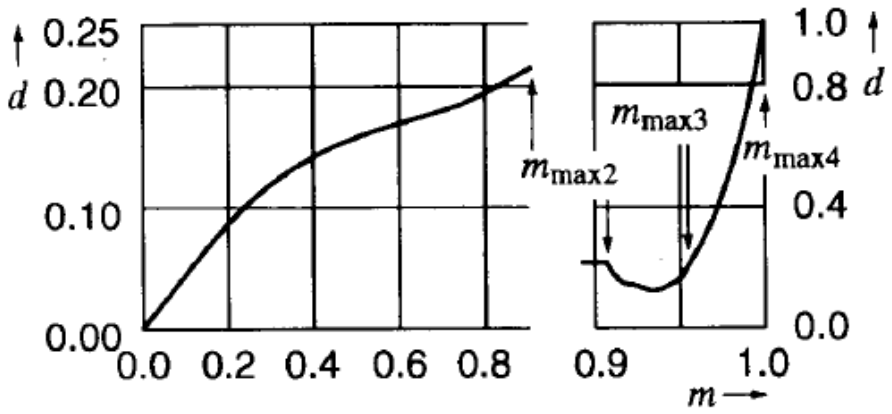

Figure 5- Distortion factor versus modulation index.

SIMULATION OF SVPWM IN MATLAB/SIMULINK

This chapter will discuss the implementation of the SVPWM method in the MATLAB/SIMULINK program**.** It should be noted that this method is presented in two types of modulation regions, under-modulation (linear modulation) and over-modulation (Mod I and Mod II). For this system, the subsystems are presented in details, showing the role of each of them. It is worth noting that no filters were used to filter the frequency output signal (VFD), but we analyze how the non-linear load (motor) at the output plays the role of the filter at high frequencies (it has an inductive character).

SVPWM Model:

Figure 6 shows the SVPWM model built in Matlab/Simulink which is composed of 7 blocks (sub-systems) through which transformations occur. Above, in every block there are numbers (in red color) showing the order on sub-systems and its function.

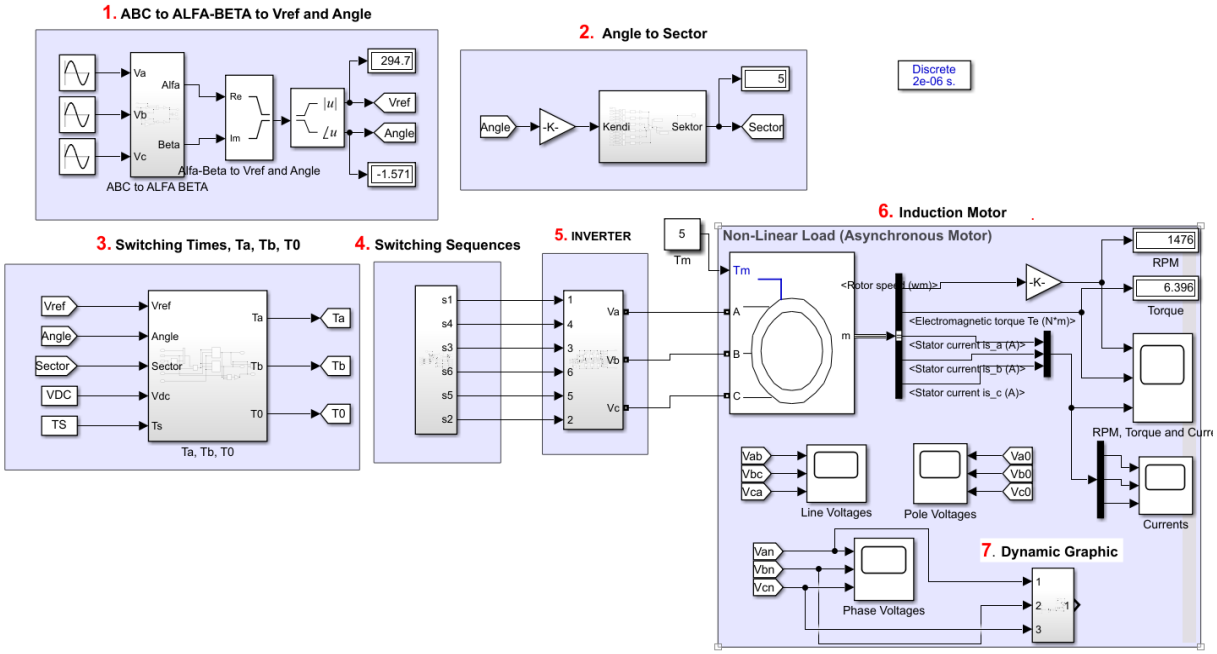

Figure 6 - SVPWM Model Matlab/Simulink.

The waveforms of simulation are presented in figure 7, where it shows the RPM (first waveform), electromagnetic torque (second waveform) and stator currents (third waveforms).

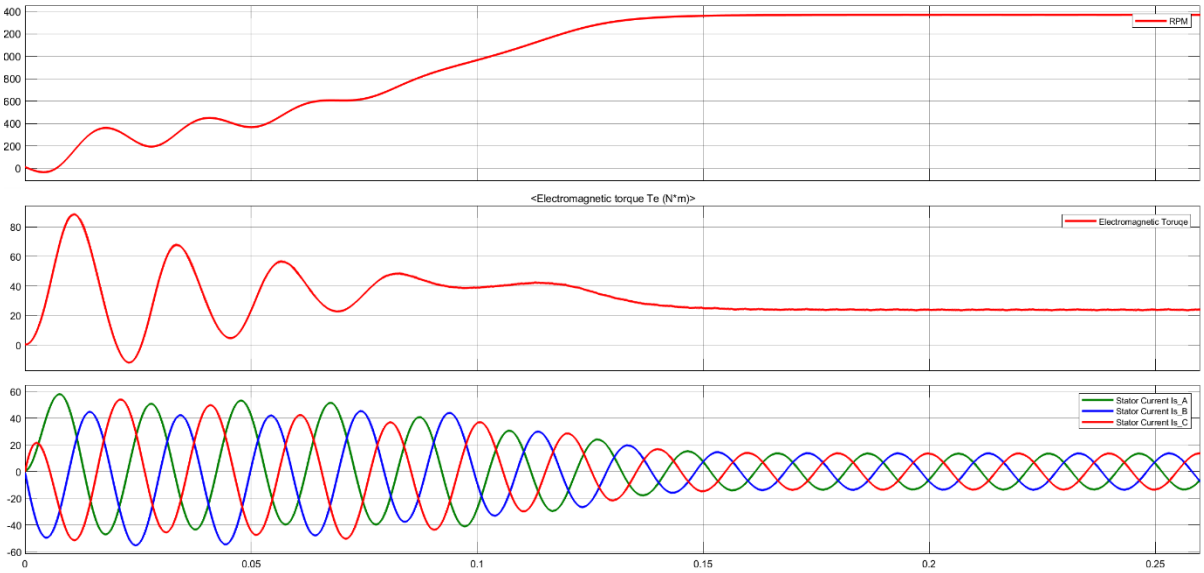

Figure 7 - RMP, Electromagnetic Toruqe, Stator Currents.

The simulation was carried out under the following conditions:

Switching frequency $f_{sw} = 2050Hz$

Inverter frequency $f_{inv} = 50Hz$

Modulation Index $m_i = 0.906$

Motor parameters: 4kW, 400V, 50Hz, 1430RPM

RESULTS AND DISCUSSION

From figure 8 and table 1 we notice that at low frequencies we have the presence of some harmonics which compared to the fundamental harmonic they have low values. Then the presence of harmonics appears in the 48th and 52nd harmonics which have more emphasized values and these stresses appear in the 98th and 102nd harmonics but have halved values compared to the previous harmonics. It is observed that at high frequencies, the harmonics only begin to soften and are "eliminated".

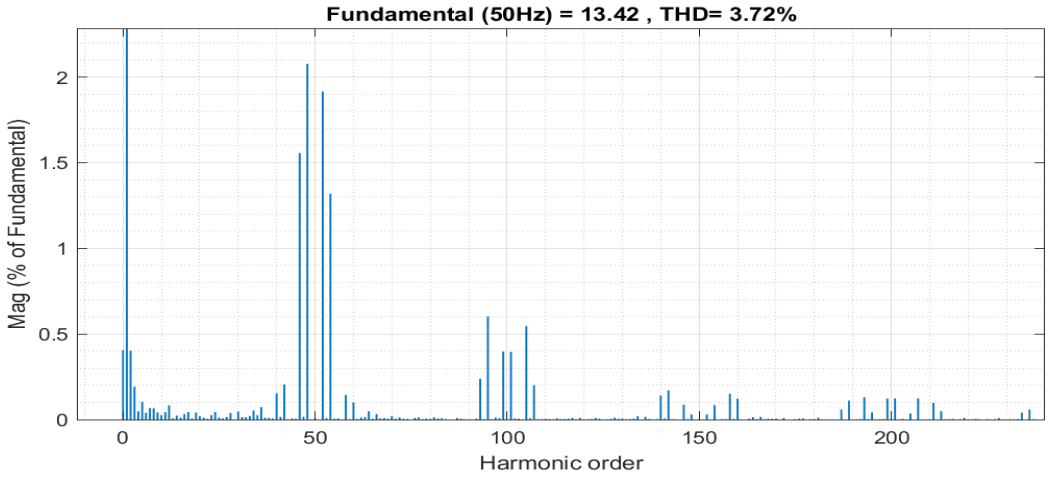

Figure 8 - The spectrum of I_s at the frequency of $2500H_z$.

With the increase of the switching frequency to 5000 Hz, the 48th and 52nd harmonics, which were present in figure 8, have moved to higher orders, to the 98th and 102nd harmonics, thus halving the amplitudes. While the 98th and 102nd harmonics that were present in figure 9 are also shifted to higher frequencies.

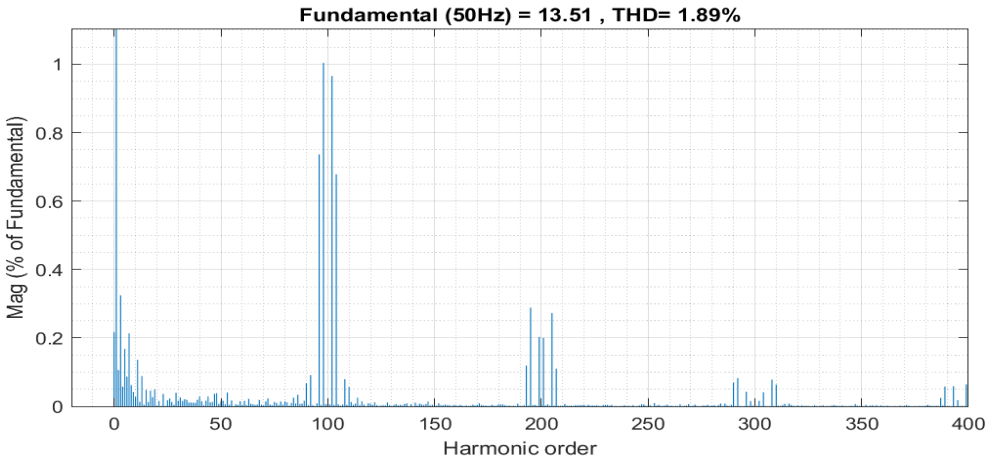

Figure 9 - The spectrum of I_s at the frequency of $5000H_z$.

This phenomenon is also observed in table 1 in which the fundamental values and the THD are presented. It can be seen that the transition from 2500 Hz to 5000 Hz results in a decrease in amplitudes, an increase in the value of the fundamental from 13.42 to 13.51 and a decrease in the overall THD almost half of the initial value from 3.72% to 1.89%.

Table 1 - Current I_s in linear region of SVPWM

(Hz)	THD(%)	Fund.	h2	h3	h4	h48	h50	h52	h98	h100	h102
2500	3.72	13.42	0.62	0.24	0.04	2.07	0.01	1.91	0.40	0.00	0.39
5000	1.89	13.51	0.11	0.32	0.06	0.04	0.01	0.01	1.01	0.01	0.97
8000	1.53	13.61	0.40	0.22	0.03	0.03	0.01	0.02	0.01	0.01	0.00
13500	1.24	13.63	0.81	0.26	0.18	0.02	0.01	0.02	0.01	0.01	0.00
20000	0.86	13.73	0.22	0.14	0.18	0.02	0.01	0.02	0.01	0.00	0.01

With the increase of the switching frequency, then the order of the harmonics would have shifted as:

f_{sw}=8000 Hz --------- > h158=0.62 h160=0.00 h162=0.60

f_{sw}=13500 Hz ----------> h268=0.36 h270=0.00 h272=0.13

f_{sw}=20000 Hz ----------> h398=0.12 h400=0.00 h402=0.11

Figure 10 and table 2 present the results of V_{a0} pole voltage harmonics in the linear region of the SVPWM. In table 2, five (5) modulation indices are presented which starts with the value in the linear region of the SPWM and ends in the linear region of the SVPWM.

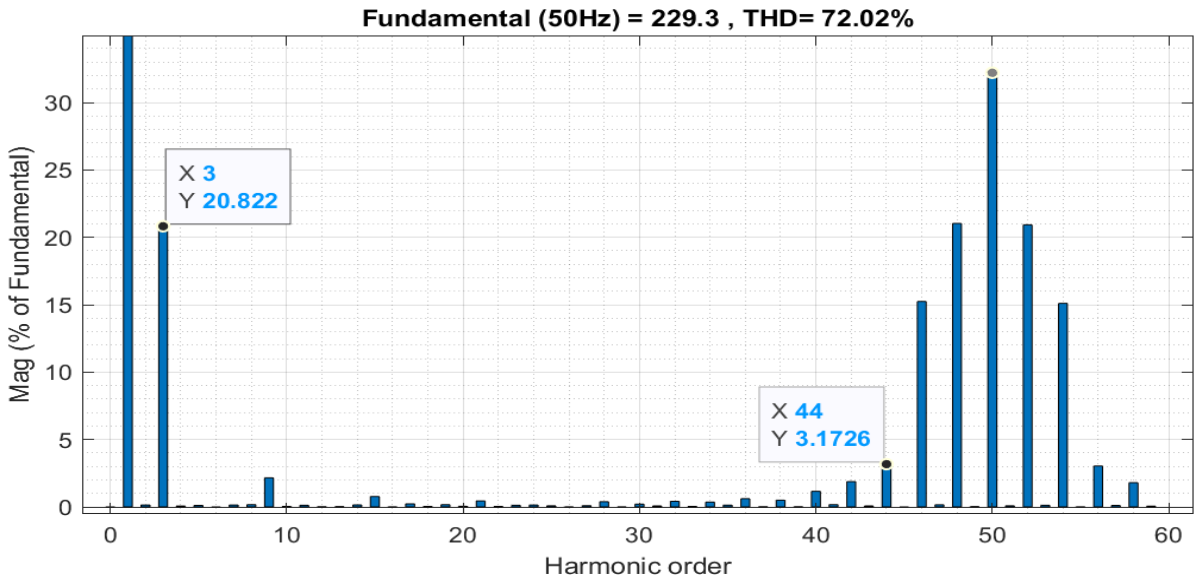

Figure 10 - Spectrum of V_{a0} for SVPWM in the linear modulation region.

For small value of modulation index corresponds to high value of THD. In figure 10 it is also observed that the 40th, 42nd, 56th and 58th harmonics contain values but the values are smaller than 6 volts.

Table 2 - Harmonics of V_{a0} for SVPWM in the Linear modulation region.

MI	THD(%)	Fund.	h3	h46	h48	h50	h52	h54
0.775	103.47	196.4	20.44	13.30	19.30	58.89	19.30	13.37
0.785	100.96	198.9	20.87	13.93	19.24	56.52	19.25	13.87
0.806	95.58	204.3	20.89	14.30	19.59	51.73	19.58	14.20
0.856	84.05	216.3	20.56	14.33	20.39	41.91	20.51	14.46
0.906	72.02	229.3	20.82	15.25	21.03	32.21	20.93	15.11

Table 3 presents the harmonic results of the pole voltage V_{a0} in the overmodulation region of mode I of SVPWM. If compared with table 2, which represents the linear region of SVPWM, it can be observed that the harmonic spectrum appears similar at first glance; however, in the overmodulation region, the THD is lower, and the fundamental voltage increases with the increase of the modulation index.

Table 3 - Pole voltage - Harmonics of V_{an} for SVPWM in over-modulation region Mode I.

MI	THD(%)	Fund.	h3	h46	h48	h50	h52	h54
0.912	103.47	230.5	20.50	15.02	21.26	31.50	21.19	14.90
0.932	100.96	234.6	20.70	14.86	21.13	28.48	21.14	14.89
0.952	95.58	237.3	21.03	14.79	20.99	26.58	21.01	14.81

Table 4 presents the harmonic values in the overmodulation region of mode 1I of SVPWM. It can be observed that the THD values decrease and the fundamental voltage increases further with the increase in the modulation index up to the maximum value of $m_i = 1$.

Table 4 - Pole voltage - Harmonics of V_{an} for SVPWM in over-modulation region Mode II.

MI	THD(%)	Fund.	h3	h46	h48	h50	h52	h54
0.963	63.86	238.2	21.28	14.80	20.88	25.88	20.79	14.71
0.983	62.09	240.1	21.53	14.54	20.59	24.48	20.63	14.60
1.00	59.22	243.1	22.60	14.21	19.68	21.91	19.64	14.13

Table 5 - V_{ab} in linear modulation region of SVPWM..

MI	THD(%)	Fund.	h3	h46	h48	h50	h52	h54
0.785	69.07	344.5	0.17	13.76	19.31	0.05	19.40	13.82
0.806	67.06	351.0	0.03	13.92	19.46	0.11	19.48	13.82
0.856	60.35	373.1	0.05	14.44	20.29	0.08	20.29	14.46
0.906	52.99	397.4	0.12	15.06	21.05	0.06	21.04	15.01

Table 6 - V_{an} in over-modulation region Mode I of SVPWM.

MI	THD(%)	Fund.	h3	h46	h48	h50	h52	h54
0.912	52.38	230.5	0.22	15.09	21.15	0.12	21.14	14.99
0.932	50.07	234.7	0.06	14.98	21.07	0.08	21.05	15.01
0.952	48.65	237.3	0.01	14.79	20.99	0.03	20.97	14.83

Simulations on the 2D dynamic graph.

Figure 11 shows two circles representing the operating regions of the two methods. The smaller circle represents the linear operating region of the SPWM method, while the larger circle represents the SVPWM method. The distances between the points labeled O, P, Q, R, and S in this figure indicate the segments over which the vectors extend and represent the maximum values achieved by these methods.

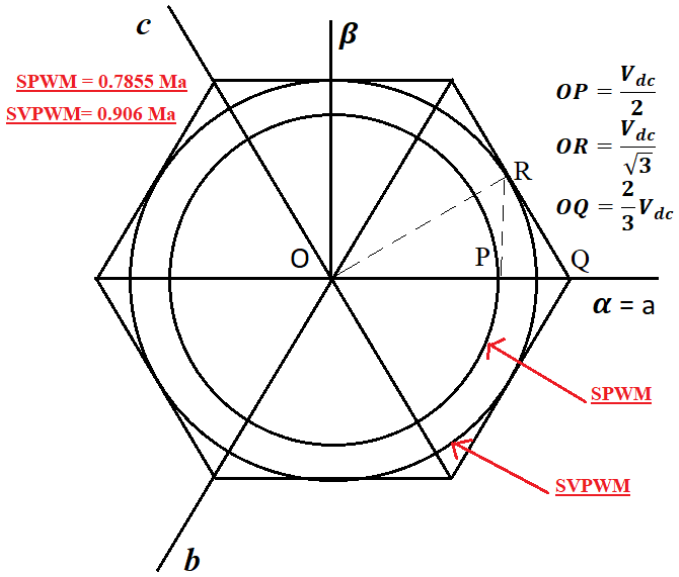

Figure 11 - The SPWM and SVPWM waveforms for maximum voltage values.

Segment *OP* presents the maximum value of SPWM:

$$OP = RO\ x\ \cos 30° = \frac{V_{dc}}{\sqrt{3}}\ x\ \frac{\sqrt{3}}{2} = \frac{V_{dc}}{2} (11)$$

Segment *OR* presents the maximum value of SVPWM in linear mode:

$$RO = OQ\ x\ \cos 30° = \frac{2}{3}V_{dc}\ x\ \cos 30° = \frac{2}{3}V_{dc}\ x\ \frac{\sqrt{3}}{2} = \frac{V_{dc}}{\sqrt{3}} (12)$$

Segment OQ presents the maximum value of SVPWM in Overmodulation mode II.

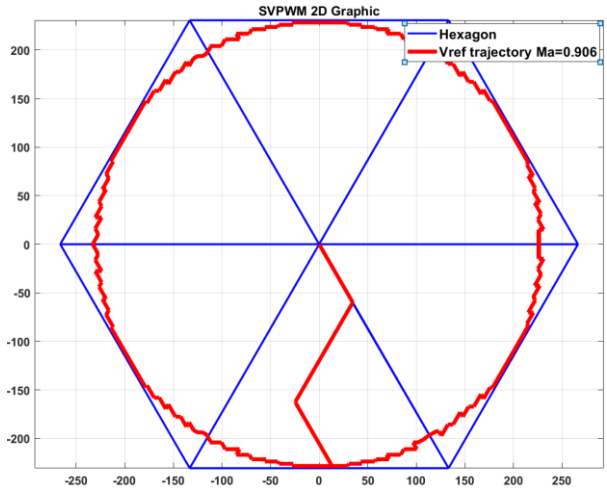

Figure 12 - SVPWM curve in a) linear region, b) over-modulation Mod I

In figures 12 and 13 are shown the trajectories of the reference vector $\vec{V}_{ref}$ which describe different paths, a part of the path inside the hexagon and the other part (or set) in the hexagon, which means they made part circular and part (or all) hexagonal paths.

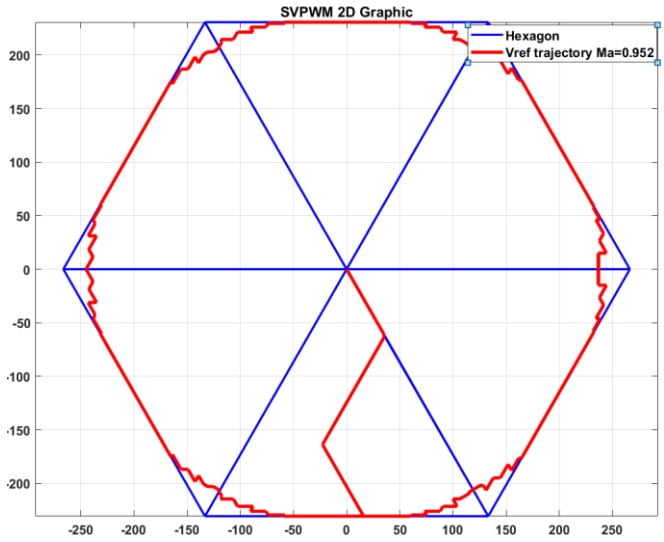

Figure 13 - SVPWM curve in over-modulation region Mod I.

Since Mod I overmodulation starts at amplitude modulation $M_a = 0.906$ and ends at $M_a = 0.952$, this space in between provides sufficient expansion for voltage amplification in this Mod. While in Modin II which ends at $M_a = 1.0$ only the vector $\vec{V}_{ref}$ describes the whole hexagon (figure 13), even though it offers high voltage amplification in the drum also with this increase the complexity starts to increase for which additional study is needed.

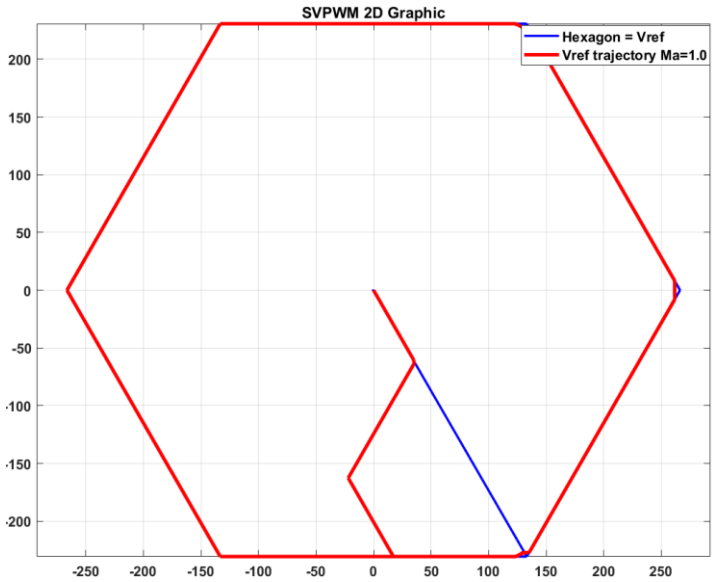

Figure 13 - SVPWM curve in over-modulation region Mod II.

CONCLUSION

As can be seen from the simulation results, the SVPWM technique is more suitable for three-phase inverters, as it increases the overall efficiency of the system. The advantages of this method include:

- The modulation index is higher in SVPWM compared to SPWM.
- The output voltage is approximately 15.5% higher in the case of SVPWM.
- Current and torque harmonics, as well as switching losses, are lower in SVPWM.

Therefore, research into the SVPWM technique has become very widespread in recent years, making it one of the most sought-after methods for three-phase inverters.

From the simulation results, it is confirmed that in the linear region, the SVPWM technique provides a higher output level with a maximum modulation index of 90.6%, and the maximum fundamental output signal is $0.577V_{dc}$, compared to the SPWM technique, which in the linear region has a maximum modulation index of 78.54% and provides a maximum fundamental output signal of $0.5V_{dc}$.

Whereas in the overmodulation regions of modes I and II, the modulation indices reach maximum values of 95.2% and 100%, respectively. From this, it is observed that there is an increase in the modulation index of 5% in mode I and 10% in mode II.

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DESIGN OF A STANDALONE SOLAR-POWERED WATER PUMPING SYSTEM WITH A SINGLE-PHASE SINUS-PWM PUSH-PULL INVERTER FOR GREENHOUSE APPLICATIONS USING A 1 KW PUMP

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ABSTRACT

This paper examines the design and implementation of a solar-powered water pumping system that utilizes a Sinus PWM push-pull inverter, a 1 kW pump, and an integrated battery storage system, intended for greenhouse applications. The primary objective is to develop an efficient, cost-effective solution capable of operating in various solar irradiation conditions, optimizing energy consumption, and providing a sustainable water supply to support agricultural practices. The system is designed to reduce the reliance on conventional energy sources, reduce operational costs, and enhance the sustainability of agricultural operations. By incorporating a battery storage system, the design ensures reliable, uninterrupted operation even during low solar availability, storing excess energy generated during peak sunlight hours for later use. This integration of solar energy with battery storage enhances the system's efficiency, providing an effective and renewable solution for water pumping needs. Additionally, the proposed system provides a secure connection with other renewable energy systems for larger agricultural or industrial applications. The system’s performance, including the inverter, pump, and battery storage unit, was extensively analyzed and simulated using Matlab/Simulink, providing accurate and reliable data on energy consumption, operational efficiency, and system behavior under different environmental conditions. The results demonstrate the feasibility and potential of this integrated solution in meeting the increasing demand for sustainable and renewable energy systems in the agricultural sector, particularly in Kosovo's rural areas.

KEYWORDS: battery storage, greenhouse applications solar energy, push-pull inverter, sinus PWM, water pump.

INTRODUCTION

This paper examines the design and implementation of a standalone solar-powered water pumping system, utilizing a sinusoidal PWM push-pull inverter, a 1 kW pump, and an integrated battery storage unit intended for greenhouse applications. The primary objective is to develop an efficient and cost-effective solution capable of operating under varying solar irradiance conditions, optimizing energy consumption, and providing a sustainable water supply to support agricultural practices. Given the growing need for water-efficient solutions in agriculture, particularly in regions with limited

access to reliable grid power, the proposed system aims to address both environmental and economic challenges in rural areas.

By integrating a battery storage system, the proposed design ensures reliable and uninterrupted operation even during periods of low solar availability. Excess energy generated during peak sunlight hours is stored for later use, enhancing the overall system efficiency and ensuring continuous operation. This self-sufficient approach minimizes dependence on external energy sources, making it particularly suitable for remote locations. Furthermore, the system allows for scalability by integrating with other renewable energy sources for larger agricultural or industrial applications, providing flexibility for expansion and adaptation to future energy demands.

The system’s components—including the inverter, pump, and battery unit—were modeled and analyzed using MATLAB/Simulink to evaluate energy consumption, operational efficiency, and dynamic behavior under different environmental conditions. These simulations allow for an accurate assessment of the system’s performance and provide valuable insights into optimizing the overall design. The results demonstrate the feasibility and potential of this integrated renewable energy solution to meet the growing demand for sustainable water pumping, particularly in rural and off-grid areas, where access to reliable electricity is limited or unavailable.

In Kosovo, the demand for year-round fresh vegetables is largely met through imports, as well as domestic production in open fields and greenhouses. Over the past decade, greenhouse cultivation has expanded significantly, reducing reliance on imports and improving the country’s trade balance. This shift has led to a greater focus on sustainable agricultural practices, with an increasing number of farmers turning to renewable energy solutions to enhance productivity. The Ministry of Agriculture in Kosovo has consistently allocated over 23% of its budget toward subsidies for the vegetable and greenhouse sector, including infrastructure for long-term vegetable storage, which highlights the government's commitment to advancing sustainable agriculture.

Although there is limited governmental support for automating greenhouses, there are financial incentives for installing water pumps, well-drilling systems, solar panels, inverters, and battery banks—technologies that support more sustainable agricultural practices. These incentives are critical in promoting green technologies and reducing farmers' dependence on costly, non-renewable energy sources. In remote rural regions lacking access to the electrical grid, solar-powered water pumping systems provide a cost-effective and environmentally friendly solution. The inefficiency and high operating costs of fuel-based systems further drive the transition toward solar-based alternatives.

This study is particularly motivated by the context of Kosovo’s rural agricultural landscape, where solar-powered greenhouses are emerging as key contributors to food security and economic sustainability. By providing reliable and renewable water pumping solutions, the proposed system aligns with the broader goal of improving agricultural efficiency and promoting energy independence. An example of such an application is shown in Figure 1.

Figure 1. Greenhouse with pepper cultivation in Llausha, Skenderaj (Central Kosovo), photographed on July 11th, 2024.

LITERATURE REVIEW

Makwana and Rathod (2019) proposed a cost-effective DC-AC converter design using solar energy and a single-phase PWM push-pull topology, specifically tailored for rural applications without access to the electrical grid. Similarly, Unni and Mini (2015) introduced an efficient topology for a three-phase induction motor drive system intended for solar-powered water pumping, showcasing the potential of solar energy in agricultural infrastructure. Reddy and Rao (2013) focused on increasing the efficiency and performance of agricultural pumping systems by integrating three-phase induction motors powered by photovoltaic (PV) systems.

Naik and Venugopal (2018) argued against the use of low-frequency transformers, citing drawbacks such as low efficiency, bulky size, heavyweight, and high costs. On the other hand, Parvathy and Vivek (2015) highlighted the advantages of battery-less solar pumping systems, which offer longer lifespan, lower cost, and higher efficiency, despite the common use of batteries in conventional systems.

Shim (2015) analyzed a high-frequency insulated-gate bipolar transistor (IGBT) model, noting benefits such as reduced component size, faster transient response, and lower system cost. However, the study also identified challenges such as electromagnetic interference (EMI) and increased switching losses. In a related study, Maswood (2008) developed a mathematical model to estimate switching losses in three-phase inverters, aiding in the optimal selection of switching frequency for IGBT operation.

Stevens and Corey (1996) examined energy losses during battery charging processes and emphasized the importance of charge efficiency and charge rate management in PV systems. Battery selection and testing procedures for PV-based applications are detailed in the IEEE Standards (2014). Moreover, charge controller technologies, especially PWM and MPPT, have been compared in terms of performance, cost, and compatibility with various PV system designs (Morningstar Corporation,

2020).

Vanek, Albright, and Angenent (2016) described solar energy as a clean, renewable, and abundant resource, also capable of powering other renewable technologies such as wind and biomass. They emphasized that PV systems convert sunlight into electricity through semiconductors and highlighted that solar-powered water pumping is one of the most suitable and direct applications of PV in rural and agricultural settings. These systems are particularly beneficial in areas where water sources are spread across large distances and electrical infrastructure is lacking (Parvathy & Vivek, 2015).

Parvathy and Vivek (2015) also noted that traditional PV water pumping systems comprise PV panels, batteries, converters, and motors. Despite the ongoing challenge of reducing the overall cost of PV systems, inverter designs—especially push-pull topologies—can be optimized for fewer components and higher efficiency. Although batteries help stabilize operations under varying solar radiation conditions, their limited lifespan—typically about two years—contrasts sharply with the 20-year lifespan of PV modules. This makes proper battery management crucial to prolonging system operation (Morningstar Corporation, 2020).

MATERIALS AND METHODS

This study presents the design and simulation of a hybrid solar-powered water pumping system tailored for a 0.1-hectare greenhouse. The system was engineered to operate efficiently under variable solar irradiance conditions while ensuring reliable water delivery. All components were selected to balance performance, energy efficiency, and cost-effectiveness.

The main components of the system include:

- Solar Panels (9 x 300 W): Connected in series and parallel configuration to achieve a total capacity of 2.7 kW, sufficient to meet the greenhouse's daily energy requirements.
- Batteries (12V, 2 x 200Ah): Two 12V batteries connected in parallel provide a total storage capacity of 400Ah, enabling energy supply during nighttime or cloudy periods.
- MPPT Charge Controller: Optimizes energy transfer from solar panels to batteries by continuously tracking the maximum power point, ensuring efficient and safe charging.
- Sinusoidal PWM Inverter (2 kW, Pure Sine Wave): Converts DC power to clean AC power using SPWM, providing stable voltage and frequency for the pump.
- 12V/220V Transformer (2 kW): Steps up the voltage to 220V AC, compatible with the water pump specifications.
- Solar Water Pump (1 kW, 220V): Drives water irrigation using solar energy, eliminating reliance on grid or fuel-based sources.
- Wiring and Fuses: Ensure safe connections and protection for all components.

Based on the irrigation demands of the greenhouse, the system’s energy capacity was found to be sufficient to power the pump sustainably.

Figure 2 illustrates Kosovo’s photovoltaic (PV) potential, demonstrating favorable conditions for implementing solar-powered systems.

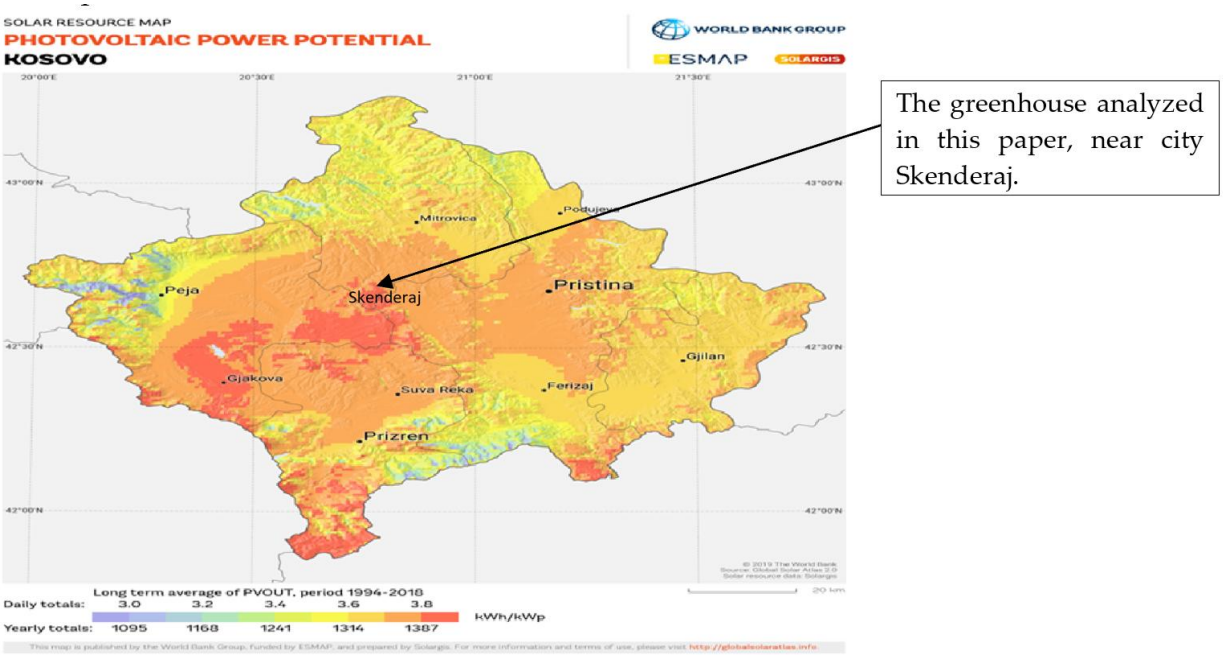

Figure 2. Photovoltaic potential of the Republic of Kosovo (World Bank, 2019).

Figures 3(a) and 3(b) provide the monthly Global Horizontal Irradiance (GHI) and ambient temperature profiles for Skenderaj, which are crucial for evaluating seasonal system performance.

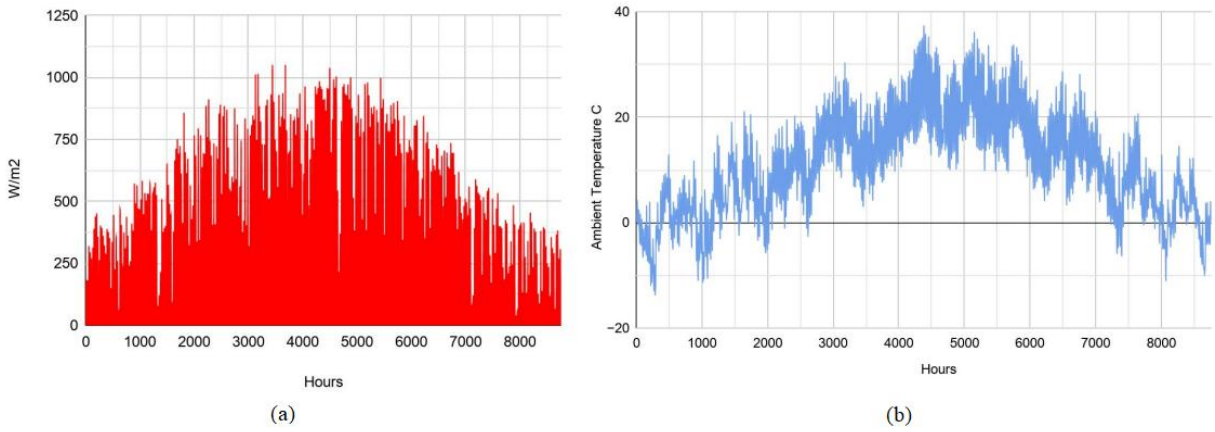

Figure 3. (a) Global Horizontal Irradiance (GHI) and (b) Ambient Temperature for Skenderaj, Kosovo.

SIMULATION AND MODELING IN MATLAB

To analyze the system's performance and dynamic behavior under varying environmental conditions, a complete simulation model was developed using MATLAB/Simulink.

The simulation included:

- A single-phase SPWM inverter with a push-pull topology,
- An MPPT algorithm to maximize solar energy harvesting,
- An AC motor representing the water pump as the primary load.

In our proposed system, the IM is used for water-pumping systems, and its topology is shown in

Figure 4.

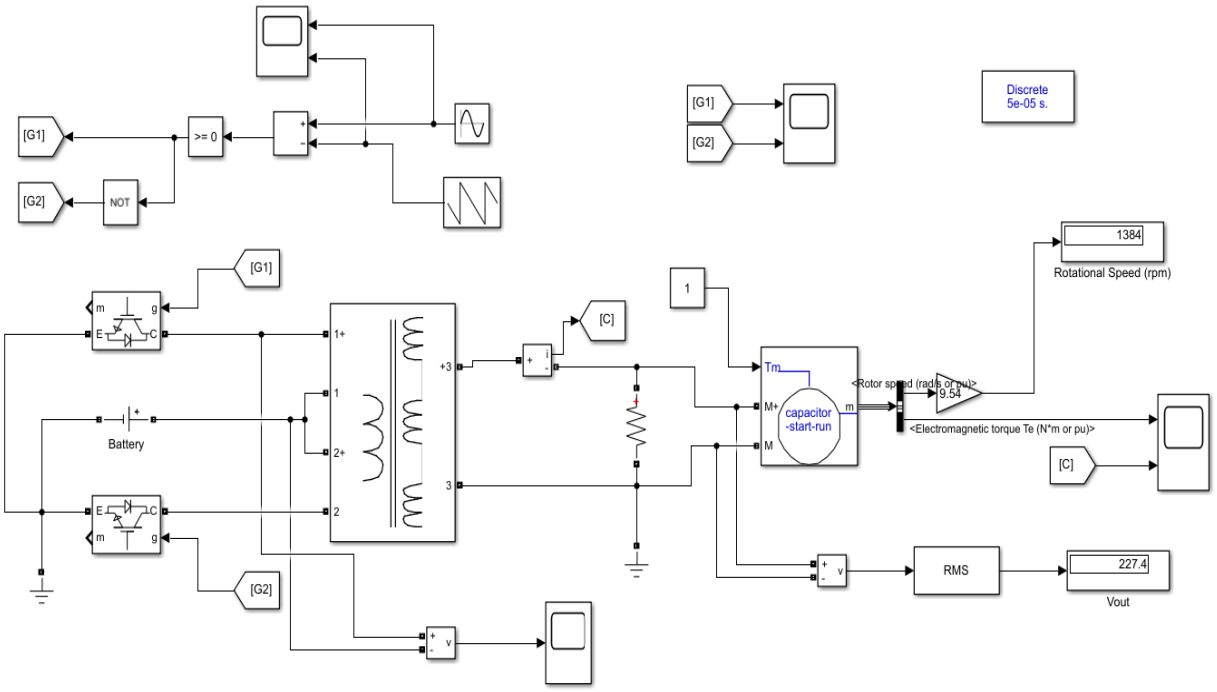

Figure 4. Simulation of the single-phase SPWM inverter in MATLAB/Simulink.

The SPWM technique involves comparing a high-frequency triangular carrier waveform with a sinusoidal reference signal. A switching frequency of 2 kHz was selected, as shown in Figure 5, offering a balance between reduced harmonic distortion and manageable switching losses.

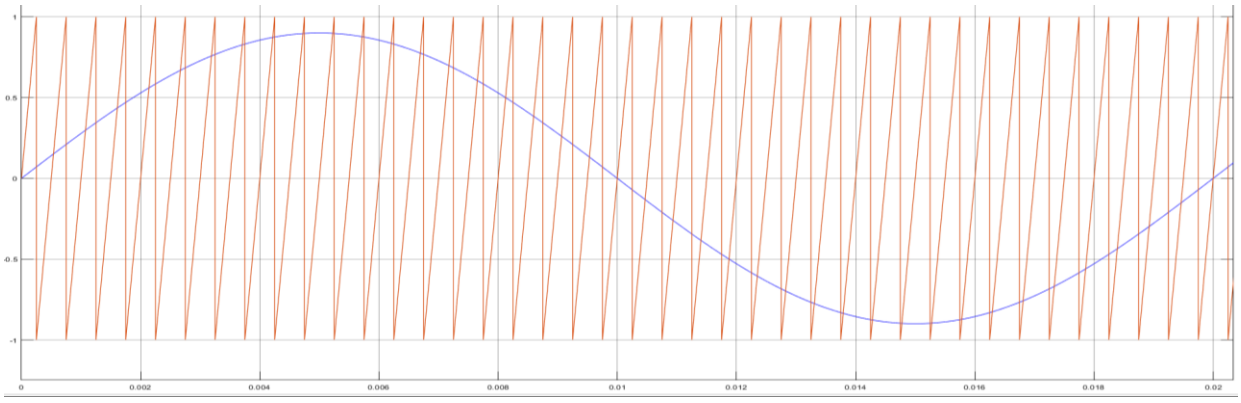

Figure 5. Comparison of triangular carrier and modulating sinusoidal signal.

Figure 6 shows the resulting gate pulses applied to the IGBT switches, derived from the SPWM technique.

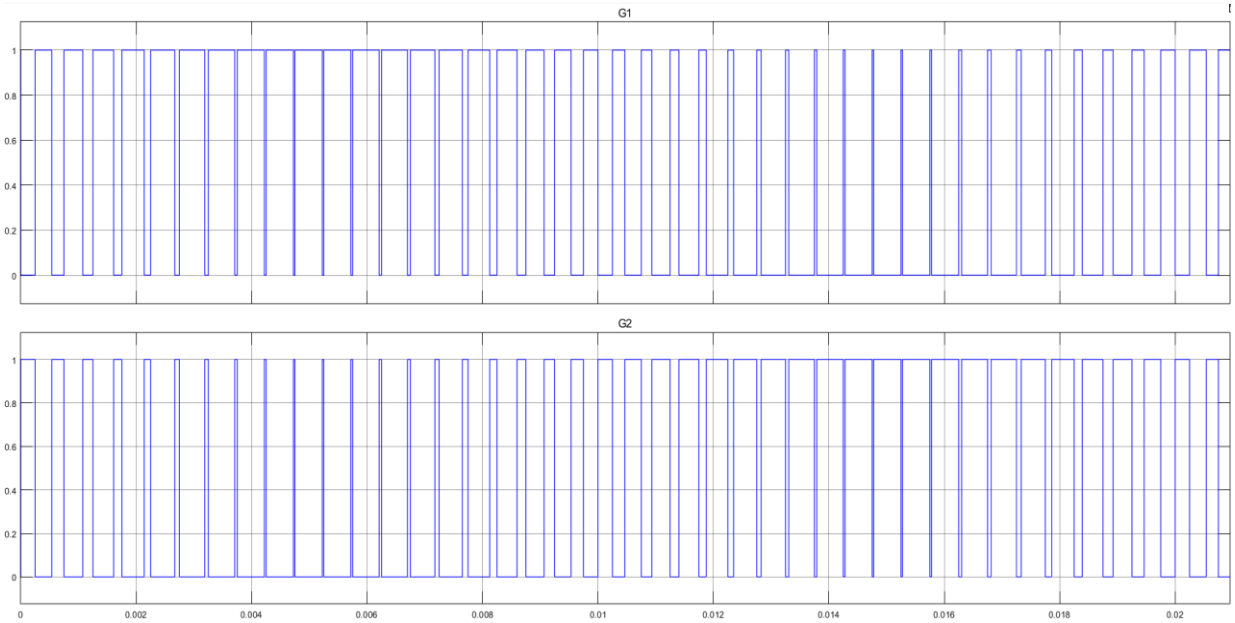

Figure 6. Gate signals applied to the IGBT switches.

THD ANALYSIS AND MOTOR RESPONSE

Figures 7 and 8 present the Total Harmonic Distortion (THD) of the output current and the corresponding current and torque waveforms at a switching frequency of 2 kHz.

At this frequency, the motor acts as a natural low-pass filter, attenuating high-frequency harmonics and delivering a waveform close to a pure sine wave.

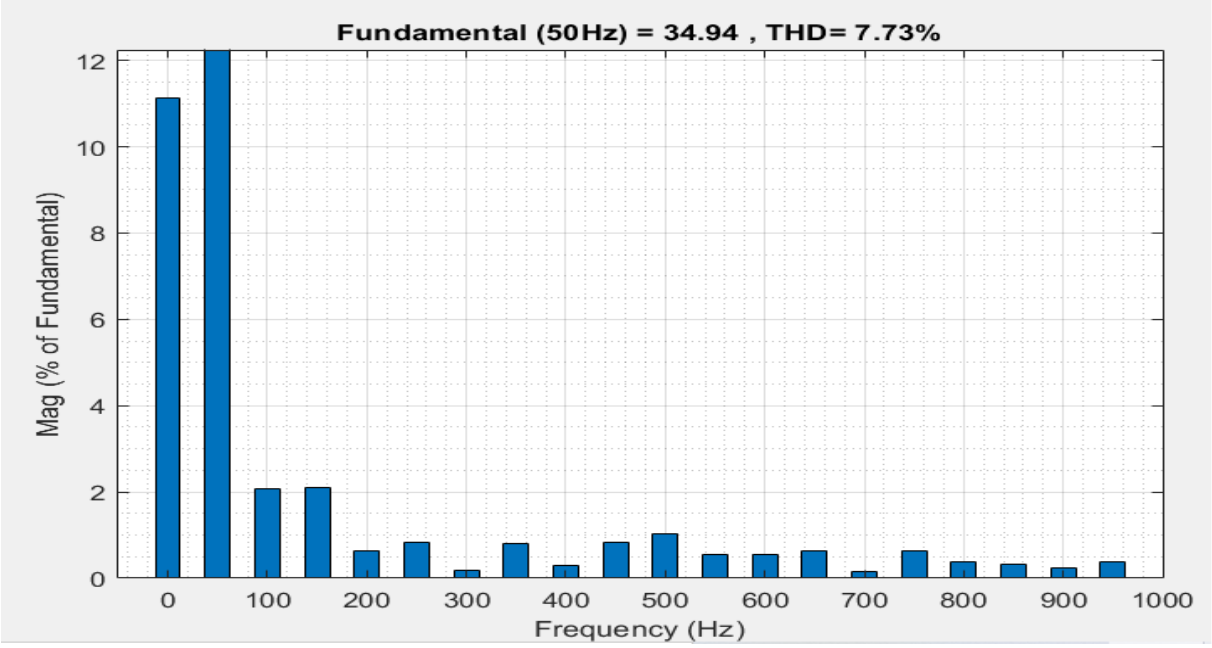

Figure 7. Output current THD at 2 kHz switching frequency.

To investigate the impact of increased switching frequency, simulations were repeated at 10 kHz, resulting in degraded waveform quality and a higher THD, as shown in Figure 9.

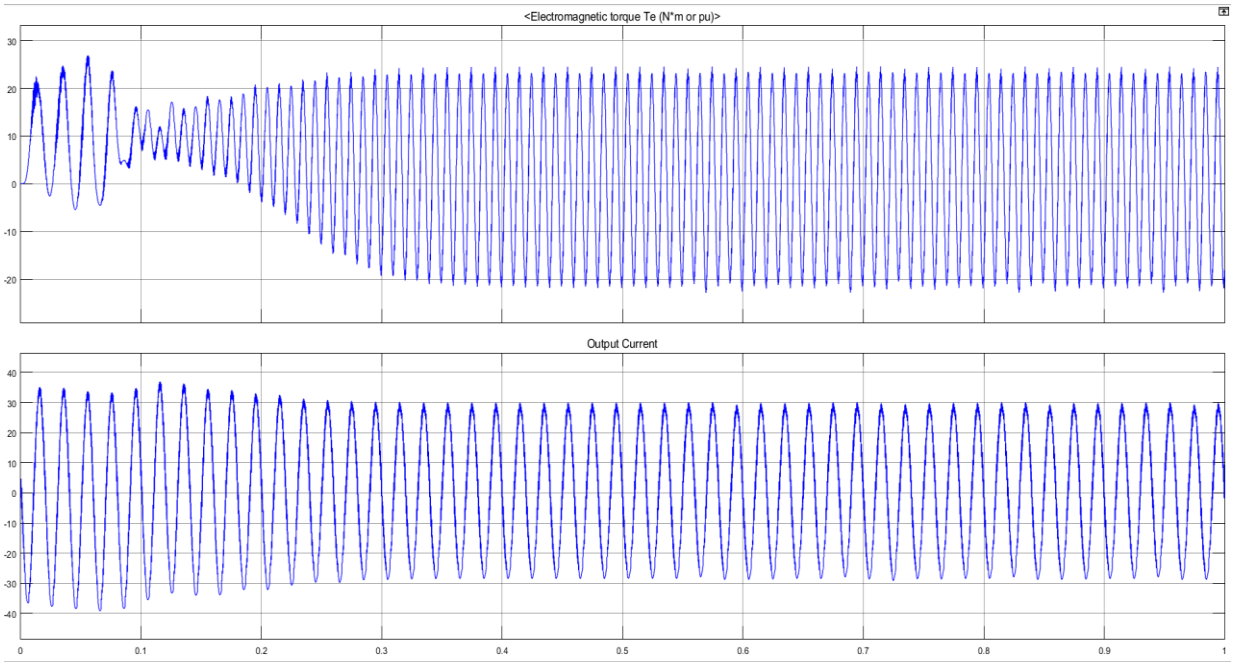

Figure 8. Motor torque and output current waveform for 2 kHz switching frequency.

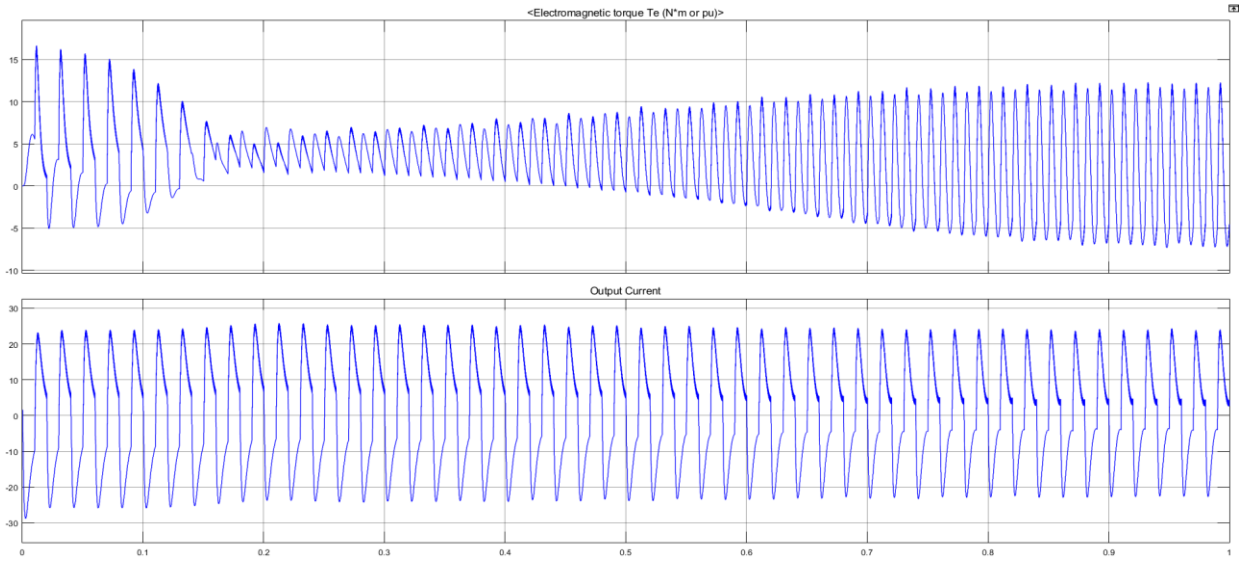

Figure 9. Motor torque and current waveform for 10 kHz switching frequency.

DISCUSSION OF RESULTS

Contrary to expectations in literature, increasing the inverter switching frequency from 2 kHz to 10 kHz resulted in higher THD in the output current. Several potential causes were identified:

- Transformer Impedance: At higher frequencies, core and winding losses in the transformer increase. Leakage inductance and parasitic capacitance also become more significant, distorting the output.
- Push-Pull Topology Imbalances: The center-tap push-pull topology may suffer from cycle

imbalance at high switching speeds, which can lead to magnetic saturation and waveform distortion.

These findings emphasize the importance of validating switching frequency choices through detailed simulations and taking real-world component behavior into account.

CONCLUSION

This study addressed key challenges in designing photovoltaic (PV) systems for driving electric motors in greenhouse environments, with a focus on implementing a sinusoidal PWM push-pull inverter and integrating battery storage for improved reliability.

Simulation results showed that increasing the inverter's switching frequency from 2 kHz to 10 kHz unexpectedly led to higher Total Harmonic Distortion (THD), which negatively impacts energy efficiency and power quality. These findings emphasize the importance of carefully selecting the switching frequency, where 2 kHz emerged as the most effective for minimizing distortion and maintaining stable performance.

In addition, the use of ferrite core transformers contributed to reduced energy losses and better waveform quality, enhancing the overall operation of the water pumping system and ensuring smoother motor functionality.

Overall, the findings highlight the need for a well-balanced design approach when developing standalone solar-powered systems for agricultural use. Attention to component selection and system parameters can lead to improved efficiency, longer operational lifespan, and better suitability for off-grid rural areas—particularly in locations like Kosovo, where grid infrastructure is limited or unavailable.

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STABILITY ANALYSIS OF AUTOMATIC VOLTAGE REGULATOR SYSTEM WITH FRACTIONAL PI CONTROLLER

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ABSTRACTS

The need for electrical energy is constantly increasing with the development of modern societies. Power systems are a critical building block in meeting this need. Uninterrupted and reliable operation of the system is of great importance in all processes from electricity generation to the end user. This trust is based on the stability of the system. For this reason, analyses on the stability of power systems constitute an important part of the studies in the field of energy. In this paper, the stability of the Automatic Voltage Regulator (AVR) system is analysed by using a fractional PI controller. The fractional PI controller is preferred because it offers a wider control parameter range than the conventional PI and provides design flexibility. In this study, using the Stability Boundary Locus (SBL) method, the regions of the controller gains (Kp, Ki) that determine the stable, unstable and critically stable states of the system are determined based on the characteristic equation of the system. The stability boundary curves obtained for different fractional integral degrees ($\lambda = 0.4, 0.5, 0.6$) are shown in the Kp-Ki plane and graphically analysed with which gain pairs the system will operate stably. The time responses of three different points selected from these regions were tested in MATLAB/Simulink environment. According to the results of the analyses; parameters within the stability boundary curves make the system stable, parameters above the boundary make the system critically stable and parameters outside the boundary make the system unstable. Simulations confirmed the theoretical stability analyses and showed that fractional PI controllers are effective in improving the AVR system performance and providing a wider stability domain. The study demonstrates the applicability of fractional controllers to AVR systems and provides designers with more flexible and safe control strategies.

KEYWORDS: Automatic voltage regulation, stability boundary locus, stable parameters space, electric power system, fractional order PI controller

INTRODUCTION

Power systems play an important role in meeting the energy needs of modern societies. Reliable and continuous operation of the system is of great importance in the processes from generation to distribution of electrical energy. Continuous and reliable operation of power systems is directly related to the stability of the system. Therefore, stability analysis of power systems has been an important research topic. The ever-increasing demand for uninterrupted electrical energy has made the stable operation of power systems a necessity [1].

One of the parameters that determines the stability of an electrical network is to keep the network at the nominal voltage level [1]. The method that provides this is called Automatic Voltage Regulator (AVR). The AVR helps to regulate the generator terminal voltage by providing control of the generator exciter [1-2]. In this method, one of the main objectives is to keep the generator voltage at the desired level without changing as much as possible [3].

AVR uses a set of control mechanisms that detect and correct problems such as fluctuations, overvoltages or undervoltages in the power grid [3]. However, there are cases of inadequacy due to terminal voltage fluctuations [4]. Therefore, adding a controller to the AVR system will eliminate this problem.

PID type controllers, which are frequently used in the industry, are used in the control of control systems. Among the PID type controller, PI controller is a commonly used controller to control the feedback control system. PI controller is a simplified version of PID control.

The PI controller is widely used, especially in applications with continuous and constant control requirements. The PI controller takes into account both instantaneous error and error accumulation over time to bring the system output closer to the desired value. Therefore, PI controller is effective to approach the target value with zero error and ensure stable operation [5-6]. Furthermore, the PID controller is used to control the system output more precisely and to adapt to dynamic systems [2]. However, PI controller is advantageous as they provide simpler, lower cost and less complexity in applications.

From this point of view, the AVR system is widely controlled by full and fractional order PID/PI type controllers [7-19]. In these studies, full and fractional order controllers have been widely used and optimisations have been performed to improve the performance of the AVR system. In these studies, the AVR system was also not analysed in terms of stability. Although the stability of the AVR system with a full-order PI controller has been investigated in [6], AVR systems using fractional order controllers have not been discussed much in terms of stability. For control systems, fractional order controllers provide advantages such as greater design flexibility and a large stability region [8-9]. Therefore, analysing the stability of the AVR system with fractional degree controllers has been the main motivation for this study.

Stability boundary locus method is an effective method used in the stability analysis and design of many control systems [20-21]. Thanks to this method, design convenience is provided by determining the control parameter space in which full and fractional degree PID type controllers will keep the system in a stable state [22-23].

The most important parameter for the sustainable operation of power systems is system stability. Although stability analyses have been performed for AVR systems with full-degree controllers [6], it is seen that these analyses with fractional-degree controllers have not been applied for AVR systems. In this study, the stability analysis of the AVR system controlled by fractional PI controller according to the controller parameters, $K_p - K_i$, is carried out. Stability analysis is provided by the stability boundary curves method. The obtained results are verified by simulations. After this section, the linear model and structure of the AVR system will be given in the second section and the mathematical model of the AVR system with fractional PI controller will be obtained. In addition, system parameters and frequency dependent controller parameters were obtained by using the stability boundary locus method over the mathematical model obtained. In the third section, according to the results obtained, the stability boundary region in $K_p - K_i$ space is calculated and the results are verified with time domain simulations describing the system in MATLAB/Simulink environment. The results will be discussed in the fourth section.

MATERIAL AND METHOD

According to the standards, the network voltage change must be kept within certain limits. Therefore, AVR plays an important role in ensuring voltage stability and power quality in electrical systems [24]. In order to ensure that the grid voltage variation changes as little as possible, structures such as AVR are needed. Therefore, the terminal voltage must be continuously controlled by the AVR [25-26].

AVR System Linearised Model

Figure 1 shows the linearised model of the AVR system. The mathematical model of each subsystem in this block diagram as a transfer function is described as follows.

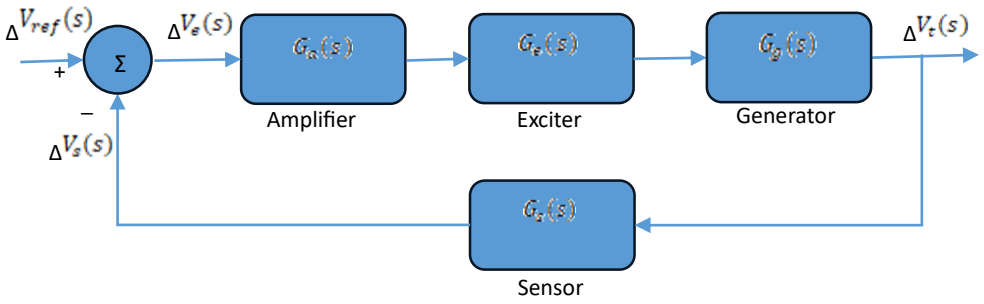

Figure1. AVR system block diagram

As shown in Figure 1, the AVR system generally consists of four components: amplifier, exciter, generator and sensor. A linearised model was used to analyse the dynamic character of the AVR.

The transfer functions of these components are respectively shown as follows [6,27].

Amplifier model: The typical value of K_a ranges from 10 to 500 and τ_a from 0.02 to 0.1 s. In this study, $K_a = 10$ and $\tau_a = 0.1s$.

$$G_a(s) = \frac{K_a}{1 + \tau_a s} \quad (1)$$

Exciter model: The transfer function of a modern exciter can be represented by the gain K_e and the time constant τ_e, with the typical value of K_e ranging from 1 to 10 and the time constant τ_e from 0.4 to 1 s. In this study, $K_e = 1$ and $\tau_e = 0.4s$.

$$G_e(s) = \frac{K_e}{1 + \tau_e s} \quad (1)$$

Generator model: In the linearised model, the transfer function connecting the generator terminal voltage to the field voltage can be represented by a gain K_g and a time constant τ_g.

$$G_g(s) = \frac{K_g}{1 + \tau_g s} \quad (1)$$

The typical value of K_g ranges from 0.7 to 1.0 s and τ_g from 1.0 s to 2.0 s. In this study, $K_g = 1$, $\tau_g = 1s$.

Sensor model: K_s is the sensor gain and τ_s is the sensor time constant.

$$G_s(s) = \frac{K_s}{1 + \tau_s s} \quad (1)$$

Here K_s ranges from 1.0 to 2.0, τ_s from 0.001 s to 0.06 s. In this study, $K_s = 1, \tau_s = 0.01s$.

Stability Boundary Locus Analysis of AVR System with Fractional PI Controller

Figure 2 shows the block diagram of the AVR system balanced with a fractional PI controller.

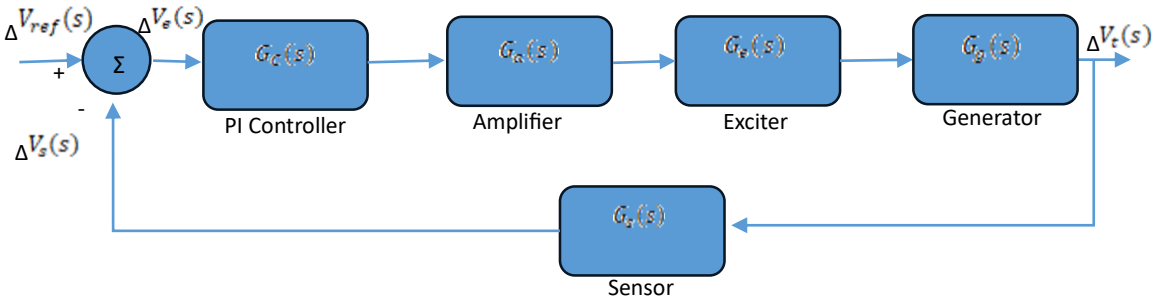

Figure 2. Block diagram of fractional PI controlled AVR system

Fractional PI Controller Model:

Mathematically, the transfer function of a fractional PI controller is as follows:

$$G_c(s) = K_p + \frac{K_i}{s^\lambda} \quad (1)$$

It's here:

$G_c(s)$: Transfer function of fractional PI controller

K_p: Proportional gain coefficient

K_i: Integral gain coefficient

λ: Fractional integral degree

K_p , generates a control signal proportional to the instantaneous value of the error. This determines how close the system is to the target value. K_i, corrects the cumulative error of the control signal over time. This helps to reduce long-term deviations in the system. The fractional integral degree, λ, will intervene in the system as a third control parameter in addition to the conventional PI controller.

Using the subsystem models mentioned above, the transfer function of the system given in Figure 2 is obtained as follows.

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{\Delta_N(s)}{\Delta_D(s)} = \frac{G_a(s)G_e(s)G_g(s)G_c(s)}{1 + G_a(s)G_e(s)G_g(s)G_c(s)G_s(s)} \quad (1)$$

The numerator polynomial of the transfer function obtained in Equation (6) is obtained as follows.

$$\Delta_N(s) = K_p s^{\lambda+1} q_3 + K_p s^\lambda q_2 + K_i s q_1 + K_i q_0 \quad (1)$$

From there;

$q_3 = q_1 = \tau_s K_a K_e K_g$

$q_2 = q_0 = K_a K_e K_g$

will be obtained as.

The characteristic equation of the system shown in Figure 2 will be obtained as follows.

$$\Delta_D(s) = s^{\lambda+4} p_5 + s^{\lambda+3} p_4 + s^{\lambda+2} p_3 + s^{\lambda+1} p_2 + s^\lambda (1 + K_p p_1) + K_i p_0 \quad (1)$$

From there;

$$p_5 = \tau_a\tau_e\tau_g\tau_s$$

$$p_4 = \tau_a\tau_g\tau_s + \tau_a\tau_g\tau_e + \tau_a\tau_s\tau_e + \tau_g\tau_s\tau_e$$

$$p_3 = \tau_a\tau_g + \tau_a\tau_e + \tau_a\tau_s + \tau_g\tau_s + \tau_g\tau_e + \tau_s\tau_e$$

$$p_2 = \tau_a + \tau_g + \tau_s + \tau_e$$

$$p_1 = p_0 = K_aK_eK_gK_s$$

will be obtained.

CRB (Complex Root Boundary), which is one of the stability boundary locus, will be able to obtain K_p and K_i values depending on the system parameters, fractional integral degree and frequency by equating the characteristic equation of the fractional PI controlled AVR system to zero for $s = j\omega$. Since these are the frequency values at which the system is critically stable, there will be a stability limit in the $K_p - K_i$ plane. The gain values K_p and K_i can be calculated by setting the real and imaginary parts of the characteristic equation equal to zero.

$$Re = K_p|\omega|^\lambda \cos\left(\lambda\frac{\pi}{2}\right)p_1 + K_ip_0 + \cos\left(\lambda\frac{\pi}{2}\right)(\omega^4p_5 - \omega^2p_3 + 1) + \sin\left(\lambda\frac{\pi}{2}\right)(\omega^3p_4 - \omega p_2) = 0 \quad (1)$$

$$Im = K_pj\left|\omega\right|^\lambda \sin\left(\lambda\frac{\pi}{2}\right)p_1 + j\left|\omega\right|^\lambda\left(\cos\left(\lambda\frac{\pi}{2}\right)(-\omega^3p_4 + \omega p_2) + \sin\left(\lambda\frac{\pi}{2}\right)(\omega^4p_5 - \omega^2p_3 + 1)\right) = 0 \quad (1)$$

The gain values of the fractional PI controller are obtained as follows.

$$K_i = \frac{\left(j\left|\omega\right|^\lambda \sin\left(\lambda\frac{\pi}{2}\right)p_1\right)\left(\cos\left(\lambda\frac{\pi}{2}\right)(\omega^4p_5-\omega^2p_3+1)+\sin\left(\lambda\frac{\pi}{2}\right)(\omega^3p_4-\omega p_2)\right)-\left(|\omega|^\lambda\cos\left(\lambda\frac{\pi}{2}\right)p_1\right)\left(j|\omega|^\lambda\left(\cos\left(\lambda\frac{\pi}{2}\right)(-\omega^3p_4+\omega p_2)+\sin\left(\lambda\frac{\pi}{2}\right)(\omega^4p_5-\omega^2p_3+1)\right)\right)}{-\left(j|\omega|^\lambda\sin\left(\lambda\frac{\pi}{2}\right)p_1\right)p_0}$$

(11)

$$K_p = \frac{j|\omega|^\lambda\left(\cos\left(\lambda\frac{\pi}{2}\right)(-\omega^3p_4 + \omega p_2) + \sin\left(\lambda\frac{\pi}{2}\right)(\omega^4p_5 - \omega^2p_3 + 1)\right)}{-\left(j|\omega|^\lambda\sin\left(\lambda\frac{\pi}{2}\right)p_1\right)} \quad (1)$$

RRB (True Root Boundary) is $K_i = 0$. *IRB* (Infinite Root Boundary) does not exist for this system since it does not depend on the values of K_p and K_i. Therefore, there will be CRB and RRB in the $K_p - K_i$ plane.

RESULTS AND DISCUSSION

In this section, the stability boundary locus of the AVR system whose characteristic equation is given in the Materials and Methods section will be obtained. Also, the calculated region in the $K_p - K_i$ plane will be tested. The results will be verified with the simulations obtained.

Determination of the Stability Region of AVR Systems with Fractional PI Controllers

For system parameter values ($K_a = 10, K_e = 1, K_g = 1, K_s = 1;\ \tau_a = 0.1s, \tau_e = 0.4s, \tau_g = 1s, \tau_s = 0.01s$), K_p and K_i are used in equations (11) and (12) respectively to determine the CRB, which is one of the stability limits of the system. *RRB* was set to $K_i = 0$. Considering the roots of the characteristic equation of the system in the $K_p - K_i$ plane, the closed region between CRB and RRB is stable. Figure 3 shows the stability boundary locus of the AVR system in the $K_p - K_i$ plane for different degrees of integration,

$\lambda = 0.4, 0.5, 0.6$, of the fractional PI controller. Note that as the degree of integration λ changes, the controller parameter space that stabilises the system in the $K_p - K_i$ plane also changes. This will provide a flexible space for the designer who wants to improve the performance of the system.

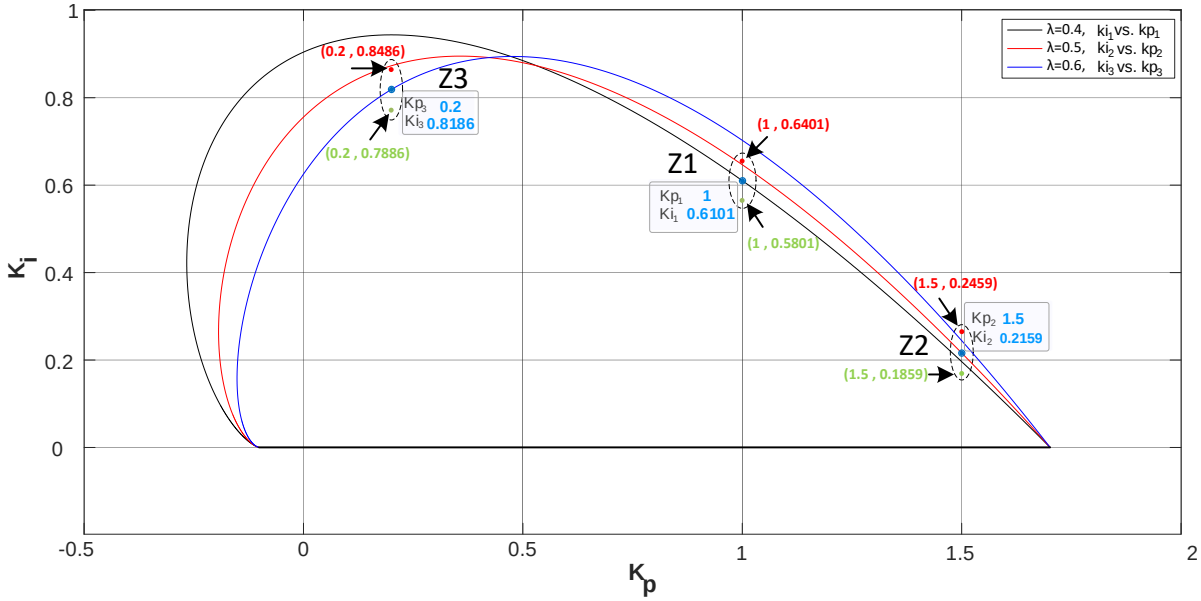

Figure 3. Stability boundary locus of the AVR system

The poles of the three different systems obtained for the parameter values $K_p - K_i$ given in Z1, Z2 and Z3 for each λ value taken differently from each other are shown in Table1, Table2 and Table3.

In the $K_p - K_i$ plane, parameter values $K_p - K_i$ chosen outside the closed region will destabilise the system. $K_p - K_i$ parameter values selected within the closed region will stabilise the system.

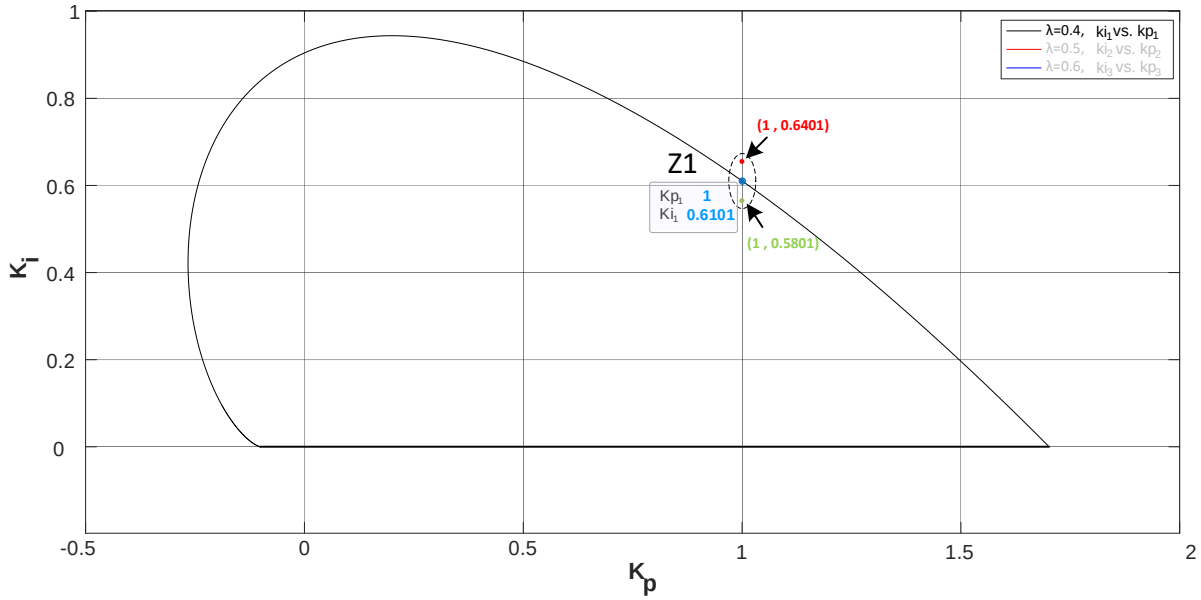

Figure 4. Stability boundary locus of the OGR system for Z1 region

Table 1. Poles of the system in Z1 region for PI controller gain pair

	Gains of PI			Poles of the System			
	K_p	K_i	λ	s_1	s_2	s_3	s_4
Z1	1	0.5801	0.4	-12.6183	-12.6183	-0.02212 – 4.97808 i	-0.02212 + 4.97808 i
	1	0.6101	0.4	-12.6257	-12.6257	-0.000212992	-0.000212992
	1	0.6401	0.4	-12.6332 – 0.3667 i	-12.6332	0.0213845 – 5.01042	0.0213845 + 5.01042

For Z1, the roots of the characteristic equation obtained in equation (8) for the case where the parameter pair $K_p - K_i$ in the closed region is (1, 0.5801) and $\lambda = 0.4$ are obtained in Table 1. When the poles are analysed, the system has no pole in the right half s-plane. For these parameter pairs, the system is stable and there will be a damped oscillation in the system.

When the system poles for the parameter pair $K_p - K_i$ (1, 0.6101) on the boundary line are considered, it is seen that there are no poles in the right half s-plane. However, since the real parts of the s_3 and s_4 poles take values very close to zero, the system is critically stable.

For the parameter pair $K_p - K_i$ (1, 0.6401) outside the closed region, the poles s_3 and s_4 are in the right half s-plane. Therefore, the system is unstable for these parameter pairs.

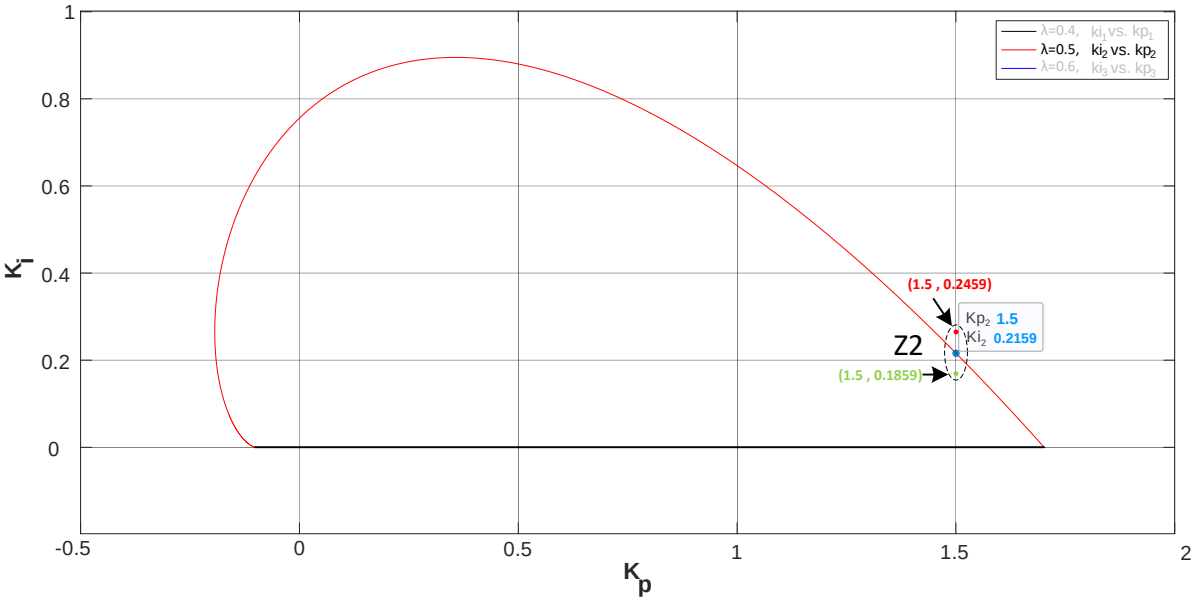

Figure 5. Stability boundary locus of AVR system for Z2 region

Table 2. Poles of the system in Z2 region for PI controller gain pair

	Gains of PI			Poles of the System			
	K_p	K_i	λ	s_1	s_2	s_3	s_4
Z2	1.5	0.1859	0.5	-13.2721 – 0.0726 i	-13.2721	-0.0186 – 5.5316 i	-0.0186 + 5.5316 i
	1.5	0.2159	0.5	-13.2724 – 0.0843 i	-13.2724	-0.0002 – 5.5386 i	-0.0002 + 5.5386 i
	1.5	0.2459	0.5	-13.2727 – 0.0960 i	-13.2727	0.0181 – 5.5458 i	0.0181 + 5.5458 i

For Z2 values where $\lambda = 0.5$, the poles of the system are obtained in Table 2. For the parameter pair $K_p - K_i$ (1.5, 0.1859) the system is stable while for the parameter pair $K_p - K_i$ (1.5, 0.2459) the system is unstable. For the parameter pair $K_p - K_i$ (1.5, 0.2159), the system is marginally stable.

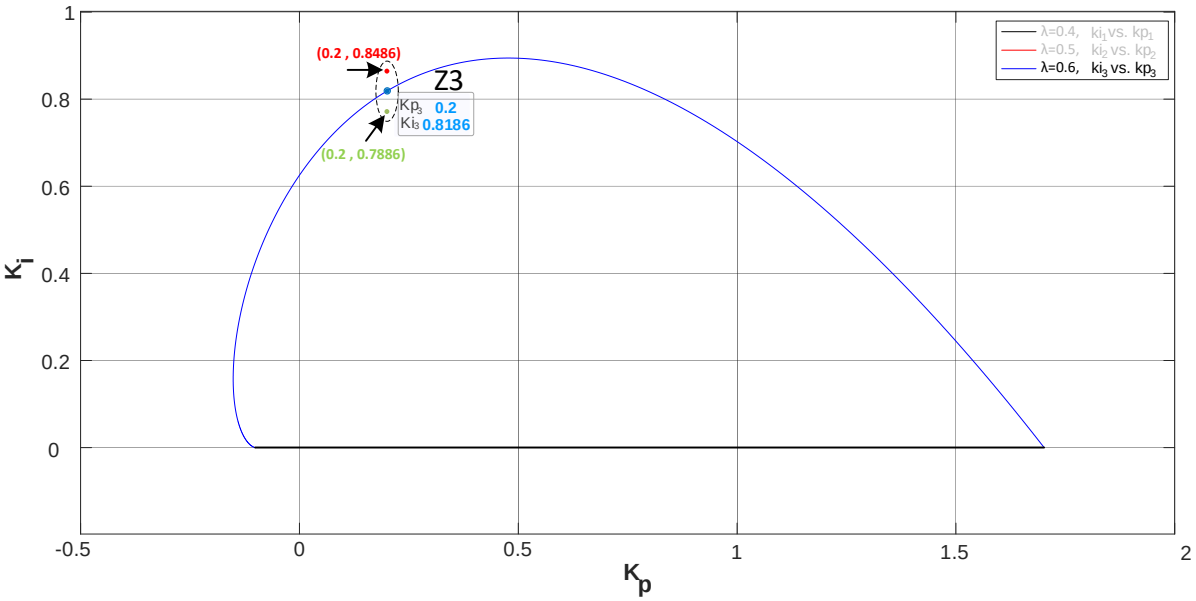

Figure 6. Stability boundary locus of AVR system for Z3 region

Table 3. Poles of the system in Z3 region for PI controller gain pair

	Gains of PI			***Poles of the System***			
	K_p	K_i	λ	s_1	s_2	s_3	s_4
Z3	0.2	0.7886	0.6	-10.6043	-10.6043	-0.0259658	-0.0259658
	0.2	0.8186	0.6	-10.604	-10.604	-0.0000527498	-0.0000527498
	0.2	0.8486	0.6	-10.604	-10.604	0.0251506 – 3.16487	0.0251506 + 3.16487

For Z3, where $\lambda = 0.6$, the system is stable for the parameter pair $K_p - K_i$ (0.2, 0.7886) and unstable for the parameter pair $K_p - K_i$ (0.2, 0.8486). Furthermore, for the parameter pair $K_p - K_i$ (0.2, 0.8186) the system is marginally stable.

Time Response Simulation Results of AVR System

In this section, the simulation results of the system designed in MATLAB/Simulink as shown in Figure 4 for the parameter pair values $K_p - K_i$ determined in Figure 3 will be presented.

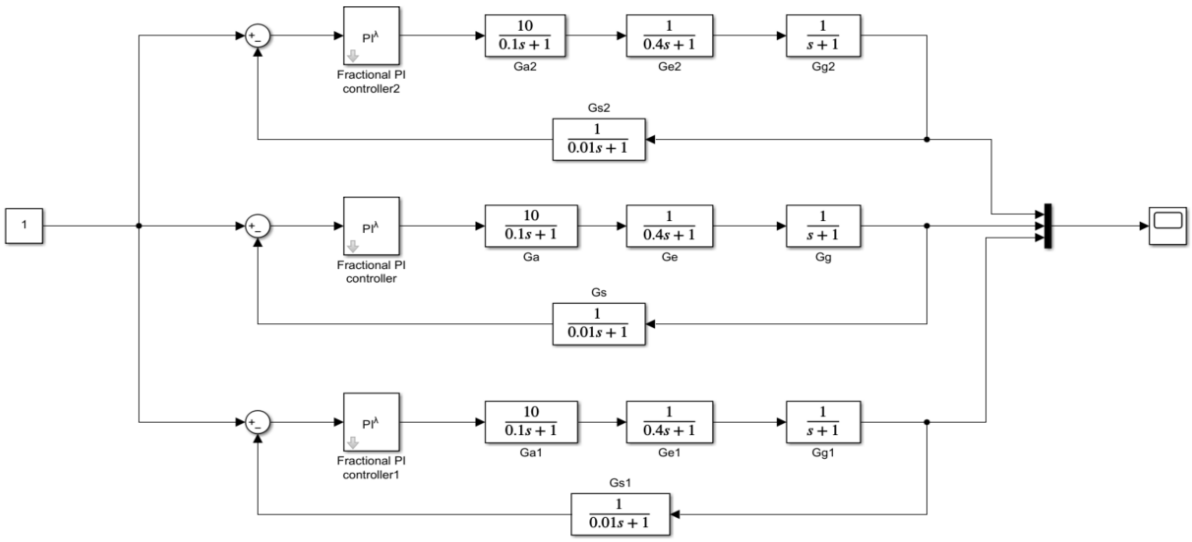

Figure 7. Simulink model of AVR system for Z1, Z2 and Z3

In order to test the accuracy of the region obtained in Figure 3 at different λ values, for each λ value, three different points were selected from inside, border and outside of the region and analysed. The time responses of the system at Z1, Z2 and Z3 are as shown in Figure 8, Figure 9 and Figure 10 respectively. The same colours are used for the time responses of the systems. When the selected parameters are from the stable region, they are indicated in black colour and show a stable behaviour. It is observed that the time response of the system exhibits oscillations with decreasing amplitude.

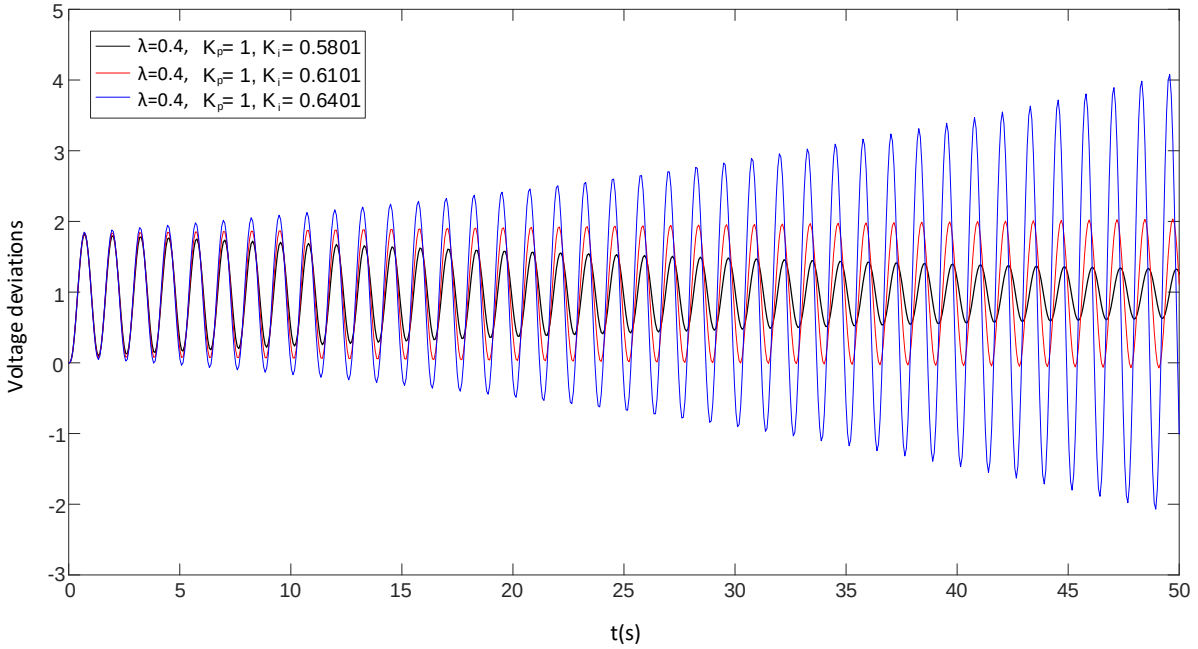

Figure 8. Time responses of the system for the parameters in Z1

If the parameters are selected at the boundary of the stable region, the response of the system will be critically stable, indicated by the red colour. The time response of the system is seen as undamped oscillations with constant amplitude. If parameters outside the stable region are selected, the response of the system will be unstable in blue colour. The time response of the system will appear as an oscillation with increasing amplitude.

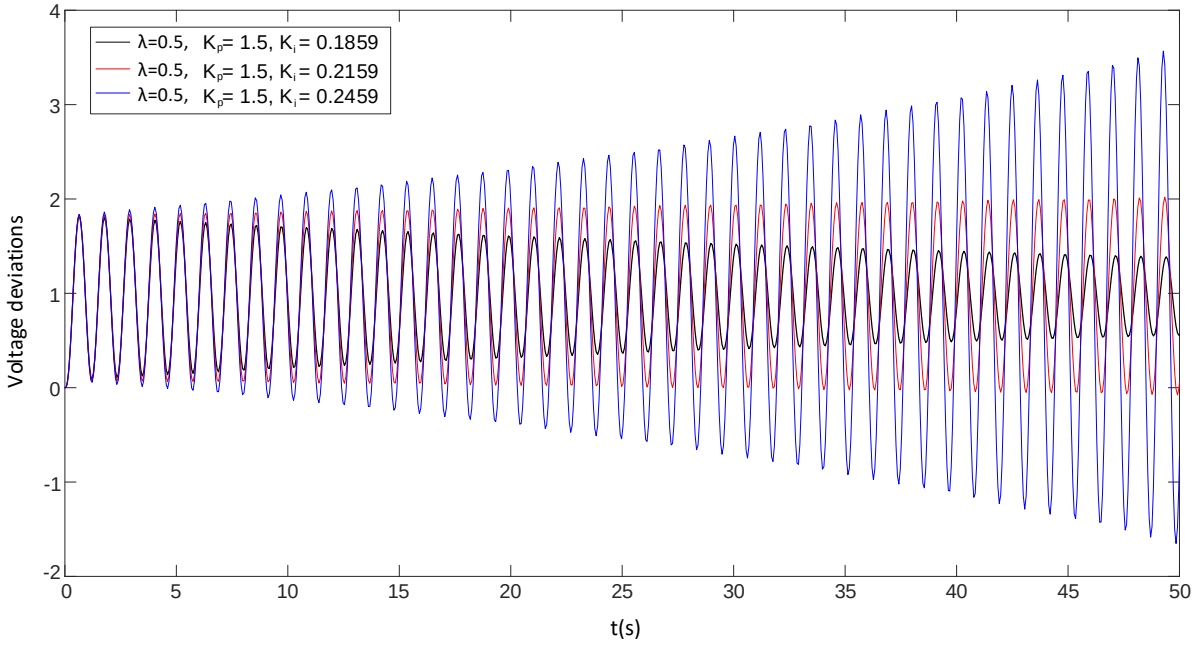

Figure 9. Time responses of the system for the parameters at Z2

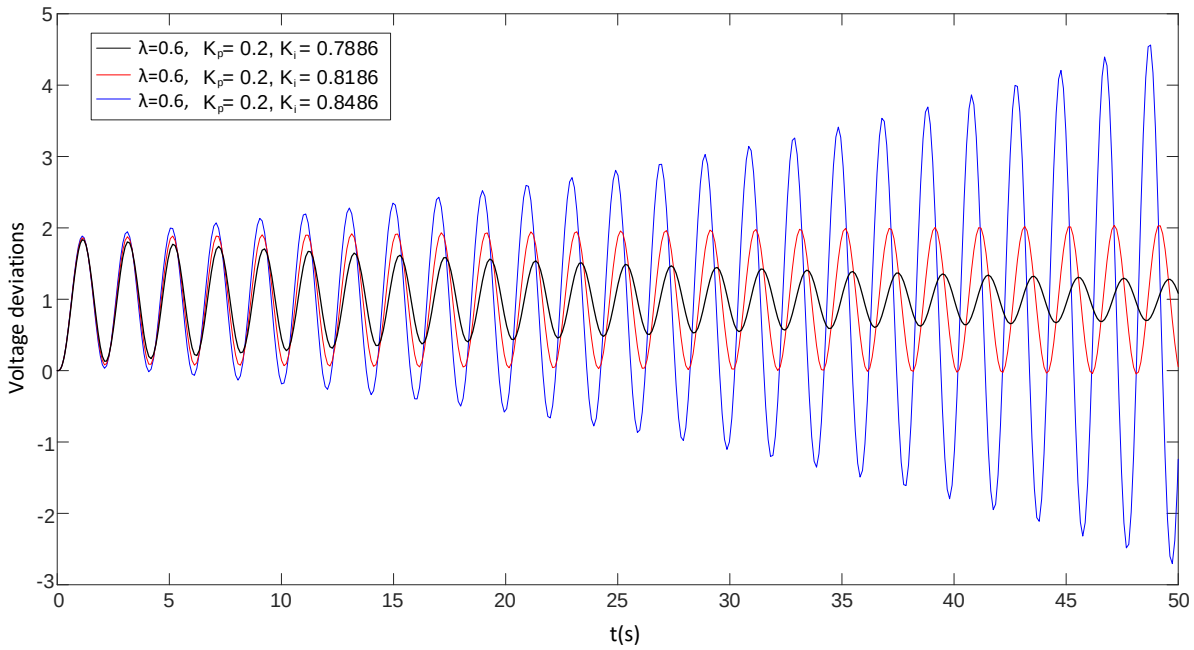

Figure 10. Time responses of the system for the parameters in Z3

For all different values of Z1, Z2 and Z3 generated with different values of λ, the AVR system is unstable for controller gains outside the boundary as predicted by the stability boundary locus method. For controller gains within the limit, the AVR system is stable and above it is critically stable.

CONCLUSION

Closed loop control systems aim to improve the performance of the controlled system. Along with the improvement, maintaining the stability of the system is also important for AVR systems as in all control systems. In this study, fractional degree controllers, which have more control parameters than full degree controllers, are used. *For AVR, it is aimed to create a stable parameter space by using a fractional degree controller.* In order to determine the stable region, the characteristic equation of the AVR system was first obtained. Then the stability boundary locus were obtained by using the characteristic equation. It is shown that the closed region between the boundary curves obtained for three different λ values is stable and time response simulations of the AVR system are performed using fractional PI controller parameters inside, on the boundary line and outside the closed region. *Simulations in MATLAB/Simulink environment verify the stability analysis for the AVR system with fractional PI controller.* According to the results of the analyses obtained, the fractional PI controller not only determines the controller parameters that will keep the AVR system in a stable state, but also expands the controller parameter space that will keep the system stable for different fractional integral degree, λ values. Thus, the search space will be expanded to improve the system performance.

In conclusion, this study emphasises the applicability of fractional PI controllers in AVR systems and shows that these controllers have a significant potential to improve the stability and performance of power systems due to the design flexibility and performance advantages of this design flexibility. Thus, it is concluded that the flexibility provided by fractional PI controllers is promising for developing more efficient and reliable control systems in power system applications such as AVR.

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SMART MANAGEMENT SOLUTIONS FOR FOOD WASTE: DEEP LEARNING AND IoT TECHNOLOGIES

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ABSTRACT

The use of deep learning algorithms in food waste management holds significant potential, particularly in the detection, classification, and management of waste. This study comprehensively examines the application of deep learning algorithms aimed at improving food waste management. Specifically, algorithms like Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) offer important applications in the image-based classification of food waste, waste quantity prediction, and management. Additionally, the study emphasizes the importance of deep learning techniques in predicting food waste and managing it more efficiently. Artificial Neural Networks (ANN) and Recurrent Neural Networks (RNN) can be utilized to predict food waste and enable timely interventions, while Generative Adversarial Networks (GANs) can help develop new solutions for sustainable packaging materials and efficient waste management. Furthermore, deep learning algorithms integrated with Internet of Things (IoT) sensors enable real-time data analysis, making it possible to track food waste more effectively. This study discusses the advantages of deep learning algorithms in managing food waste and presents results derived from existing application examples. The study also outlines key challenges and future research directions in the integration of deep learning and IoT technologies. The study highlights the potential of deep learning algorithms to support informed decision-making in various food waste management scenarios, contributing valuable insights to research in this area.

Keywords: Food Waste Management, Deep Learning Algorithms, IoT Sensors

INTRODUCTION

Food waste has become one of the most pressing global challenges, causing significant environmental degradation, economic losses and social hardship. Despite efforts to reduce food waste, the amount of food waste generated throughout the supply chain from production to consumption is increasing. Effective food waste management and minimizing food waste is important not only to minimize environmental impact but also to improve resource allocation, sustainability and food security (Batool et al., 2024; Sarker et al., 2024; Rakesh & Mahendran, 2024; Liu et al., 2025; Werkman et al., 2025).

Traditional food waste management methods such as manual sorting, recycling and disposal often lack the precision and adaptability needed to address the complexities of modern food systems. They can also be costly and prone to human error (Das et al., 2024; Trabold and Nair, 2018; Wani et al., 2024). In recent years, deep learning algorithms have emerged as next-generation tools for improving food waste management.

Deep learning techniques such as Convolutional Neural Networks (CNNs), Long Short-Term Memory (LSTM) networks, Recurrent Neural Networks (RNNs), and Generative Adversarial Networks (GANs) offer innovative approaches to detecting, predicting, and managing food waste. By leveraging large amounts of data including images, sensor inputs, and historical waste patterns, these algorithms become ideal tools to address the complexities of food waste management (Sanghi et al., 2022; Singh and Kaunert, 2024; Truong and Luong, 2024).

The application of deep learning in food waste management covers a variety of areas, from waste detection and classification to real-time monitoring and waste quantity estimation. For example,

CNNs have been widely used in image-based classification tasks, enabling systems to automatically identify and categorize food items in waste streams. LSTMs and RNNs, on the other hand, are effective in predicting future waste trends based on historical data, allowing for more proactive and targeted interventions. Additionally, Generative Adversarial Networks (GANs) can help create innovative solutions such as sustainable packaging or efficient waste treatment systems (Lubura et al., 2022; Geng et al., 2024; Truong and Luong, 2024).

In parallel with advances in deep learning, the integration of the Internet of Things (IoT) has further enhanced the capabilities of food waste management systems. IoT devices such as smart bins, sensors, and connected devices enable continuous collection of real-time data on food storage conditions, consumption patterns, and waste generation. When combined with deep learning algorithms, this data can be analyzed to identify inefficiencies, predict waste accumulation, and trigger timely interventions. This synergy between IoT and deep learning not only improves monitoring and response, but also enables smarter, more automated, and more sustainable food waste management practices (Hong et al., 2024; Öztürk et al., 2025; Zhang et al., 2025).

This study aims to investigate various applications of deep learning algorithms in food waste management and focuses on their role in waste detection, classification, and prediction. It also discusses the integration of deep learning with other emerging technologies such as the Internet of Things (IoT) and examines real-time waste monitoring and management systems. In addition, it identifies key challenges and futre research directions in deep learning and IoT technologies in food waste management. The findings of this research reveal how deep learning and integrable technologies contribute to more sustainable and data-driven approaches to managing food waste.

DEEP LEARNING ALGORITHMS IN FOOD WASTE MANAGEMENT

Deep learning is a sub-branch of machine learning that can learn patterns in high-dimensional and complex data structures through multi-layered artificial neural networks. These methods exhibit superior performance in terms of accuracy and generalization capacity, especially in big data environments. In applications aimed at reducing food waste, deep learning algorithms offer effective solutions in areas such as supply chain optimization, process automation, and development of decision support systems. In this context, architectures such as CNNs, LSTM networks, RNNs, and GANs are used in tasks such as image classification, time series prediction, data synthesis, and anomaly detection, and are among the most researched and applied models in the context of food waste management (Afsharpour et al., 2024; Singh et al., 2024; Olawale et al., 2025).

CONVOLUTIONAL NEURAL NETWORKS

Convolutional Neural Networks (CNNs) are specialized deep learning architectures that mimic the neural connectivity structures in the human visual cortex, especially developed for spatial data analysis. CNNs, which have shown high success in applications such as image recognition, image description, and image retrieval, consist of convolutional layers that can automatically detect low-level features such as edges, textures, and shapes. These layers are supported by linear (e.g. convolution) and nonlinear (e.g. activation) operators, pooling, and fully connected layers, forming a typical CNN architecture (Zhao et al., 2024a).

The image-based classification capabilities of CNNs have made them highly effective tools for food waste management. These algorithms can be trained on food images to automatically identify and classify spoiled or partially spoiled foods, and can be integrated into automated sorting systems in food processing plants, supermarkets, and retail chains. This can help reduce waste by preventing food that is still edible from being accidentally thrown away(Castro-Bello et al., 2025; Nazir et al., 2025).

CNNs can detect signs of spoilage in fruits, vegetables, and meat products—such as rot, mold, or discoloration—with high accuracy. Such early detection ensures that spoiled products are promptly removed from the system, improving food safety and preventing unnecessary waste. ResNet, one of the deep CNN architectures, is widely used in food classification, while U-Net offers effective solutions for segmenting defective areas such as mold on fruits (Altun and Turker, 2025; Ganapathy and Srinivasan, 2025).

Additionally, CNNs can monitor grocery and restaurant shelves to identify products that are nearing their expiration date. This can help prevent waste by facilitating the implementation of dynamic pricing strategies or the donation of products. CNN systems integrated into smart bins can analyze the type of food being thrown away, allowing individuals and businesses to assess and optimize their consumption habits. To this end, startups like Winnow are promoting the widespread use of CNN-based systems in commercial kitchens to optimize ingredient usage and track waste (Espinoza, 2019; Ouyang et al., 2024).

In agriculture, CNN-enabled drones and field cameras can predict crop maturity by analyzing plant health and growth status, which can help prevent food losses due to early or late harvest. These applications are supported by projects such as Microsoft's AI for Earth initiative and Google's Food Recognition Challenge, encouraging the integration of CNNs into crop monitoring and waste estimation in real-world conditions (Kaushal et al., 2024; Rokhva et al., 2024).

For CNN-based models to be trained effectively, large and labeled image datasets are needed. Frequently used datasets for this purpose include UECFOOD256, Food-524, WasteNet and custom datasets (Bansal and Tripathi, 2024; Phiphitphatphaisit and Surinta, 2024).

RECURRENT NEURAL NETWORKS

Recurrent Neural Networks (RNNs) are deep learning algorithms designed to work with sequential data structures and capable of modeling temporal dependencies. RNN architecture enables learning past-based patterns and making future predictions by keeping information from previous time steps in memory through repetitive hidden layers. Thanks to this structure, RNNs can analyze food waste data that includes time-dependent variations such as seasonal fluctuations, weekly cycles, special days, holidays and vacations and predict future waste amounts with high accuracy (Ding et al., 2025).

The application potential of RNNs is wide-ranging. They can be used effectively in various areas such as waste estimation according to weekly menu plans in university cafeterias, demand estimation and related stock optimization in retail food chains, portion planning according to customer density in hotels and restaurants, and harvest timing estimation in agricultural production (Lee et al., 2020; Boechel et al., 2022; Said et al., 2023). In this context, the RNN-based Foodforecast system developed by Hübner et al. (2024) has produced effective results especially in the bakery sector. The system in question has provided a 30% reduction in the return of bakery products, especially bread and buns, and this improvement corresponds to the prevention of approximately 2000 tons of food waste in 175 bakeries. Similarly, Lekhya et al. (2024) learned historical data on spinach stem processing methods using RNN models and predicted the most appropriate processing method with 84.10% accuracy, thus minimizing spinach stem waste.

LONG SHORT-TERM MEMORY NETWORKS

Long Short-Term Memory (LSTM) networks are a special deep learning architecture developed to overcome the limitations of RNNs in learning long-term dependencies and especially the problem of vanishing gradient. The LSTM structure consists of three basic gates to control the data flow: forget gate, input gate, and output gate. The forget gate determines how much of the information in the previous cell state will be preserved; the input gate decides which part of the new information will be

learned. The output gate controls which part of the information stored in the cell will be transferred to the next layers. This dynamic structure enables LSTMs to effectively learn long-term relationships in time series (Sherstinsky, 2020).

LSTM algorithms have significant application potential in the context of food waste management. LSTM-based models can be used in areas such as estimating daily waste amounts in institutional cafeterias, menu planning and portion optimization in restaurant and hotel kitchens, shelf life estimation and stock surplus detection in the retail sector, and predicting post-harvest losses in agricultural production and logistics. In this way, proactive interventions can be carried out at different stages of the food supply chain to prevent food waste (Han et al., 2023; Rodrigues et al., 2024).

In this context, in a study conducted by Han et al. (2023), the estimation of methane production in anaerobic digestion processes was carried out with 99.75% accuracy thanks to the integration of the LSTM network and the synthetic minority oversampling technique (SMOTE). In addition, it was stated that with the use of this model, a 25.77% increase in methane production per m^3 of feed could be achieved and system feeding rates could be managed more effectively over time. On the other hand, Rodrigues et al. (2024) reported that food demand could be predicted more accurately using historical long-term data in food catering services, and thus a 14% to 52% reduction in the number of wasted meals was achieved.

GENERATIVE ADVERSARIAL NETWORKS

Generative Adversarial Networks (GANs) are deep learning architectures based on unsupervised learning, consisting of two separate artificial neural networks, one generator and the other discriminator. While the generator network tries to produce synthetic data that looks like real, the discriminator network aims to distinguish real and synthetic data. The competitive learning process established between these two networks allows both structures to improve their performance over time. The fact that GAN architectures do not require the use of labeled data makes them advantageous in unsupervised data environments. Different GAN architectures have been developed for use in areas such as image synthesis and data augmentation. These include advanced models such as BigGAN, Self-Attention GAN (SA-GAN), StyleGAN, Progressively Growing GAN (ProGAN), Super Resolution GAN (SR-GAN), Information Maximizing GAN (InfoGAN), CycleGAN, Coupled GAN (CoGAN), Deep Convolutional GAN (DCGAN) and Transformer-based GAN (TransGAN) (Lu et al., 2022).

The potential applications of GANs in the context of food waste management are increasing. These architectures offer effective solutions in many areas such as food recognition and classification, spoilage detection, shelf life prediction and supply chain optimization. Bacchin et al. (2024) reported that the performance of robotic waste separation systems increased by 5.8% thanks to the GAN-based wasteGAN model they developed. Iyer (2020) stated that a 12% improvement in classification accuracy was achieved by using the synthetic image generation DA-GAN model in the classification of fresh, defective and spoiled products using Fruit360, USDA and strawberry image datasets. Mandal et al. (2019) performed food identification with 96.43% accuracy on the ETH Food-101 dataset and 98.30% accuracy on the Indian Food dataset with the SSGAN they developed.

GAN architectures have also been successfully applied in the field of fruit and vegetable detection. For example; CycleGAN has been used in applications such as sweet/bell pepper, orchard and vineyard; CGAN has been used in kiwi fruit identification; CGAN/CDCGAN has been used in grapevine berries analysis (Lu et al., 2022). All these studies reveal that GAN-based deep learning architectures have high potential in reducing food waste and can contribute to more efficient management of food systems in the future.

IoT IN FOOD WASTE MANAGEMENT

The Internet of Things (IoT) refers to a network structure consisting of physical objects (devices, vehicles, equipment, etc.) connected to the Internet, capable of collecting data and making decisions based on this data. The ability of IoT systems to make autonomous decisions based on real-time data increases operational efficiency and provides a high level of optimization in process management. The basic components of IoT can be grouped into three main groups: (i) connection — technologies such as Wi-Fi, Bluetooth, 5G, Zigbee, LPWAN that provide communication between devices; (ii) data processing — the analysis of collected data on cloud-based platforms and its conversion into meaningful outputs; (iii) user interface — the layer that allows users to interact with systems via mobile applications, dashboards or alert systems (Laghari et al., 2021).

IoT applications collect data from the physical environment through sensors. These sensors include temperature, infrared (IR), ultrasonic, gyroscope, accelerometer, rain, soil moisture, light, water flow, heart rate, alcohol, color, gas, smoke, humidity, flexibility, touch, vibration, and neural sensors. These sensors play a critical role in reducing food waste by allowing the monitoring and control of conditions at every stage of the food supply chain (da Costa et al., 2023)

IoT technologies are considered a strategic tool in reducing food waste by providing real-time monitoring, automation and data-driven decision-making capabilities in the food supply chain. In this context; IoT sensors integrated into refrigerators, warehouses and transportation vehicles can monitor parameters such as temperature, humidity and shelf life of products and trigger automatic notification and order mechanisms when there is a risk of spoilage or when the expiration date is approaching. For example, IoT devices used in food transportation monitor environmental conditions in real time and send alerts in case the temperature range is exceeded, allowing instant intervention (Ramanathan et al., 2023).

Hong et al. (2014) reported that food waste was reduced by 33% with an IoT-based smart waste management system implemented in the Gangnam district of Seoul, South Korea, for a period of one year. In addition, many companies are actively implementing IoT solutions to reduce food waste. The system developed by Winnow and used in commercial kitchens provides chefs with real-time data by weighing and analyzing waste food. This system has reduced kitchen waste by 76% and post-customer waste by 55% in 13 Hilton Hotels locations in the United Arab Emirates. Strella Biotechnology uses IoT sensors to manage shelf life and determine the ideal sales time by monitoring the gases released by fruits during the ripening process. This technology, implemented in apple and pear packaging facilities across the US, has reduced food losses on store shelves by approximately 50%. Surge Alert monitors changes in environmental conditions through IoT-based signals used in greenhouses, cold chain transportation, and warehouse environments, and provides users with real-time information and the opportunity to intervene. In addition to these; Companies such as Grind2Energy by Emerson & AT&T, Transparent Path, Disruptive Technologies also digitize waste management processes by integrating IoT technology and contribute to the prevention of food waste.

INTEGRATION OF IoT AND DEEP LEARNING ALGORITHMS IN FOOD WASTE MANAGEMENT

The integration of IoT (Internet of Things) and deep learning algorithms stands out as a very promising strategy for reducing and managing food waste. The combination of these technologies enables the collection, analysis and decision-making of real-time data to minimize food waste in the food supply chain (Algethami, 2024; Rathore et al., 2024; Öztürk et al., 2025). These systems offer smart solutions to effectively track and manage food waste.

IoT components collect data on food type, quantity and freshness simultaneously using smart boxes integrated with various technologies such as weight sensors, gas sensors, cameras and RFID in waste monitoring systems. Deep learning algorithms can analyze this data to detect food spoilage and

predict potential waste. Thus, smart systems can make data-driven decisions to effectively reduce food waste (Morchid et al., 2024).

Gull et al. (2021) stated that an eNose system with MQ4 (detects CH_4 gas) and MQ135 (detects CO_2 and NH_3 gases) sensors was used to detect gas emissions of different food items (meat, rice, bread). In addition, weight sensors were integrated with HX711 A/D converter to measure the weight of the waste. The obtained data was uploaded to the Arduino UNO board and the amount of food waste was estimated using a decision tree algorithm. The study was able to estimate food waste with 92.65% accuracy. Rahman et al. (2022) used the CNN deep learning algorithm to classify waste in smart trash cans as digestible and non-digestible waste through a microcontroller using IoT and Bluetooth technology. This study achieved a successful classification with 95.31% accuracy.

In smart storage systems, IoT-based sensors provide simultaneous data by monitoring temperature, humidity, and ethylene gas levels, and CNN and LSTM algorithms can predict the spoilage timelines of products in light of this data. Such smart systems can accurately predict the shelf life of products and suggest which foods should be consumed faster, thus contributing to the reduction of food waste (Mohammad et al., 2020).

KEY CHALLENGES & FUTURE DIRECTIONS

Although deep learning algorithms have great potential in minimizing food waste, some challenges need to be overcome to fully realize this potential. These challenges include data limitations, generalizability issues, high computational costs, model interpretability, and integration difficulties with existing systems. While deep learning algorithms demand large, high-quality, and annotated datasets, food waste datasets are often limited, heterogeneous, and lack standardization. This means that deep learning models, especially those developed with training based on food types from specific restaurants or geographic regions, cannot be generalized to other environments without requiring a new process. This limits the scalability of the algorithms (Huang et al., 2024; Zhao et al., 2024b) .

The high computational complexity of deep learning algorithms complicates their applicability and interpretability in decision-making processes in small-scale food service operations. This can hinder trust and adoption of algorithms among food chain collaborators. Furthermore, the integration of deep learning algorithms into existing food supply chain infrastructure and waste management systems can require significant technical and financial resources (Li et al., 2022; Xua and Yang, 2025).

Although the integration of IoT (Internet of Things) technologies in food waste management provides many advantages, there are also some significant challenges. These include data security and privacy, lack of compatibility and standardization between devices, energy consumption and hardware limitations, device maintenance requirements, and device lifespan. Since IoT devices continuously collect data, data security and user privacy are critical concerns, especially for businesses and public institutions. The integration of IoT devices from different manufacturers can lead to issues such as data inconsistencies and protocol incompatibilities, which can negatively affect the overall efficiency of the system. In addition, since IoT devices generally operate on low energy, lightweight and optimized models are required for deep learning algorithms to run on these devices. This means additional effort in terms of software engineering (Zikria et al., 2021).

In systems that work with large data volumes, the real-time integration of deep learning algorithms with IoT can cause latency problems and negatively affect the decision-making process. In addition, regular maintenance, software updates, and hardware replacement are required for the sustainability of IoT systems, which increases the economic cost of the system (Algethami, 2024).

Future studies should focus on developing standardized datasets for food waste, designing lightweight and efficient models for the integration of deep learning algorithms in low-power devices such as smart bins and kitchen sensors, developing hybrid systems supported by IoT and Edge AI, and improving the interpretability and explainability of deep learning models. In this way, more holistic

solutions and interdisciplinary research should be aimed at managing food waste, as well as affecting collaborative behaviors and policy integration.

CONCLUSION

Reducing food waste remains a critical issue for sustainability and efficiency in the modern food supply chain. The integration of deep learning algorithms and Internet of Things (IoT) technologies is one of the most promising strategies to address this issue. By collecting real-time data at every stage in the food supply chain, IoT can provide instant information about the status of products. Deep learning algorithms can analyze this data to predict spoilage processes and create decision-making mechanisms to minimize food waste.

However, there are several significant challenges to the wider application of these technologies. Data limitations, heterogeneity of existing food waste data, and lack of standardization hinder the effectiveness of deep learning models. At the same time, obstacles such as generalizability of these models, processing costs in small-scale operations, and interpretability issues limit their potential effectiveness in combating food waste. Continuous data collection of IoT devices, lack of inter-device compatibility, energy efficiency, and security are also significant challenges. These obstacles may limit the widespread adoption of deep learning algorithms and IoT systems.

As a result, deep learning and IoT integration holds great potential for food waste management, and it is critical that future research addresses these challenges for more efficient application of these technologies. Future work strategies include developing standardized datasets, improving IoT devices in terms of security and energy efficiency, and developing holistic solutions and interdisciplinary collaborations for food waste management. These strategies will not only reduce food waste, but will also contribute to supply chain optimization and sustainability goals.

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ANALYSIS OF SURFACTANT ADSORPTION ON ROCK SURFACES TO OPTIMIZE SURFACE TENSION

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Abstract

In oil and gas wells, flow challenges and downhole problems especially liquid loading, sand production, and highly viscous fluid flow are often linked to surface tension and interfacial interactions at the phase boundaries between rock, water, oil and gas. Surfactants are commonly injected to modify surface tension which improves phase mobility. However, their effectiveness depends heavily on how they interact with the reservoir rock. A significant portion of injected surfactants tends to adsorb onto mineral surfaces. This decreases the active concentration of surfactant and reduces the overall efficiency of the treatment.

This study investigates the adsorption behavior of a nonionic and bio-green surfactant-alkyl polyglucoside (APG) on three distinct rock types with different concentrations. Ultraviolet (UV) spectrophotometry method was used in evaluation of remaining concentration of surfactant after static adsorption tests. It also examines the influence of formation brine on surfactant retention. Experimental results showed that high salinity brines (Mg^{2+} and Ca^{2+}) increased APG adsorption due to ion exchange and changes in rock surface charge. Results showed that shale had the highest adsorption capacity by 3.42 mg/g with Ca^{2+} ions because of their larger ionic radius and stronger water structure disruption. These findings highlight the importance of fluid–rock interaction when designing surfactant-based treatments.

This research also emphasizes the impact of alkali additive as a mitigation method to reduce adsorption. Ethanolamine was used as a sacrificial agent by altering the surface charge of the rock. It increased electrostatic repulsion between APG molecules and mineral surfaces and this led to a measurable reduction in APG retention where ethanolamine lowered adsorption by up to almost 9% in Ca^{2+}-rich conditions.

Overall, results demonstrate the effectiveness of alkali implementation to minimize surfactant loss and maintain interfacial modification to optimize wellbore stability and production rate in different flow environments.

Keywords: Surface Tension, Surfactant Adsorption, Divalent Ions, Alkyl Polyglycoside (APG), Ultraviolet (UV) Spectrophotometry

Introduction

Downhole challenges like liquid loading, sand production, and highly viscous fluid flow can significantly reduce hydrocarbon production and well performance in oil and gas wells. These problems are strongly connected to surface tension and interfacial interactions at the boundaries between rock, water, oil, and gas phases.

Surfactant injection is one of the commonly employed methods to address these flow limitations (Yin et al., 2023). Surfactant is a chemical agent that modifies surface tension and interfacial tension (IFT) between immiscible phases. It enhance the mobility of phases by reducing surface forces. In multi-phase systems, IFT reduction between water-gas, oil-water, and oil-gas interfaces is crucial to optimize fluid displacement.

However, the success of surfactant-based treatments is limited by their interaction with reservoir rocks. Surfactant adsorption is a significant challenge which decreases the amount of available surfactant for surface tension modification (Belhaj et al., 2020). High levels of adsorption can lead to substantial chemical loss which can cause high operational costs.

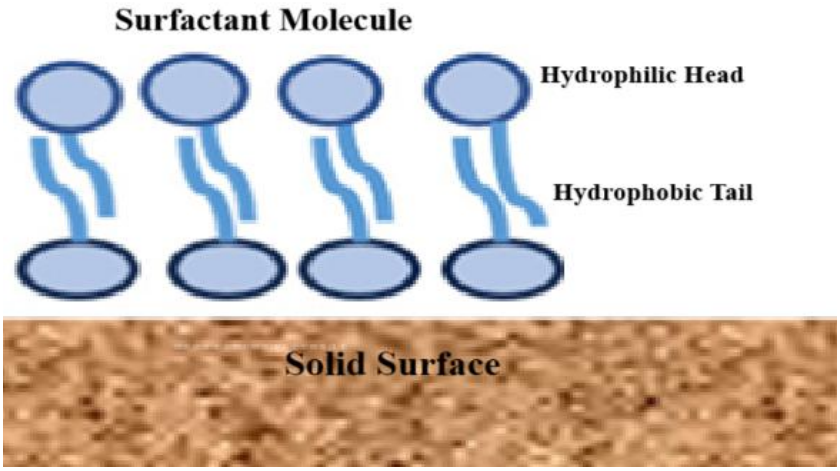

Figure 1. Description of surfactant adsorption process on solid surface

Another critical factor in the adsorption process is the presence of divalent ions in formation brines. These Ca and Mg based salts interact with both the surfactant molecules and the rock surface and alter the surface charges which causes stronger surfactant binding (Kun et al., 2013).

This work also investigates the application of alkali additives as a sacrificial agent to mitigate surfactant loss due to adsorption. Alkali addition increases repulsion forces between the molecules of surfactant and rock (Hadi et al., 2014).

Consequently, surfactant and rock interactions control in various environments is essential to modify surface tension and IFT for optimization of wellbore stability and maintenance of high production rates (Tiwari et al., 2022).

Materials and Methods

This section gives the used materials and applied methodology to investigate the adsorption behavior.

Three types of natural reservoir rocks — sandstone, limestone, and shale were utilized as the solid sample. Samples were crushed and washed multiple times to remove impurities. Nonionic surfactant-Alkyl polyglucoside (APG) was employed due to its known resistance to high salinity and temperature environments. Static adsorption experiments were conducted by mixing rock powders with various concentrations of APG solution. Samples were placed in an oven and mixtures were centrifuged to separate the rock particles from the surfactant solution after an appropriate aging period.

The concentration of remaining surfactant in solution after adsorption was determined by ultraviolet (UV) spectrophotometry. The UV spectrometer operates based on the principle that molecules absorb light at specific wavelengths (Ismayilov, 2024). In this study, UV measurements were used to construct a calibration curve to accurately determine the adsorption capacity.

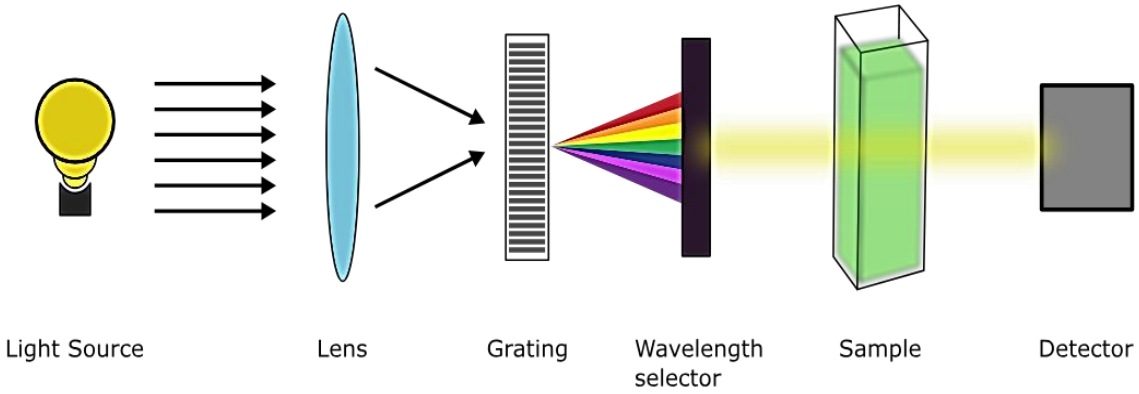

Figure 2. Working principle of UV spectometer device

Additionally, different concentrations of CaCl2 and MgCl2 were prepared to include divalent cations into the system. Ethanolamine was selected as the alkali additive due to its organic nature, high stability and its ability to adjust the surface charge of mineral surfaces (Tackie-Otoo et al., 2020). It was introduced as a sacrificial agent to minimize surfactant loss by decreasing electrostatic attraction between surfactant molecules and mineral surfaces.

Results and Discussion

This section presents the adsorption behavior of the surfactant on shale which showed the highest adsorption values. Therefore, all figures and analyses in this section belong to shale samples.

The adsorption of surfactant on shale increased sharply at lower concentrations and approached onstant near 1 mg/mL which is also known as the critical micelle concentration (Reyani et al., 2023). At this point, the adsorption reached 2.5 mg/g in the absence of salts. The presence of divalent ions extensively increased APG adsorption. As shown in Figure 3, the addition of $CaCl_2$ at maximum molarity enhanced adsorption to 3.5 mg/g. This indicates a strong salting-out effect and surfactant-ock interaction under high ionic strength conditions.

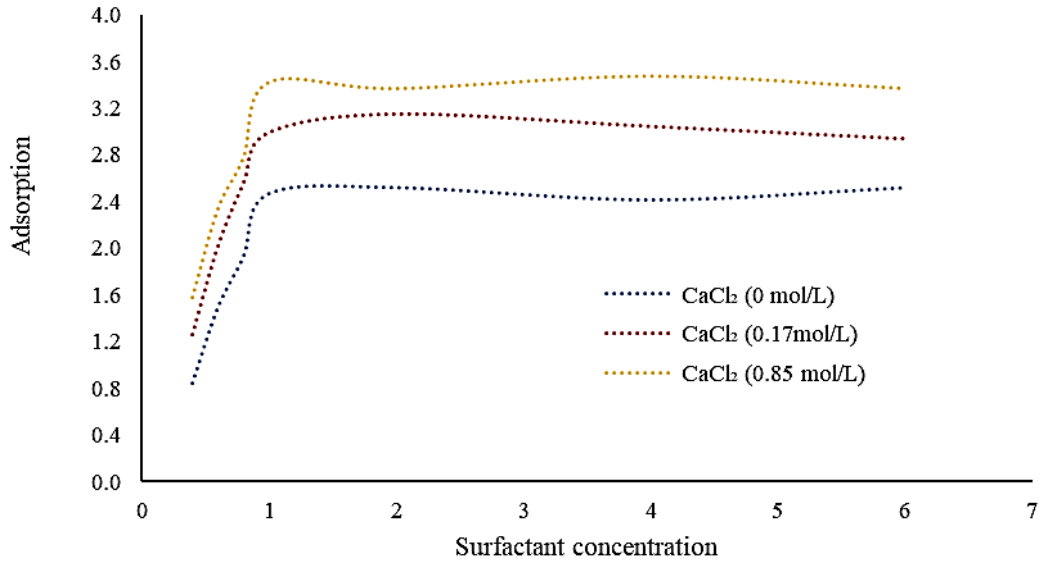

Figure 3. Adsorption value change through various surfactant concentrations on shale rock

The introduction of ethanolamine resulted in a measurable reduction in APG adsorption on shale. Ethanolamine reduced adsorption by approximately 9% in the presence of $CaCl_2$. Although in the presence of Mg^{2+} the adsorption was not higher than Ca^{2+}, a similar trend was observed with $MgCl_2$ (Wei et al., 2020). This describes that alkali addition can measurably mitigate excessive surfactant loss under saline conditions. These adsorption changes are depicted in Figure 4.

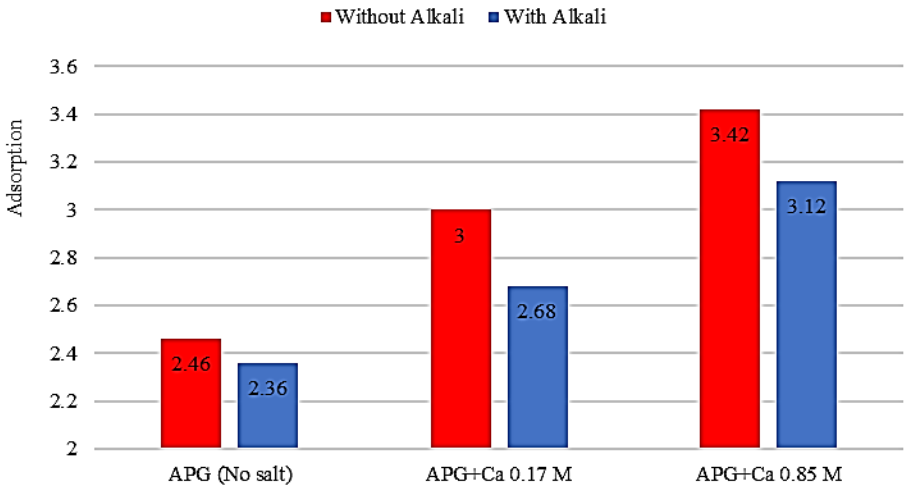

Figure 4. Impact of alkali on adsorption value on shale

Conclusion

This research was conducted to investigate the surfactant adsorption challenge on reservoir rocks, which can cause reduced efficiency in surface tension modifications. During static adsorption testing, it was observed that APG adsorption increases with concentration and is significantly influenced by the ionic composition of the solution. Furthermore, divalent cations such as Ca^{2+} tremendously increased adsorption levels on shale with a maximum adsorption of 3.5 mg/g. Additionally, the implementation of ethanolamine as an alkali additive proved effectiveness in mitigation of surfactant loss. It prevented APG adsorption up to 9% in calcium-rich environments. These results explains the importance of fluid–rock interaction, salinity and solution chemistry in the efficiency of surfactant applications.

Recommendations

In further studies, it is recommended to expand these results by testing a wider variety of surfactants with different molecular structures and ionic properties. Additionally, the impact of other salt types and mixed ion environments at varying concentrations should be investigated to better simulate real reservoir conditions and optimize surfactant selection and formulation strategies.

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MACHINE LEARNING MODELS: THE MATHEMATICAL POWER OF MATRIX DIAGONALIZATION AND QUADRATIC FORMS

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ABSTRACT

Machine learning has become a powerful tool for decision-making and prediction, yet the mathematical foundations that support these models often receive less attention. This paper explores the significant roles of matrix diagonalization and quadratic forms in improving both the performance and clarity of machine learning algorithms. First, we show how diagonalization helps uncover hidden structures in large datasets, particularly through Principal Component Analysis (PCA). Second, we examine how quadratic forms help model and understand the shape of cost functions in optimization tasks. A key contribution of this work is the proposal of a new hybrid technique that combines diagonalization with regularization to speed up convergence in gradient-based learning methods. We support our theoretical insights with real-world examples, such as medical diagnostics and financial predictions. By combining the precision of linear algebra with the adaptability of machine learning, this study enhances both computational efficiency and model interpretability—moving a step closer to truly explainable AI.

Keywords: Matrix Diagonalization; Quadratic Forms; Explainable AI; Principal Component Analysis.

ENHANCING LIGHTWEIGHT AND ENERGY EFFICIENT CONSENSUS ALGORITHMS FOR BLOCKCHAIN BASED IOT

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Abstract

The Energy Reputation Proof of Leadership (ERPoL) consensus algorithm introduces a hybrid model that integrates permissioned network structure with public, performance-based metrics to achieve scalable, energy-efficient, and resilient blockchain consensus. Designed to overcome the energy-intensive nature of traditional consensus protocols and the centralization risks of stake-based models, ERPoL organizes nodes into multiple structured clusters, each consisting of a fixed number of participants. Within each cluster, leadership is dynamically assigned based on a composite metric called the Energy-Reputation Product (ERP), which multiplies a node's current energy reserve with its reputation score. This score is derived from historical performance factors such as uptime, validation success, and fault behavior.

To promote fairness and prevent leader monopolization, ERPoL implements a leader rotation mechanism triggered either by time intervals (every 50 time units) or when a leader's energy drops below a defined threshold (20% of initial energy). The consensus process accounts for energy usage in three distinct operations: transaction processing (1.0 unit), block creation (2.0 units), and validation (0.5 units). Nodes are also subject to random failure events with low probability, which reduce their reputation and affect future eligibility for leadership roles.

Validation is carried out within clusters by up to three nodes, enabling faster block confirmation and reducing network congestion. ERPoL also incorporates comprehensive performance monitoring, evaluating transaction throughput, latency, network availability, and fairness of energy usage using statistical distribution metrics. By combining structured permissioned clustering with dynamic, auditable metrics for leader selection and role rotation, ERPoL provides a practical and adaptable alternative to conventional blockchain consensus mechanisms. It ensures sustainable energy consumption, enhanced fault tolerance, and a decentralized leadership cycle, making it well-suited for next-generation blockchain applications in both enterprise and open-network contexts.

ASSESSMENT OF THE GENETIC DIVERSITY OF THE MONOGENEAN *SPARICOTYLE CHRYSOPHRII* INFECTING GILTHEAD SEA BREAM (*SPARUS AURATA*) ALONG THE TUNISIAN COASTS

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Abstract

The gill monogenean *Sparicotyle chrysophrii* (Van Beneden & Hesse, 1863) Mamaev, 1984 is a specific and common parasite of wild and cultured gilthead sea bream *Sparus aurata* Linnaeus, 1758, able to cause disease and mortality in aquaculture systems. Morphological examination of ectoparasites from *S. aurata* across seven Tunisian sites confirmed the presence of *S. chrysophrii*. However, molecular data on this species remain limited, and its genetic variability is poorly understood. This study provides the first molecular characterization and phylogenetic analysis of *S. chrysophrii* from Tunisian coastal waters, using specimens from both wild and cage-reared hosts. Two molecular markers were used: the large subunit ribosomal RNA (28S) and the mitochondrial cytochrome c oxidase subunit I (COI) genes. Analysis of 28S sequences showed no intraspecific variation, supporting a monophyletic group. COI sequences also formed a monophyletic clade including specimens from both northern (France, Adriatic, Italy, Spain) and southern (Algeria) Mediterranean coasts, with no significant phylogenetic ramification. Haplotype network analysis revealed no distinct haplogroups, suggesting strong gene flow between wild and farmed populations. This was supported by low nucleotide diversity ($\pi = 0.00445$) and high haplotype diversity (Hd = 0.821). Shared haplotypes indicated the potential for pathogen transmission between wild and cultured hosts along Tunisian coasts. AMOVA results showed that 92.77% of genetic variation was within populations, 7.62% among populations within groups, and 0% among groups (north, central, south Tunisia), indicating no population structuring. These findings suggest homogeneous dispersal of *S. chrysophrii* along the Tunisian coast, likely facilitated by high gene flow and host mobility, with implications for pathogen transmission between wild and farmed stocks.

Key words: *Sparicotyle chrysophrii*, 28S, COI, genetic variability, phylogenetic analysis, pathogen transmission.

MOLECULAR IDENTIFICATION AND PHYLOGENETIC STUDY OF *HEPATOZOON* AND *THEILERIA* SPP. IN RODENT POPULATIONS FROM SAUDI ARABIA

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Abstract

The genera *Hepatozoon* and *Theileria*, belonging to the phylum Apicomplexa, are associated with infections in wild animals in Saudi Arabia. However, research on rodents remains limited, potentially underestimating protozoan diversity. This study aims to detect *Hepatozoon* spp. and *Theileria* spp. and identify rodent reservoirs using molecular tools across Saudi Arabia. Molecular analysis of the 16S gene identified five rodent species. Based on 18S gene analysis, 9 and 31 rodent samples tested positive for *Theileria* spp. and *Hepatozoon* spp., with a prevalence of 8% and 28%, respectively. Phylogenetic analyses revealed two sister clades comprising *Hepatozoon* spp. and *Theileria* spp. sequences. They further showed that *Hepatozoon* sequences from rodents and reptiles formed a distinct clade, separate from those in felines and canids. The *Hepatozoon* sequences from Saudi Arabian rodents formed a well-supported cluster. The seven Saudi Arabian haplotypes formed a distinct haplogroup with a star-like pattern, suggesting specificity to rodent species in Saudi Arabia. This pattern indicates the presence of novel *Hepatozoon* haplotypes predominantly associated with rodents and reptiles. These findings support the hypothesis that rodents play a key role in the epidemiological cycle of reptile-associated *Hepatozoon* spp., rather than species linked to Carnivora. This study provides the first molecular evidence of *Theileria* spp. and *Hepatozoon* spp. in Saudi Arabian rodents, expanding the known host range. Additionally, it enhances the understanding of *Hepatozoon* spp. diversity by identifying novel haplotypes unique to Saudi Arabian rodents and closely related to those previously reported in rodents and reptiles.

Key Words: *Hepatozoon*, *Theileria,* Saudi Arabia, Rodents, Phylogenetic, Haplogroup.

GENETIC AND PHYLOGENETIC CHARACTERIZATION OF TRICHOMONADIDA SPECIES INFECTING DOMESTIC CHICKENS (*GALLUS GALLUS DOMESTICUS*, AVES: PHASIANIDAE) IN TUNISIA

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Abstract

Trichomonadida are flagellated protozoans that infect a wide range of vertebrates, including poultry such as *Gallus gallus domesticus*. These organisms are of veterinary importance due to their association with diseases that can significantly impair productivity and cause economic losses. Traditional morphological identification methods are limited by the subtle interspecies differences. However, molecular investigations of Trichomonadida in North African poultry remain limited. This study provides the first molecular characterization of Trichomonadida species in poultry farms across Tunisia, employing a multilocus approach using 18S rRNA and α-actinin 1 genes to explore their genetic diversity and phylogenetic relationships. Based on 18S rRNA sequences, the isolates were grouped into four main clades. One of these, identified as *Histomonas meleagridis*, was detected in both caecal samples and in *Heterakis gallinarum* nematodes collected from ten different Tunisian regions. This clade was further divided into two clusters, termed genotype-1 and genotype-2. Combined analysis of the two markers showed that Tunisian haplotypes clustered with French isolates, all belonging to genotype-2, and revealed a 4% (18S rRNA) genetic divergence between the two clusters. Notably, *H. meleagridis* and *Parahistomonas wenrichi* were found co-infecting *H. gallinarum*, suggesting potential mixed infections. Additional species, including *Simplicomonas* sp. and *Tetratrichomonas gallinarum*, were also identified in caecal content. Phylogenetic analysis using the Maximum Likelihood method revealed close relationships between *H. meleagridis* and *P. wenrichi*, and between *Simplicomonas* sp. and the *Monoceromonas–Tritrichomonas* group. Both genotypes of *H. meleagridis* formed a sister group to *P. wenrichi*, indicating a likely common evolutionary origin. This study represents the first investigation into the genetic diversity of Trichomonadida species in Tunisian poultry, highlighting the utility of the 18S rRNA locus for evaluating genetic variation and identifying potential mixed infections.

Key words: Trichomonadida, *Gallus gallus domesticus*, genetic diversity, 18S rRNA, α-actinin 1, mixed infection.

THE NEXT WAVE OF AI AND DATA SCIENCE: INDUSTRIAL-GRADE MACHINE LEARNING AND THE RISE OF SELF-GENERATING AI SYSTEMS

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Abstract

The artificial intelligence landscape is undergoing a paradigm shift from research-oriented experimentation to production-grade systems deployment. This study presents a novel conceptual framework for understanding the synergistic relationship between two transformative developments: the industrialization of data science workflows and the advent of self-evolving artificial intelligence architectures. We analyse three critical dimensions of this evolution: (1) the standardization and automation of machine learning operations (MLOps), (2) the emergence of AI systems capable of generating and optimizing other AI systems, and (3) the development of closed-loop, self-reinforcing AI ecosystems. Through multidimensional analysis, we demonstrate how these innovations are fundamentally restructuring business operations, creating new professional competencies, and introducing unprecedented considerations in AI ethics and oversight. The paper offers both conceptual models and actionable strategies for enterprises transitioning to institutionalized AI implementation.

Keywords: Data Science Techniques, artificial intelligence, Industrial-Grade Machine Learning, Generating AI Systems

DATA COLLECTION AND ANALYSIS FOR REAL-TIME INTELLIGENT GUIDANCE OF MOBILE ROBOTS IN SMART CITIES

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Abstract:

In the dynamic and ever-changing environments of modern urban areas, mobile robots face significant challenges in navigation and decision-making. Smart cities, characterized by the integration of Internet of Things (IoT) technologies, provide an innovative framework to address these challenges. This study explores how IoT-enabled sensors and real-time data processing can optimize the trajectory planning of mobile robots, enhancing their performance and adaptability in urban contexts.

The primary objective is to utilize IoT technologies to collect, analyze, and integrate real-time data into robotic navigation systems. IoT sensors deployed across urban areas collect diverse data, including traffic patterns, environmental conditions, and potential obstacles. These data streams are analyzed using advanced machine learning algorithms through edge and cloud computing systems, enabling real-time decision-making. The robots' navigation systems leverage this information to dynamically adjust their trajectories, ensuring efficiency, safety, and coordination in complex environments.

This approach addresses key urban challenges such as unpredictable obstacles, traffic congestion, and fluctuating environmental conditions. The use of edge computing ensures immediate response capabilities, while cloud computing supports deeper analyses and long-term optimization. Additionally, the system supports multi-robot coordination, facilitating synchronized movements and collision avoidance in shared environments.

Applications of this framework include urban logistics, such as optimizing delivery routes in densely populated areas, infrastructure maintenance, and assistance for individuals with mobility challenges. By integrating IoT technologies into the navigation systems of mobile robots, this research contributes to the development of smarter, more efficient, and sustainable urban spaces.

Keyword: IoT, Smart Cities, Mobile Robots, Trajectory Planning, Real-Time Data, Edge Computing, Urban Navigation, Machine Learning.

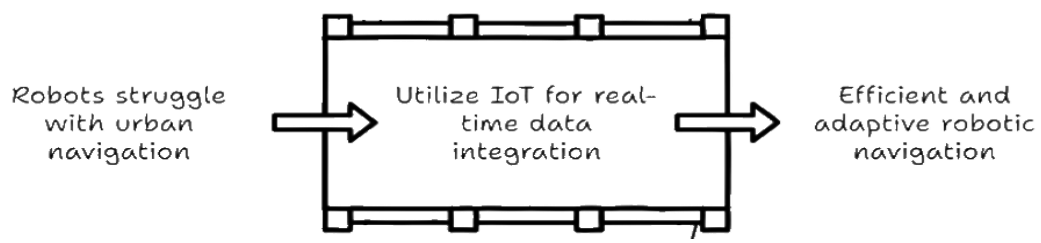

Figure 1: IoT Integration Framework for Real-Time Data and Robotic Navigation in Urban Environments

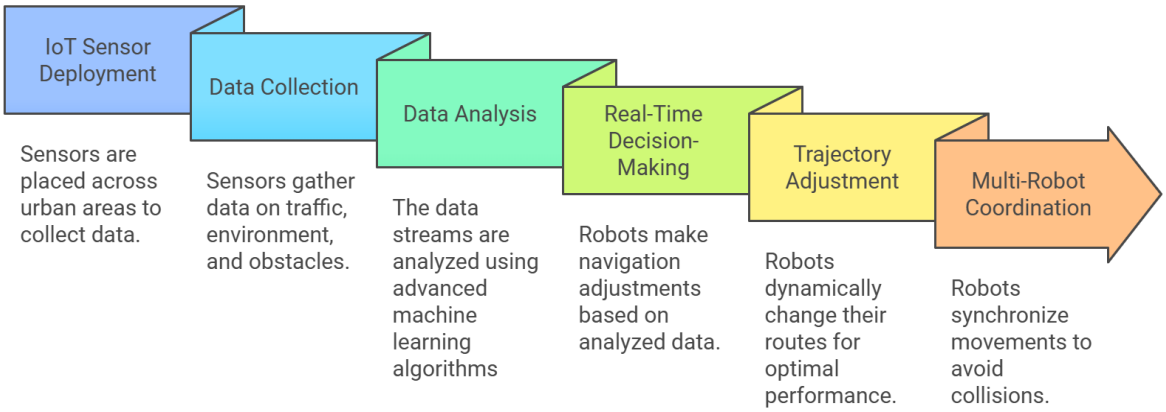

Figure 2 : Stepwise Workflow: From IoT Sensor Deployment to Multi-Robot Coordination

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COMPUTATIONAL FLUID DYNAMICS OF SPERM MOTILITY THROUGH CERVIX

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Abstract

The sperm swimming mechanism has been proposed as a possible resource for soft micro-robots in confined spaces, with potential applications in biomedical engineering. Human sperm cells essentially swim through the non-Newtonian liquid (cervical mucus) to reach their target. Thus, sperm cells swimming through non-Newtonian fluids is not vital only for physiology, but also for the fabrication of swimming micro-robots. Inspired by these remarkable applications, we examine the basic mechanics of spermatozoa motility using an undulating sheet model. This undulating sheet is bounded between two rigid walls which is self-propeling in the negative axial direction. The Carreau fluid is approximated as cervical mucus and electro-osmotic effects are also considered. The application of the lubrication approximation results in the reduction of momentum equations into a fourth-order ordinary differential equation. The present mathematical model is solved numerically via the finite difference method and MATLAB's built-in routine bvp5c. The unknowns that are present in the boundary conditions are refined by the root-finding algorithm. Power losses, cell speed, flow rate, velocity of the fluid, and streamline pattern are visualized by graphs. The findings of this study have important implications for the designing and optimization of electrically controlled microswimmers.

Keywords: Stokes equations, Electric force, Galilean transformation, non-Newtonian fluid, Newton-Raphson method.

ANALYSIS OF COMMERCIAL CENTRALITY IN CONSTANTINE: APPROACH BY GEOGRAPHIC INFORMATION SYSTEMS

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Abstract

This study aims to analyze commercial centrality in the city of Constantine using geographic information systems (GIS) for an accurate and visual assessment of commercial dynamics. The methodology adopted is based on several key steps.

First, we will collect geospatial data on retail distribution, customer flows, and surrounding infrastructure. We will then use GIS tools to map and analyze this data, enabling us to identify areas of high commercial activity as well as less developed sectors.

The analysis will also focus on factors influencing centrality, such as accessibility, population density, and neighborhood socioeconomic characteristics. Finally, we will propose recommendations based on the results of the analysis to support the strategic development of commercial areas in Constantine.

This research will contribute to a better understanding of the challenges of commercial centrality and provide a solid foundation for guiding public policies and local development initiatives.

Keywords: Commercial Centrality,Constantine, Geographic Information Systems,Spatial Analysis, Business Dynamics, Accessibility, Local Developmen,Public Policy.

SYSTEMATIC REVIEW OF HOW ML MODELS FROM FINANCE CAN PREDICT AND MITIGATE CASCADING FAILURES IN COMPLEX ENGINEERING SYSTEMS

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ABSTRACT

Cascading failures in complex engineering systems—from power grids to transportation networks—pose significant risks to reliability and safety, mirroring systemic vulnerabilities observed in financial markets. This paper explores the transferability of machine learning (ML) models from finance to predict and mitigate cascading failures in complex engineering systems. By synthesizing insights from financial risk analysis and engineering resilience, it examines how techniques like portfolio optimization, volatility forecasting, and stress-testing can enhance the reliability of infrastructures. The analysis spans diverse engineering domains, including power grids, transportation networks, and IoT systems, highlighting the cross-disciplinary applicability of ML methodologies. While ML offers powerful tools for predicting systemic risks and improving resilience, challenges persist in addressing data scarcity, interpretability, and scalability. The review concludes by proposing integrative frameworks and future research directions to foster innovation at the intersection of finance and engineering, ultimately aiming to build more resilient interconnected systems. Future research should prioritize multi-agent RL for adaptive mitigation, real-time hybrid modeling, and standardized cross-domain validation protocols to fill the gap between theoretical risk models and practical engineering resilience.

Keywords: Machine Learning, Cascading Failures, Systemic Risk, Engineering Resilience, Financial Models.

INTRODUCTION

The integration of machine learning (ML) into systemic risk analysis and its implications for predicting cascading failures in engineering systems has emerged as an important research frontier. Financial systems, characterized by interconnectedness and risk transmission dynamics, face threats from cascading failures akin to those in engineering infrastructures like power grids and transportation networks. This review synthesizes insights from finance and engineering to explore how ML methodologies—originally designed for financial risk prediction—can enhance resilience in complex engineered systems.

Recent studies underscore ML's dual role in identifying systemic risks and mitigating cascading failures. In finance, seminal work by Kou et al. (2019) distinguishes systemic risk from traditional risk by its capacity to propagate liquidity crises across interconnected networks, advocating ML for real-time anomaly detection. Similarly, Andriosopoulos et al. (2019) highlight the evolution of computational finance, where stochastic programming and optimization models address loan portfolio risks—a framework adaptable to engineering resource allocation. Parallel advancements in engineering, such as predictive maintenance frameworks (Miller & Dubrawski, 2019), reveal limitations in scaling traditional methods to interconnected systems, necessitating ML-driven holistic models.

A central challenge lies in bridging domain-specific constraints. Pan et al. (2021) emphasize the tension between data-centric ML and physics-based engineering models, noting that purely data-

driven approaches often neglect structural knowledge, raising reliability concerns in safety-critical environments. For instance, deep learning models, while powerful, face skepticism due to vulnerabilities like adversarial attacks. Conversely, hybrid approaches integrating physics-informed ML (Liu et al., 2022) demonstrate promise in balancing accuracy and interpretability, particularly in mechanical failure prediction.

Power systems exemplify successful cross-disciplinary applications. Md Sami and Naeini (2023) categorize ML techniques by cascade phases, showing how graph neural networks (GNNs) outperform traditional models in predicting grid failures. Meanwhile, financial stress-testing frameworks (Chen & Tang, 2024) offer blueprints for engineering resilience, emphasizing adaptability to rare events and data privacy. However, gaps persist in generalizability, real-time scalability, and domain-specific data scarcity, as seen in transportation (Zhang et al., 2020) and cybersecurity (Nguyen et al., 2024).

This review examines the transferability of financial ML models—such as portfolio optimization and volatility forecasting—to engineering contexts, identifies domain-specific barriers, and proposes integrative frameworks. By synthesizing methodologies like LSTM, GNNs, and federated learning, it highlights pathways to enhance systemic reliability while addressing challenges in interpretability and cross-disciplinary validation. The findings aim to inspire innovations at the intersection of finance and engineering, fostering resilience in an era of increasingly interconnected systems.

RESEARCH METHODOLOGY

This systematic review employs a structured, multi-phase approach to synthesize existing literature on the application of ML models from finance to predict and mitigate cascading failures in complex engineering systems. A comprehensive search was conducted across academic databases, including Google Academic, Scopus and Web of Science, using keywords such as *"machine learning," "cascading failures," "systemic risk," "portfolio optimization,"* and *"engineering resilience."* The search was limited to peer-reviewed articles, conference proceedings, and preprints published between 2010 and 2024 to capture contemporary studies. Inclusion criteria prioritized studies that (1) explicitly address ML applications in financial risk prediction or mitigation, (2) explore cascading failures in engineering systems, or (3) propose cross-disciplinary methodologies bridging finance and engineering.

Exclusion criteria removed non-English publications, purely theoretical papers without empirical validation, and studies focused on non-systemic risks. A total of 45 studies were initially identified, with eight selected for in-depth analysis based on relevance and methodological robustness. Data extraction focused on key attributes: *author/year, aim, methodology, domain application, gaps, and conclusions* (summarized in Table 1). Critical gaps were identified through iterative comparison of study limitations, while conclusions were synthesized to highlight cross-disciplinary synergies.

The main objectives of this research are the following:

1. **To evaluate the transferability of financial ML models** (e.g., portfolio optimization, volatility forecasting) to engineering systems for predicting cascading failures.

2. **To identify domain-specific challenges** (e.g., data sparsity, real-time scalability) that hinder the application of financial ML techniques in engineering resilience.

This methodology ensures a holistic understanding of the intersection between financial ML and engineering resilience, providing actionable insights for future research and cross-disciplinary innovation.

LİTERATURE REVİEW EXAMİNATİON

Cascading failures are common phenomena in complex engineered systems and have attracted increasing attention over the past two decades. In a cascading failure, an initial, relatively small failure event triggers a chain of further failures, leading to a complete breakdown of the system. Cascading failures cost societies vast amounts of resources, degrade essential services, and threaten human safety and security. Forecasting such disasters is therefore a crucial step in avoiding them. Nevertheless, the intricate nature of many engineered systems makes it challenging to predict and mitigate cascading failures.

In recent years, progress in acquiring real-time monitoring technologies and the corresponding massive availability of data from large-scale complex engineered systems such as power grids, traffic networks, and meteorological systems have fueled interest in applying machine learning techniques to prediction problems. Meanwhile, the advent of intelligent algorithms involving complex data processing and complicated model architectures has made applying machine learning to cascading failures increasingly attractive and versatile.

Cascading failures of complex engineered systems are explored and analyzed in this review. This empirical research focuses on identifying key insights from various pivotal articles that explore the intersection of financial risk management and engineering system resilience and it synthetizes in a comprehensive table the main findings of the most relevant studies in this field.

The article "Machine learning methods for systemic risk analysis in financial sectors" by Kou et al. (2019) provides a comprehensive examination of the role of ML in understanding and managing systemic financial risk. The authors highlight the critical distinction between traditional financial risk and systemic risk, emphasizing the interconnectedness of financial systems and the potential for cascading failures that can emerge from a single point of failure within the network.

A key insight from the article is the authors' assertion that systemic financial risk is characterized by its ability to trigger a chain reaction of crises, particularly liquidity risks that can propagate throughout the financial system. This notion of risk transmission is crucial, as it underscores the necessity for effective risk assessment and management strategies that can preemptively identify and mitigate such risks. The authors argue that traditional risk assessment methods may fall short in the face of the complexities inherent in modern financial systems, which are increasingly global and interdependent.

In terms of critical evaluation, the article effectively outlines the pressing need for innovative methodologies in systemic risk analysis, particularly in light of recent financial crises that have exposed vulnerabilities within interconnected financial networks. However, while the authors present a robust argument for the application of ML, there remains a need for empirical validation of these methods in real-world scenarios. Additionally, the article could benefit from a more detailed exploration of specific ML algorithms that have shown promise in this domain, as well as the challenges associated with their implementation in practice.

The article titled "Computational approaches and data analytics in financial services: a literature review" by Andriosopoulos et al. (2019) presents a comprehensive overview of the computational methodologies applied within the financial services sector, particularly emphasizing loan portfolio management. The authors delineate the distinctions between traditional financial modeling approaches and innovative computational strategies that have emerged to address the complexities of financial decision-making.

The authors effectively highlight the parallels between loan portfolio management and investment portfolio selection, while also acknowledging the unique challenges posed by the former. The discussion on dynamic portfolio management utilizing stochastic and dynamic programming models is particularly pertinent, as it underscores the necessity for adaptive strategies in the face of uncertainty—an aspect relevant for predicting and mitigating cascading failures in complex engineering systems.

Moreover, the article's exploration of optimization models for value-at-risk and computationally efficient simulation methods provides valuable insights into the risk management processes inherent in financial services. These methodologies are not only applicable to financial contexts but can also be extrapolated to engineering systems where risk assessment and management are critical for operational stability.

The article "System-Level Predictive Maintenance: Review of Research Literature and Gap Analysis" by Miller and Dubrawski (2019) offers a comprehensive examination of the current landscape in predictive maintenance, particularly within the context of complex engineering systems. The authors highlight critical distinctions between condition estimation and failure risk forecasting, emphasizing that these differences arise from various factors, including latent degradation states and the interdependencies of maintenance actions.

One of the article's significant contributions is the identification of challenges associated with scaling predictive maintenance methods from individual components to subsystems and entire systems. The authors argue that traditional methods, while effective at the component level, often fall short when applied to larger, interconnected systems. This limitation is particularly relevant in the context of cascading failures, where the failure of one component can precipitate a chain reaction affecting multiple subsystems. The authors advocate for a holistic modeling approach that integrates structural and physical knowledge to better manage these complexities.

The article titled "Data-Centric Engineering: integrating simulation, ML and statistics. Challenges and Opportunities" by Pan et al. (2021) provides a comprehensive examination of the intersection between ML, artificial intelligence (AI), and various engineering disciplines. The authors highlight the increasing prevalence of ML applications across fields such as chemical process systems, fluid mechanics, smart energy systems, and structural health monitoring. However, they also emphasize critical challenges that arise when deploying these technologies, particularly in complex engineering environments where data may be scarce and the implications of errors can be severe.

A significant insight from the article is the notion that while ML/AI models have shown promise in isolated applications, their effectiveness diminishes when addressing more intricate problems that require domain-specific knowledge. The authors argue that a purely data-driven approach often neglects the fundamental physical laws that govern engineering systems. This lack of integration can lead to skepticism among operations engineers regarding the reliability of decisions made based on ML outputs, especially in safety-critical scenarios. The article effectively illustrates this point by noting that deep learning models are susceptible to adversarial examples, which can lead to misclassification and potentially catastrophic outcomes.

The integration of physics-based models with data-driven approaches, as proposed by the authors, presents a promising pathway to reconcile the challenges of interpretability and accuracy in engineering applications. By adopting a data-centric engineering perspective, practitioners can leverage the strengths of both methodologies, potentially leading to more robust and reliable systems capable of predicting and mitigating cascading failures in complex engineering environments.

The article titled "Machine Learning Applications in Cascading Failure Analysis in Power Systems: A Review" by Md Sami and Naeini (2023) provides a thorough examination of the application of ML techniques in understanding and mitigating cascading failures within power systems. The authors articulate the critical nature of cascading failures, emphasizing their potential to disrupt power grids and the consequent impact on society.

The review effectively synthesizes various ML methodologies employed in the analysis of cascading failures, categorizing them according to the different phases of the cascade process. This structured approach not only enhances clarity but also allows for a comprehensive understanding of how these techniques can be applied at various stages of failure analysis. The authors highlight the advancements in monitoring technologies and the availability of large datasets as pivotal factors that have contributed to the growing interest in ML within this field.

A significant strength of the article lies in its systematic categorization of ML techniques, which aids in delineating the specific roles these algorithms play in modeling and analyzing cascading failures. The authors also delve into the concept of cascade resiliency, providing insights into how ML can be harnessed to bolster the robustness of power systems against such failures. This focus on resiliency is particularly relevant, as it underscores the proactive measures that can be taken to mitigate the risks associated with cascading failures.

The article titled "Transformational application of Artificial Intelligence and Machine learning in Financial Technologies and Financial services: A bibliometric review" by (Kanaparthi, 2024) provides a comprehensive overview of the integration of ML techniques within the financial sector, focusing on their applications in risk assessment, credit research, and fraud detection. The analysis reveals that Support Vector Machines (SVM) and Neural Networks are at the forefront of these applications, particularly in areas such as bankruptcy prediction and systemic risk analysis. This highlights the potential of these models not only to predict financial risks but also to mitigate cascading failures that may arise from interconnected financial systems.

Kanaparthi (2024) emphasizes the significant advancements in financial fraud detection through supervised learning approaches, notably SVM and Neural Networks, which have proven effective in identifying credit card fraud, insider trading, and money laundering. This is particularly relevant to the topic of cascading failures in complex engineering systems, as financial fraud can lead to systemic failures within interconnected financial infrastructures. The successful application of these models suggests that similar methodologies could be adapted to predict and prevent failures in engineering systems by identifying anomalies and risk patterns.

The article also notes the underutilization of certain ML techniques, such as Naive Bayes and K-Nearest Neighbors (KNN), in financial intermediation and portfolio management. This observation points to unexplored avenues where alternative ML methods could be employed to enhance predictive capabilities and risk mitigation strategies. By extending the application of these lesser-utilized techniques, researchers could potentially uncover new insights into the dynamics of cascading failures within engineering systems, paralleling the financial context discussed in the article.

Furthermore, the discussion on deep learning models, including recurrent neural networks (RNNs), long short-term memory (LSTM) networks, and convolutional neural networks (CNNs), illustrates their capacity to model complex relationships within data. This capability is very important for understanding the multifaceted interactions that can lead to cascading failures in engineering systems. The article suggests that the rising trend of employing deep learning in finance may provide a framework for similar applications in engineering, where the complexity of data and interactions can be effectively captured.

The article "From Factor Models to Deep Learning: Machine Learning in Reshaping Empirical Asset Pricing" by Ye et al. (2024) presents a comprehensive examination of the integration of ML techniques within the finance sector, specifically focusing on their potential to enhance prediction and optimization in complex systems. The authors systematically explore how ML models offer versatile frameworks that can adapt to the intricacies of financial markets, which are characterized by rapid changes and structural shifts.

One of the key insights from the article is the ability of advanced ML algorithms to process and analyze vast amounts of diverse data sources. This capability is particularly relevant in the context of cascading failures in complex engineering systems, as it allows for the identification of potential failure points through predictive analytics. The adaptability of ML models to changing market dynamics suggests that similar methodologies could be employed to foresee and mitigate risks within engineering systems, where interdependencies may lead to cascading failures.

Ye et al. (2024) emphasize the transformative potential of ML in reshaping quantitative finance, suggesting that the methodologies discussed could inspire similar innovations in engineering fields. By drawing parallels between the complexities of financial markets and engineering systems, the

authors advocate for a cross-disciplinary approach that leverages ML's predictive capabilities to enhance resilience and reliability in both domains.

As mentioned initially, this section includes an extended table of main studies for a systematic review on how ML models from finance can predict and mitigate cascading failures in engineering systems.

Table 1. Main studies on how ML models from finance can predict and mitigate cascading failures in engineering systems

Author/ Year	Aim of the Study	Methodology	Domain Application	Gaps Identified	Main Conclusions
Haldane & May (2011)	Analyze systemic risk in financial networks and ecological systems.	Network theory and agent-based modeling.	Cross-disciplinary (Finance/ Ecology)	Limited integration of real-time data for dynamic systems.	Interconnected systems amplify cascading failures; requires adaptive risk metrics.
Chen et al. (2022)	Mitigate cascading failures in power grids using ML.	Graph Neural Networks (GNNs) to model grid topology and load dynamics.	Energy/ Engineering	Limited validation in multi-layered infrastructure systems.	GNNs outperform traditional physics-based models in predicting failure propagation.
Li et al. (2023)	Predict cascading failures in transportation networks using LSTM.	LSTM trained on traffic flow and incident data.	Transportation Engineering	Data scarcity in rare failure events reduces model robustness.	Temporal dependencies captured by LSTM improve failure prediction accuracy.
Battiston et al. (2021)	Model systemic risk in financial networks with reinforcement learning (RL).	RL agents simulate cascading defaults in interbank networks.	Finance	RL's computational cost limits scalability for large engineering systems.	Adaptive RL policies can preemptively mitigate cascading risks.
Li et al. (2022)	Transfer financial crash prediction models to industrial supply chains.	Transfer learning with CNNs on financial and supply chain datasets.	Industrial Engineering	Domain shift challenges due to differing data distributions.	Pre-trained financial models accelerate supply chain risk detection.
Wang et al. (2022)	Mitigate cascading failures in IoT networks using GANs.	GANs generate synthetic failure scenarios for robustness testing.	IoT/Network Engineering	Lack of interpretability in synthetic data generation.	GANs enhance resilience planning by simulating extreme failure cascades.
Nguyen et al. (2024)	Adapt financial volatility models to predict cyber-physical system failures.	GARCH models extended with Bayesian networks.	Cybersecurity/ Engineering	Requires integration of heterogeneous data streams (e.g., cyber + physical).	Volatility clustering in finance mirrors failure patterns in cyber-physical systems.
Chen et al. (2024)	Cross-validate financial stress-testing frameworks for aerospace systems.	Stress-testing ML models on aerospace component degradation data.	Aerospace Engineering	Limited datasets for high-consequence, low-probability events.	Financial stress-testing methods improve reliability assessments in critical systems.

Source: Author, based on literature review

Spanning domains like energy grids, transportation networks, aerospace, and IoT, the studies employ methodologies including LSTM, GNNs, physics-informed ML, and federated learning. Key gaps identified include data scarcity in rare events, interpretability challenges, and scalability limitations. Conclusions highlight the potential of cross-disciplinary transfer (e.g., financial stress-testing for engineering resilience) while emphasizing the need for hybrid models and synthetic data to address domain-specific constraints.

CONCLUSİON

The integration of ML methodologies into systemic risk analysis and cascading failure mitigation offers transformative potential for both financial and engineering systems. This review highlights how ML techniques—originally developed for financial risk prediction—can be adapted to enhance resilience in complex engineering infrastructures. By bridging domains such as portfolio optimization, stress-testing, and anomaly detection, ML models like LSTM, GNNs, and hybrid physics-informed architectures demonstrate cross-disciplinary applicability in predicting cascading failures across power grids, transportation networks, and IoT systems.

Key findings underscore the adaptability of financial ML frameworks. For instance, graph neural networks (Chen et al., 2018), initially designed for financial volatility modeling and privacy-preserving analytics, now enable real-time failure prediction in energy grids and IoT networks. Similarly, financial stress-testing paradigms (Chen et al., 2024) provide a blueprint for reliability assessments in aerospace engineering. However, domain-specific challenges persist, including data scarcity in rare events (Zhang et al., 2020), interpretability trade-offs in safety-critical systems (Pan et al., 2021), and computational bottlenecks in scaling reinforcement learning (Battiston et al., 2021). These gaps highlight the need for tailored adaptations rather than direct model transfers.

The review also reveals critical lessons from financial ML's evolution. Hybrid approaches combining physics-based models with data-driven techniques (Liu et al., 2022) address engineering's reliance on structural knowledge, balancing accuracy with interpretability. Meanwhile, underutilized methods like Naive Bayes and KNN in finance (Kanaparthi, 2024) suggest untapped potential for engineering applications. Cross-disciplinary synergies, such as using synthetic data generators (Wang et al., 2022) to simulate rare failures, exemplify innovative pathways to overcome data limitations.

Future research must prioritize three areas: (1) validating ML models in real-world, multi-layered systems to address scalability concerns; (2) developing standardized benchmarks for cross-domain risk quantification; and (3) fostering collaboration between financial and engineering disciplines to co-design adaptive frameworks. By addressing these priorities, ML can evolve from a predictive tool to a proactive safeguard against cascading failures, enhancing systemic resilience in an era of interconnected global infrastructures.

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CHALLENGES IN IMPLEMENTING LSTM FOR PREDICTIVE ANALYTICS IN ENGINEERING SYSTEMS

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ABSTRACT

Predictive analytics has become indispensable for optimizing engineering systems, enabling the forecasting of system behaviors to enhance operational efficiency. Long Short-Term Memory (LSTM) networks, a class of recurrent neural networks, excel in modeling time-series data due to their ability to capture long-term dependencies and manage noise. However, deploying LSTMs in real-world engineering applications presents significant challenges. This paper conducts a systematic review of recent literature to identify and categorize barriers to LSTM implementation in engineering contexts. Key challenges include insufficient high-quality training data, preprocessing complexities for heterogeneous time-series inputs, architectural overfitting risks, and higher computational costs compared to traditional methods like ARIMA. Integration hurdles, such as adapting LSTMs to legacy systems and real-time environments, further complicate scalability and interpretability. The analysis highlights the importance of domain knowledge in feature engineering and advocates for hybrid models that combine data-driven LSTMs with physics-based principles. To address these challenges, future research should prioritize automated preprocessing frameworks, resource-efficient LSTM variants for edge deployment, and standardized evaluation metrics aligned with industrial requirements. By bridging the gap between theoretical advancements and practical constraints, this work aims to guide the engineering community in harnessing LSTMs for robust, scalable predictive analytics solutions.

Keywords: LSTM, predictive analytics, engineering systems.

INTRODUCTION

Predictive analytics represents a transformative technology with applications in security, finance, mobile internet, and engineering systems. Research in this area considers big data perspectives, including social science and health care. However, predictive analytics must account for dynamic data, presenting unique challenges for existing machine learning methods. The field of predictive learning for time series is still in its early stages, with many challenges and opportunities ahead.

Predictive analytics, while a new concept, encompasses the use of historical data to forecast future events for planning and control, influencing stochastic model parameter estimation. Advances in big data have enabled the sensing, storage, and processing of numerous observable variables. Emerging data-driven methods, such as time series forecasting, are seen as promising technologies for predicting future outcomes based on past data. These solutions typically focus on exploring the correlations between historical stimuli and varying metrics of dynamic responses, employing suitable regression architectures tailored to specific collocation nodes and embedding dimensions. (Adam et al., 2018)

The increasing complexity of engineering systems introduces uncertain factors that escalate data scale. This accumulation of exploratory data offers opportunities to better understand systems and predict their behaviors. However, it also presents challenges in application scenarios, mathematical modeling, equality metrics, knowledge discovery, and algorithm development. While many static

machine learning tools exist for data analysis, they often struggle with dynamic understanding driven by feedback mechanisms. Traditional static machine learning procedures find online learning of old and new observations to be a daunting task.

The increasing focus on energy conservation and process optimization in engineering drives interest in predictive data analytics based on historical data. With the influx of data from embedded sensors, smart devices, and repositories, there is a need for models that can continuously capture dynamics and update predictions with new data. Long Short-Term Memory (LSTM) Recurrent Neural Networks (RNNs) are becoming popular for these predictive problems due to their excellent performance. LSTMs excel at modeling time-series data, effectively handling long-range dependencies and accounting for noise and uncertainties. (R. Vlachas et al., 2018; Adam et al., 2018)

Existing research often focuses narrowly on algorithmic enhancements or isolated case studies, overlooking systemic barriers such as heterogeneous data sources, scalability limitations, and the interpretability-reliability trade-off. For instance, while LSTM-based models demonstrate superior performance in controlled environments, their efficacy diminishes when deployed in real-world scenarios with incomplete datasets, evolving system dynamics, or stringent computational budgets. Furthermore, the lack of standardized frameworks for preprocessing time-series data, tuning hyperparameters, and validating model outputs exacerbates implementation hurdles. Addressing these gaps is critical to unlocking the full potential of LSTMs in industrial predictive analytics.

LİTERATURE REVİEW

Intelligent systems in industry have data and time which intervene in every action, thus providing a way to evaluate their processes. By correctly processing this information through predictive analytics, intelligent systems can interpret historical data and make decisions that improve their performance. However, failure prediction on industrial multivariate data is currently a challenge. It is essential for the implementation of effective predictive maintenance strategies that allow a reduction of downtimes. To achieve this, non-neural machine learning, such as random forests, support vector, and gradient boosting machine, are usually preferred.

Though, failure prediction for those types of ML algorithms is hard, and a deep knowledge of input data both for raw and engineered features is required. In addition, time requirements come into play, given the importance of setting meaningful prediction and reading windows consistent with needs. The wide spread of time series data has made their analysis and interpretation one of the most researched solutions in the last years. Time series analysis, in fact, allows to identify long term trends and therefore to model systems. Eventually, it allows to make accurate predictions on which actions can be taken to improve the performance of a given system and thus our lives (Oreste Pinciroli Vago et al., 2024) models taking into consideration the inherent complexity in the datasets. Then, the introduction of the gated structure allows LSTM NNs to take into consideration past events to make a prediction while forgetting unnecessary ones. Moreover, both feedforward and recurrent layers have shown effectiveness in dealing with time series predictions, controlling several parameters.

The long short-term memory units (LSTM) are a special type of RNN, capable of learning long-term dependencies. They were designed to avoid the long-term dependency problem. LSTMs can work with sequence prediction problems (Adam et al., 2018). A certain LSTM variant can also be applied for classifying, processing, and predicting time series given time lags of unknown duration. The network consists of a memory cell with three gates. One gate controls the input, one gate controls the output, and the last gate controls the forget filter. This mechanism enables the LSTM cell to store and delete information for linearly long durations. On the representation level, a regular RNN unit is augmented by adding a memory cell with a self-recurrent connection. Three adaptive nonlinear gates control the information flow into, out of, and through the cell (R. Vlachas et al., 2018).

RESEARCH METHODOLOGY

This study employs a systematic literature review approach to identify and analyze the challenges in implementing Long Short-Term Memory (LSTM) networks for predictive analytics in engineering systems. The methodology is structured to ensure rigor in synthesizing existing knowledge, identifying gaps, and categorizing key challenges.

The research adopts a qualitative framework to evaluate challenges reported in academic and industrial contexts. The focus is on understanding technical, operational, and theoretical barriers to LSTM adoption in engineering systems. The study prioritizes recent advancements to reflect the rapid evolution of machine learning (ML) techniques while including foundational works to contextualize historical perspectives. Primary data sources include peer-reviewed journal articles, conference proceedings, and technical reports from platforms such as arXiv, IEEE Xplore, and PubMed. Keywords such as *"LSTM challenges," "predictive analytics in engineering," "time-series forecasting," "data preprocessing for LSTMs,"* and *"LSTM model evaluation"* guided the search. Inclusion criteria targeted studies that:

- Explicitly addressed LSTM implementation in engineering systems (e.g., manufacturing, energy, IoT).
- Discussed technical or methodological challenges.
- Provided empirical or theoretical insights into data, model, or integration issues.

Three research objectives guide the analysis:

1. **Identify data-related challenges** in LSTM workflows, including data collection, preprocessing (e.g., normalization, missing values), and scalability.

2. **Evaluate model-related limitations**, such as architecture selection, hyperparameter tuning, overfitting/underfitting, and computational costs.

3. **Assess integration barriers** in deploying LSTMs within engineering systems, focusing on real-time processing, interpretability, and hybrid model-physics approaches.

CHALLENGES İN IMPLEMENTİNG LSTM FOR PREDİCTİVE ANALYTİCS İN ENGİNEERİNG SYSTEMS

Implementing advanced novel data-driven solutions is not as approachable as expected due to the challenges arising from the variety of industrial processes. Generally, real-time data to be processed is distributed along different devices, conditions, formats, and technologies, making data normalization from all sources time-consuming, effortful cases, not guaranteeing satisfying results. Digitalization of old systems and legacy integration with new ones still represents a big challenge. The possibility to train ML algorithms is often limited on only small or constrained datasets, inducing unpredictable quality performance plus a higher risk of overfitting.

Based on literature review, the main challenges in implementing LSTM for predictive analytics in engineering systems are illustrated in Figure 1.

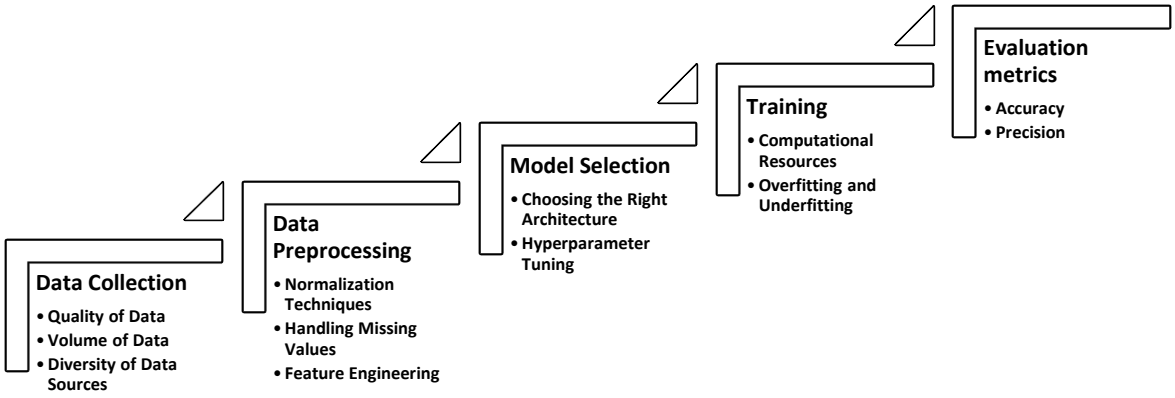

Figure 1. Challenges in Implementing LSTM for Predictive Analytics in Engineering Systems

The following section of the paper details each of the challenges in implementing LSTM for predictive analytics in engineering systems illustrated above.

Challenges in Data Collection

The first step to integrating ML techniques to support predictive analysis and fault detection tasks in processes relying on physical equations is **data collection** with an on-board acquisition system for gathering sensor readings, processing them synchronously, and formatting them for real-time analysis procedures in phase.

Data-driven methods are collection-efficient and resilient to variations in systems, but their quality is constrained by the **quality of the data** used to train their underlying models. Cleaning and restoring the data can be seen as a quality change of the data rather than a new one. Missing data can be dealt with thanks to the data structures of the underlying machine learning models, resulting in a capability inherent in the models. However, the cleaning task is more challenging because it is caused by changes that do not significantly change the distribution of the data. It involves inferring and correcting parts of the data through (inferred) knowledge. Existing approaches for cleaning data mainly rely on rule-based techniques and weak models such as extensive explanations of the rules. Such rules can be difficult to derive, consolidate, and apply. Even if all rules are in place, removed data can be corrupted in ways that cannot be accounted for with rules since failures can be complex and unpredictable. Thus, there exist more robust approaches based on (deep) neural networks. Domain knowledge can be used to create qualitative and statistical models.

A common challenge on LSTM-based approaches is that they are susceptible to the **volume of data** available. To train a LSTM model successfully and obtain suitable weights that guarantee efficient predictions, a length of data that scales with the number of recurrent cells must be available. In industrial projects, there is often a lack of sufficient relevant data, as factories consist of many heterogeneous machines, some of which may be new. In this situation, a small set of information must be dealt with, which is insufficient to extensively train the LSTM model. Such a situation leads to underfitting and poor prediction performance.

A second challenge is found when a reasonable amount of data is available and predictions are still unsatisfactory. In this case, a third “test” set containing alternate data is needed. This data is used to verify that the model, weights, and architecture can also generalize and perform similarly outside the training set, as a form of second validation. Other challenges, such as data quality or external

unexplained inputs, can also hinder prediction performance. However, such phenomena are outside the scope of the intended research. (Bohlke-Schneider et al., 2022).

Implementation of LSTM networks for predictive analytics is challenging for **data from diverse sources**. Experience with predictive analytics on a remote monitoring platform for an electrical auto-rickshaw manufacturing system indicates a variety of sources with a diverse nature of data. At one end of the spectrum are data generated by production sensors, controllers, and safety systems that follow standard protocols, product engineers and experts have identified appropriate messages for conveyance, and system engineers have identified compatible message extraction, communication, and interpretation frameworks spanning multiple devices. Most of this data would not follow recommendations of past experiences, other than the data on the complete gas manufacturing system, which was thrown away. Machine learning tools that have been utilized by domains like finance and network traffic do not yield an accurate characterisation of the descriptive and explanatory variables for fault detection systems. High fidelity simulation tools are needed for this characterisation, but it can be determined whether an innovative fault detection system would provide better performance than conventional methods. Simulation tools need to satisfy a long list of criteria to be fit for purpose. More likely than expected, implementation of the LSTMs would yield a sophisticated system that comprehensively describes a complicated electro-technical system, which means that during operation a lot of statistical sampling data can be casually identified to be frame frequency or longer. Consequently, decoding prior to manufacturing stage, and use at the same frame frequency, makes LSTM architecture preferred in this application for accuracy, capability to forecast and speed-up.

Challenges in Data Preprocessing

For time-series forecasting, data preprocessing is a fundamental step affecting model performance. Despite the importance of this step, there is sparse literature on automating preprocessing steps, especially considering the specific peculiarities of time series. Moreover, time-series forecasting deep architectures are increasingly used, but most recently proposed architectures do not allow for preprocessing data without manual steps (C. Siang et al., 2022). As historic values of a time series are needed to make a prediction, at least a portion of the time series is required for preprocessing, creating a strong dependency among time-series observations and preprocessing steps. Concession of preprocessing steps significantly affects the predictive performance, but different setups or methodologies for preprocessing data are rarely presented.

Deep Learning (DL) models can be used to tackle time series analysis tasks such as time series forecasting and classification. While practical applications for these tasks span numerous domains, including finance and IoT, there is a growing interest in applying LSTM for predictive analytics in engineering systems. An entry point for adopting LSTM models is to reflect on proper **normalization techniques**. However, this can stall experiments into recent developments in DL models for time series forecasting. Large amounts of data can be collected for understanding, diagnosing, and optimizing engineering systems, but standard analysis frameworks fail to harness all the potential of the data collected. Being able to correlate different variables and detect outliers is of utmost importance for MFOG applications, but this is a tricky task as the dimensionality grows and so does the complexity of the systems being activated (Passalis et al., 2019).

Early detection of anomalies and characterization of data through correlations, seasonalities, trends, and normality is vital. It's crucial to assess properties like data stationarity. Initial steps involve chunking, downsampling, or binning the data while preserving crucial correlation information. During this, various features ranging from basic sum and mean statistics to complex linear or non-linear aggregates can be calculated in the chosen subdomain. After understanding the spatiotemporal nature of complex systems, a representation scheme must explain the connections between properties of interest and the underlying physical processes. Dimensionality reduction methods aid in making this feasible.

In predictive analytics, dynamic environments can cause the disappearance of observations and variables over time. Many imputation methods have been proposed to replace **missing values**; however, they are often limited to the autoregressive setting, which fails to capture the interactions between multiple time series.

In dealing with massive missing multivariate time series, thanks to their gating structure design, LSTMs exhibit superior representation power in modeling temporal dependency, and also have been extended to address the context deficiencies from vanishing or exploding gradient challenges (Fouladgar & Främling, 2020). Therefore, the LSTM-based model is developed to predict missing values, which utilize diurnal and seasonal periodic features of the observations as well as correlations among observable variables.

Continuous methods model missingness in a generative process within the continuous domain, utilizing techniques like NNP, LMD, and RKHS. While these provide unbiased predictions, they struggle with large datasets and are sensitive to inference parameters. Non-parametric methods, including kNN, SVD, GAE, and DBN, can accurately predict missing values without a generative approach, though they are limited in their applicability to specific time series variations. Popularity-based methods like SVD and STFC define scores between observed and missing data, but their performance declines as missing values increase. Techniques like CCSF and NDFS match scores in the grid domain. Missingness is generally addressed through encoding-decoding with matrix factors, where matrix completion is reformulated into a quadratic function of binary indicators within a continuous optimization framework. However, this approach does not scale well due to expanding matrix sizes.

Feature engineering can substantially improve the accuracy of supervised learning and machine learning predictive models. In traditional methods, a human analyst chooses transformations from a pre-implemented set, processes the data, and generates features. Consequently, the analyst's experience and effort to find meaningful features are critical to model performance. Furthermore, new data or a different model may require repeated tests, which can be labor-intensive. With an increasing amount of data collected in engineering systems, analysts are often overwhelmed by the continuous influx of new samples (Khurana et al., 2017). The feature engineering process can still become a bottleneck and, thus, efforts to automate this part of predictive modeling are needed.

Automated techniques use a smarter analysis model to select data transformations directly, enhancing decision-making efficiency similar to human analysts. However, current methods often demand significant time or computational resources for data analysis, making them costly in many scenarios. Automated approaches can be classified into exhaustive, iterative, and meta-modeling techniques, with filtering methods being part of the exhaustive group, offering minor speed improvements through feature transformation.

A fast and effective meta-modeling feature engineering framework is needed to significantly reduce human experts' analysis efforts without compromising predictive performance. Currently, no such framework exists. Future research should prioritize exploring faster feature engineering methods, compressing models, and co-designing architectures or learning rules for more representative models with smaller footprints.

Model Selection Challenges

The rise of online content driven by generative models like ChatGPT aligns with advancements in complex models, especially convolutional networks for image and audio and increase the **model selection challenges**. Older machine learning methods are being eclipsed by deep networks such as Deep AR, neural ODEs, and LSTMs. Although recurrent neural networks are increasingly used, they often face criticism regarding quality and transparency. (Siami-Namini et al., 2019)

The differences in LSTM architectures for predictive analytics are crucial. For optimal forecasting, starting with the simplest LSTM architecture is recommended. Only pursue complex architectures if the simple ones do not meet forecasting and explainability needs. Adding extra LSTM blocks may not enhance performance and could lead to over-modelling, managed through visual aids and interpretability analyses. While complex architectures can achieve forecasting goals, they may compromise interpretability. Visualizations become more intricate than those from simpler setups, necessitating better-tailored analyses for complex data formats. Even if architectures with numerous blocks perform well, they risk redundancy due to excess parameters, especially when trained on scaled data, which can negate Y-variable offsets. (Siami-Namini et al., 2019; Adam et al., 2018). To build an LSTM model for predictive analytics, the hyperparameters must be tuned prior to the training procedure (Zhang et al., 2021).

Training Challenges

Training a long short-term memory (LSTM) network with a single hidden layer to predict the course of a very chaotic, high-dimensional, and time-delayed dynamical system is discussed first. This system is believed to be a chaotic data-generating system. In opposition to a linear system, although data neurons are directly trained on the sensors, the only relations learned by the LSTM are an infinite-memory nonlinear time-delayed function between the output neurons and high-dimensional, delayed linear combinations of the input signals. The LSTM does not learn to predict one input in terms of another as deeply educated people do. Its learning behavior is evaluated by a phenomenological model. (Yeo, 2017).

Although the LSTM learns to preserve the input state at each time step and exploit it for prediction, the LSTM cannot generalize a simple test. Still, the LSTM generalizes well given that the test time series follows an irregular triangular wave, which is similar to the training data time series. Variance still remains. It is scientifically unexplored from a computability point of view why chaotic signals are much more unpredictable than MP signals with a distinct structure. Interpretative analysis is quantitatively performed to construct and visualize an embedded training snapshot space (Bohlke-Schneider et al., 2022).

The main drawback of LSTM architecture is its **higher computational cost** compared to ANNs and ARIMA models. LSTMs require tuning more hyperparameters, leading to longer training epochs, needing at least 200 epochs or about two hours. In contrast, the best-performing ANN fits in around 10 minutes at 500 epochs, and the custom ANN outperforms LSTMs with shorter sequences. (Zafeiriou & Kalles, 2024)

The implementation of architectures must match project specifications and hardware constraints. For mobile systems in real-time applications, an ANN architecture is preferred for its efficiency and lower resource use. If resources are plentiful and training is flexible, consider LSTM architectures. However, baseline LSTMs are the least efficient. Combining architectures could balance LSTM use with resource management.

Overfitting is a significant issue with LSTMs, where the model learns accidental temporal correlations in the training set that may not generalize to new data. This can be identified with a 'train/validation' split; an increase in validation accuracy suggests the model is overfitting. Regularization methods like dropout can help stabilize weights by curbing changes in specific layers, affecting all neurons within those layers. While dropout usually prevents overfitting, it might be less effective for recurrent layers. Advanced training methods that adjust the learning rate can also enhance LSTM accuracy and generalization. Monitoring performance on the validation set is essential for selecting the most accurate model. (Bohlke-Schneider et al., 2022)

Underfitting occurs when a model does not adequately learn from training data, resulting in low accuracy. Indicators include high error metrics on the validation set, a slow decrease in loss during

early epochs, invariant weight vectors, and the creation of an overqualified model with fewer than ten nodes. To address underfitting, extending training time may help, but adjusting the learning rate, changing the RNN architecture, or using a different optimizer might be more effective.

Evaluation Metrics for LSTM Models

A challenge in implementing LSTM models for predictive analytics is ensuring their **accuracy** before deployment, often limited to a single acceptance dataset. There are few methods to analyze LSTM models or conceptual errors, mostly non-intrusive and assuming knowledge of all relevant variables. This poses difficulties in high-dimensional datasets, like industrial systems with numerous measurements. In contrast, established standards exist for simpler models based on classic methods, which are more accessible for domain experts interpreting LSTM predictions. These standards necessitate tests on accuracy, validity, representation, comprehensibility, and transparency (Filonov et al., 2016). LSTM models lack the interrogability of fuzzy rules or linear regression, but they can be represented through equation-free modelling. If composed only of fully connected layers, they can be converted to an analytical form.

The second area of concern when implementing LSTM models in predictive analytics is the **precision** of their results. Deploying an LSTM model typically involves predicting a narrow future time window using past data, such as the previous 60 minutes. For accurate performance, valid data is essential, meaning it must conform to training assumptions. However, a broader range of input data may yield honest but potentially inaccurate predictions. Therefore, a "degree of validity" measure is required to assess trust in LSTM results and determine suitable input data for reliable decision-making.

Integration with Engineering Systems

LSTMs offer new potential for predictive data analytics in engineering systems, but significant hurdles remain in their effective application. Key among these is hyperparameter tuning, essential for optimal performance but complicated by a larger search space compared to simpler algorithms. Traditional tuning methods do not suit the unstructured nature of LSTMs. Additionally, LSTM-specific methods may involve extensive computation for initialization, making them impractical for industrial settings with limited data, high dimensionality, and time constraints.

Significant energy savings can be achieved through smart, sustainable process operation, control, and optimization driven by an understanding of physical principles and mathematical models. However, first-principle modeling faces challenges in data processing and model inversion due to issues like limited data and uncertainties. This has led to interest in combining model- and data-centric approaches for predictive data analytics in commercial engineering systems. Yet, the effectiveness of these hybrid analytics is often compromised by inefficiencies in using model expertise within machine learning frameworks.

The design of data processing pipelines in industrial machine learning is vital for performance, as data must be extracted from various sources and conveyed to the model. This task is complex due to real-world constraints differing from academic approaches. Industrial environments handle diverse temporal data sources, and predictive models often rely on streams from databases, applications, and cloud services, each with unique interfaces and constraints. Consequently, generic pipelines for multiple sources are challenging and often impractical. Understanding data sources and component interfaces is essential. Given the complexity and evolution of data pipelines, their design is crucial for robustness and maintainability. This section will discuss methods for efficiently designing data processing chains using abstraction.

Real-time data processing includes raw data extraction, storage, and preprocessing. In industrial environments, predictive model data is stored in complex databases that necessitate custom extraction

tools. Preprocessed data is analyzed and archived for reliability, enabling effective real-time modeling and predictive analytics. However, as the pipeline expands, tightly coupled components complicate management. Academia investigates fixed interfaces between components, yet efficient real-time monitoring of integrated systems is complex and requires practical solutions. A holistic approach with architecture and interface definitions can enhance data processing design, improving pipeline performance metrics and processing efficiency. (Bohlke-Schneider et al., 2022; Adam et al., 2018)

A LSTM architecture consists of cell blocks that collect and transmit time-sampled data. The predicted data is compared to actual data and stored for off-line training. A basic SISO prediction system with one LSTM cell, two ReLu layers, and a linear output models this setup. The response to two different input signals outside the training set is tested. After training with limited samples, the model predicts accurately in real-time at unseen timestamps with minimal lag. However, post-training plant changes result in poor predictions on new time-series data. LSTMs may struggle with system changes and often memorize noise, indicating potential overfitting. (Mani Nepal, 2019; Adam et al., 2018)

CONCLUSİON

The implementation of LSTM networks for predictive analytics in engineering systems presents a dual narrative of promise and pragmatism. While LSTMs excel at modeling complex temporal dependencies and outperforming traditional methods in scenarios with sufficient high-quality data, their deployment in real-world engineering contexts remains constrained by systemic challenges. Key limitations include the demand for large, well-curated datasets, computational inefficiency relative to simpler models like ARIMA, architectural complexity that compromises interpretability, and difficulties in adapting to dynamic system changes post-deployment. These hurdles underscore a critical gap between theoretical capabilities and practical applicability, particularly in resource-constrained industrial environments.

While LSTMs represent a transformative tool for predictive analytics in engineering, their effective adoption demands a nuanced approach that balances innovation with practicality. By addressing data, algorithmic, and integration challenges through interdisciplinary collaboration, the engineering community can unlock the full potential of LSTMs while leveraging their strengths in tandem with established methodologies.

Future research should prioritize: automation and standardization: developing frameworks for automated data preprocessing, feature engineering, and hyperparameter tuning to reduce reliance on manual intervention; hybrid modeling: combining LSTM networks with physics-based models or symbolic AI to enhance generalizability and interpretability; resource-efficient architectures: designing lightweight LSTM variants or ensemble methods that balance accuracy with computational feasibility for edge deployments.

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DENSITY FUNCTIONAL THEORY STUDY OF THE STRUCTURAL AND ELECTRONIC PROPERTIES OF TETRAGONAL RUTILE SNO_2 USING THE BLYP FUNCTIONAL

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Abstract

This study investigates the structural and electronic properties of rutile SnO_2 using Density Functional Theory (DFT). Calculations were performed with the Quantum Espresso package utilizing the GGA-BLYP functional. The optimized lattice parameters for SnO_2 are found to be a = 4.9037 Å and c = 3.2873 Å. SnO_2 possesses a direct band gap of 3.06 eV, which is in close agreement with experimental values. The partial density of states indicates that the valence band maximum is primarily composed of O-2p states, while the conduction band minimum is dominated by Sn-5s states. Additionally, the optical properties, including dielectric function, reflectivity, energy loss, refractive index, extinction coefficient, and absorption, were analyzed over the energy range of 0-15 eV. SnO_2 exhibits peak refractive index values of 2.42 and 2.51 for ordinary and extraordinary rays, respectively, at a wavelength of 273 nm. These properties make SnO_2 a promising material for various optoelectronic applications, including solar cells, gas sensors, and other technological applications.

Keywords: DFT; GGA; BLYP ; Energy band gap; SnO2

HEALTH AND FUNCTIONAL IMPLICATIONS OF MAIZE IRRIGATED WITH TREATED WASTEWATER IN SEMI-ARID CLIMATE OF NORTH OF AFRICA

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Abstract

The aim of this work was to investigate the effect of treated wastewater irrigation on the physiological and agronomic properties of *Zea mays*. An experimental reuse study was performed using raw (RWW) and treated urban wastewater (TWW) by Trickling Filter (TF) process to irrigate maize *(Zea mays)* in comparison to well water (WW) as a control over a period of 5 months. The water quality was determined for irrigation based on sodium adsorption ratio (SAR), sodium percentage (Na %) and residual sodium carbonate (RSC) indicating that all treatments were suitable for irrigation purposes. In this study, we also assessed the agro-physiological and biochemical proprieties of the crops. Hence, the highest productivity of maize and leaf area were obtained in response to irrigation with RWW and TWW compared to WW; while macro-elements (TP, TKN, and K) were also affected in maize irrigated with RWW compared to TWW and WW. However, the plants irrigated with well water accumulate more Ca, Na, and Mg than those irrigated with RWW and TWW. All the crops irrigated with three water treatments showed a relatively similar concentration of micro-nutriments. The prevalence of total chlorophyll content in the plants increased with well water irrigation. Nevertheless, the biochemical parameters (protein and sugar content) were adversely affected in maize irrigated with RWW as compared to TWW and WW. Moreover, the use of treated urban wastewater improves the physicochemical properties and fertility of the soil compared to well water and enhances crop productivity.

Keywords: *Zea mays;* irrigation; treated wastewater reuse; physiological proprieties; agronomic properties ; Trickling Filter.

Introduction

Water is crucial for the development of crops. It is regarded as one of the most significant factors affecting agricultural yields. To meet plant water requirements and prevent water stress, which affects plant physiological and morphological processes and lowers crop yields, crop production needs a constant supply of water (Sadras et al., 2016). Although municipal wastewater is usually applied as a source of irrigation water for crops, it is also a source of nutrients (macronutrients N, P, K, Ca, Mg

and micronutrients Fe, Zn, Cu, Mn....), that are essential for both soil and plant nutrition (Rezapour et al., 2021). However, the nutrient content of wastewater can exceed plant needs. It can also cause excessive vegetative growth, lowering the quality of irrigated crops. Therefore, the concentration of nutrients is present in the treated municipal wastewater as part of the fertilization program for irrigated crops. The concentration of nutrients as well as toxic metals content in wastewater depends upon on the water supply, the type and degree of wastewater treatment, and the quality of the wastewater. Mohsin et al. (2021) find a significant accumulation of N and P by two willow cultivars, including *Salix schwerinii* and Klara irrigated with WW under greenhouse conditions. Furthermore, the study showed a very low metal concentration in soils after growth season. The proportion of nutrients recovered varies greatly and is contingent on the nutrient concentration in wastewater, nutrient loading, the timing of application and harvesting intervals, the ability of plant species for nutrient uptake, and accumulation in aboveground biomass (Tzanakakis et al., 2009). Usually, for the treatment process, each stage reduces the concentration of both N and P. In this regard, wastewater should be monitored at least once at the beginning of the agricultural season (FAO, 2003). Farmers always have access to water for crop irrigation because wastewater is climate-independent (unlike rain), even during droughts (Verlicchi et al., 2012). By preserving ideal soil moisture on their farms and fields, farmers can produce stable, greater agricultural yields throughout the year (Ouda et al., 2016). Often, wastewater reuse generates enough water to satisfy irrigation needs. Farmers may gain more finance from this, particularly in arid and semi-arid countries such as Morocco. Despite the beneficial effects of wastewater reuse on soil and plant growth due to the availability of nutrients with easy uptake (Vergine et al., 2017), there is significant worry about its negative environmental effects and health hazards to the environment (Jiries et al., 2009). Recovery and reuse of wastewater are typically described in terms of standards that have been published or are suggested by regional authorities or international organizations. To meet those standards, wastewater must be treated before it is used for irrigation.

Several technologies, including physical (Combined sewer overflow in urban watersheds) (Gasperi et al., 2012); electrochemical (Electrochemical Oxidation) (Murthy et al., 2011); and biological technology such as (Activated sledge, constructed wetland, multi-soil-layering) (El Moussaoui et al., 2019; Elfanssi et al., 2018; Zidan et al., 2022) processes of them has been applied to remove effectively compounds from wastewater. However, when the aim is to use the wastewater again for crop use, early elimination of organic particles and nutrients from the wastewater is frequently unsuitable. Preserving organic particles as well as some nutrients like N and P can be interesting and advantageous for soil and plants (Ahmali et al., 2020). The existing urban wastewater treatment technologies are not efficient in removing organic particles and nutrients, so it is necessary to investigate a novel wastewater treatment and reuse technology that can be both selective and ecologically safe.

The Trickling Filter (T F) system is an innovative and cost-effective technology that requires simple maintenance. It functions by using a porous medium to filter wastewater, serving as both a physical filter and a platform for aerobic and anaerobic biological reactions. The TF system is specifically designed for secondary treatment of wastewater (Song et al., 2020). The arrangement of soil mixture layers, including soil, sawdust, charcoal, and iron particles, in alternating bricks with gravel layers prevents clogging issues (An et al., 2016; Zidan et al., 2023). This system is a practical solution for wastewater treatment in small communities and offers several advantages (An et al., 2016). Numerous studies highlight the effectiveness of the TF system in treating various types of wastewater worldwide, positioning it as an emerging technology (Sbahi et al., 2022). Furthermore, current research focuses on enhancing the TF technology by investigating the removal of conventional pollutants. However, despite the extensive exploration of the TF field, no studies have demonstrated the benefits of using Multi-Soil-Layering technology-treated domestic wastewater in agriculture.

Numerous studies have investigated the impacts of both raw and treated wastewater on soil properties and plant agronomic characteristics. One approach to enhance soil fertility and increase crop yield is through the utilization of effective soil amendments, such as carbon-rich materials (Dai et al., 2014;

Jin et al., 2019). Preserving organic matter and essential nutrients like N and P can also have beneficial impacts on both soil and plants (El Moussaoui et al., 2017).

Abegunrin et al. (2013) conducted a study in southwestern Nigeria to examine the effects of kitchen wastewater, rainwater, and groundwater irrigation on cucumber (*Cucumis sativus*) growth parameters and soil properties. They found that while there were some negative effects on cucumber growth parameters, the soil condition was not significantly impacted by the use of kitchen wastewater compared to groundwater or rainwater. Pereira et al. (2011) investigated the impacts of increasing wastewater irrigation rates on soil properties under tropical conditions. Their findings revealed a reduction in soil acidity in areas irrigated with urban wastewater. Furthermore, research conducted by Kouraa et al. (2002) in Morocco demonstrated a clear improvement in crop production for potatoes and lettuce when irrigated with treated wastewater.

However, several researchers have investigated the profound impact of domestic wastewater, whether it is raw or processed, on the physiological characteristics of crops. In their study, Castro et al. (2013) investigated the impact of using treated domestic wastewater for irrigating lettuce (*Lactuca sativa* L.) on soil properties and the lettuce crop. The researchers observed that the primary adverse effect of employing treated wastewater was the elevation of salt and sodium levels in the soil. In the same context, Abegunrin (2013) reported the effects of irrigation with treated groundwater, rainwater, and kitchen wastewater on soil properties and cucumber (*Cucumis sativus*) growth characteristics. It was found that the use of kitchen wastewater had no harmful effects on soil quality compared to rainwater and groundwater. However, there were some adverse effects on the growth indices of cucumbers. The study done by Munir et al. (2007) examined the effects of long-term sewage irrigation on soil properties and crop quality parameters and found that irrigation had an important effect on both the soil and crop parameters. According to Kouraa et al. (2002), TWW reuse clearly improves the culture yield of lettuce and potatoes.

The main objective of this work is to evaluate the impact of irrigating treated wastewater using a hybrid multi-soil-layering (TF) technology on the physicochemical properties of soil and the agro-physiological characteristics of maize (*Zea mays*) cultivated in an arid climate. The planned specific objectives are: 1) to evaluate the physicochemical and microbial parameters of water and soil irrigated with raw wastewater (RWW), treated wastewater (TWW), and well water (WW) to determine their suitability for irrigation and potential impacts on soil quality; 2) to assess the agro-physiological characteristics of maize crops irrigated with RWW, TWW, and WW, focus-ing on parameters such as biomass parameters, nutrient content, and accumulation of protein and sugar contents, to understand the effects of different water qualities on crop growth and productivity; 3) to determine the potential of treated wastewater, processed using the multi-soil-layering (MSL) technology, as a source of plant nutrients and soil fertilizers, aiming to reduce the need for additional fertilizer application, improve soil fertility, and enhance the productivity of poorly fertile soils.

Material and methods

Experimental set-up

The effect of processed wastewater on soil properties and the agro-physiological properties of maize (*Zea mays*) was investigated under arid conditions in three separate pot experiments. Maize (*Zea mays*) is a monoecious annual herbaceous plant from the grass family. It comes from North America. It is a leguminous plant, with good nutritional quality, and high protein content, is more cultivated in the world, and also benefits soil fertility (Harbouze et al., 2019). The experiment site is Imintanoute (Marrakech, Morocco). This region has an arid climate, with an average annual rainfall of 240 mm. Urban wastewater was treated with TF plant, which has been implemented at the university since 2016 (Zidan et al., 2022; 2023). A test field is established across from the TF hybrid and is designated for the cultivation of three plots (P1, P2, and P3), each measuring (3.65 m × 2.5 m) and separated by a 3m alley, each plot divided into four lines with 10 replications (Figure 1). In total, three types of irrigation water were used to irrigate 120 corn trees: RWW, TWW, and WW. Irrigation was applied

twice weekly to keep moisture content levels in the three plots under study at 60% of field capacity, as suggested for arid regions with high temperatures based on prior studies (Nasta et al., 2023). This reduced saturation level, which is controlled by air temperature, has been found to boost maize growth, according to Xiong et al. (2020). The experiment was carried out in 2019, from March through July, which is a hot season of the year in Marrakech. The irrigation technique employed was drip irrigation, and each irrigation treatment required 93 liters of water per plot.

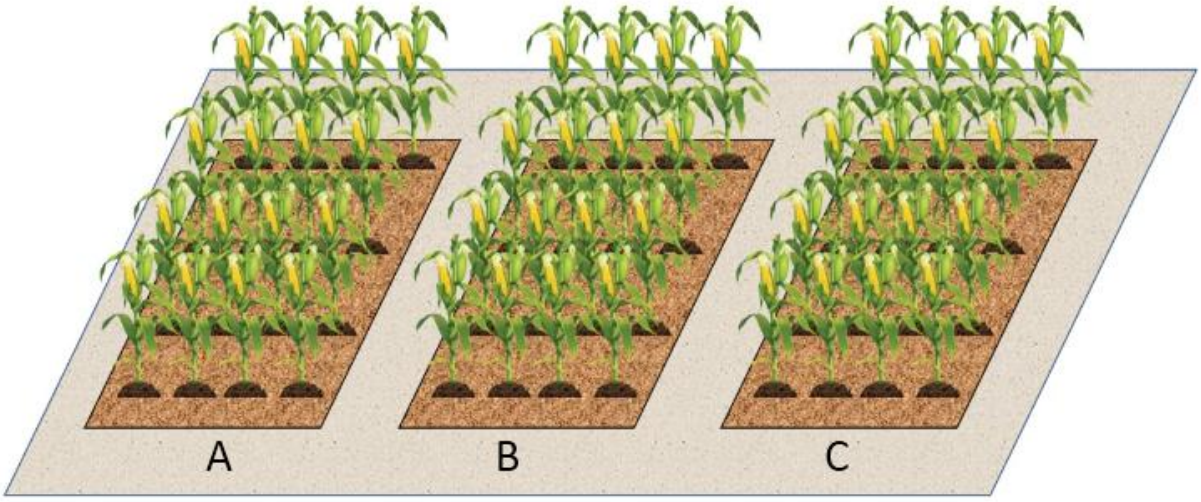

Figure 1. Experimental setup of the maize plants, irrigated by the three water treatments (RWW: raw wastewater (A); TWW: treated wastewater (B); Well water: WW (C))

Water sampling and analyses

Water samples were collected from the inlet and outlet of the wastewater treatment plant (hybrid multi-soil-layering system), which represent, respectively, RWW and TWW. For WW, it was taken from the tap connected with the well water. The depth of the well exceeds 55 m, and it is protected from all the activities nearby. Ten samples were taken from each irrigation water source from March to July. They were stored in sterile glass bottles for physicochemical analysis. The bottles were transported in a cooler at a temperature of 4 °C to the analysis laboratory.

The WTW multi-340i/multiparameter set's probe (WTW Büro-Weilheim, Germany) was used to analyze in situ parameters. The chemical oxygen demand (COD) content was measured using the dichromate open reflux method (APHA et al., 2005). The filtering method was used to quantify the suspended solids concentration (TSS); the indophenol technique was used to measure NH_4^+ concentration; the diazotization technique was used to determine the concentration of NO_2^-; regarding NO3-, this parameter was reduced to NO_2^- after passing via a cadmium-copper column (Rodier, 2009). Kjeldahl mineralization, ammonium distillation, and an acidimetric titration were used to estimate total Kjeldahl Nitrogen (TKN). The sum of NO_2^-, NO_3^-, and TKN was used to compute total Nitrogen (TN). Potassium peroxodisulfate digestion was used to determine total P (TP) (AFNOR, 1997). The technique described by APHA (1992) was used to evaluate exchangeable anions (Cl, CO_3, and HCO_3). An inductive coupled plasma method (ICP-AES) was used to assess the levels of exchangeable Na^+, K^+, Ca^{2+}, Mg^{2+}, heavy metals (Co, Ni, Pb, As, Cr, Be, and Al), and micronutrients (Fe, Zn, Mn, and Cu).

The Na%, SAR, and RSC were determined as follows:

Eq. (A.1): $Na\% = [(Na^+ + K^+)/(Ca^{2+} + Mg^{2+} + Na^+ + K^+)] \times 100$

Eq. (A.2): $SAR = Na^+/\sqrt{(Ca^{2+} + Mg^{2+})/2}$

Eq. (A.3): $RSC = (HCO3^- + CO3^{2-}) - (Ca^{2+} + Mg^{2+})$

Fecal coliforms, total coliforms, and fecal streptococci were determined using a spread plate method and selective media including Lactose 2,3,5 Triphenyl Tetrazolium Chloride (TTC) (Panreac, Spain),

Tergitol agar (Himedia, India), and Bile Aesculin Agar (Biokar Diagnostics, France). The dilution process was employed for RWW, and the filtering method employing a membrane (0.45 μm) was applied for TWW and WW (Moroccan Standards, 2006). The number of bacterial indicators was measured in colony-forming units (CFU) per 100 milliliters (log CFU/100 ml) (Moroccan Standard 03.7.001, 2006).

Soil sampling and analyses

Twelve discrete soil samples were taken from each plot (three per line). Composite soil samples were made as bulk aliquots (200 g) from the previously homogenized twelve discrete soil samples taken from each plot. Soil samples were collected at 30 cm depth (Rocco et al., 2016). Soil sampling was done before the irrigation experiment began (T0) and then after the irrigation took place by the three different water qualities (RWW, TWW, and WW). The soil collection took place in the study area by gathering the different samples in plastic bags before analysis. After combining certain grams of soil with distilled water (1:2 w/v soil water for pH and 1:5 w/v soil water suspensions for the EC), a multi-parameter probe (HI 9829, Hana; Romania) was used to measure the potential of hydrogen (pH) and electrical conductivity (EC). The Kjeldahl technique was used to investigate total N (Bremner, 1996). According to Nelson and Sommers (1982), the Smith-Weldon method was used to analyze soil organic matter. P (P) was analyzed with the OLSEN extraction using 0.5 M of $NaHCO_3$ (Olsen et al., 1954).

The concentration of Macro and micro-elements (Ca, Na, K, Mg, Mn, Zn, Fe, and Cu) was analyzed using an inductive coupled plasma mass spectroscopy (ICP-AES).

Plant sampling and analytical methods

When the crops reached maturity, a total of eight plants were randomly selected from each field per treatment (RWW, TWW, and WW). From each chosen plant, leaves at level four, measured from the plant's height, were collected in a random manner. They were subsequently measured in the laboratory.

Growth parameters such as root, aerial, and grain dry weights were measured when the crops reached maturity. The maximum leaf area is calculated by the product of the maximum length and width (L_{max} and l_{max}), influenced by the coefficient 0.75 (Ruget et al., 1996). The plants underwent 48 hours of 70°C drying before being weighed to determine their dry weight. The amount of total chlorophyll in the plant leaves was settled using acetone in tubes, followed by sedimentation for 48 hours. A spectrophotometer was used to measure chlorophyll a, b, and c at three different wavelengths (470, 644, and 662 nm) (Upadhyaya & Panda, 2004). Ethanol and liquid N were used for the plant's extraction determined for the examination of total proteins and sugar, followed by centrifugation for 20 minutes and then left at -20° until analysis by Bradford reactor for the proteins (Bradford, 1976), phenol, and H_2SO_4 for the total soluble sugars (DuBois et al., 1956). For the plant grain, the total P was determined by the OLSEN extraction. The ash was melted in chloride acid after being converted to ash by around 0.5 g of plant grain in a furnace for 6 hours at 500°C. Using the molybdate blue technique, a calorimetric determination of the P concentration was made (Murphy & Riley, 1962). After color development at 100 °C for 10 minutes, the P concentration was determined by reading the absorbance at 820 nm. The Kjeldahl technique was used to quantify the concentration of N (Bremner, 1996). The P content was determined by observing the absorbance at 820 nm following 10 minutes of color development at 100 °C. Using the Kjeldahl technique, the concentration of N was determined (Bremner, 1996). Macro/Micronutrients (Ca, K, Mg, Na, Mn, Fe, Zn, and Cu) and heavy metals were determined by the Inductive Coupled Plasma Analyzer (ICP-AES). The ash was melted in chloride acid after being converted to ash by using 0.5 g of plant grain in a furnace for 6 hours at 500 °C. Using the molybdate blue method, a calorimetric analysis of the P concentration was made (Murphy and Riley, 1962). After color development at 100°C for 10 minutes, the absorbance at 820 nm was read to determine the P content. N (N) concentration was measured using the Kjeldahl method (Bremner, 1996). Macro/micronutrients (Ca, K, Mg, Na, Mn, Fe, Zn, and Cu) and heavy metals were identified using an inductive coupled plasma analyzer (ICP-AES).

Statistical analysis

To examine the significant differences, the normality test has been verified before the Tukey test. The Tukey test is employed at the significance level of $\alpha = 0.05$. A notched boxplot test was used to demonstrate the impacts of three water treatments on the characteristics of soil and plants.

RESULTS AND DISCUSSION

Suitability of Water for irrigation

Physicochemical analysis

The investigation of the new Trickling Filter TF technology in a Moroccan urban community unit confirmed the efficiency of this technology to remove organic matter, nutrients, and fecal contamination from domestic wastewater under an HLR between 160 and 250 L m^{-2} day^{-1}. resulted in significant organic matter removal as well as a significant reduction ($p < 0.05$) in N and P, with an abatement of 97%, 79%, 76%, and 27%, respectively, for TSS, COD, TP, and TN. For fecal bacteria indicators, the hybrid MSL system achieved high log removals, reaching 2.88 log units during two years of monitoring (Zidan et al., 2022). The performance of the TF system was good, and no clogging problem was detected during the monitoring period. The MSL system has the capacity to disinfect domestic wastewater due to the implication of different mechanisms, including filtration, precipitation, and biodegradation (Zidan et al., 2023). For example, the major part of organic matter was reduced by biological degradation, especially in the upper parts where oxygenated conditions were more developed, causing a proliferation of microorganisms and the overgrowth of biofilms in the soil-based layer (SBL) (Sato et al., 2011). The performance of the hybrid technology was very high due to the adsorption and precipitation of P through the addition of iron metal to SBL (Zhang et al., 2020). The presence of nitrification and denitrification processes has a significant impact on TN removal inside the TF system. Finally, the removal of coliforms in the TF system is carried out by physical filtration, adsorption, and other processes, including predation and microbial cell death (die-off) (Song 2020; Sbahi et al. 2022).

Table 1 presents the physicochemical characteristics of three different water qualities used in the experimental study. The pH values of the three types of water were within the WHO limits of 6.5–8.5 (WHO, 2012). The (EC) and total dissolved solids (TDS) were higher in the RWW and WW than TWW. The greater values of these two parameters could be a result of the geological composition of the soil found in the groundwater of the study area.

Additionally, the EC values of three different water qualities were within the permissible limits of Morocco's irrigation standards. The total hardness is due to the concentration of magnesium and calcium in the different waters (Dudziak et al. 2019). The total hardness of treated water equals the hardness of hard water (350–550 mg $CaCO_3$/L). Regarding Na, K, Ca, and Mg, which are crucial elements for plant production and better soil fertility, the results showed high concentrations in WW compared to RWW and TWW.

The WW exhibited higher average concentrations of $CaCO_3$, Na, Ca, Mg, Cl, HCO_3, and TDS compared to both the RWW and TWW. Additionally, the levels of Cl and HCO_3 surpassed the limits set by Morocco's irrigation standards. In the continental zone, particularly in the Marrakech region, the natural salinization of groundwater by aquifer rocks (Hssaisoune et al., 2020) and anthropogenic contamination from agricultural activities (El Mokhtar et al., 2012) contribute to this phenomenon. Such characteristics make it difficult to consider this well water as a reference of good water quality to compare with.

The most important water indicators to measure water quality are organic matter, total P, and N. COD, TSS, TP, NH_4^+, and NO_3^- were not detected in WW. The quality of the treated water conformed to

Morocco's irrigation standard limits. The concentration of chlorides was higher in WW, and a significant difference was found between the three water qualities. The concentration of chlorides in TWW and RWW was below the permissible limits of Morocco's irrigation standards.

Table 1: Physicochemical characteristics of the three water treatments (RWW: raw wastewater; TWW: treated wastewater; WW: WW) used for maize irrigation (mean ± standard deviation)

Parameters	Unit	RWW	TWW	WW	The admissible limit for wastewater reuse
pH		8.11 ± 0.33[a]	7.70 ± 0.37[a]	8.60 ± 0.1[a]	6.5 -8.4
EC (20°C)	dS/m	1.109 ± 0.003[a]	1.006 ± 0.002[b]	1.65±0.003[c]	12
TDS	mg/l	980±3.55[a]	672±3.87[b]	1020±4.98[a]	7680
$CaCO_3$	mg/l	468±2.1[a]	477±1.1[a]	706±2[b]	
COD	mg/L	130.69 ± 42.77[a]	27.74 ± 13.70[b]	Not detected	_
TSS	mg/L	56.58± 37.97[a]	1.54 ± 1.75[b]	Not detected	2
NH_4^+	mg/L	18.19 ± 3.75[a]	3.05 ± 2.17[b]	0.1 ± 0.02[c]	
NO_3^-	mg/L	1.92 ± 1.09[a]	14.23 ± 5.69[b]	0.02 ± 0.001[c]	30
TP	mg/L	2.31 ± 0.95[a]	0.55 ± 0.46[b]	0.10 ± 0.02[c]	
Na	meq/L	4.74 ± 0.03[a]	4.87 ± 0.038[a]	11.57 ± 0.04[b]	
Ca	meq/L	6.98 ± 0.05[a]	6.49 ± 0.036[a]	9.58 ± 0.02[b]	
K	meq/L	0.82 ± 0.041[a]	0.72 ± 0.031[b]	0.23 ± 0.024[c]	
Mg	meq/L	2.96 ± 0.037a	2.97 ± 0.04a	4.28 ± 0.03c	
Cl	mg/l	57±1.2[a]	162±3.2[b]	863±2.1[c]	350
CO_3^-	meq/L	0.0±0[a]	0.3±0.01[a]	0.1±0.02[a]	
HCO_3^-	meq/L	0.24±0.01[a]	3.25±0.01[b]	2.4±0.03[c]	8.48 mg/l
Al	g/l	<0.001	<0.001	<0.001	0.005
B	g/l	<0.001	<0.001	<0.001	0.003
Be	g/l	<0.001	<0.001	<0.001	0.0001
Cd	g/l	<0.001	<0.001	<0.001	0.00001
Cr	g/l	<0.001	<0.001	<0.001	0.001
Cu	g/l	0,001	<0.001	0,002	0.002
Fe	g/l	0,001	<0.001	0,001	0.005
Zn	g/l	<0.001	<0.001	<0.001	0.002
Hg	g/l	<0.001	<0.001	<0.001	10-6
Li	g/l	<0.001	<0.001	<0.001	$2.5*10^{-3}$
Mn	g/l	<0.001	<0.001	<0.001	0.0002
Mo	g/l	<0.001	<0.001	<0.001	0.00001
Ni	g/l	<0.001	<0.001	<0.001	0.002
Pb	g/l	<0.001	0.001	0,001	0.005
Total coliforms	Log.	6.50 ± 0.77	3.48 ± 0.48	Not detected	
Fecal coliforms	Log.	5.44 ± 0.5	2.56 ± 0.40	Not detected	3
Total streptococci	Log.	5.2 ± 0.57	2.36 ± 0.33	Not detected	

The different letters (a, b, and c) represent the significant difference according to the Tukey test at $p < 0.05$.

The concentrations of micronutrients (Fe, Mn, Cu, and Zn) and heavy metals (Al, Cd, Cr, Hg, Li, etc.) are noted in Table 1. The results showed that the average concentration of micronutrients and heavy metals was well within the standard limits for agricultural irrigation (Moroccan Standards, 2006).

The findings demonstrated that the average concentration of micronutrients and heavy metals was within the permissible limits for irrigation of agricultural land (Moroccan Standards, 2006).

The microbiological characteristics of the three treatments of irrigation water are presented in Table 1. The average content of fecal bacteria in treated water was 3.48 ± 0.48log/100 ml, 2.56 ± 0.40 log /100 ml and 2.36 ± 0.33 log /100 ml for total coliform (TC), fecal coliform (FC), and fecal streptococci (FS), respectively.

The comparison between the three irrigation water qualities shows that RWW contains a high content of fecal bacteria, whereas WW was free from fecal contamination (not detected). However, TWW quality was below the norms suggested by Moroccan standards for irrigating crops that are destined for human consumption: 3 logs/100 ml for FC (Moroccan Standards, 2006).

Sodium absorption ratio (SAR)

SAR is defined as a monitoring indicator to determine water quality for the irrigation of crops and to calculate the sodium hazard linked with the application of irrigation water for determining the sodium hazard associated with an irrigation water application (Alam et al. 2012). In addition, if the SAR value is less than 6, the water is suitable for irrigation. However, if the SAR is higher than 6, the water can produce sodium accumulation in the soil, which could negatively impact soil infiltration and cause soil crusting (Lesch & Suarez, 2009). Table 2 showed that values of SAR were between 2.12 and 4.39 meq/L. The three types of water were within permissible limits for irrigation, and soil sodification risk is considered slight to moderate.

Sodium percentage (Na %)

The proportion of sodium was determined using the Doneen method. The results of the sodium percentage of the water samples are categorized into three categories: good (20-40 Na%), acceptable (40-60 Na%), and doubtful (60-80 Na%) (Doneen, 1975). The sodium percentages of all treatments were in the permissible range (40-60 Na%) (Table 2).

Residual sodium carbonate (RSC)

Other parameters are most important for evaluating the irrigation suitability of water, such as the residual sodium carbonate (RSC), which helps identify the negative effects of carbonate (CO_3^{2-}) and bicarbonate (HCO_3) on the availability of water used for agricultural purposes (Raju, 2007).
The precipitation of magnesium and calcium ions is influenced by the high content of CO_3^{-2} and HCO_3^- ions. When the content of Ca^{2+} and Mg^{2+} ions is higher than the content of CO_3^{-2} and HCO_3^- ions in wastewater, the effluent is acceptable for irrigation.
According to Table 2, the RSC values are less than zero, which indicates that the three water qualities are safe for irrigation practices and that there is a possibility that Ca^{2+} and Mg^{2+} ions did not completely precipitate as carbonates.

Table 2. SAR, Na%, and RSC values at the three irrigations' water quality

	Unit	RWW	TWW	WW
SAR	meq/L	2.12±0.02^a	2.24±0.03^b	4.39±0.02^c
Na% (SSP)	meq/L	44%±1%^{a}	46%±2%^{a}	53%±1%^{b}
RSC	meq/L	-9.7±0.1^a	-5.9±0.2^b	-11.3±0.1^c

Effect of water quality on irrigated soil

The properties of the soil collected before and after the application of the three different treatments are summarized in Table 3.

A slight difference in pH was observed between the soils after the maize harvest. The soil irrigated with WW showed the highest value of pH (8.54) compared to the soil irrigated with TWW (8.51) and RWW (8.35). But no significant difference ($p > 0.05$). Compared to RWW and WW, irrigated soil with TWW has a lower conductivity (Table 3). According to previous studies by Elfanssi et al. (2018) and El Moussaoui et al. (2018), the primary contributor of salt accumulation in the soil is the irrigation water. In our own research, we found that the average electrical conductivity (EC) of the soil irrigated with TWW was 0.367 ± 0.02 ds/m. This value indicates a low level of salinity, posing no significant risk to crop yields. Overall, the water quality during the crop seasons was considered quite satisfactory. Other researchers have also noted the inconsistent effects of irrigation on the soil EC. For example, El-Nahhal, (2013) noted that water irrigation increased soil salinity, measured as the EC of the 1:5 soil extract in ds/m, due to the accumulation of less soluble salts in the topsoil layer. The solubilization, transportation, and redistribution of salts within the root zone, as well as additions from external sources such as irrigation water, could all be contributing to the increase in soil salinity levels (Ganjegunte et al. 2017; Musslewhite et al. 2009). Additionally, Munir et al. (2007) claimed that irrigation of wastewater for 2, 5, and 10 years increased the salt content of the soil. Salts will continue to accumulate in the topsoil, which will negatively affect plant development, soil productivity, and the activity of soil microorganisms (Durán–Álvarez & Jiménez–Cisneros, 2014). There were significant effects on the total organic carbon (TOC) of the soil ($p < 0.001$) due to different water irrigation applications. The TOC concentrations of the soils irrigated with RWW were more significant than those of other irrigated soils ($p<0.05$). The parameters (TOC) dropped significantly with TWW irrigation (3.38%) compared to soil irrigated by RWW soils (4.43%). The soil irrigated with WW showed the lowest concentrations of organic matter (2.53%). The TKN and TP concentrations of soil irrigated with RWW, TWW, and WW were higher than before irrigation (Table 3), which is probably due to the fertigation effect. However, an increase in TKN and TP concentrations was noticed on soil that had been irrigated with RWW compared with TWW and WW (Table 3). It found a similarity between the organic matter and nitrogen contents of the soils. In accordance with this topic, many investigations showed that, after wastewater use, there was an increase in organic matter and N in soils, which was strongly related to the nutrients and organic compounds in the wastewater irrigation used (El Moussaoui et al. 2019; Elfanssi et al. 2018; Kiziloglu et al. 2008). Other studies, including short- and long-term investigations, claimed that wastewater treatments enhanced soil fertility (Adrover et al., 2017; Chakrabarti, 1995; Kiziloglu et al., 2008). According to the findings of Munir et al. (2007) and Segal et al. (2011) from their experiments, the concentration of N and P in the soil increased as the duration of wastewater irrigation prolonged. The researchers attributed this increase in the upper layer of soil to the intensive application of wastewater. The element contents (Na, Ca, and Mg) were significantly higher in WW-irrigated soils than in the other soil treatments (RWW and TWW). Compared to soils irrigated with TWW and WW, soils irrigated with RWW had higher K concentrations. The concentrations of the macro-elements in the applied waters were likely the cause of the differences between the macro-element content in soils irrigated with RWW, TWW, and WW (Table 1). Burns et al. (1985) found in their experiment that wastewater irrigation applied in this study increased N, P, and K in contents 4, 10, and 8 times more than those recommended for forage crops. Regarding the concentrations of micronutrients reported in Table 3, the plots tested in the three treatments had no significant differences. It should be mentioned that, as reported in many studies, the accumulation of microelements and heavy metals as a response to wastewater irrigation is evident, especially under long-term application, and can lead to toxicity problems either because of heavy metals and/or high levels of nutrient accumulation or because of deterioration of soil and crop quality parameters. Especially, accumulation of microelements and heavy metals from wastewater application could be caused directly by the wastewater composition or indirectly through increasing solubility of the indigenous insoluble soil

heavy metals (Friedel et al. 2000; Rattan et al. 2005; Lucho- Constantino et al. 2005; Mapanda et al. 2005; Qian and Mecham 2005).

Table 3: Characteristics of the soil after the application of different treatments.

Parameters	**T_0**	RWW	TWW	WW
EC (ds/m)	0,327±0.04[a]	0.565±0.03[c]	0.367±0.02[a]	0.432±0.10[b]
pH	8.05±0.02 [a]	8.35±0.01[b]	8.51±0.03[c]	8.54±0.01[d]
NTK (%)	1,1±0.11[a]	8.90±0.28[d]	8.08±0.20[c]	7.66±0.10[b]
COT (%)	2,51±0.01[a]	4.43±0.07[c]	3.38±0.03[b]	2.53±0.01[a]
TP (mg kg-1)	187±0.30[a]	240±0.40[d]	194±0.30[c]	190±0.10[b]
Ca %	19±0.03[a]	20.85±0.04[c]	20±0.03[b]	25.48±0.02[d]
Mg %	4,14±0.01[a]	4.71±0.02[b]	5.21±0.06[c]	5.49±0.01[d]
K %	4,01±0.01[a]	4.63±0.04[d]	4.34±0.04[c]	4.17±0.04[b]
Na %	0.67±0.01[a]	0.68±0.02[c]	1.69±0.01[c]	1.76±0.03[b]
Fe %	9.32±0.01[a]	9.34±0.02[a]	10.03±0.02[b]	10.46±0.01[d]
Mn %	0.02±0.01[a]	0.04±0.01[b]	0.03±0.02[b]	0.05±0.01[b]
Cu (g/t)	3.8±0.20[a]	4±0.80[b]	5±0.40[b]	6±0.30[b]
Zn (g/t)	55±0.40[a]	59±0.20[a]	56±0.30[a]	60±0.20[a]

The different letters (a, b, c) indicate the significant difference at $p<0.05$ by Tukey test.

Effect of irrigation water quality on maize (*Zea mays*) crop

Growth parameters

Figure 2 presents the biomass production (roots, aerial, and grain dry weight) and leaf area of maize plants under different irrigation treatments: RWW, TWW, and WW during the experimental study. Notably, there was a significant increase ($p < 0.001$) in maize biomass when irrigated with RWW, followed by the TWW plots. The leaf area also showed a similar trend, reaching approximately 162.48 ± 7.67 cm^2 when irrigated with RWW. In contrast, the leaf area was lower, not exceeding 152.26 ± 2.45 cm^2 and 147.31 ± 4.31 cm^2 when irrigated with TWW and WW, respectively. The influence of wastewater irrigation on plant productivity varied depending on the chemical composition of the irrigation water. The contrasting nutrient content among the different water sources can account for the observed differences in productivity and growth. The results highlight that the higher nutrient content in RWW, acting as a fertilizer source, contributed to an increase in plant productivity.

Consistent with prior research, our findings demonstrate the positive impact of utilizing domestic wastewater on biomass production compared to crop cultivation with well water. This aligns with the observations made by Rusan et al. (2007), who noted that barley irrigated with wastewater exhibited taller biomass compared to barley irrigated with well water. The increase in biomass was attributed to the nutrient content in the wastewater. Similarly, Abegunrin et al. (2013) reported enhanced growth traits in cucumber irrigated with kitchen wastewater compared to groundwater. Mojiri et al. (2013) also found that irrigation with wastewater significantly increased root length and shoot length in *Lepidium sativum* compared to plants irrigated with fresh water. These improvements in biomass can be attributed to various factors, such as changes in cell wall extensibility associated with protein composition (Hasegawa et al., 1984), reduction in photosynthetic capacity (Erice et al., 2011), and alterations in hormonal metabolism (Wilkinson and Davies, 2002). *Zea mays* exhibited better adaptation to the quality of treated wastewater, as it benefited from the nutrients present, particularly

nitrogen and phosphorus. These nutrients significantly contribute to plant growth compared to the relatively limited growth associated with well water.

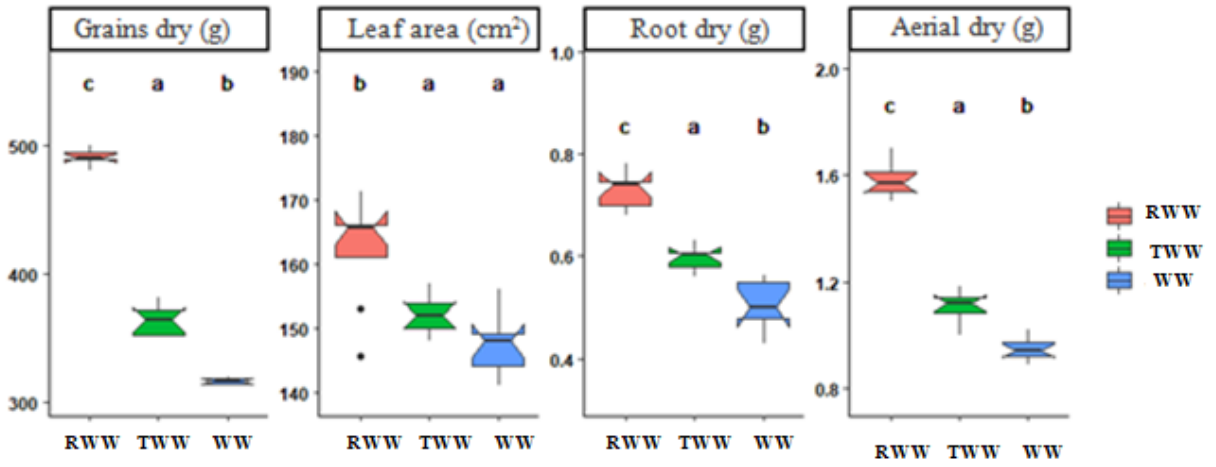

Fig. 2. The biomass production (roots, aerial parts, and grain dry) and leaf area of maize plants, irrigated by the three water treatments (RWW: raw wastewater; TWW: treated wastewater; WW: WW). The three letters (a, b, and c) represent a significant difference by notched boxplot test.

Macro and micronutrient parameters

Water quality was not found to be detrimental to plant health, taking into account macroelements (N, P, K, Ca, Mg, and Na), which are considered necessary for the health of *Zea mays* (N, P, K, Ca, Mg, and Na), as reported by Orhue (2005) and Rezapour et al. (2021). Domestic wastewater application significantly affected the content of macro-elements (N, P, K, Ca, Mg, and Na) in *Zea mays* (Fig. 3). Plants irrigated with RWW produced the highest amounts of N with 6.7 ± 0.91%, P with 6.2±1.1%, and K with 2.05±0.5%. However, the plants irrigated with WW had a high content of Ca with 0.3±0.8%, Na with 0.4±0.95%, and Mg with 0.1±0.82 %. Furthermore, compared to RWW and WW, the TWW yielded a medium concentration of N (4.3±0.45%), P (5.62±1.2%, and K (1.85±0.15%, Ca (0.17±0.68%), Mg (0.5±0.87%), and Na (1±0.96%). This was the direct consequence of the important amount of nutrients provided by irrigation with RW, TWW by the multi-soil-layering system. Based on these results, it can be concluded that water irrigation significantly affects Zea mays yield and mineral content. The enhancement of plant macronutrient content with domestic wastewater irrigation indicates that wastewater irrigation supplied the soil with these nutrients, which improved plant growth and soil fertility (Orhue et al., 2005). Indeed, plant growth and nutrient content can be enhanced by properly managed irrigation with preserved nutrients in treated wastewater (Alawsy et al., 2018). Consequently, TWW-irrigated plants showed medium levels of biomass production and nutrient content compared to those irrigated with RWW and WW. As we discussed previously, these treated wastewaters by multi-soil-layering system, in addition to the significant load of nutrients, meet standards for wastewater reuse in agriculture (Blumenthal et al. 2000; Moroccan standards 2007). The micronutrient contents (Fe, Zn, Mn, and Cu) of Zea mays treated by water of the three different qualities are shown in Fig. 4. These micronutrients are necessary for plant nutrition only if they are required by the crops in much lower quantities compared to macronutrients (Elfanssi et al., 2018). The metrics indicate that *Zea mays* uptake a lower and similar content of micronutrients than RWW, TWW, and WW. These results were in line with prior research investigating the effect of short-term

irrigation on micronutrient accumulation in plants (Adrover et al., 2012; Kiziloglu et al., 2008; Mapanda et al., 2005; Younas et al., 2022). Additionally, the accumulation of micronutrients might be affected directly by irrigation water quality or indirectly by an increase in the solubility of the native, insoluble soil micronutrient (El Moussaoui et al., 2019; Lucho-Constantino et al., 2005; Mapanda et al., 2005; Yu et al., 2007).

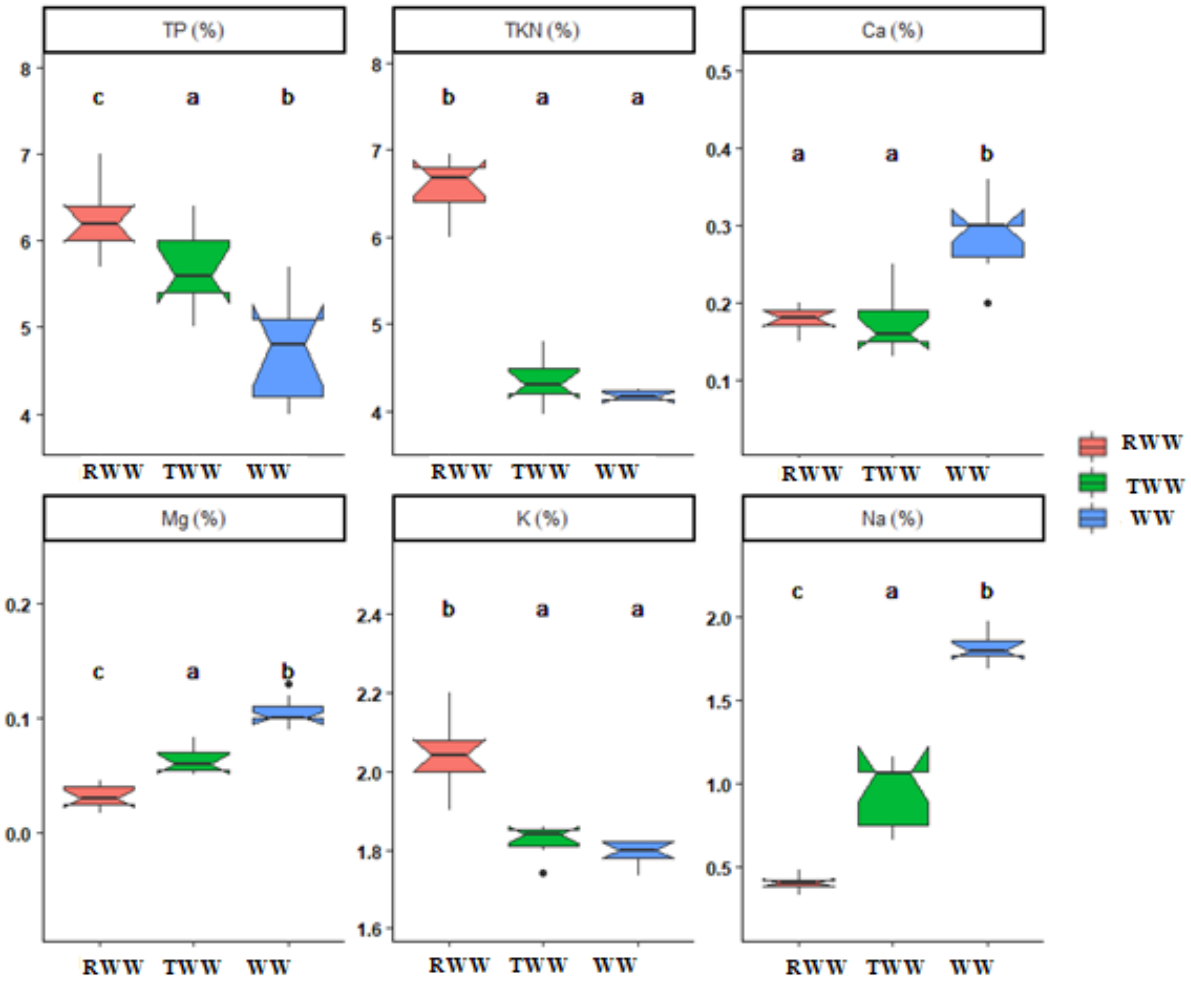

Fig. 3. The macronutrient contents of plant grain, irrigated by the three water treatments (RWW: raw wastewater; TWW: treated wastewater; WW: WW)

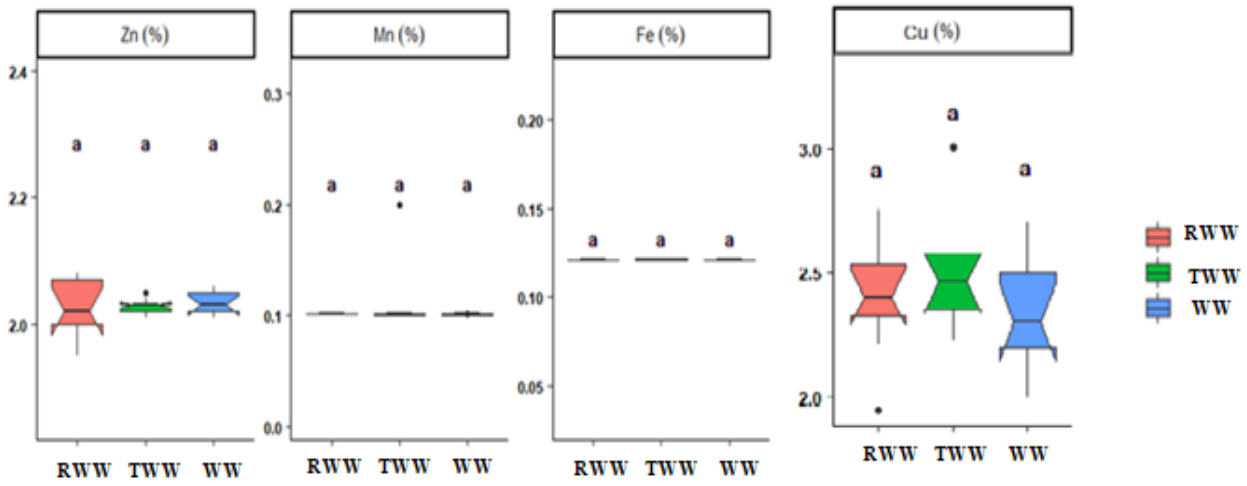

Fig. 4. The micronutrient contents (Fe, Mn, Cu, and Zn) of plant grain, irrigated by the three water treatments (RWW: raw wastewater; TWW: treated wastewater; WW: WW)

Total Chlorophyll

Figure 5 illustrates the impact of the three water qualities on the total chlorophyll content of *Zea mays* crops. The application of WW and TWW resulted in significantly higher chlorophyll content. The obtained results confirmed that even after irrigation with WW and TWW, the chlorophyll concentration in the plants remained higher. This indicates a greater potential for capturing light energy and enhancing photosynthetic activity. Additionally, TWW did not demonstrate any discernible effect on the photosynthetic activity of the plants under investigation. These findings align with the research conducted by Jóźwiakowski et al. (2020), who reported that potassium (K) deficiency had the most significant inhibitory impact on photosynthesis in maize plants. Conversely, the study did not observe any notable influence of phosphorus (P) content on overall chlorophyll levels during a short-term deviation from optimal macronutrient levels. Previous studies have utilized chlorophyll content to explain phenomena such as heavy metal stress (Mallick & Mohn, 2003), nutritional deficiencies in raw domestic wastewater (Elfanssi et al., 2018), and reclaimed wastewater (Bañón et al., 2011). Conversely, Ahmali et al. (2020) found that irrigation water with high salinity can induce photosynthetic stress in plants, with total chlorophyll serving as an indicator of this stress.

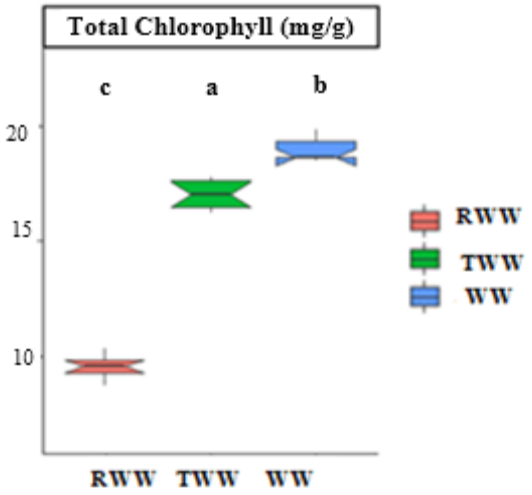

Figure 5. Total chlorophyll leaves contents of the corn irrigated by the three water treatments (RWW: raw wastewater; TWW: treated wastewater; Well water: WW).

Biochemical parameters

Sugar

Figure 6A shows the concentrations of sugars determined in *Zea mays* leaves obtained under irrigation with WW, RWW, and TWWs. However, significant variations ($P < 0.05$) were observed among treatments. Maize crops grown under irrigation with RWW and TWW showed comparable concentrations of total sugars. Indeed, Zea mays irrigated with WW showed significantly lower values of total sugar compared to those irrigated with RWW and TWW. The lower abundance of sugars in *Zea mays* leaves might be ascribable to the salinity of the WW used for irrigation, which showed a Cl concentration exceeding the Moroccan legal limits for water reuse (Table 1). The high concentrations of chloride (Cl) present in the irrigation water could have resulted in a water deficit within the maize plants. This salt stress can have detrimental effects on plant growth, including a reduction in relative water potential, as observed in previous studies (El Sabagh et al., 2020). Additionally, the negative impacts of salt stress can extend to the quality of both soil and water, both in the short and long term, as highlighted by research conducted by Seleiman et al. (2021).

Protein

Figure 6B illustrates the impact of irrigation water quality on the protein content of maize leaves. It was observed that plants irrigated with raw wastewater (RWW) exhibited higher protein accumulation, reaching 22.01 ± 2.53 mg/g. In contrast, the protein content in leaves irrigated with TWW and WW did not exceed 13.23 ± 1.33 mg/g and 12.90 ± 2.03 mg/g, respectively. This disparity suggests that while RWW induced physiological stress, TWW and WW did not adversely affect the physiological state of maize, as supported by findings from Newson et al. (2015).
Similar observations have been reported by Suke et al. (2011), who found that maize protein content increased with higher levels of NPK and biofertilizers. Rija et al. (2005) also reported comparable outcomes in their study on the impact of sewage irrigation on crops such as *Cicer arietinum*, *Lens culinaris*, and *Vigna radiata*. They attributed the rise in total protein and carbohydrate levels in leaf samples from *C. arietinum* and *L. culinaris* to the activities of various microorganisms present in sewage water, which convert organic matter into by-products such as CO_2, NH_3, H_2S, NO_3, PO_4, SO_4, and CH_4. Furthermore, Latef and Ahmad (2015) proposed that the higher concentrations of macronutrients in wastewater serve as cofactors for the enzymes involved in protein production in maize plants.

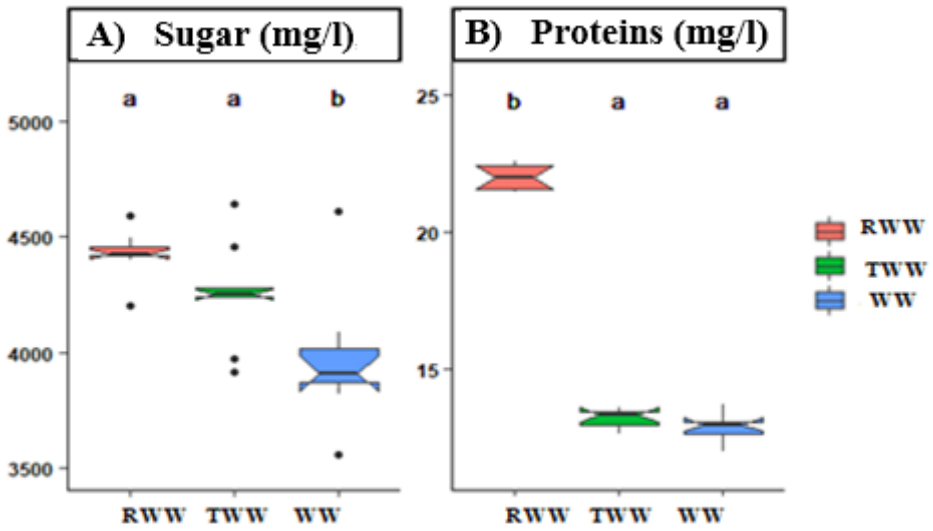

Figure 6. Sugar (A), and Proteins (B) leaves contents of crops, irrigated by the three water treatments (RWW: raw wastewater; TWW: treated wastewater; Well water: WW).

Conclusions

In arid regions, treated wastewater is a valuable resource for irrigation as it provides water and some nutrients (N, P, and K) to crops. The present study reveals significant variations in the physicochemical and microbial characteristics of water and soil, as well as the physiological responses of maize crops, among the three types of irrigation waters investigated (WW, RWW, and TWW). The quality of TWW, treated using the Trickling Filter (TF) technology, has successfully met the permissible limits for reuse in irrigation without posing any health risks according to Moroccan standards. However, WW exhibits high salinity, with chloride concentrations surpassing the legal limits for water reuse in Morocco.

Moreover, the values of RSC, SAR, and Na% indicate that all treatments are suitable for irrigation. However, soil analyses reveal that soils irrigated with RWW contain elevated levels of physicochemical parameters such as COT, NTK, and TP, which can be detrimental to plants when they exceed specific thresholds. Despite the fact that RWW has a high nutritional value that can promote plant growth, albeit with noticeable variations compared to TWW using the TF eco-technology, irrigation with RWW leads to a decrease in overall chlorophyll content in maize, but stimulates the significant accumulation of parameters such as total soluble protein and sugars. In contrast, TWW demonstrates important nutritive value that has the potential to enhance plant growth, reduce the need for fertilizer application (including the cost of mineral fertilization), and increase the productivity of infertile soils. However, WW results in a lower abundance of sugars in *Zea mays* leaves, which might be attributed to the salinity of the WW used for irrigation, thereby questioning its use as a reference.

In conclusion, among the investigated irrigation water sources, TWW produced through the *TF process could be considered the most suitable option for water reuse in agriculture and* can serve as a valuable source of plant nutrients and soil fertilizers. TWW possesses significant nutritive value that can enhance plant growth, reduce the need for fertilizer application and associated costs, and ultimately improve the productivity of infertile soils. Nonetheless, further research is necessary to evaluate the long-term effects of TWW irrigation on soil and crops.

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PLANNING FALLACY IN SIMPLE PROJECT TASKS

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Abstract

A biased forecast is a major source of incorrect project planning. Therefore, a project tasks execution requires thorough planning based on a forecast of activities and required resources. By identifying the biases, managers can adjust the forecasted value and improve the project planning accuracy. Our research is based on 3 experiments aimed at analyzing planning fallacy in short tasks arrangement. Study 1 showed a significant bias in the estimation ($p<.05$, $M=121.82$, $SD=375.16$). It means that 80% of the participants overestimated the required time of the task completion. Study 2 showed that there was a difference in the overestimation as a dependency of the anchor given to the participants. Study 3 showed that the subjects overestimated the task duration and underestimated their potential of performance improvement ($p<.05$, $M=2.57$, $SD=1.23$). A thorough sensitivity analysis to evaluate the impact of various biases which may occur during the estimation of the simple projects duration was also conducted in this study

Keywords: planning fallacy, bias, anchor, project scheduling, underestimation, overestimation.

THE RISE OF DIGITAL JUSTICE: ETHICAL AND LEGAL TRANSFORMATION IN AI-POWERED LEGAL SYSTEMS

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Abstract

In today's world, artificial intelligence (AI) technologies are receiving growing attention in legal and justice systems, as in many other sectors. The integration of AI applications into judicial mechanisms offers significant advantages, such as accelerating legal proceedings, enhancing impartiality in decision-making processes, and minimizing human-induced errors. However, these technological advancements also raise various ethical, legal, and societal challenges and debates. This study aims to comprehensively examine the positive and negative consequences of AI integration into legal systems. In conclusion, the study presents a set of precautionary measures and policy recommendations to ensure that digitalized legal systems remain compatible with human rights and universal ethical principles.

Keywords: Artificial Intelligence, Digital Justice, Algorithmic Justice, Legal Transformation, Ethics and Law

Introduction

Since the early 21st century—an era marked by rapid technological advancement—the integration of such developments into legal systems has become inevitable. Notably, the striking progress in artificial intelligence (AI) technologies has found practical applications in courts, law firms, and forensic informatics, triggering both structural and functional transformations within justice systems. This transformation extends beyond mere technical changes in procedural workflows; it also generates profound implications for legal theory, professional ethics, and the safeguarding of fundamental rights and freedoms.

Recent studies demonstrate that AI-based systems can analyze patterns from previous legal cases to offer judges decision-making suggestions and, in certain circumstances, even trigger automated judgment mechanisms. These developments contribute significantly to accelerating judicial processes, reducing caseloads, and enhancing impartiality. However, alongside these advantages, there emerge critical ethical and legal risks. Specifically, the opacity of the algorithms governing AI systems, their inaccessibility to human oversight, and the reflection of social biases present in training datasets into algorithmic decisions pose a direct challenge to the principle of impartiality in justice. This not only undermines legal certainty but also threatens public trust in the justice system and the institutional legitimacy of the judiciary.

In this context, the question of accountability in the event of erroneous decisions made by AI-driven systems becomes a pivotal point of debate. The extent to which AI systems can operate in harmony with classical legal norms and how the boundaries of such systems should be defined lie at the heart of contemporary legal discourse. Therefore, the core research problem of this study revolves around

how AI-supported legal systems can be effectively integrated into existing legal frameworks, and within which ethical and legal boundaries they should function.

This study primarily aims to discuss how the principles of transparency and impartiality can be upheld in AI-based adjudication systems, how biases in decision-making processes can be minimized, and how algorithmic decision-making mechanisms can be aligned with the principle of accountability. Furthermore, the study seeks to develop proposals for more ethical cooperation between AI and human judges and to examine how such collaboration can contribute to the legal system.

Technological transformation must not be viewed solely as a technical evolution but also as a sociological, ethical, and philosophical reconstruction. The prediction of Japan's Robotics Policy Committee—that by 2030, humans and robots will actively coexist—indicates that this transformation demands not only technological adaptation but also social regulation. Indeed, such transformation in the legal domain is already underway. One of the earliest conceptual foundations of AI in law can be traced to Gottfried Wilhelm Leibniz, who stated, "The only way to rectify our reasoning is to make them as tangible as those of the mathematicians, so that errors can be discovered at a glance..." This notion offers a seminal philosophical basis for algorithmic decision-making.

AI systems, through their predictive and inferential capacities derived from large datasets, can at times achieve a level of speed and accuracy that surpasses human judgment. The current extent of this transformation was aptly captured by then-Chief Justice of the United States, John G. Roberts Jr., who in 2017 responded to a journalist's question regarding whether AI systems were being used in judicial decisions by stating, "That day has already arrived." Several pilot projects involving AI-based legal systems have been launched across the globe; however, these initiatives have sparked significant debates concerning transparency, accountability, and compatibility with human rights.

Accordingly, the significance of this study lies in its examination of how digitalized legal systems supported by AI can be embedded within an ethical framework, the extent to which these systems can safeguard individual rights, and how they may shape public perceptions of justice. These questions are not only central to academic discourse but also to policymakers, legal practitioners, and society at large. Therefore, this study not only contributes to the academic literature but also holds the potential to serve as a guiding reference for future legislative reforms and technology policy development.

Literature Review

The use of artificial intelligence (AI) technologies in the legal domain has gained significant momentum at both academic and practical levels, particularly in the last decade. Initially envisioned as tools for decision-support mechanisms, these systems have now evolved to the point of directly intervening in decision-making processes. Processes such as electronic filing and classification of court documents, initiation and management of lawsuits online, and remote hearings via video conferencing are increasingly shaped by AI technologies. For instance, in countries such as the United Kingdom and Canada, small-scale legal disputes are now being resolved through online court platforms [1].

AI's functions within legal systems are not limited to data management. From serving as a judicial assistant to presenting similar case precedents to expedite decision-making, AI plays an active role in numerous legal processes. Some systems can predict legal outcomes before court proceedings begin, while others are capable of offering draft judgments to judges [2]. These applications are observed in various fields, from insurance companies to mediation services. For example, AI systems that predict the outcomes of jurisdictional disputes operate similarly to human decision-makers; however, they are often criticized for lacking discretionary authority and empathetic reasoning capacities [3].

Machine learning algorithms are capable of analyzing past judicial decisions to make probabilistic predictions. The Lex Machina software developed at Stanford University exemplifies this capability

by analyzing historical data from judges and courts to predict legal outcomes with high accuracy. In a 2002 U.S. study, a group of 83 human experts achieved a prediction accuracy rate of 59.1%, whereas a computer-supported system reached 75%. A replication of this study in 2017 yielded similar results [4].

In China, "internet courts" employ facial recognition systems for identity verification and manage all stages of litigation—from filing to judgment—entirely through digital means. While these applications are seen as advantageous in terms of time and resource efficiency, they must be carefully assessed in light of ethical foundations and individual rights [5]. Estonia has also proposed a project involving AI judges, where binding decisions in certain legal matters would be made by algorithms. The fact that these decisions are open to appeal reflects a legal search for balance regarding the concept of digital judges [6].

Nevertheless, the assumption that algorithmic systems are inherently neutral has been refuted by numerous academic studies. For instance, the COMPAS system used in the United States has been shown to assign higher risk scores to African American defendants, thereby reproducing racial bias [7]. Similarly, recruitment algorithms developed by major technology companies have been found to discriminate against female candidates. These examples reveal how systemic biases embedded in datasets can be perpetuated by algorithmic decision-making. Hence, it is imperative to evaluate these systems not only for their technical accuracy but also against principles of transparency, explainability, and accountability [8].

One of the most debated topics in digital adjudication systems is the issue of legal responsibility for decisions made by AI. While countries like China actively promote AI to reduce judicial workload, the European Union adopts a more cautious approach. Within the framework of the European Convention on Human Rights, the question of how the "right to a fair trial" can be protected in digital environments remains unresolved. Although current legal doctrine generally favors human judges rendering final decisions, ongoing technological advancements continually erode this boundary [9].

To establish a legal foundation for AI, the European Union launched the RoboLaw project in 2012 and published the "Guidelines on the Regulation of Robotics" in 2014. A draft of the EU Artificial Intelligence Act prepared in 2021 stated that high-risk algorithms could be banned, barred from entering the EU market, and subject to fines of up to 4% of global annual turnover for violations [10].

In contrast, the United States has implemented sector-specific and state-level regulations for AI. The Algorithmic Accountability Act (2019) aims to require companies to audit their systems for bias and discrimination. Additionally, the Commercial Facial Recognition Privacy Act proposes mandatory consent and data protection measures for facial recognition technologies [11]. Countries like Canada, Japan, and Australia promote responsible AI use through ethics-based and flexible regulatory models.

All of these developments must be supported not only by technical and legal frameworks but also through ethical analysis. From a Kantian ethics perspective, individuals must be treated as ends in themselves, not as means. Therefore, neglecting principles such as active participation in legal proceedings and consideration of personal circumstances would be ethically unacceptable under Kantian logic [12].

The utilitarian perspective, in contrast, may view the efficiency and accuracy of AI-supported systems as ethically desirable due to their contribution to societal welfare. However, this approach also entails the risk of ignoring the rights of minority groups [13].

Contractarianism, grounded in the concept of a social contract freely entered into by individuals, demands that legal systems ensure impartiality and trustworthiness. John Rawls' "veil of ignorance" principle underscores the necessity of fairness. If algorithmic systems systematically disadvantage specific groups, they would be deemed illegitimate from a contractarian ethical standpoint [14].

In conclusion, the development of AI-supported legal systems entails an inevitable transformation. However, for this transformation to be sustainable and legitimate, technical success alone is insufficient. Robust ethical and legal oversight mechanisms must be firmly established.

AI-Powered Legal Systems: Components, Applications, and Risks

Artificial intelligence (AI)-powered legal systems play a strategic role in the digital transformation of modern legal structures. From blockchain-based contracts to decision-support tools, from automated document analysis to predictive sentencing models, numerous AI-driven applications aim to enhance speed, efficiency, and predictability in legal processes. However, these advancements simultaneously raise significant ethical, legal, and sociopolitical concerns.

Smart Contracts

Smart contracts, which are based on blockchain technology, enable agreements between parties to be automatically executed when predefined conditions are met. These contracts operate digitally without the need for intermediaries, thereby reducing transaction costs and increasing reliability. Nonetheless, they have been subject to serious criticisms regarding technical errors, coding flaws, and a lack of flexibility in legal interpretation [15].

Legal Chatbots

Legal chatbots powered by AI are designed to offer individuals basic legal guidance, assist in document preparation, and provide directional support. Examples such as “DoNotPay” allow users to resolve minor legal issues at low cost. However, these systems also carry risks, including the potential for misinformation and for prompting legally unqualified individuals to make binding decisions [16].

AI Judges

In internet courts established in China, AI systems analyze case files, generate draft decisions, and in some instances, issue final judgments. Some academic studies report that AI can predict rulings of the European Court of Human Rights with up to 79% accuracy [17]. Nonetheless, these implementations remain controversial in terms of their compatibility with fundamental legal principles such as the right to a fair trial, judicial impartiality, and the obligation to provide reasoned decisions.

Court Automation Systems

Automation systems for courts—covering areas such as hearing scheduling, document management, evidence analysis, and process tracking—are increasingly used to reduce the administrative burden on judges and minimize case backlog. Pioneering digital litigation management systems in India and Estonia exemplify this trend. However, the impact of such systems on judicial independence and impartiality raises philosophical and jurisprudential questions [18].

Judicial Decision-Support Systems

Judicial decision-support systems are AI-based tools designed to assist judges during the decision-making process. Platforms such as ROSS Intelligence facilitate faster legal research, enable the comparison of similar cases, and promote consistency. However, the potential risk of judges relying solely on suggested data may weaken human reasoning and discretion. Therefore, a balanced interaction between algorithmic output and human judgment is essential [19].

Predictive Sentencing Models

Predictive sentencing models are AI systems used to assess the likelihood of recidivism among offenders. In the United States, the COMPAS system calculates risk scores and predicts whether defendants are likely to reoffend or receive custodial sentences. However, the potential bias embedded

in training datasets poses a significant threat of systematic discrimination, especially against minority groups. The COMPAS system has been widely criticized for assigning disproportionately high-risk scores to Black defendants [20].

AI in Evidence Analysis

AI can process and analyze large volumes of text, audio, visual, and other digital materials found in case files to identify misleading or suspicious elements. In this context, AI complements human expertise by enhancing the accuracy and reliability of evidence review. Nevertheless, the inability to fully interpret contextual nuances remains a fundamental limitation of such systems [21].

Datasets and Algorithmic Training

AI systems in the legal domain are trained using diverse sources such as historical court decisions, legal statutes, trial transcripts, evidence records, and scholarly publications. Databases like LexisNexis, Westlaw, and CaseText serve as primary training resources. Constitutional, criminal, and commercial codes provide the normative foundation for legal comprehension by AI systems. Furthermore, platforms such as Google Scholar and SSRN, along with demographic and criminal statistics, are vital inputs for developing predictive sentencing models [22].

Algorithmic Bias and Its Effects

Algorithmic bias refers to the production of discriminatory decisions by an AI system due to flaws in its training data or the conscious/unconscious assumptions of its developers. Since AI typically replicates historical patterns, it is prone to reproducing past biases. For instance, the COMPAS system reflected racially biased practices embedded in its dataset by systematically assigning higher risk scores to Black defendants [20]. A similar dynamic can be observed in international law, where AI systems trained on precedent containing biases against specific countries or ethnic groups may perpetuate those injustices. Additionally, the “black box” problem in AI decision-making significantly limits the interpretability and accountability of such systems, as their internal workings often remain opaque [23].

Legal and Ethical Transformation

Technological transformation impacts not only infrastructure and economic structures but also reshapes legal systems and ethical norms. The integration of artificial intelligence (AI) technologies into legal decision-making has necessitated the evolution of legal frameworks and prompted the reinterpretation of core values such as responsibility, transparency, bias, and justice. In this context, legal and ethical transformation is vital for the legitimacy and sustainability of digital legal practices.

Digital Law and Legislative Development

AI's direct involvement in individual privacy, data security, and online identity rights has highlighted the urgent need for new legal regulations. Turkey’s Personal Data Protection Law (KVKK) and the European Union’s General Data Protection Regulation (GDPR) represent critical steps toward protecting individual rights in digital environments [24]. These frameworks aim particularly to enhance transparency and accountability in algorithmic decision-making processes.

Artificial Intelligence and Legal Responsibility

The integration of AI systems into decision-making processes has challenged traditional concepts of legal liability. A central unresolved issue is whether responsibility for erroneous or discriminatory decisions lies with the software developer, the end user, or the autonomous system itself. When the decision-making process of such systems lacks transparency, it becomes difficult to determine whether a ruling is based on lawful reasoning or inherent bias. This opacity may also hinder individuals’ ability to access effective appeal mechanisms [25].

Similar concerns arise in the context of autonomous vehicles, where programming algorithms to reflect specific moral judgments presents complex challenges related to legal and criminal liability [26]. The ethical dilemmas faced by software developers are exacerbated by the lack of standardized legal frameworks and independent oversight mechanisms. Even in technologically advanced nations, the legal infrastructure for such systems remains incomplete [27].

Ethical Issues

Non-neutral training datasets for AI systems give rise to algorithmic bias, which in turn digitally replicates existing societal inequalities. The inclusion of sensitive attributes such as race, gender, or social status in decision-making processes carries the potential for severe human rights violations. One of the most prominent examples is the COMPAS software, which systematically classified African American individuals as higher risk, providing a concrete case of algorithmic discrimination [20].

In response to such concerns, the European Union published two key documents in 2019 following the adoption of the EU Ethics Charter in December 2018: *Ethics Guidelines for Trustworthy AI* and *Policy and Investment Recommendations for Trustworthy AI*. These documents emphasize the need to safeguard fundamental values such as transparency, accountability, anti-discrimination, and human-centricity in AI applications [28].

Transparency, Bias, and the Justice Balance in Digital Courts

While the digitalization of judicial systems provides notable gains in efficiency and accessibility, it also introduces new challenges related to transparency, bias, and justice.

Transparency: Although digital courts offer advantages such as recorded hearings, digitized documentation, and accelerated processes, the inner workings of AI-based decision systems often remain opaque. When it is unclear which data points are weighted and how decisions are made, the so-called *black box* problem arises [23]. This can result in individuals being unable to understand the rationale behind decisions affecting their lives, thereby undermining their right to appeal. The delegation of consequential decisions to incomprehensible algorithms threatens individual dignity and autonomy.

Bias: Algorithms are prone to reproducing biases inherent in their training data. Historical prejudices embedded in prior court decisions may be transmitted to AI systems, potentially resulting in discrimination based on ethnicity, gender, or socioeconomic status [20].

Justice Balance: Ensuring neutrality, openness, and equal access in the use of digital systems is of critical importance. Disparities in technological literacy among individuals may lead to systemic inequality. Furthermore, the influence of algorithms on judicial discretion and the extent to which human agency remains central in legal reasoning must be examined thoroughly from ethical and normative standpoints.

Potential Risks and Future Scenarios

While the development of artificial intelligence (AI)-powered legal systems offers numerous advantages, it also raises significant risks and uncertainties. In particular, issues such as the lack of transparency, the ineffectiveness of appeal mechanisms in automated decision-making processes, and data privacy concerns present new challenges that may conflict with the universal principles of law. As the human factor becomes increasingly marginalized in judicial systems, the risks associated with access to justice and the protection of fundamental rights grow accordingly.

Transparency Challenges and Regulatory Imbalance

The current immaturity of AI systems renders their unrestricted use in judicial processes problematic. In particular, the persistence of a “black box” nature in decision-making processes prevents

individuals from understanding the rationale behind punitive actions or restrictions on their rights. Furthermore, overly rigid and systematic regulations introduced in the early stages of emerging technologies may stifle innovation. To address this, the European Commission emphasizes that accountability for high-risk systems should be assigned to those actors best positioned to control the associated risks [29].

The Risk of Digital Authoritarianism

The expansion of AI technologies into legal systems brings with it the threat of digital authoritarianism from a human rights perspective. Digital authoritarianism refers to the use of AI by states to control society, suppress dissent, or implement mass surveillance. The full automation of justice mechanisms, in particular, poses a threat to both individual privacy and the impartiality and independence of the judiciary [30].

Artificial Intelligence and the Human Factor

AI systems have evolved from supportive roles in judicial processes to assuming decision-making authority. For example, the internet courts established in Hangzhou, China, employ the "AI Judge" system, where robotic judges render legal decisions. This system has since been extended to Beijing and other regions, significantly diminishing the role of human judges and raising fundamental questions about the human-centered nature of justice [31].

Similarly, AI-driven "robot lawyers" have reached a level of sophistication that allows them to provide legal consultancy services. In tasks such as contract review, AI systems have demonstrated the ability to produce faster and more accurate results than experienced legal professionals [32]. However, these developments increase the risk of sidelining human judgment, intuitive reasoning, and ethical evaluation capabilities.

Privacy and Data Security

With technological advancements making information more accessible, the surveillance of individuals in digital environments has also intensified. Surveillance cameras, mobile phone signal tracking, and online behavior analysis are increasingly encroaching upon the boundaries of personal privacy. As such, AI systems pose serious risks in terms of data security and privacy protection [33].

AI applications used in judicial processes must fully comply with standards such as the European Union's General Data Protection Regulation (GDPR). It is essential that principles of data security, anonymity, and informed consent be upheld throughout data collection, processing, and storage procedures. Failure to do so may result in systemic violations of individual rights by digital justice systems [34].

Autonomous Legal Systems

Autonomous legal systems refer to frameworks in which decision-making processes are entirely conducted by algorithms with minimal or no human intervention. In these systems, AI undertakes responsibilities such as case evaluation, legal norm interpretation, and rendering judgments. While, in theory, it may be possible to fully delegate legal functions to AI, the current ethical, legal, and societal structures are not adequately prepared for such a transformation [35].

Autonomous justice is not merely a technical advancement—it necessitates a fundamental redefinition of our understanding of justice, the philosophical foundations of law, and human-centered value systems. Removing elements such as human intuition, empathy, social context, and ethical deliberation risks the mechanization of justice and could lead to a profound crisis of legitimacy.

Solutions and Policy Recommendations

To ensure that the potential benefits of artificial intelligence (AI)-powered legal systems are implemented sustainably and in alignment with human rights, comprehensive solutions and policy

recommendations are essential. The following proposals are structured around core principles such as transparency, accountability, ethical values, international standardization, and public awareness.

Transparency and Accountability Mechanisms

The lack of transparency in AI decision-making processes undermines legal legitimacy. Therefore, in accordance with the principle of *explainable AI*, the data sets used by algorithms, the outcomes they produce, and the reasoning behind their decisions must be clearly communicated to the public and legal professionals.

Additionally, in the event of errors, it is critical to define which actor bears responsibility, as this is essential for accountability. The implementation of applications such as robot judges must be contingent upon legal authorization and the establishment of oversight mechanisms conducted by independent authorities. For example, the Council of Europe's Office of the Commissioner for Human Rights has proposed that independent oversight mechanisms be instituted to ensure the compatibility of algorithms with fundamental rights [36].

Collaboration Between AI and Human Judges

At present, delegating final judicial decisions entirely to AI systems is deemed ethically and legally problematic. However, hybrid models in which AI systems collaborate with human judges are considered more rational solutions. In this context, AI systems may be used for tasks such as large-scale data analysis, precedent comparison, and rapid information retrieval, while human judges should lead processes involving ethical evaluation, intuitive reasoning, and empathetic understanding [37].

Fairer and More Neutral Algorithms

The risk of AI systems reproducing historical biases may lead to discriminatory decisions within the legal system. Therefore, algorithms must be trained in accordance with the principle of impartiality. To achieve this, training datasets should be diverse, adequately representing minority and disadvantaged groups, and algorithms should undergo regular discrimination audits [38]. Documenting these processes transparently and publishing publicly accessible assessment reports are also essential for ethical oversight.

International Standards and Legal Regulations

The use of AI in the legal domain must be addressed not only at the national level but also globally. The European Union's *AI Act*, the United Nations' human rights-based technology principles, and the OECD's ethical guidelines represent important milestones in this direction. Such frameworks are essential for developing common norms to ensure cross-border consistency in digital legal systems, safeguard fundamental rights, and strengthen ethical oversight.

However, the effective implementation of these norms requires joint commitments from states and the adoption of binding legal instruments. Without such coordination, discrepancies between national regulations may jeopardize both individual rights and the functioning of digital justice systems [39].

Education and Awareness

To effectively manage the ethical, social, and legal implications of AI systems in the legal domain, legal professionals must receive adequate training. Courses such as "Artificial Intelligence and Law" and "Digital Ethics" should be made compulsory in law faculties to increase competence in this field. Furthermore, raising public awareness about digital justice systems will contribute to the establishment of a transparent and trustworthy digital legal infrastructure [40].

Conclusion

Artificial intelligence (AI) continues to expand its influence across nearly every domain of modern life as one of the most transformative technological tools of our era. In the legal field, the use of AI-powered systems offers significant advantages in terms of efficiency, speed, and decision accuracy. However, it simultaneously introduces critical risks concerning fundamental principles such as ethics, transparency, and accountability. This duality reveals that law is not merely a technical discipline but a field inherently intertwined with normative, ethical, and human values.

The effective use of AI systems—particularly in big data analysis and decision support tools—can facilitate judicial processes. Nonetheless, the inability of these systems to replicate human values, empathy, and intuitive reasoning underscores the necessity of defining clear boundaries for their application. Granting AI systems full authority in rendering final judicial decisions could pose serious threats to individual rights, the impartiality of justice, and institutional legitimacy. Therefore, the sources, scope, and analytical methods of datasets used in AI applications must be transparently disclosed to the public.

While the United States maintains a leading position in the development of AI technologies, it adopts a more cautious stance concerning regulation. In contrast, the European Union prioritizes ethical oversight and regulatory processes based on a human rights-centered approach. A careful balance between these two approaches is essential to simultaneously foster technological innovation and safeguard individual rights. Striking this balance—between mitigating risks and promoting technological progress—will be pivotal for ensuring the stability of digital justice systems in the coming years.

In conclusion, the establishment of secure, fair, and sustainable AI-powered legal systems necessitates comprehensive and binding legal frameworks. Digital justice systems must be designed to be transparent, accountable, accessible, and subject to oversight. Special protection mechanisms should be created to uphold the rights of vulnerable and disadvantaged groups, and equal participation in the justice process must be guaranteed for every individual. Achieving these goals requires a foundation built upon multidisciplinary collaboration, alignment with international norms, and increased public awareness.

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THE FUTURE OF ELECTRIC VEHICLE CHARGING MANAGEMENT IN SMART GRIDS: AN ARTIFICIAL INTELLIGENCE-BASED APPROACH

AKILLI ŞEBEKELERDE ELEKTRİKLİ ARAÇ ŞARJ YÖNETİMİNİN GELECEĞİ: YAPAY ZEKÂ TABANLI BİR YAKLAŞIM

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ÖZET

Küresel düzeyde iklim değişikliğiyle mücadele ve sürdürülebilir kalkınma hedeflerine ulaşma çabaları, enerji sistemlerinin yeniden yapılandırılmasını zorunlu kılmaktadır. Bu dönüşüm sürecinin merkezinde konumlanan elektrikli araçlar (EA), fosil yakıt tüketimini azaltan çevreci nitelikleri sayesinde enerji sektörü açısından stratejik bir rol üstlenmektedir. Ancak elektrikli araç kullanımındaki hızlı artış, geleneksel elektrik şebekelerinde alışılmışın dışında yük profillerinin oluşmasına ve mevcut şarj altyapısının daha etkin bir biçimde planlanıp yönetilmesine yönelik yeni gereksinimleri beraberinde getirmektedir.

Bu bağlamda, yapay zekâ (YZ) teknolojilerinin akıllı şebekelerle bütünleşik bir şekilde kullanımı, şarj yönetim süreçlerinin esneklik, verimlilik ve sürdürülebilirlik ekseninde optimize edilmesine olanak tanımaktadır. Bu çalışmada, yapay zekâ destekli akıllı şebeke uygulamalarının elektrikli araç şarj yönetimindeki rolü kapsamlı biçimde analiz edilmiştir. Talep tahmini, optimum şarj zamanlaması, yük dengeleme, dinamik enerji fiyatlandırması ve araçtan şebekeye enerji aktarımı (V2G) gibi kritik süreçlerde yapay zekâ algoritmalarının sunduğu çözüm önerileri; güncel uygulama örnekleri ve literatürden elde edilen bulgular ışığında değerlendirilmiştir.

Anahtar Kelimeler: Elektrikli Araçlar, Yapay Zekâ, Akıllı Şebekeler, Şarj Yönetimi, V2G, Enerji Yönetimi, Sürdürülebilirlik, Makine Öğrenmesi

ABSTRACT

Global efforts to combat climate change and achieve sustainable development goals are driving fundamental transformations in energy systems. At the core of this transition, electric vehicles (EVs) play a critical role in the energy sector with their environmentally friendly structure that reduces dependence on fossil fuels. However, the rapid increase in the number of EVs has led to the emergence of new load profiles in existing power grids and has intensified the need for efficient management of charging infrastructure.

In this context, the integration of artificial intelligence (AI) technologies with smart grids contributes significantly to optimizing charging management processes in terms of flexibility, efficiency, and sustainability. This study provides an in-depth analysis of the role of AI-supported smart grid applications in electric vehicle charging management. The capabilities of AI algorithms in processes such as demand forecasting, charging scheduling, load balancing, dynamic pricing, and vehicle-to-grid (V2G) energy transfer are evaluated through current application examples.

Furthermore, strategic planning recommendations specific to Türkiye are presented in light of findings from global practices. The study demonstrates that, with the effective and accurate use of artificial intelligence technologies, EV charging infrastructure can be managed in a way that is both user-friendly and grid-compatible. This approach reveals significant potential for sustainable energy management and digital transformation.

Keywords: Electric Vehicles, Artificial Intelligence, Smart Grids, Charging Management, V2G, Energy Management, Sustainability, Machine Learning

CREATING CARBON SUBSTRUCTURE FOR CITIES: MALATYA METROPOLITAN GOVERNMENT'S GPD BASIC+ EXPERIENCE

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Özet

Günümüzde kentlerin sürdürülebilirliği ve iklim değişikliği ile mücadelede etkin karbon yönetimi oldukça önemli bir noktadadır. Bu çalışmada, Malatya Büyükşehir Belediyesi'nin karbon salınımını azaltma ve yönetme amacıyla hayata geçirdiği GPD Basic+ sistemine ilişkin deneyimleri ele alınmaktadır. Çalışma kapsamında, belediyenin karbon ayak izini ölçme, azaltma ve dengeleme süreçlerini içeren bütüncül bir model geliştirme süreci analiz edilmektedir. GPD Basic+ altyapısının teknik bileşenleri, veri yönetimi süreçleri ve saha uygulamaları detaylandırılarak, sistemin yerel yönetimler için nasıl bir örnek teşkil edebileceği incelenmektedir. Ayrıca, karbon yönetimi politikalarının etkinliğini artırmaya yönelik öneriler sunulmaktadır. Çalışmanın sonuçları, kent yönetimlerinde karbon yönetimi altyapısının oluşturulmasına yönelik stratejik bir çerçeve sunarak, benzer uygulamalar için rehber niteliği taşımaktadır.

Anahtar Kelimeler: Karbon Yönetimi, Sürdürülebilir Kentler, İklim Politikaları, GPD Basic+, Malatya Büyükşehir Belediyesi

Abstract

Today, effective carbon management is of critical importance in the sustainability of cities and the fight against climate change. This study examines the experiences of Malatya Metropolitan Municipality regarding the GPD Basic+ system, which it implemented to reduce and manage carbon emissions. Within the scope of the study, the municipality's process of developing a holistic model that includes the processes of measuring, reducing and balancing its carbon footprint is analyzed. The technical components, data management processes and field applications of the GPD Basic+ infrastructure are detailed and how the system can serve as an example for local governments is examined. In addition, suggestions are presented to increase the effectiveness of carbon management policies. The results of the study provide a strategic framework for the establishment of carbon management infrastructure in urban administrations and serve as a guide for similar applications.

Keywords: Carbon Management, Sustainable Cities, Climate Policies, GPD Basic+, Malatya Metropolitan Municipality

GİRİŞ

Dünya genelinde iklim değişikliğiyle ilgili artan kaygılar, bir ürünün, hizmetin ya da organizasyonun neden olduğu toplam sera gazı emisyonlarının hesaplanmasına yönelik ilgiyi önemli ölçüde

artırmıştır. Bu durum, "karbon ayak izi" terimini, iklim değişikliğine uyum sağlama ve sera gazlarının olumsuz etkilerini azaltma konularında toplum tarafından sıkça kullanılan bir kavram haline getirmiştir (Grosbois & Fennell, 2011). İnsanlar artık çevresel etkileri daha iyi anlamak ve bu etkileri en aza indirmek için bu terimi günlük yaşamlarında ve tartışmalarında giderek daha fazla benimsemektedir. Global ölçekte, birçok organizasyonun iş faaliyetleri karbon emisyonlarının ortaya çıkmasına neden olabilmektedir. Bu gerçeklik, çevre dostu veya "yeşil organizasyon" algısının oluşturulmasını bir zorunluluk haline getirmiştir. Ancak, akademik literatürde karbon ayak izi ile yeşil organizasyonların birlikte ele alındığı çalışmaların sayısı oldukça azdır. Bu durum hem karbon ayak izlerinin hem de yeşil organizasyonların çevresel etkilerinin bir arada ve daha kapsamlı bir şekilde değerlendirilmesi gerekliliğini açıkça ortaya koymaktadır. Böyle bir yaklaşım, sürdürülebilirlik çabalarını daha etkili hale getirebilir. Endüstriyel toplumlarda kullanılan binlerce kimyasal maddenin çevreye ne ölçüde salındığını belirlemek son derece karmaşık ve zor bir süreçtir. Bunun nedeni, her bir kimyasalın emisyonlarını doğru ve tutarlı bir şekilde ölçmek için yoğun çaba ve uzmanlık gerektirmesidir (Laurent vd. 2012). Bu zorluk, çevresel etkilerin izlenmesi ve kontrol altına alınması konusunda bilim insanlarının ve karar vericilerin karşılaştığı engelleri gözler önüne sermektedir. Ayrıca, bu tür ölçümlerdeki belirsizlikler, çevresel politikaların geliştirilmesini de zorlaştırmaktadır. Karbondioksit emisyonlarının büyük bir bölümü, enerji santralleri, petrol rafinerileri, gaz işleme tesisleri, gübre üretim birimleri, petrokimya tesisleri, çelik fabrikaları, çimento üretim merkezleri ve kâğıt fabrikaları gibi organizasyonlardan kaynaklanmaktadır (Balat vd. 2003). Bu tür organizasyonlar, faaliyetlerini sürdürebilmek için genellikle bu emisyon kaynaklarına bağımlıdır. Ancak, bu faaliyetler sırasında açığa çıkan karbon emisyonları çevre üzerinde ciddi tahribatlara yol açabilir. Özellikle, çevresel farkındalık eksikliğiyle gerçekleştirilen iş uygulamaları ya da kısa vadeli kâr hedefleri doğrultusunda gerekli önlemlerin alınmaması, karbon salınımlarının artmasına ve çevresel kirliliğin kötüleşmesine neden olmaktadır. Bu tür ihmaller, uzun vadede hem ekosistemlere hem de insan sağlığına zarar verebilir. Organizasyonların gerçekleştirdiği faaliyetler bağlamında, kurumsal karbon ayak izleri bir yıl boyunca analiz edilerek iklim değişikliği üzerindeki etkileri detaylı bir şekilde incelenir. Sera gazı emisyonlarının çevresel sonuçlarını değerlendirmek için elektrik tüketimi, fosil yakıt kullanımı ya da iş seyahatleri gibi unsurların oranları dikkate alınır. Bireylerin karbon ayak izlerinden farklı olarak, organizasyonların kurumsal ayak izleri belirli kurallar, standartlar ve karşılaştırmalar çerçevesinde hesaplanır (Walenta, 2021).

Bu sistematik yaklaşım, organizasyonların çevresel etkilerini daha şeffaf ve ölçülebilir bir şekilde ortaya koymayı amaçlar. Organizasyonlar, tüketicilerin çevre dostu ürünlere olan talebinin artacağını öngördükleri için yeşil üretim alanında yenilikçi adımlar atmaktadır (Green vd. 2000). Bu yenilikler, karbon ayak izi oluşumu ile yeşil organizasyon faaliyetleri arasındaki ilişkiyi açıkça ortaya koymaktadır. Daha açık bir ifadeyle, bir organizasyon ne kadar çevreye duyarlı bir üretim yaklaşımı benimserse, karbon emisyonları o oranda azalır. Bu tür bir anlayış hem yerel hem de küresel düzeyde çevre dostu veya yeşil organizasyonlara yönelik olumlu bir algının oluşmasına katkıda bulunur. Ayrıca, bu çabalar organizasyonları sürdürülebilir bir ekonomiye geçişte lider konuma getirebilir ve toplumda çevre bilincinin yaygınlaşmasına destek olabilir. OECD (Ekonomik İş birliği ve Kalkınma Örgütü) ülkelerinde yaşanan ekonomik durgunlukların, organizasyonların yeşil ve sürdürülebilir teknolojik yeniliklerini olumsuz yönde etkilediği belirtilmektedir. Bu durum, dolaylı yoldan karbondioksit (CO2) emisyonlarında artışa yol açmaktadır (Khattak & Ahmad, 2022). Ekonomik zorluklar, çevre dostu teknolojilere yapılan yatırımları sınırlayarak sürdürülebilirlik hedeflerinden uzaklaşılmasına neden olabilmektedir. Son olarak, dünya nüfusunun hızla artmasıyla birlikte, enerji talebi pek çok alanda yükselmektedir. Bu talep artışı, teknolojinin daha yoğun bir şekilde kullanılmasını ve doğal kaynakların daha fazla tüketilmesini beraberinde getirmektedir. Bu bağlamda, teknolojik ilerlemeler ve değişimler nedeniyle son yıllarda çevresel sorunlar hem ülkeler hem de küresel toplum için en önemli meselelerden biri haline gelmiştir. Küresel iklim değişiklikleri, birçok bölgenin doğal dengesini bozarak kuraklık, yangın ve sel gibi afetlere yol açabilmektedir. Bu tür çevresel değişimler, birçok organizasyonun iş faaliyetleri sırasında ürettiği karbondioksit emisyonlarıyla doğrudan veya dolaylı olarak bağlantılı olabilir. Dolayısıyla, organizasyonların çevre

üzerindeki etkilerini azaltmak için daha bilinçli ve sorumlu bir yaklaşım benimsemesi, bu küresel sorunların çözümünde önemli bir rol oynayacaktır.

Küreselleşme ile birlikte bilim ve teknolojideki hızlı ilerlemeler, kontrolsüz tüketim alışkanlıkları, sanayi faaliyetlerinin yaygınlaşması, nüfusun sürekli artması ve yoğun rekabet koşulları, doğayı tehdit eden yeni tehlikelerin her geçen gün ortaya çıkmasına zemin hazırlamaktadır. Bu tehlikeler, özellikle 20. yüzyılın sonlarına doğru çevre üzerinde ciddi etkiler yaratmış; toprak, su ve hava kirliliğinin artmasına, küresel ısınma gibi iklim sorunlarının belirginleşmesine, biyolojik çeşitliliğin azalmasına ve doğal kaynakların alarm verici bir hızla tükenmesine yol açmıştır (Ertekin, 2012). Söz konusu gelişmeler, insan ile doğa arasındaki hassas dengenin bozulmasına neden olurken, ekosistemlerin taşıma kapasitesinin aşılmasında da önemli bir rol oynamaktadır. İnsan faaliyetleri, ekolojik sistemlerin işleyişinde belirleyici bir unsur olarak öne çıkmaktadır. İnsanların doğaya verdiği zararlar, çevresel felaketlerin sıklığını ve şiddetini artırmakta; bu da doğal sistemler üzerinde giderek büyüyen bir baskı yaratmaktadır. Örneğin, endüstriyel atıkların neden olduğu kirlilik, ormansızlaşma sonucu oluşan toprak kaymaları veya fosil yakıtların aşırı kullanımıyla tetiklenen iklim değişiklikleri, bu felaketlere örnek teşkil eder. İnsan kaynaklı bu sorunlar hem yerel hem de küresel ölçekte ekosistemlerin dengesini tehdit ederek, uzun vadeli sürdürülebilirlik açısından ciddi riskler oluşturmaktadır. Çevre problemlerinin temel kaynağı insan faaliyetleri olduğu için, bilim insanları artık yalnızca doğaya verilen zararı onarmaya çalışmak yerine, insanların çevre üzerindeki etkilerini anlamaya ve bu etkileri en aza indirmeye yönelik stratejiler geliştirmeye odaklanmaktadır. Bu yaklaşım, çevresel sorunlara kökten çözümler üretmek için insan davranışlarını ve alışkanlıklarını değiştirmenin gerekliliğini vurgular. Örneğin, enerji tüketim alışkanlıklarının gözden geçirilmesi veya geri dönüşüm gibi uygulamaların yaygınlaştırılması, bu stratejilerin birer parçası olabilir.

Sürdürülebilir bir gelecek inşa etmek adına, karbon ayak izi ve ekolojik ayak izi gibi kavramlar büyük önem taşımaktadır. Karbon ayak izi, bir bireyin, kurumun veya ürünün sera gazı salımlarını ölçerek çevresel etkisini ortaya koyarken; ekolojik ayak izi, insanların doğadan talep ettiği kaynak miktarını, gezegenin bu kaynakları yenileme kapasitesiyle karşılaştırarak bir denge analizi sunar. Bu kavramlar, bireylerin ve toplumların çevreye verdikleri zararın boyutlarını fark etmelerine yardımcı olmakta ve daha bilinçli yaşam tarzlarına geçişi teşvik etmektedir (Ertekin, 2012). Örneğin, günlük hayatta enerji tasarrufu sağlamak veya toplu taşıma kullanmak gibi küçük adımlar bile bu ayak izlerini küçültmede etkili olabilir. Gelecek nesillerin, kaynakların bilinçli kullanımı ve sürdürülebilir kalkınma ilkeleri doğrultusunda doğayla uyumlu bir yaşam sürmesi için çevre okuryazarlığı vazgeçilmez bir gerekliliktir. Bu bağlamda, ekolojik ayak izi gibi kavramların doğru bir şekilde öğrenilmesi ve içselleştirilmesi, gençlerin çevresel sorunlara duyarlı bireyler olarak yetişmesinde kilit bir rol oynar (Aydede, Deveci ve Gönen, 2019). Çevre okuryazarlığı, yalnızca teorik bilgiyle sınırlı kalmamalı; aynı zamanda bireylerin doğayı koruma yönünde pratik adımlar atmasını sağlayacak bir bilinç ve sorumluluk duygusu geliştirmelidir. Okullarda çevre eğitimine daha fazla yer verilmesi, doğa temalı projeler düzenlenmesi ve ailelerin çocuklarına erken yaşta çevre bilinci aşılaması, bu hedefe ulaşmada etkili yöntemler arasında yer alır.

Toplumların çevre konularındaki bilgi düzeyi, duyarlılıkları ve farkındalıkları, çevresel sorunlarla mücadelede başarıyı doğrudan etkileyen unsurlardır. Bu nedenle, eğitimciler ve araştırmacılar, bireylerin bu konularda ne kadar bilinçli olduğunu değerlendirmek ve bu bilinci artırmakla yükümlüdür. Bu amaçla, anketler, bilinçlendirme kampanyaları veya interaktif eğitim programları gibi araçlar kullanılarak halkın çevresel farkındalık seviyesi ölçülebilir. Ayrıca, araştırmacılar, çevre eğitimi yöntemlerini analiz ederek hangi yaklaşımların daha etkili olduğunu belirleyebilir ve bu bulguları eğitim sistemine entegre edebilir. Bu bağlamda küreselleşme ve teknolojik gelişmelerin sunduğu fırsatların yanı sıra, bu süreçlerin doğa üzerindeki olumsuz etkileri göz ardı edilemez. İnsan faaliyetlerinin çevreye verdiği zararları en aza indirmek ve gelecek nesillere yaşanabilir bir dünya bırakmak için, bireysel ve toplumsal düzeyde bilinçli adımlar atılması şarttır. Çevre okuryazarlığının yaygınlaşması, sürdürülebilirlik göstergelerinin anlaşılması ve insan-doğa ilişkisinin yeniden dengelenmesi, bu süreçte temel öncelikler olmalıdır. Eğitimciler, bilim insanları ve karar vericiler, bu

hedeflere ulaşmak için iş birliği içinde çalışmalı; böylece hem bugünün hem de yarının çevresel sorunlarına karşı etkili çözümler üretilebilmelidir.

Küresel ısınma ve iklim krizinin etkileri giderek belirginleşirken, şehirler bu sürecin merkezinde yer almaktadır. Dünya genelinde, kentler toplam sera gazı emisyonlarının %70'ine varan bir paya sahiptir. Bu durum, şehirlerin iklim krizine karşı mücadelede kritik bir rol üstlenmesini gerektirmektedir. Yerel yönetimler, kentlerin enerji tüketimi, ulaşım ve endüstriyel faaliyetleri gibi alanlarda sergiledikleri etkin politikalarla, sera gazı emisyonlarını yönetmede stratejik bir aktör olarak öne çıkmaktadır. Bu bağlamda, GPC (Greenhouse Protocol for Cities) protokolü, kent düzeyinde sera gazı emisyonlarının ölçülmesi, raporlanması ve yönetilmesinde önemli bir standardizasyon aracı olarak karşımıza çıkmaktadır. GPC, şehirlerin iklim stratejilerini belirlerken bilimsel verilere dayalı ve karşılaştırılabilir bir çerçeve sunarak, yerel yönetimlerin emisyon azaltım politikalarını daha etkili hale getirmeyi amaçlamaktadır. Türkiye'de GPC uygulayan belediye sayısının sınırlı olması, sürdürülebilir kent yönetimi açısından önemli bir eksiklik olarak değerlendirilmektedir. Bu noktada, Malatya Büyükşehir Belediyesi'nin GPD Basic+ sistemi çerçevesinde gerçekleştirdiği karbon yönetimi çalışmaları, hem yerel yönetimler için örnek teşkil etmekte hem de ülkemizde bu alandaki uygulamaların yaygınlaştırılması için stratejik bir model sunmaktadır. Çalışmamız, Malatya örneği üzerinden, şehirlerin iklim krizindeki payını azaltmaya yönelik yerel yönetim stratejilerini ve GPC protokolünün kent düzeyindeki standardizasyonunu ele alarak, sürdürülebilir şehir yönetimine dair önemli veriler sunmayı amaçlamaktadır.

YÖNTEM / YAKLAŞIM

GPC Nedir ve Neden Önemlidir?

İklim değişikliğiyle mücadelede kentlerin rolü, küresel sera gazı emisyonlarının %70'inden fazlasının şehirlerden kaynaklanması nedeniyle kritik öneme sahiptir. Bu bağlamda, karbon ayak izinin hesaplanması, izlenmesi ve yönetilmesi, sürdürülebilir kentsel planlama için temel bir adımdır. Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), bu süreçte kentlere metodolojik bir çerçeve sunan uluslararası bir standarttır. GPC'nin BASIC+ seviyesi, özellikle gelişmekte olan ülkelerdeki kentlerin kapasitelerini dikkate alarak tasarlanmış, dengeli bir raporlama ve yönetim modelidir.

GPC, Dünya Kaynakları Enstitüsü (WRI), C40 Kentleri İklim Liderlik Grubu ve ICLEI (Yerel Yönetimler için Sürdürülebilirlik) tarafından geliştirilen, kentsel ölçekli sera gazı emisyon envanterleri oluşturmak için kullanılan bir protokoldür. İlk versiyonu 2014'te yayınlanan GPC, şehirlerin emisyon kaynaklarını **standart bir metodolojiyle** sınıflandırmasına, veri toplamasına ve raporlamasına olanak tanır. Bu protokol, uluslararası karşılaştırılabilirlik, şeffaflık ve bilimsel tutarlılık sağlamayı amaçlar.

GPC'nin önemi, şu unsurlarla özetlenebilir:

- **Kapsamlı Sınıflandırma:** Emisyonlar, enerji, ulaşım, atık yönetimi gibi sektörlerde **Scope 1 (doğrudan), Scope 2 (dolaylı enerji kaynaklı) ve Scope 3 (diğer dolaylı)** emisyonlar olarak ayrıştırılır.
- **Politika Uyumu:** Paris Anlaşması ve UNFCC (Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi) hedefleriyle uyumlu raporlama.
- **Yerel Eylem Planları:** Azaltım stratejilerinin bilimsel verilerle desteklenmesi.

GPC Raporlama Seviyeleri: BASIC, BASIC+ ve Advanced

GPC, kentlerin kapasitelerine göre üç raporlama seviyesi tanımlar: BASIC, BASIC+ ve ADVANCED. Bu seviyeler, veri detayı, metodolojik karmaşıklık ve raporlama kapsamına göre farklılaşır.

BASIC Seviyesi

- Temel Emisyon Kaynakları: Yalnızca Scope 1 ve Scope 2 emisyonlarını kapsar.
- Veri Kalitesi: Genel tahminler ve ulusal ortalamalara dayalı aktivite verileri kullanılır.
- Sektörel Kapsam: Ana sektörlerde (enerji, ulaşım, atık) sınırlı alt kategoriler.
- Amaç: Hızlı ve düşük maliyetli bir başlangıç sağlamak.

ADVANCED Seviyesi

- Kapsam: Tüm Scope 1, 2 ve 3 emisyonları dahil.
- Veri Detayı: Yüksek çözünürlüklü veriler, tesis bazlı ölçümler.
- Metodoloji: IPCC (Hükümetlerarası İklim Değişikliği Paneli) kılavuzlarıyla tam uyum.
- Doğrulama: Üçüncü taraf denetimi zorunluluğu.

BASIC+ Seviyesi

BASIC+ seviyesi, BASIC ile ADVANCED arasında bir köprü görevi görür. Temel özellikleri şunlardır:

Kapsam Genişliği:

o Scope 1 ve 2 emisyonlarının tüm alt kategorileri zorunludur.

o Scope 3 emisyonları için isteğe bağlı raporlama (örneğin, kent dışındaki çöp sahalarından kaynaklanan metan).

o Sektörel Detay: Enerji tüketiminde konut, ticari binalar ve sanayi ayrımı; ulaşımda karayolu, demiryolu ve hava yolu alt kategorileri.

Veri Toplama ve Hesaplama:

o Aktivite Verileri: Yerel ölçekte toplanan veriler (örn., belediye elektrik tüketim verileri).

o Emisyon Faktörleri: Ülke veya bölgeye özgü faktörlerin kullanımı (Türkiye için TEİAŞ veya TÜİK verileri).

o Hesaplama Araçları: GPC'nin önerdiği çevrimiçi araçlar (ICLEI ClearPath) veya IPCC katsayıları.

2. Raporlama ve Şeffaflık:

o CRF (Common Reporting Format): UNFCC ile uyumlu tablolar.

o Belirsizlik Analizi: Veri eksikliklerinin etkisinin açıklanması.

o Dış Paydaş Katılımı: Sivil toplum ve özel sektörle veri paylaşımı.

3. Avantajları:

o Maliyet Etkinliği: ADVANCED'e göre daha az kaynak gerektirir.

o Politika Geliştirme: Temiz ulaşım veya enerji verimliliği projeleri için somut veri sağlar.

- Uluslararası Fonlara Erişim: Dünya Bankası veya Avrupa İmar ve Kalkınma Bankası (EBRD) projelerinde ön koşul olarak kabul görür.

BASIC+'ın Zorlukları ve Fırsatları

Zorluklar:

- Veri Eksikliği: Özellikle ulaşım ve atık sektörlerinde yerel ölçekli veri toplama kapasitesinin sınırlı olması.
- Kurumsal Koordinasyon: Enerji dağıtım şirketleri veya sanayi tesisleriyle veri paylaşımındaki bürokratik engeller.
- Teknik Kapasite: Yerel yönetimlerde GHG protokollerine hâkim personel sayısının azlığı.

Fırsatlar:

- Kapasite Geliştirme: Belediye çalışanları için GPC eğitim programları (örneğin, UNDP destekli projeler).
- Akıllı Şehir Uygulamaları: IoT tabanlı enerji izleme sistemleriyle veri kalitesinin artırılması.
- Sürdürülebilir Finansman: Yeşil tahvil çıkarma veya karbon kredisi pazarlarına erişim.

Malatya Büyükşehir Belediyesi Örneği ve BASIC+ Uyumluluğu

Malatya'nın GPC BASIC+ seviyesine geçiş sürecinde dikkat çeken adımlar şunlardır:

- Enerji Sektörü: Kentteki kamu binalarının enerji tüketim verilerinin dijitalleştirilmesi ve güneş enerjisi yatırımlarının izlenmesi.
- Ulaşım: Toplu taşımada elektrikli araç kullanımı artışı ve yolcu sayımlarına dayalı emisyon modellemesi.
- Atık Yönetimi: Katı atık döküm sahalarından metan geri kazanım projelerinin raporlanması.

Ancak, Malatya'nın karşılaştığı temel zorluklar arasında sanayi tesislerinden emisyon verisi toplama ve kırsal alanlardaki tarımsal emisyonların hesaplanması yer almaktadır. BASIC+'ın gerektirdiği detaylı raporlama için belediye, üniversiteler ve STK'larla iş birliği mekanizmaları geliştirmiştir.

Şekil 1. Malatya'da Endüstriyel Simbiyoz ve Çevreci Üretimin Yenilenebilir Enerji Entegrasyonu ile Modellemesi Projesi

2020 yılında Malatya Büyükşehir Belediyesi, kentin çevresel sürdürülebilirliğini artırmak ve enerji üretiminde dışa bağımlılığı azaltmak amacıyla stratejik bir adım atarak "Endüstriyel Simbiyoz ve Temiz Üretimin Yenilenebilir Enerji ile Modellenmesi" başlıklı projeyi hayata geçirmiştir. Bu proje, atık yönetimi ile enerji üretimini entegre eden ve döngüsel ekonomi ilkelerini benimseyen kapsamlı bir model geliştirmeyi amaçlamaktadır. Projede, atık su arıtma tesislerinden elde edilen çamurlar ile organize sanayi bölgesi atıklarının değerlendirilmesine odaklanılmış; hazırlanan fizibilite raporu, projenin çevresel ve ekonomik katkılarını ortaya koyarak yerel kalkınmaya yönelik yeni bir perspektif sunmuştur.

Proje, üç ana uygulama senaryosu çerçevesinde yapılandırılmıştır:

- **Atık Çamurun Enerjiye Dönüşümü:** MASKİ Genel Müdürlüğü'ne ait atık su arıtma tesislerinde biriken çamurlar, kurutma ve yakma işlemleriyle değerlendirilecektir. Bu süreçte ortaya çıkan termal enerji, elektrik üretiminde kullanılarak belediyenin enerji maliyetlerine katkı sağlarken, çevreye zararlı etkilerin azaltılmasına ve karbon ayak izinin düşürülmesine olanak tanımaktadır.
- **Atıl Isıların Verimli Kullanımı:** Katı Atık Entegre Çevre Yönetim Tesisi'nde ortaya çıkan atıl ısı enerjisi, çamur kurutma sürecinde değerlendirilmek üzere entegre edilecektir. Üretilen elektrik fazlasının şebekeye satılması veya çamurun ekonomik değerinin değerlendirilmesi, projenin finansal sürdürülebilirliğine katkıda bulunacaktır.
- **Endüstriyel İş Birliği ile Kaynak Verimliliği:** Yeni kurulması planlanan enerji üretim tesisi, organize sanayi bölgesi ile sinerji sağlayarak sanayi tesislerinden çıkan atık ısı ve organik atıkların enerji üretim sürecine dahil edilmesini öngörmektedir. Bu yaklaşım, endüstriyel simbiyozun yerel ölçekte uygulanabilirliğini kanıtlamayı hedeflemektedir.

UYGULAMA SÜRECİ VE DENEYİMLER

Proje kapsamında gerçekleştirilen uygulamalar, atıkların bertarafı ve enerji üretimi süreçlerinin dijitalleşme, akıllı sistemler ve veri analitiği gibi teknolojik altyapılarla desteklenmesiyle daha verimli hale getirilmektedir. Bu bağlamda, ileri kurutma teknolojileri, kojenerasyon sistemleri ve sensör tabanlı izleme mekanizmaları hem enerji verimliliğini artırmakta hem de çevresel etkilerin minimize edilmesine katkı sağlamaktadır. Projenin çevresel katkıları arasında kirlilik kontrolü, metan gazı salınımının engellenmesi ve hava kalitesinin iyileştirilmesi yer almaktadır. Ekonomik açıdan ise, üretilen elektrik ve çamur satışından elde edilecek gelirler belediyenin diğer çevre projelerine finansal kaynak yaratırken, proje aynı zamanda yeni istihdam olanaklarının ortaya çıkmasına da vesile olmaktadır. Malatya'nın bu projesi, Birleşmiş Milletler'in Sürdürülebilir Kalkınma Amaçları kapsamında SKH 7 (Temiz Enerji), SKH 9 (Sanayi, Yenilikçilik ve Altyapı), SKH 11 (Sürdürülebilir Şehirler) ve SKH 12 (Sorumlu Üretim ve Tüketim) hedefleriyle uyumlu bir yapıyı ortaya koymaktadır. Ayrıca, projenin başarılı uygulanması, yerel yönetimlerin benzer döngüsel ekonomi modellerini geliştirmeleri için önemli bir örnek teşkil etmektedir. Nitekim Malatya Büyükşehir Belediyesi'nin bu projesi projesi, çevresel ve ekonomik sürdürülebilirlik açısından kapsamlı bir çözüm sunmakta; atık yönetimi, enerji verimliliği ve endüstriyel simbiyoz alanlarında elde edilen kazanımlarla yerel kalkınmaya önemli katkılar sağlamaktadır.

Malatya Büyükşehir Belediyesi'nin GPC protokolünü ilk kez uygulamaya koyması, deneyimsel süreçte önemli yapısal ve operasyonel zorlukları da beraberinde getirmiştir. İlk uygulama sürecinde, belediyenin geleneksel veri toplama yöntemleriyle elde ettiği veriler arasında dağınıklık gözlemlenmiş; bu durum, özellikle endüstriyel süreçlere ilişkin (örneğin, IPPU – Endüstriyel Proseslerden Salınan Sera Gazları) veri eksikliği şeklinde kendini göstermiştir. Bu eksiklikler, GPC'nin sağladığı standardizasyon prensipleriyle uyumlu raporlama yapabilmek için kritik bir engel teşkil etmiştir. Kurum içi farkındalık düzeyinin yetersiz olması, uygulama sürecinin en önemli zorluklarından biri olarak ortaya çıkmıştır. GPC uygulamasının kapsam ve gerekliliklerine dair bilgi eksikliği hem yöneticiler hem de uygulama ekibi arasında koordinasyon sorunlarına yol açmış; bu

durum, sürecin planlama ve uygulama aşamalarında aksamalara neden olmuştur (URL-1, 2025). Süreç içinde düzenlenen kurum içi koordinasyon toplantıları, farkındalık düzeyini artırma ve bilgi paylaşımını sistematik hale getirme açısından önemli rol oynamıştır. Bu toplantılar sayesinde, paydaşlar arasında iletişim ve veri akışı sağlanarak, veri toplama sistematiği oluşturulmuş ve eksiklikler giderilmeye çalışılmıştır. Ayrıca, teknik kapasitenin artırılması için alınan danışmanlık desteği, uygulama sürecinin kritik bir parçası olmuştur. Dış kaynaklardan sağlanan uzman danışmanlık, belediyenin GPC'ye uyum sağlama aşamasında ortaya çıkan teknik ve metodolojik sorunların çözülmesine önemli katkılar sağlamıştır. Bu deneyim, belediyenin gelecekteki uygulamalarda, her yıl güncelleme yapılabilmesi için sürdürülebilir bir sistem kurmasının ve veri sahiplerinin (örneğin, MASKİ ve EPDK) aktif sürece katılımının şart olduğunu göstermiştir. Nitekim Malatya Büyükşehir Belediyesi'nin ilk GPC uygulama deneyimi, yerel yönetimlerin karbon yönetimi süreçlerinde karşılaşabileceği zorlukları ve bunların üstesinden gelmek için geliştirilen stratejik iyileştirme adımlarını ortaya koymuştur. Uygulama sürecinde edinilen bu deneyimler, benzer uygulamaların yürütüleceği diğer belediyeler için de yol gösterici niteliktedir (Talu, 2019).

GÖZLEMLER VE TARTIŞMA

Öncelikle, emisyonların büyük bir kısmının sabit enerji ve ulaşım kaynaklı olduğu gözlemlenmektedir. Bu durum, enerji üretimi ve tüketiminin yanı sıra ulaşım faaliyetlerinin kent ölçeğinde salım envanterlerinde belirleyici bir paya sahip olduğunu göstermektedir (IPCC, 2006; Çevre, Şehircilik ve İklim Değişikliği Bakanlığı, 2022). Ayrıca, yapılan çıkarımlarda kapsam 1 emisyonlarının öne çıktığı saptanmıştır. Kapsam 1 emisyonları; doğrudan yakıt tüketimi, ısıtma sistemleri ve sanayi süreçlerinden kaynaklanan salımları ifade etmekte olup, bu emisyonların şehirler düzeyinde belirgin bir oranı temsil ettiği anlaşılmaktadır. Böylece, doğrudan kontrol altında bulunan faaliyetlerden kaynaklanan emisyonların, yerel karbon yönetimi stratejilerinde öncelikli hedef alınması gerektiği vurgulanmaktadır.

Bunun yanında, kişi başına düşen karbon ayak izinin Türkiye genel ortalamasının altında seyretmesi, Malatya'nın nüfus yapısı ve ekonomik faaliyetlerinin, diğer büyük metropollerle kıyaslandığında daha düşük emisyon profiline sahip olduğunu göstermektedir. Bu durum, yerel dinamiklerin ve kentsel yapının, karbon ayak izi hesaplamalarında önemli rol oynadığını ortaya koymaktadır. Son olarak, Malatya örneği, orta büyüklükteki bir şehirde dahi GPC Basic+ uygulamasının başarıyla hayata geçirilebileceğini göstermektedir. Bu başarı, yerel yönetimlerin karbon yönetimi altyapılarını güçlendirerek, ulusal ve uluslararası iklim hedeflerine ulaşma çabalarına önemli katkılar sağlayabileceğini göstermektedir (Örneğin, Malatya Büyükşehir Belediyesi'nin uygulamaları). Bu çıkarımlar, yerel iklim eylem planlarının oluşturulması ve uygulanması süreçlerinde, veriye dayalı ayrıntılı analizlerin yanı sıra, uygulamaya özgü yerel dinamiklerin ve yapısal özelliklerin de dikkate alınmasının önemini vurgulamaktadır.

SONUÇ VE ÖNERİLER

Bu çalışmanın sonuçları, GPC uygulamasının (Greenhouse Protocol for Cities) sadece bir emisyon hesaplama aracı olmanın ötesinde, yerel yönetimlerin stratejik karar destek sistemlerinin geliştirilmesinde kritik bir rol oynadığını göstermektedir. GPC'nin kapsamlı metodolojisi, belediyelerin çevresel performanslarını izleyip değerlendirmelerine olanak tanırken, aynı zamanda politika yapıcılar için veri odaklı ve bilimsel temelli kararlar almalarını desteklemektedir. Bu yaklaşım, çevre dostu stratejilerin ve sürdürülebilir kalkınma politikalarının oluşturulmasında yol gösterici niteliktedir. Malatya örneği, kapasite geliştirme, veri yönetimi ve kurumsal koordinasyon açısından önemli dersler sunmaktadır. Malatya Büyükşehir Belediyesi'nin GPC BASIC+ uygulaması, orta büyüklükte bir şehirde bile etkili bir sera gazı envanteri oluşturulabileceğini ve bu sayede yerel düzeyde iklim stratejilerinin belirlenmesinde model teşkil edebileceğini ortaya koymaktadır. Bu durum, diğer büyükşehir belediyelerinin de benzer yapısal dönüşümlere gitmesinde ilham verici bir

örnek olarak değerlendirilebilir. Öte yandan, Türkiye genelinde sürdürülebilir çevre yönetimi ve iklim politikalarının güçlendirilmesi amacıyla, tüm büyükşehirlerde zorunlu hale getirilecek Sera Gazı Envanteri (SGE) uygulamasının yaygınlaştırılması önerilmektedir.

Böyle bir uygulama, belediyelerin emisyon kaynaklarını sistematik bir şekilde izleyip yönetmesine olanak tanırken, ulusal ve uluslararası raporlama standartlarına uyum sağlamada da önemli bir adım olacaktır. Son olarak, yerel yönetimlerin kapasitesini artırmak ve sürdürülebilir çevre politikalarını etkin bir biçimde uygulayabilmeleri için merkezi destek mekanizmalarının kurulması gerekmektedir. Bu destek mekanizmaları, teknik danışmanlık, finansal kaynaklara erişim, veri yönetimi sistemlerinin entegrasyonu ve kurumsal koordinasyonun güçlendirilmesi gibi alanlarda yerel yönetimlere yardımcı olacak yapısal reformların uygulanmasına zemin hazırlayacaktır. Bu politik sonuçlar, GPC uygulamasının yerel düzeyde çevresel sürdürülebilirliği destekleyen entegre bir karar destek sistemi olarak benimsenmesinin, diğer belediyelere çıkarılabilecek önemli dersler içerdiğini göstermektedir. Böylece, veri temelli stratejik planlamalar, yerel kapasitenin güçlendirilmesi ve merkezi destek mekanizmalarının oluşturulması, ülkemizde sürdürülebilir kentsel gelişim ve iklim değişikliğiyle mücadelede belirleyici rol oynayacaktır.

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THERMODYNAMIC PROPERTIES FOR LiNaS COMPOUND

LiNaS BİLEŞİĞİNİN TERMODİNAMİK ÖZELLİKLERİ

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ÖZET

Half-Heusler (HH) bileşikleri, termoelektrik, optoelektronik, spintronik, süperiletkenlik ve mekanik sistemler gibi çok çeşitli uygulama alanlarına sahiptir. Özellikle enerji dönüşümü, elektronik aygıtlar ve manyetik malzemeler gibi teknolojik alanlarda önemli bir potansiyel sergilerler. Half-Heusler bileşikleri, genellikle XYZ formülüne uyan ve yarı iletken ya da metalik özellik gösterebilen intermetalik malzemelerdir. Bu bileşiklerin termodinamik özellikleri, elementel bileşimlerine ve kristal yapılarına bağlı olarak değişiklik göstermektedir. Half-Heusler bileşiklerinin negatif oluşum entalpisi, genellikle yüksek termodinamik kararlılığına işaret eder. Malzemelerin elektronik ve termodinamik özelliklerini değerlendirmek için kuantum mekaniğine dayalı Yoğunluk Fonksiyonel Teorisi (DFT) hesaplamaları yaygın olarak kullanılmaktadır. Gibbs programı, sıcaklık ve basınca bağlı termodinamik özellikleri öngörerek serbest enerji hesaplamaları yapmaktadır. Heusler tipi malzemelerin aygıt üretiminde yaygın olarak kullanılmaları nedeniyle, bu malzemelerin farklı termodinamik koşullardaki davranışlarının anlaşılması büyük önem taşımaktadır. Bu nedenle, Debye modeli kullanılarak LiNaS bileşiğine ait hacim, izotermal kütle modülü, sabit hacimde ısı kapasitesi, Grüneisen parametresi, Debye sıcaklığı ve termal genleşme katsayısı gibi termodinamik parametrelerin sıcaklık ve basınca bağlı değişimleri analiz edilmiştir. Yarı-harmonik Debye modeli ile, LiNaS bileşiğinin yüksek sıcaklık ve yüksek basınç koşullarında termodinamik özelliklerindeki değişim incelenmiştir. Bu çalışmada, incelenen malzemenin termodinamik parametrelerini belirlemek amacıyla gerekli hesaplamalar yapılmış ve 0-1000K sıcaklık aralığında incelenmiştir.

Keywords: Half Heusler, LiNaS, Thermodynamik özellikler, DFT

ABSTRACT

Half-Heusler (HH) compounds have a wide range of applications in thermoelectric, optoelectronic, spintronic, superconducting, and mechanical systems. They exhibit significant potential, particularly in technological fields such as energy conversion, electronic devices, and magnetic materials. Half-Heusler compounds are intermetallic materials that generally follow the XYZ formula and can exhibit either semiconducting or metallic properties. Their thermodynamic properties vary depending on their elemental composition and crystal structure. The negative formation enthalpy of Half-Heusler compounds typically indicates high thermodynamic stability. Based on quantum mechanics, density Functional Theory (DFT) calculations are commonly used to evaluate materials' electronic and thermodynamic properties. The Gibbs program calculates free energy by predicting temperature- and pressure-dependent thermodynamic properties. Since Heusler materials are widely recognized for their applications in device fabrication, understanding their behavior under various thermodynamic conditions is crucial. Therefore, using the Debye model, variations in thermodynamic parameters

such as volume, bulk modulus, heat capacity at constant volume, Grüneisen parameter, Debye temperature, and thermal expansion coefficient of LiNaS were analyzed as a function of temperature and pressure. The quasi-harmonic Debye model was employed to investigate how the thermodynamic properties of LiNaS change under high-temperature and high-pressure conditions. In this study, the necessary calculations were performed to determine the thermodynamic parameters of the examined material, and the results were obtained within the temperature range of 0 to 1000K.

Keywords: Half Heusler, LiNaS, Thermodynamic" properties, DFT

GİRİŞ

Heusler alaşımları, 1903 yılında Alman mühendis Friedrich Heusler tarafından keşfedilmelerinden bu yana bilim dünyasında büyük ilgi görmektedir [1]. Bu keşif, ferromanyetik elementler içermemesine rağmen Cu_2MnAl bileşiğinin ferromanyetik özellik göstermesiyle dikkat çekmiştir. Bu olağanüstü durum, Heusler alaşımlarının fiziksel özelliklerine olan ilgiyi artırmıştır. Özellikle, yarı-Heusler alaşımları (Half-Heusler), genel formülü XYZ olan ve X ile Y yerlerine geçiş metalleri, Z yerine ise genellikle III-V grubu elementlerin yerleştiği bileşiklerdir. Bu yapılar, bileşenlerin konumlarına göre büyük çeşitlilik göstererek çok sayıda teknolojik açıdan önemli fiziksel özelliğe sahip olabilirler. Yarı-Heusler bileşikleri; süperiletkenlik [2], piezoelektriklik [3], spintronik uygulamalar [4], manyetizma [5] gibi birçok farklı alanda fonksiyonel malzemeler olarak öne çıkmaktadır. Ayrıca, çevre dostu ve düşük maliyetli termoelektrik uygulamalar için umut verici adaylar olarak değerlendirilmektedirler [6]. Bu çok yönlü özellikler, kristal yapıdaki X, Y ve Z konumlarına farklı elementlerin yerleşimiyle mümkün hale gelmektedir.

Günümüzde, üçlü yarı-Heusler alaşımları üzerine yapılan çalışmalar genellikle elektronik ve manyetik özellikler üzerine yoğunlaşmış olsa da, bu bileşiklerin **termodinamik ve termoelektrik özellikleri** üzerine yapılan araştırmalar sınırlı kalmıştır. Bu çalışmada ele alınan alaşım seçimi, birim hücre başına 18 valans elektronuna sahip yarı-Heusler bileşiklerinin 0–1.1 eV arasında bir bant aralığına sahip olmalarının, orta sıcaklık aralığında çalışan termoelektrik cihazlar için uygun olduklarını gösteren teorik hesaplamalara dayanmaktadır [7–9]. Deneysel ve teorik verilerin kısıtlı olduğu bu bağlamda, söz konusu yarı-Heusler alaşımının **yapısal, elektronik, termodinamik ve termoelektrik özelliklerine** yönelik kestirici bir çalışma yapılması, bu malzemenin genel davranışını anlamak adına büyük fayda sağlayacaktır.

LiNaS bileşiğinin farklı sıcaklık ve basınç koşulları altındaki davranışını anlamak amacıyla, Gibbs programı [10] içerisinde Debye yarı-harmonik modeli kullanılarak normalize hacim (V/V_0), izotermal kütle modülü (B), Debye sıcaklığı (Θ_D) ve sabit hacimde ısı kapasitesi (C_V) gibi termodinamik özellikler hesaplanmıştır. Bu sonuçlar, enerji-hacim korelasyonları temel alınarak elde edilmiştir. İncelenen bileşiklerin termal özellikleri, 0 ile 500 K arasındaki sıcaklık aralığında hesaplanmıştır. Basınç etkilerini incelemek amacıyla ise 0–5 GPa aralığında yarı-harmonik model kullanılmıştır. Gibbs programı, yarı-Heusler (Half-Heusler) bileşiklerin **termodinamik özelliklerini** belirlemek için oldukça etkili bir araçtır. Bu program, **Debye yarı-harmonik modeli** kullanarak sıcaklık ve basınç etkilerini göz önünde bulundurur ve çeşitli termodinamik parametrelerin teorik hesaplamalarını yapar.

METOT

Bu çalışmada, ilk- ilkeler (first-principles) hesaplamaları, pseudopotansiyel düzlem dalga yöntemi kullanılarak gerçekleştirilmiş ve Vienna Ab Initio Simulation Package (VASP) kodu [11] ile uygulanmıştır. Düzlem dalga tabanlı bu hesaplamalarda, kinetik enerji kesme değeri 700 eV olarak belirlenmiştir. Elektron değişim-korelasyon etkilerini tanımlamak için, Genelleştirilmiş Gradyan Yaklaşımı (GGA) çerçevesinde Perdew–Burke–Ernzerhof (PBE) işlevseli kullanılmıştır [12, 13]. Atomik pozisyonların gevşemesi (relaksasyonu), sistemdeki Hellmann–Feynman kuvvetlerini

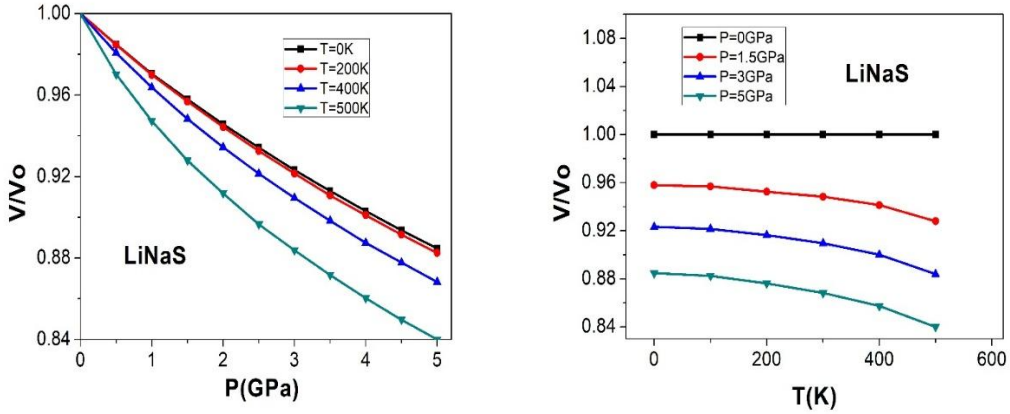
minimize etmek amacıyla gerçekleştirilmiş olup, enerji ve kuvvet toleransı sırasıyla 10^{-8} eV ve 0.00001 eV/Å olarak alınmıştır. Brillouin bölgesi entegrasyonu için 16×16×16 Monkhorst-Pack k-uzayı örgüsü kullanılmıştır. Termodinamik parametrelerin hesaplanmasında, Gibbs programı kullanılmıştır. Bu program, yarı-harmonik Debye modeline dayanmakta olup [10], termal denklem (EOS) ve ilgili standart termodinamik bağıntılar temelinde çalışmaktadır. Bu yöntem, farklı sıcaklık ve basınç koşulları altında hacim, ısıl genleşme, Debye sıcaklığı, özgül ısı ve grüneisen parametresi gibi çeşitli termodinamik büyüklüklerin hesaplanmasına olanak sağlar.

BULGULAR

Termodinamik; ısı, iş, sıcaklık ve enerji arasındaki ilişki ile ilgilenen bilim dalıdır. Basit bir ifadeyle termodinamik, enerjinin bir yerden başka bir yere ve bir biçimden başka bir biçime transferi ile ilgilenir. Bu süreçteki anahtar kavram; ısının, belirli bir mekanik işe denk gelen bir enerji biçimi olmasıdır. Debye modeli, özellikle düşük sıcaklıklarda katıların **ısıl kapasite, Debye sıcaklığı, özgül ısı, termal genleşme katsayısı** gibi termodinamik özelliklerini açıklamak için kullanılır. GIBBS, özellikle **basınç ve sıcaklık altında** malzemenin termodinamik özelliklerini hesaplamak için kullanılır. Girdi olarak genellikle **enerji-hacim (E-V)** eğrileri gerekir. Bunlar genellikle DFT (VASP,) ile hesaplanır.

Farklı sıcaklık ve basınç koşulları altındaki LiNaS davranışını anlamak için, termodinamik özellikler (normalleştirilmiş hacim V/V0, bulk modülü (B), Debye sıcaklığı (Θ_D) ve sabit hacimdeki ısı kapasitesi (Cv)) hesaplamak amacıyla Debye yarı-harmonik modelini [10] kullandık. Sonuçlar, enerji-hacim ilişkileri kullanılarak elde edilmiştir. İncelenen bileşiklerin termal özellikleri, 0 ile 500K arasındaki sıcaklık aralığı için hesaplanmıştır. Yarı-harmonik model, 0-5 GPa arası basınç aralığındaki etkileri incelemek için kullanılmıştır.

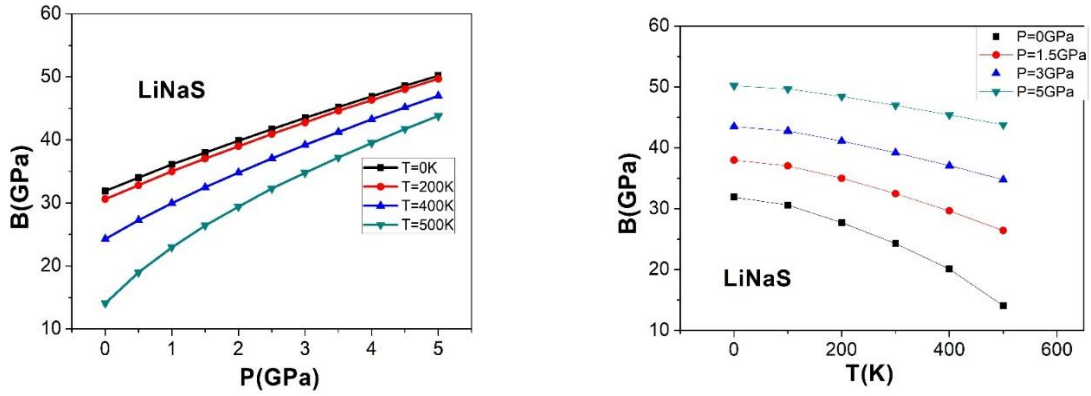
Şekil 1, normalleştirilmiş hacim V/V_0'yı gösterir. Bu, farklı basınçlar altındaki ilkel hücre hacminin (V) sıfır basınçtaki denge hacmine (V_0) oranını belirtir. Grafikler, $V/V_{0'}$ 'ın sıcaklıklar T = 0, 200, 400 ve 500 K'deki değişimle, 0-5 GPa arasındaki basınç aralığında nasıl değiştiğini gösterir. Veriler, incelenen tüm maddeler için basınç arttıkça V/V_0 oranının sürekli düştüğünü ortaya koymaktadır. Ayrıca, karşılaştırmalar, daha yüksek sıcaklıklarda V/V_0 oranının her zaman daha düşük olduğunu, ancak aynı basınç koşulları altında daha düşük sıcaklıklara kıyasla sabit kaldığını gösterir. Bu gözlem, basıncın, sıcaklıktan daha fazla bir şekilde görece hacmi etkilediğini vurgulamaktadır.



Şekil. 1 Normalize hacmin basınç ve sıcaklıkla değişimi

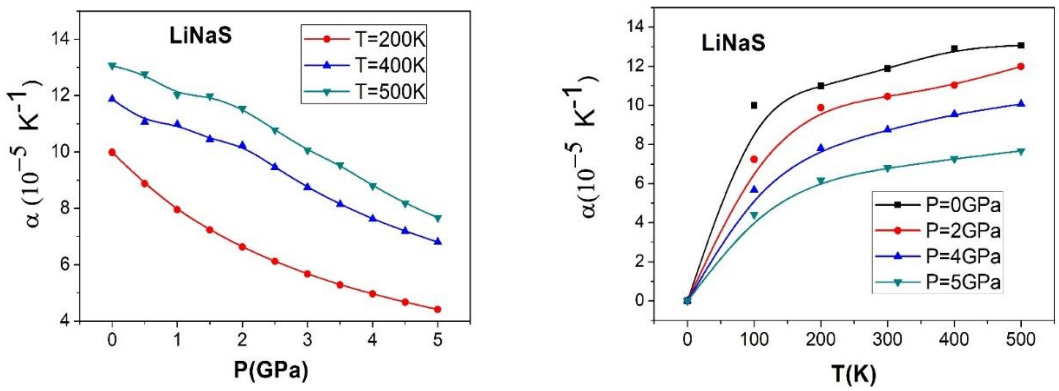
Şekil 2, LiNaS bileşiğinin izotermal bulk modülü ile basınç ve sıcaklık değişimleri arasındaki ilişkiyi göstermektedir. Belirli bir basınç altında sıcaklık arttıkça bulk modülü değerlerinde bir azalma gözlemlenmektedir. Öte yandan, sabit sıcaklık koşullarında basınç arttıkça bulk modülü değerlerinde artış meydana gelmektedir. Bulk modülündeki bu artış, bileşiğin sıkıştırılabilirliğini ifade etmektedir.

Hesaplamalar sonucunda, sıcaklık ve basıncın sıfır olduğu durumda bulk modülü değeri tam olarak 32.92 GPa olarak belirlenmiştir. Ayrıca, enerji-hacim (E-V) ilişkisi kullanılarak elde edilen 32.9 GPa'lık bulk modülü değeri, elastik özelliklerden hesaplanan 31.9 GPa'lık değerle oldukça uyumludur.



Şekil. 2 Bulk modülün basınçve sıcaklık ile değişimi

Termal genleşme katsayısı, bir malzemenin sıcaklık değişimi karşısında boyutlarında meydana gelen göreli değişimi ifade eder. Sıcaklık arttıkça atomlar daha fazla titreşir ve aralarındaki ortalama uzaklık artar ve yapı genleşir. Yüksek α değeri, malzemenin sıcaklığa karşı daha hassas olduğunu gösterir. Özellikle elektronik, uzay ve optik cihazlarda, düşük termal genleşme katsayısına sahip malzemeler tercih edilir. Termal genleşme, atomlar arasındaki bağların anharmonik doğası nedeniyle ortaya çıkar. Bu, atom titreşimlerinin simetrik olmaması anlamına gelir, sıcaklık arttıkça ortalama atomlar arası mesafe değişir ve genleşme ya da büzülme oluşur. Yarı-harmonik yaklaşım ile yapılan hesaplamalarda, frekansların sıcaklığa değil, hacme bağlı olduğu varsayılır. Bu yaklaşım altında termal genleşme katsayısı (α), sıcaklıkla birlikte hacimdeki değişimi yansıtır. Şekil 3 sabit sıcaklık altında termal genleşmenin basınçla ve sabit basınç altında termal genleşme katsayısının (α) sıcaklığa bağlı değişimi göstermektedir. 0 GPa ve 300K'de $\alpha = 9.9 \times 10^{-5}$ K^{-1}dir. Sabit sıcaklıkta basınçla birlikte azalmaktadır. Sıcaklık ile birlikte exponansiyel olarak artmakta ve 300K üzerinde artış azalmakta ve lineer olmaktadır. Sıcaklık ve basıncın α üzerindeki etkileri birbirine yakın derecede önemlidir

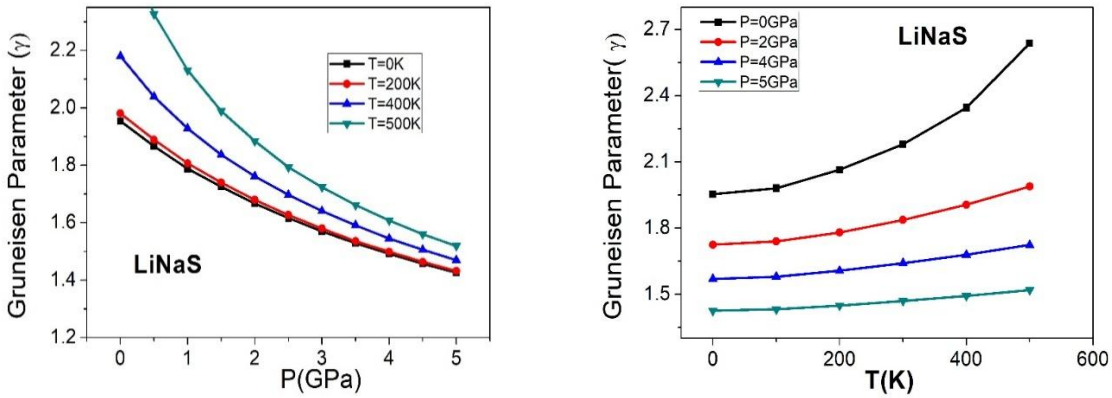


Şekil. 3 Termal genleşme katsayısının basınç ve sıcaklıkla değişimi

Grüneisen parametresi, malzemenin **anharmonik titreşimlerini** ve **termal genleşme davranışını** karakterize eden boyutsuz bir parametredir. Grüneisen parametresi, atomlar arasındaki bağların ne kadar "gevşek" veya "sert" olduğunu gösterir. Düşük γ (~1 civarı): Yapı daha kararlı, bağlar sert. Yüksek γ: anharmoniklik artmış , titreşimler çok daha düzensiz ve ısı iletimi düşebilir. γ,

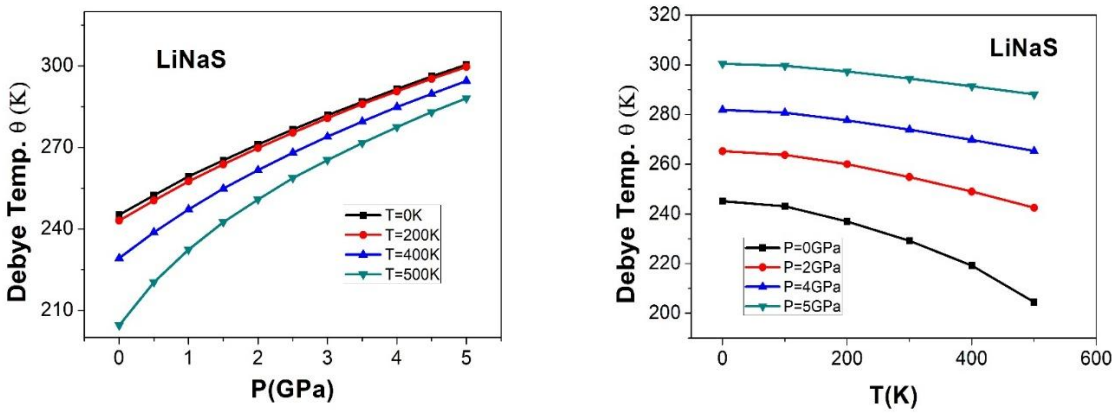
termoelektrik performans için kritik bir parametredir çünkü ısı iletkenliği ile doğrudan ilişkilidir. Genellikle yüksek γ değerleri, daha düşük kafes ısı iletkenliği anlamına gelir ve termoelektrik malzemeler için avantajlıdır. Grüneisen parametresi (γ), kristal yapıların fonon modlarının hacimle olan duyarlılığını tanımlayan önemli bir termodinamik parametredir. Bu parametre, özellikle kristallerin termomekanik özellikleri, termal iletkenlik ve termal genleşme gibi fiziksel davranışlarının anlaşılmasında kritik rol oynar. Fonon modlarının sertleşmesi veya yumuşaması, Grüneisen parametresinin basınca ve sıcaklığa olan bağımlılığı üzerinden değerlendirilebilir.

Şekil 4'de, LiNaS bileşiği için farklı basınç koşullarında sıcaklıkla değişen Grüneisen parametresi değerleri verilmiştir. Elde edilen sonuçlara göre, sabit basınç altında sıcaklık arttıkça Grüneisen parametresi monoton olarak azalmaktadır. Ancak bu azalma oldukça sınırlı olup, sıcaklığın γ üzerindeki etkisi görece zayıftır. Öte yandan, basınç artışı Grüneisen parametresi üzerinde çok daha belirgin bir etki göstermektedir. Bu durum, artan basıncın atomlar arası bağ kuvvetlerini güçlendirerek kafes titreşimlerini daha düzenli (daha harmonik) hale getirmesiyle açıklanabilir. Sayısal olarak değerlendirildiğinde, LiNaS bileşiği için sıfır sıcaklık ve sıfır basınçta elde edilen Grüneisen parametresi değeri γ = 1.954 olarak hesaplanmıştır. Basınç 5 GPa'ya yükseldiğinde, bu değer γ = 1.426 seviyesine düşmektedir. Bu düşüş, sistemin daha sıkı bağlara sahip olduğunu ve fonon modlarının hacim değişimlerine karşı daha az hassas hale geldiğini göstermektedir. Bu sonuçlar, Grüneisen parametresinin yalnızca sıcaklık değil, özellikle basınç karşısındaki duyarlılığını ortaya koymaktadır. Ayrıca, düşük γ değerleri genellikle daha düşük termal genleşme katsayısı ve daha yüksek ısıl iletkenlik ile ilişkilendirilmekte olup, bu da LiNaS'nin yüksek basınç uygulamaları altında yapısal kararlılığını ve termal performansını koruyabileceğini göstermektedir.



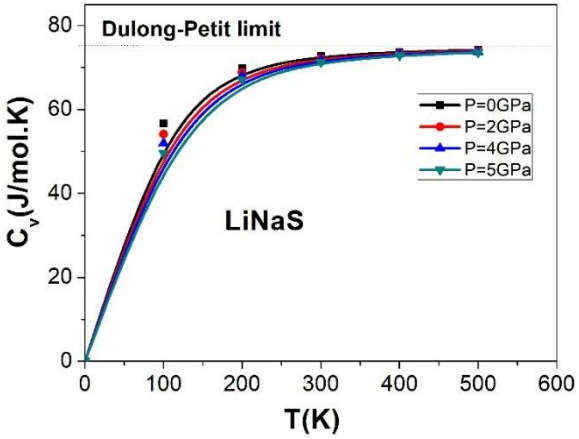
Şekil. 4 Grüneisen parametrseninin basınç ve sıcaklıkla değişimi

Debye sıcaklığı, bir kristal kafeste bulunan atomların maksimum titreşim frekansına (Debye frekansı) karşılık gelen sıcaklıktır. Malzemenin fonon (titreşim kuantumu) özelliklerini belirler. Özellikle **özısı, ısıl iletkenlik, ses hızı** gibi özelliklerle bağlantılıdır. Yarı-heusler bileşikler genellikle 300–600 K arasında olur, bu da onların yüksek sıcaklıklarda kararlı olmasına katkı sağlar. Düşük ısıl iletkenlik istenen termoelektrik malzemelerde Θ_D'nin bilinmesi, fonon yayılımının modellenmesi açısından kritiktir. Daha ağır atomlar daha düşük titreşim frekansı ve daha düşük Θ_D ye sebep olurlar. **Debye sıcaklığı (Θ_D)**, katıların çeşitli fiziksel özellikleri hakkında değerli bilgiler sunar; bunlar arasında **elastik sabitler, özgül ısı ve erime sıcaklığı** yer alır. Şekil 5(a) ve (b), Θ_D'nin basınç ve sıcaklığa bağlı olarak nasıl değiştiğini göstermektedir. **Sabit basınç altında sıcaklık arttıkça**, Θ_D neredeyse doğrusal bir şekilde **azalmaktadır.** Buna karşılık, **sabit sıcaklıkta basınç arttıkça**, Θ_D **artmaktadır**. Bu durum, basınç ve sıcaklığın Debye sıcaklığı üzerinde **zıt etkiler** oluşturduğunu göstermektedir. Özellikle, **basıncın**, LiNaS bileşiğindeki parçacıkların titreşim frekansı üzerinde sıcaklığa kıyasla **daha belirgin bir etkisi** vardır. 300 K sıcaklık ve 0 GPa basınç altında, LiNaS için hesaplanan Debye sıcaklığı **229.2 K** 'dir.



Şekil. 5 Debye sıcaklığının basınç ve sıcaklıkla değişimi

Isı kapasitesi, termodinamikte çok temel ve önemli bir kavramdır. **Isı kapasitesi (Cv)**, bir maddenin sıcaklığını belirli bir miktar artırmak için gerekli **ısı miktarını** ifade eder. Isı kapasitesi, bir maddenin ne kadar ısıyı depolayabileceğini belirler. Yüksek ısı kapasitesi ısıyı daha yavaş alır/verir ve böylece termal dengeyi sağlar. Bir malzemenin sıcaklık değişimlerine karşı **dayanıklılığı** hakkında bilgi verir. Yarı-Heusler bileşikler genellikle yüksek sıcaklıklarda çalışır (500–1000 K arası). Bu aralıkta ısı kapasitesi sabit hale gelir ve Dulong-Petit limitine ulaşır. Bu, tasarım ve mühendislik açısından güvenilir çalışma koşulları sağlar. **Bir malzemenin ısı kapasitesi (Cv)**, onun **titreşimsel özellikleri** hakkında önemli bilgiler sağlar ve bu özellikler birçok uygulama açısından kritiktir. **Şekil 6**, **Cv**'nin sıcaklıkla birlikte, **0 ila 5 GPa** basınç aralığında nasıl değiştiğini göstermektedir. Şekilden görüldüğü üzere, **düşük sıcaklıklarda Cv T^3 yasasına uymaktadır**, yani sıcaklığın küpüyle artar. **Sıcaklık yükseldikçe**, **anharmonik etkiler** belirgin hale gelir ve **Cv**, **Dulong-Petit limitine** yaklaşır. **300 K'nin üzerinde**, **Cv**'nin artış hızı yavaşlar ve **durağan hale gelerek bu sınıra ulaşır**; bu davranış, yüksek sıcaklıklarda çoğu katı madde için karakteristiktir. **300 K sıcaklık ve 0 GPa basınç** altında, **LiNaS** bileşiği için ısı kapasitesi **73.2 J/mol·K** olarak bulunmuştur.



Şekil 6. Isı kapasitesinin sabit basınç altında sıcaklıkla değişimi

SONUÇ

LiNaS bileşiği için Debye modeli üzerinden GIBBS programı yardımıyla elde edilecek termodinamik veriler, bileşiğin **kararlılığı, ısı tepkisi, iletim potansiyeli** gibi kritik mühendislik özelliklerini ortaya koyar. Bu çalışma kapsamında, LiNaS half-Heusler bileşiğinin sıcaklık ve basınca bağlı olarak

değişen termodinamik özellikleri yarı-harmonik Debye modeli kullanılarak detaylı bir şekilde analiz edilmiştir. Elde edilen veriler, bileşiğin yüksek sıcaklık ve yüksek basınç koşullarında termodinamik açıdan kararlı olduğunu ortaya koymaktadır. Özellikle negatif oluşum enerjisi, bu kararlılığın temel göstergelerinden biridir. Hesaplanan hacim, izotermal bulk modülü, sabit hacimde ısı kapasitesi (Cv), Grüneisen parametresi, Debye sıcaklığı ve termal genleşme katsayısı gibi parametreler, LiNaS bileşiğinin farklı çevresel koşullarda nasıl davranacağını öngörmek açısından kritik bilgiler sunmaktadır. Bu veriler, LiNaS'ın termoelektrik, elektronik ve spintronik uygulamalarda kullanılabilirliğine yönelik önemli bir temel sağlamaktadır. Sonuç olarak, bu çalışma LiNaS bileşiğinin yüksek sıcaklık ve basınç altında dahi yapısal ve termodinamik açıdan kararlı bir malzeme olduğunu göstermektedir. Elde edilen bulgular, LiNaS ve benzeri Half-Heusler bileşiklerin ileri teknolojili aygıtlarda kullanılma potansiyelini desteklemektedir.

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THE INVESTIGATION OF OPTOELECTRONIC PROPERTIES OF LiNaS SEMICONDUCTOR COMPOUND

LiNaS YARIİLETKEN BİLEŞİĞİNİN OPTOELEKTONİK ÖZELLİKLERİNİN İNCELENMESİ

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ÖZET

Half-Heusler (HH) bileşikleri, kübik yapılara sahip yarı iletkenlerdir ve genel kimyasal formülleri XYZ şeklindedir. Burada X ve Y, geçiş metalleri veya nadir toprak elementlerini; Z ise ana grup elementini temsil eder. HH bileşikleri, özellikle enerji üretimi ve dönüşümü gibi alanlarda sağladıkları önemli katkılardan dolayı bilim ve enerji alanlarında büyük öneme sahiptir. Bu malzemeler, bant aralığı ile temsil edilen elektronik özellikler ve malzemenin sertliğini belirleyen elastik parametrelerle ifade edilen yüksek mekanik dayanım gibi çeşitli ve etkili fiziksel özellikler sergiler. Ayrıca optik özellikleri sayesinde birçok uygulama için oldukça uygundurlar. Düşük üretim maliyetleri ve çevre dostu yapıları nedeniyle de pek çok alanda önem kazanmışlardır. Yapılan birçok çalışma, bu malzemelerin dikkat çekici özelliklerini vurgulamakta ve fotodedektörler ile güneş panelleri gibi uygulamalarda kullanılabilirliğini ön plana çıkarmaktadır. HH bileşiklerinin özellikleri halihazırda ideal ve kabul edilebilir düzeyde olsa da, araştırmacılar bu özellikleri daha da geliştirerek verimliliklerini artırmayı hedeflemektedir. Optoelektronik özellikler, bir malzemenin ışıkla olan etkileşimini ve buna bağlı olarak gösterdiği elektronik davranışı tanımlar. Half-Heusler bileşiklerinin optoelektronik özellikleri ve geniş uygulama alanları, onları yeni nesil teknolojiler için cazip malzemeler haline getirmektedir. İncelenen Half-Heusler LiNaS bileşiği, 2.94 eV bant aralığı ile yarı iletken özellikler göstermektedir. Bu çalışmada, LiNaS Half-Heusler bileşiğinin yapısal, elektronik ve optik özellikleri detaylı bir şekilde analiz edilecektir. Hesaplanan optik özellikler, LiNaS bileşiğinin optoelektronik cihazlarda kullanılabilirliğine işaret etmektedir.

ABSTRACT

Half-Heusler (HH) compounds are semiconductors with cubic structures and have a chemical formula of XYZ. X and Y represent transition or rare earth metals, while Z is a main group element. HH compounds are significant in science and energy fields, particularly due to their substantial contributions to power generation and conversion. These materials exhibit diverse and effective physical properties, including electronic properties represented by the band gap and high mechanical strength expressed through elastic parameters that determine the material’s rigidity. Their optical properties also make them highly suitable for various applications. Additionally, these materials have gained significant importance in numerous fields due to their low production cost and environmentally friendly nature. Several studies highlight the remarkable properties of these materials, emphasizing their suitability for photodetector and solar panel applications. While the properties of HH compounds are already at an ideal and acceptable level, researchers aim to enhance their characteristics further and improve their efficiency. Optoelectronic properties define a material's interaction with light and the resulting electronic behavior. The optoelectronic properties and wide range of applications of Half-Heusler compounds make them attractive materials for next-generation

technologies. The investigated Half-Heusler LiNaS compound exhibits semiconductor characteristics with a band gap of 2.94 eV. In this study, the structural, electronic, and optical properties of the LiNaS Half-Heusler compound will be analyzed in detail. The calculated optical properties of the LiNaS compound indicate its potential applicability in optoelectronic devices.

Keywords: Half Heusler, LiNaS, Optical properties, DFT

GİRİŞ

Half-Heusler bileşikleri, olağanüstü sıcaklık dayanımları, çeşitli bileşim imkânları ve ayarlanabilir bant aralıkları sayesinde optoelektronik, termoelektrik, fotovoltaik, spintronik ve topolojik yalıtkanlar gibi birçok alanda kullanılmaktadır [1-8]. Lityum bazlı Half-Heusler yarıiletkenleri arasında LiCaP, LiMgP ve LiZnP bileşikleri yer almaktadır [1-4]. Bu kristal bileşikler, lityumun (Li) kalsiyum (Ca), magnezyum (Mg) veya çinko (Zn) ile birlikte fosfor (P) elementiyle oluşturduğu yapılardır. LiCaP, LiMgP ve LiZnP malzemelerinin umut vadeden elektronik özellikleri, bu bileşiklere olan ilgiyi artırmaktadır. Bu bileşikler, özgün kristal yapıları ve yapısından gelen özellikleri sayesinde elektronik ve optoelektronik uygulamalar için cazip hale gelmektedir.

Half-Heusler yapısında, lityum (Li) atomları tetrahedral konumları işgal ederken, kalsiyum (Ca), magnezyum (Mg) veya çinko (Zn) atomları fosfor (P) ile birlikte oktahedral konumlarda yer alır. Bu özgün atomik dizilim, LiCaP, LiMgP ve LiZnP bileşiklerine kendine has özellikler kazandırmaktadır [5]. Bu bileşikler, yüksek taşıyıcı hareketliliği gibi üstün elektronik taşıma özellikleri sergileyerek [6], yüksek hızlı transistörler ve diğer elektronik aygıtlar için uygun adaylar haline gelmektedir.

Üçlü bileşikler arasında önemli bir alt grup da geçiş metali alaşımlarıdır (TMA). Bu alaşımlar, kararlı yapıları ve düzenli dizilimleriyle tanınır. TMA'lar genellikle MgAgAs tipi kübik kristal yapıya benzer bir yapı sergiler ve bu yapı 216 $F\bar{4}3m$ uzay grubuyla tanımlanır [7]. Yaygın olarak Heusler alaşımları olarak bilinen bu geçiş metali alaşımları, genellikle iki farklı formda bulunur: Tam Heusler alaşımları (A_2BC) ve Yarı- Heusler alaşımları (ABC) şeklindedir. Her iki türde de A ve B atomları genellikle geçiş metalleri olurken, C atomu genellikle sp grubu elementler veya yarıiletken atomlar olabilir. Heusler alaşımları; spintronik, süperiletkenlik, optoelektronik ve termoelektrik aygıtlar gibi birçok alanda geniş uygulama alanı bulmaktadır [8-12].

Literatür taramasından elde edilen bulgular**,** LiNaS bileşiğinin optik, titreşimsel ve termodinamik özelliklerinin yeterince araştırılmadığını ortaya koymaktadır. Bu çalışma ile, LiNaS yarı-Heusler bileşiğinin optoelektronik aygıtlar için uygun bir malzeme olup olmadığının ortaya konulması amaçlanmaktadır.

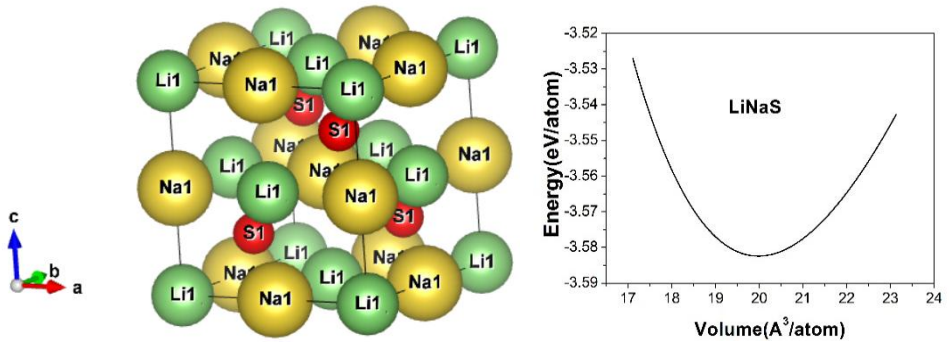
YÖNTEM

Tüm hesaplamalar, Yoğunluk Fonksiyonel Teorisi (DFT) yöntemi [13-15] kullanılarak, Vienna Ab initio Simulation Package (VASP) yazılımı [16-17] aracılığıyla gerçekleştirilmiştir. Değişim-korelasyon fonksiyonu, genelleştirilmiş gradyan yaklaşımı (GGA) çerçevesinde Perdew–Burke–Ernzerhof (PBE) parametrizasyonu ile ele alınmıştır [50]. Enerji yakınsama eşiği 10^{-8} eV/atom, düzlem dalga enerji kesim değeri ise 700 eV olarak belirlenmiştir. LiNaS yarı-Heusler bileşiği için Brillouin bölgesi, yüksek simetri yönlerinde 16 × 16 × 16 Monkhorst-Pack k-nokta ağı [18] ile örneklenmiştir.

BULGULAR

Yapısal ve Elektronik Özellikler

Yarı-Heusler kristal yapısının genellikle kübik ve merkez simetrisi olmayan bir yapı sergilediği, F4̄3m (No. 216) uzay grubunda kristallendiği kabul edilmektedir. LiNaS kristalinde, atomik konumlar şu şekildedir: Li atomu (0.00, 0.00, 0.00), Na atomu (0.50, 0.50, 0.50) ve S atomu (0.25, 0.25, 0.25) koordinatlarında yer almaktadır. Şekil 1'de gösterilen LiNaS bileşiğinin kristal yapısı, VESTA yazılımı kullanılarak görselleştirilmiştir [19]. Şekil 1b ise hücre hacmi ile enerji arasındaki ilişkiyi gösteren enerji-hacim eğrisini sunmaktadır. Bu ilişki, Murnaghan denklemi kullanılarak hesaplanmıştır [20].



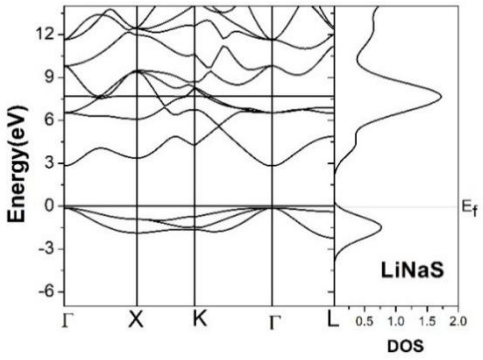
Şekil.1 (a) LiNaS için birim hücre b) Enerji –hacim grafiği

LiNaS bileşiğine ait örgü sabiti (a_0), bulk modülü (B), bulk modülünün birinci mertebeden basınç türevi (B′) ve hacim (V) gibi yapısal parametreler Tablo 1'de özetlenmiştir. Bu çalışmada GGA-PBE yöntemi ile hesaplanan örgü sabiti 6.207Å olarak bulunmuştur. Hesaplanan örgü sabiti, literatürdeki ve teorik verilerle büyük ölçüde uyum içerisindedir [21]. Ancak, GGA yöntemiyle elde edilen değer, 6.17 Å teorik değerden yaklaşık %0.5 daha yüksektir. Malzeme sertliğinin önemli bir göstergesi olan bulk modülü, bileşiğin sertliğinde meydana gelen değişimleri yansıtacak şekilde hafif bir azalma göstermektedir.

Tablo1. LiNaS bileşiği için yapısal parametreler

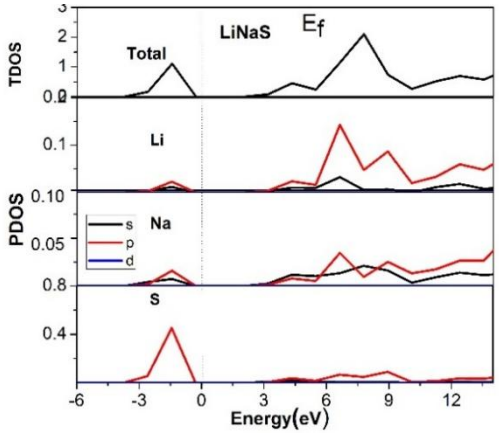
a(A)	B(GPa)	B’	V(A^3)	E_{tot} (eV)
6.207	32.96	4.14	59.95	-10.747
6.175 [21]				

Yoğunluk Fonksiyonel Teorisi (DFT), katı hal malzemelerdeki elektron davranışını anlamada kritik öneme sahip olan elektronik bant yapısı, yoğunluk durumu (DOS) ve yük yoğunluğu dağılımının analizine olanak tanır. Bu çalışmada, MgAgAs tipi yapı içerisinde LiNaS bileşiğinin elektronik özelliklerini incelemek amacıyla, denge örgü parametresinde Brillouin bölgesinin yüksek simetri doğrultularında bant yapısı hesaplamaları gerçekleştirilmiştir. 0 GPa basınç altında (GGA-PBE) etkisiyle elde edilen bant yapıları Şekil 2 de verilmiştir. Şekil 2 yüksek simetri yönleri boyunca (Γ–X–K-Γ–L) çizilmiş enerji bant yapısını ve toplam elektronik yoğunluk durumunu göstermekte olup, bileşiğin elektronik yapısının daha iyi anlaşılmasını sağlamaktadır. LiNaS bileşiği, yarıiletken özellik göstermekte olup, 0 GPa'da 2.94 eV, değerinde doğrudan bir bant aralığına sahiptir .



Şekil 2. LiNaS bileşiği için elektronik band yapısı

Ayrıca, Şekil 3 LiNaS bileşiğinin toplam ve kısmi yoğunluk durumu (PDOS) grafiğini göstermektedir. Bu grafik, valans bandı, Fermi seviyesi ve iletim bandının davranışlarını analiz etmemizi sağlamaktadır. Valans bandı bölgesinde, yaklaşık –1.5 eV civarında, yoğunluk büyük ölçüde S elementinin p-durumlarından kaynaklanmaktadır. Iletkenlik bandında, PDOS analizine göre, Li ve Na elementinin p-orbitallerinin katkısı fazladır. Bu durum, S-s orbitallerinin elektronik yapıya olan önemli katkısını ortaya koymaktadır.

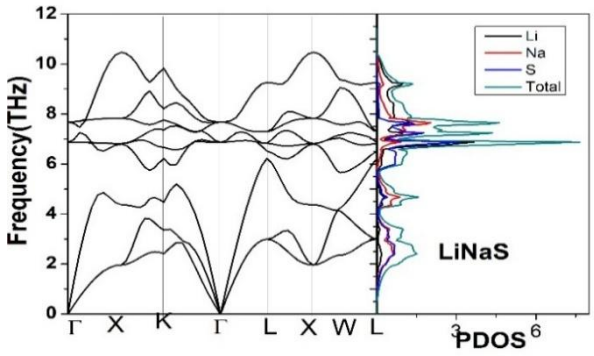


Şekil 3. LiNaS bileşiği için toplam ve kısmi durum yoğunluğu

Titreşimsel Özellikler

LiNaS alaşımının dinamik özelliklerini incelemek amacıyla, fonon dispersiyon eğrisi ve fonon yoğunluk durumu (PDOS) hesaplamaları gerçekleştirilmiştir . Bu fonon özelliklerini elde etmek için, 24 atom içeren 2 × 2 × 2 süperhücre yapısı kullanılarak Yoğunluk Fonksiyonel Pertürbasyon Teorisi (DFPT) yöntemi uygulanmış ve PHONOPY yazılım paketi ile hesaplamalar yapılmıştır [21]. LiNaS bileşiği, birim hücresinde üç atom bulundurduğundan, dokuz adet fonon moduna sahiptir: altı optik ve üç akustik mod. Fonon modları, kristallerdeki atomik titreşimleri temsil eder ve yapısal kararlılığın sağlanmasında temel rol oynar. Kristalin dinamik olarak kararlı olabilmesi için, her bir fonon moduna karşılık gelen frekansların pozitif olması gerekir; negatif değerler kararsızlığa işaret eder [22]. Bu bileşikte, iki boyuna (LO) ve dört enine (TO) optik moda, ayrıca bir boyuna (LA) ve iki enine (TA) akustik moda rastlanmaktadır. LiNaS bileşiğindeki atomların düşük kütleli olması, akustik modların frekanslarının optik modlara kıyasla daha düşük olmasına neden olurken, optik dallarda genlikler oldukça yüksektir. Hem optik hem akustik modlar için, boyuna modlar genellikle enine modlara göre daha yüksek frekanslara sahiptir. Harmonik yaklaşım çerçevesinde yapılan hesaplamalara göre, 0 GPa basınç altında LiNaS bileşiği tüm fonon modlarında pozitif frekanslar sergilemekte, bu da bileşiğin dinamik olarak kararlı olduğunu göstermektedir. Termal iletkenlik özelliklerinde, özellikle

enine akustik (TA) modlar, yüksek termal iletkenlikleri nedeniyle belirgin rol oynamaktadır. Şekil 4'ün sağ tarafında, frekanslara katkı sağlayan elementlerin kütlelerine göre dağılım gözlemlenmektedir. Hafif elementler yüksek frekanslı modlara, ağır elementler ise düşük frekanslı modlara katkı sağlamaktadır. LiNaS bileşiği için bu durum oldukça belirgindir: Ağır olan Na ve S atomu, 6 THz altındaki düşük frekans bölgesine hâkimdir. Daha hafif olan Li atomu ise, 6.0 THz üzerindeki yüksek frekans bölgesine baskın katkı sağlamaktadır.



Şekil 4. LiNaS bileşiği için fonon dağılım eğrisi

Optik Özellikler

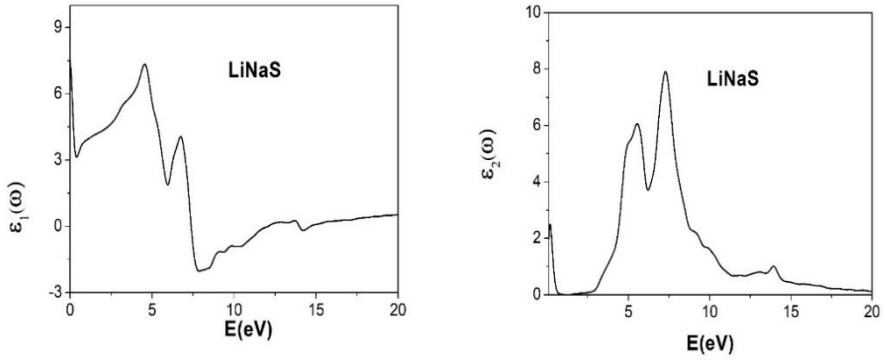
Yarı iletken malzemelerin optik özellikleri, elektronik bant yapısıyla optik davranış arasındaki ilişkiyi ortaya koymaları açısından son derece önemlidir. Belirtilen optik parametreler, malzemelerin elektromanyetik radyasyonla nasıl etkileşime girdiğini belirleyerek, optoelektronik uygulamalardaki uygunluklarını etkiler [91]. Bu çalışmada, dielektrik sabiti ε(ω), absorbsiyon katsayısı α(ω), optik iletkenlik σ(ω), sönüm katsayısı k(ω), kırılma indisi n(ω), yansıtma katsayısı R(ω) ve enerji kaybı fonksiyonu L(ω) gibi çeşitli optik özellikler incelenmiştir.

Dielektrik fonksiyonu, fotonlar ile elektronlar arasındaki etkileşimi açıklayarak bir malzemenin elektromanyetik dalgalara nasıl tepki verdiğini anlamamıza imkân tanır. Özellikle düşük dalga vektörlerinde bu etkileşim önemlidir. Dielektrik fonksiyon, kırılma indisi, sönüm katsayısı, yansıtma, iletkenlik ve absorbsiyon katsayısı gibi temel optik parametreleri belirleyen ana etkendir. Bu fonksiyon, gelen elektromanyetik radyasyona karşı sistemin doğrusal tepkisini temsil eder [23]. Kompleks dielektrik fonksiyonu, doğrultusunda şu şekilde tanımlanır:

$\varepsilon(\omega)=\varepsilon_1(\omega)+i\varepsilon_2(\omega)$

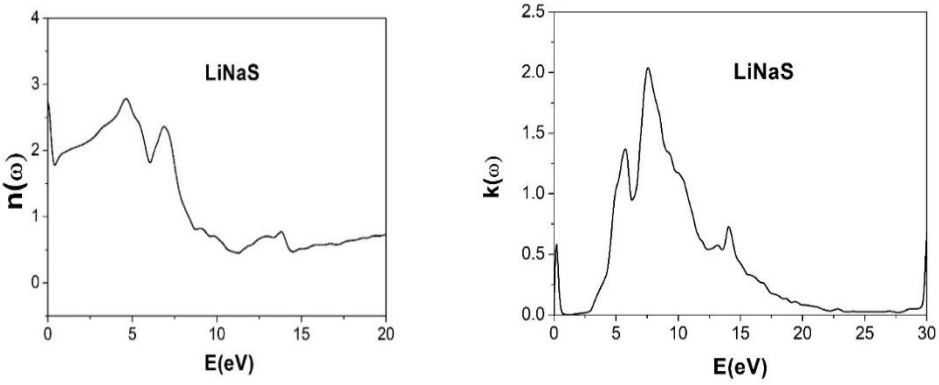
Burada, $\boldsymbol{\varepsilon_1(\omega)}$ reel kısmı temsil eder ve ışığın malzeme içindeki yayılma özelliklerini belirlerken, $\boldsymbol{i\varepsilon_2(\omega)}$ sanal kısmı gösterir ve ortamda optik absorbsiyondan sorumludur. Kramers-Kronig ilişkileri [24], $\varepsilon_1(\omega)$ ve $\varepsilon_2(\omega)$'nin frekansa bağlı bileşenlerini belirlemede kullanılır. Sıfır frekansta ($\omega = 0$ eV) elde edilen $\varepsilon_1(0)$ değeri, malzemenin gelen elektromanyetik dalgalara ne derece duyarlı olduğunu ifade eder. Şekil 5a, incelenen malzeme için $\varepsilon_1(\omega)$ değerlerinin foton enerjisine göre değişimini göstermektedir. Pozitif $\varepsilon_1(\omega)$ değerleri, optik fotonların malzemeden geçişine izin verildiğini, Negatif $\varepsilon_1(\omega)$ değerleri ise elektromanyetik dalgaların emildiğini gösterir. $\varepsilon_1(\omega)$'nin sıfır olduğu noktalarda ise boyuna polarize dalgaların yayılabildiği anlaşılır. Bu çalışmada LiNaS bileşiği için statik dielektrik sabiti $\varepsilon_1(0)$ değeri;0 GPa'da 7.1olarak bulunmuştur. $\varepsilon_1(\omega)$ fonksiyonunun negatif değerlere sahip olduğu bölgelerde, yerel yansıtıcılık maksimuma ulaşmakta ve bu durum bileşiğin metalik karakterini göstermektedir. Ayrıca, yüksek enerji aralığında (15 eV üzeri), $\varepsilon_1(\omega)$ spektrumu sıfıra yaklaşır. Görünür bölge 1.6 eV ile 3.1 eV arasında yer alırken, 0.8–1.6 eV aralığı yakın kızılötesi (NIR), 3.1–40 eV arası ise morötesi (UV) bölgeyi temsil etmektedir. LiNaS için $\varepsilon_1(\omega)$'nin ilk ve ikinci zirvesi genellikle kızılötesi bölgede, üçüncü zirvesi ise görünür bölgede yer almaktadır. Bu durum, malzemenin en yüksek optik tepkisini kızılötesi bölgede verdiğini göstermektedir. Öte yandan, $\varepsilon_1(\omega)$

negatif olduğunda, LiNaS bileşiklerinin yüzeyinde elektromanyetik radyasyon bastırılmakta ve UV bölgede metalik özellik daha baskın hale gelmektedir. Bu nedenle, LiNaS bileşiği; geniş frekans aralığında çalışan optik filtrelerde veya elektromanyetik kalkanlama uygulamalarında tercih edilmektedir.



Şekil 5. LiNaS için (a) Reel ve (b) Sanal dielektrik sabiti

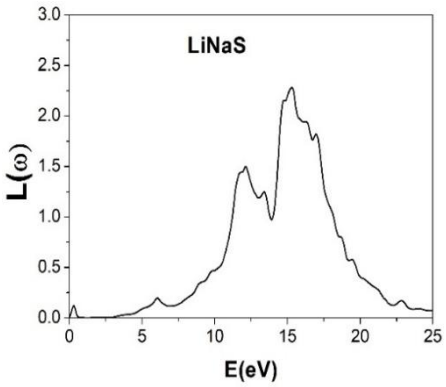
Şekil 5 (b), LiNaS bileşiğinin dielektrik fonksiyonunun imajiner (sanal) bileşeni ε₂(ω)'nin değişimini göstermektedir. Hesaplanan ε₂(ω) fonksiyonundaki en belirgin tepe noktalarının yaklaşık 7.5 eV civarında olduğu gözlemlenmiştir. ε₂(ω) fonksiyonundaki bu ilk tepe, valans bandının (VBM) en yüksek enerji seviyeleri ile iletkenlik bandının (CBM) en düşük enerji seviyeleri arasındaki elektron geçişlerine atfedilir. Bunun dışında görülen ek tepe noktaları ise, valans ve iletkenlik bandı içerisindeki farklı enerji seviyeleri arasındaki geçişlere dayanmaktadır. 2.5 eV'den sonra, ε₂(ω) bileşeni kademeli olarak azalarak 5 eV civarında küçük bir tepe yapar ve ardından 20.0 eV'ye kadar düşüşünü sürdürür.
Ayrıca, uygulanan basınçla birlikte ε₂(ω)'nin genliği artmakta ve daha yüksek enerji değerlerine doğru kaymaktadır. Bu bağlamda LiNaS bileşiğinin optik bant aralığı, 2.4eV olarak hesaplanmıştır.



Şekil 6. LiNaS için (a) kırılma indisil ve (b) sönüm katsayısı

Şekil 6(a) ve (b), LiNaS bileşiğinin kırılma indisi n(ω) ve sönüm katsayısı k(ω) fonksiyonlarını göstermektedir. Kırılma indisi (n(ω)), bir malzeme içerisinden geçen ışığın yayılma biçimini ve gelen radyasyonu ne ölçüde absorbe ettiğini karakterize eden optik bir özelliktir. Buna karşılık, sönüm katsayısı (k(ω)), malzeme tarafından soğurulan ışık enerjisi miktarını nicelendirir . LiNaS bileşiği için hesaplanan statik kırılma indisleri n(0) 2.7 olarak belirlenmiştir. Şekil 5(a) ve Şekil 6(a) birlikte incelendiğinde, n(ω) fonksiyonunun davranışının, ε₁(ω) fonksiyonu ile büyük ölçüde benzerlik gösterdiği görülmektedir. Ancak ε₁(ω)'nin aksine, n(ω) hiçbir zaman negatif değer almaz, bu da

malzemenin yüksek frekanslı fotonlara maruz kaldığında geçirgen olduğunu gösterir. Sönüm katsayısı k(ω), gelen elektromanyetik radyasyonun elektrik vektörünün salınım genliğindeki zayıflama ile ilgilidir. Şekil 6(b)'de, k(ω) fonksiyonunun tepe yaptığı enerji aralıklarının, genellikle $\varepsilon_1(\omega)$'nin minimuma ulaştığı veya sıfıra yaklaştığı bölgelerde yer aldığı gözlemlenmektedir. Maksimum değere ulaştıktan sonra, gelen radyasyonun enerjisi arttıkça k(ω) değeri düşüş göstermektedir. LiNaS bileşiği için k(ω) fonksiyonunun maksimum değeri 2.1 olarak elde edilmiştir. k(ω) ile enerji arasındaki ilişki, $\varepsilon_2(\omega)$ fonksiyonunun davranışıyla benzerlik göstermektedir çünkü her iki parametre de malzemenin elektromanyetik radyasyonu ne ölçüde absorbe ettiğini yansıtır.



Şekil 7 LiNaS için kayıp fonksiyonu

Enerji kaybı spektrumu L(ω), yüksek hızla hareket eden bir elektronun bir maddeyi geçerken harcadığı enerjiyi temsil eder. L(ω) spektrumundaki birincil tepe, plazma rezonansı ile ilişkilidir ve bu rezonansın gerçekleştiği frekans plazma frekansı ωp olarak bilinir. Bu olay, $\epsilon_2(\omega)$ değerinin birden büyük olduğu ve $\epsilon_1(\omega)$ değerinin sıfıra yaklaştığı durumda meydana gelir. Eğer gelen ışığın frekansı plazma frekansından daha yüksekse, madde şeffaf hale gelir ve bu durum plazma frekansında yansımanın büyük bir azalma göstermesine yol açar. Enerji kaybı spektrumu, 17 eV 'de belirgin plasmon enerji tepeleri göstermektedir. Bu da, plasmon enerjisidir. L(ω) değerleri, 0-7.5 eV ve 25-50 eV enerji aralıklarında minimum değerlere sahiptir, bu da bu özel bölgelerde düşük enerji kaybını gösterir.

SONUÇ

LiNaS yarı-Heusler yarıiletken bileşiği, Yoğunluk Fonksiyonel Teorisi (DFT) çerçevesinde düzlem dalga dalga potansiyel yaklaşımı kullanılarak teorik olarak incelenmiştir. Çalışmada GGA-PBE yaklaşımı kullanarak elde edilen hesaplanan örgü sabiti 6.17 Å dır. Elektronik bant yapısının incelenmesi, Γ simetri noktaları arasında yer alan ddoğrudan 2.94 eV bant aralıklarının varlığını ortaya koymuştur. Bu durum, LiNaS bileşiğinin yarıiletken doğasını desteklemektedir. Ayrıca, yapılan fonon frekansı analizleri, bileşiğin dinamiksel olarak kararlı olduğunu göstermiştir. Hesaplanan optik özellikler ise LiNaS'nin görünür ve morötesi (UV) bölgelerde yüksek potansiyele sahip olduğunu ortaya koymaktadır. Bu durum, bileşiği UV ışık yayıcılar, fotodedektörler ve güç elektroniği uygulamaları için uygun bir aday haline getirmektedir. Bu çalışma, yarıiletken yarı-Heusler bileşiklerinin optolektronik alanındaki potansiyel kullanımına yönelik önemli bilgiler sunmaktadır

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EXAMINATION OF THE CHARACTERISTICS OF LOW-CALORIE ASPHALTITE SAMPLE AND CALCULATION OF MINERAL PROPORTIONS WITH MINSQ

DÜŞÜK KALORİLİ ASFALTİT NUMUNESİNİN KARAKTERİSTİK ÖZELLİKLERİNİN İNCELENMESİ VE MİNERAL ORANLARININ MINSQ İLE HESAPLANMASI

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ÖZET

Asfaltit, petrolün yer kabuğundaki kırık ve çatlaklardan yüzeye doğru hareket etmesi ve bu boşluklarda katılaşması sonucu oluşmaktadır. Dünya üzerinde asfaltit rezervlerinin sınırlı oluşu ve bulunduğu yerlerde de çoğunlukla yakıt olarak kullanılması nedeniyle yakın zamana kadar dünya ekonomisinde katkısı olamamıştır. Literatür çalışmalarında, Türkiye'nin Güneydoğu Anadolu bölgesinde bulunan asfaltitlerinde kükürdünün oldukça yüksek ve bu nedenle kapsamlı temizlik yapılmadan yanmada doğrudan kullanıma uygun olmadığı belirtilmiştir. Bu tür asfaltit cevherlerinin konvansiyonel olmayan yöntemlerle işlenmesinden önce kimyasal ve mineralojik karakterizasyonun belirlenmesi oldukça önem arz etmektedir. Bu çalışmada, Şırnak ili Avgamasya sahasından temin edilen düşük kalorifik değere sahip asfaltit oluşumları incelenmiştir. Asfaltit örneği, orta düzeyde enerji potansiyeli taşırken, yüksek kül ve kükürt içeriği nedeniyle hem enerji verimliliği açısından hem de çevresel etkileri bakımından olumsuz bir duruma sahiptir. XRD analizleri ile asfaltit örneğinde dolomit, feldspat, kuvars, anortit, pirit, sülfür, illit, albit ve apatit gibi pek çok mineral tespit edilmiştir. Bu bulgular, örneğin silikatlar, oksitler ve sülfür bazlı minerallerden oluşan karmaşık bir mineral yapısına sahip olduğunu ortaya koymaktadır. Ayrıca, XRF analizleri, karbonatlı ve sülfatlı minerallerin yanı sıra kil, silikat ve iz elementlerin varlığını da doğrulamaktadır. MINSQ yöntemiyle hesaplanan mineral oranları, XRD verileriyle örtüşmektedir. MINSQ yöntemi, hem ekonomik olması hem de yüksek karbon içerikli kayaçlar üzerinde uygulanabilirliği ile asfaltit analizlerinde yenilikçi ve özgün bir yaklaşım sunmaktadır.

Anahtar kelimeler: Asfaltit, Karakterizasyon, MINSQ, Kantitatif Mineral Analizi

ABSTRACT

Asphaltite is formed by petroleum moving towards the surface through cracks and fractures in the Earth's crust and solidifying in these cavities. Since asphaltite reserves are limited worldwide and mostly used as fuel in the places where it is found, it has not contributed to the world economy until recently. In literature studies, it has been stated that the sulfur content of asphaltites in the Southeastern Anatolia region of Türkiye is quite high and therefore not suitable for direct use in combustion without extensive cleaning. Determining the chemical and mineralogical characterization before processing such asphaltite ores with unconventional methods is very important. In this study, a low calorific value asphaltite sample obtained from the Avgamasya field in Şırnak province was investigated. The asphaltite sample has a medium energy potential, but due to its high ash and sulfur content, it has a negative situation in terms of both energy efficiency and environmental impacts. Many minerals such as dolomite, feldspar, quartz, anorthite, pyrite, sulfur, illite, albite and apatite were detected in the asphaltite sample by XRD analysis. These findings reveal that the sample has a complex mineral structure consisting of silicates, oxides and sulfur-based minerals. In addition, XRF analysis confirms the presence of carbonate and sulfate minerals as well as clay, silicate and trace elements. The mineral ratios calculated by the MINSQ method overlap with the XRD data. Mineral ratios calculated by the MINSQ method overlap with the XRD data. The MINSQ method offers an innovative and original approach in asphaltite analysis, being both economical and applicable on rocks with high carbon content.

Keywords: Asphaltite, Characterization, MINSQ, Quantitative Mineral Analysis

GİRİŞ

Enerji ve doğal kaynakların giderek artan önemi, fosil yakıtların çeşitliliği ve bu kaynakların etkin bir şekilde kullanılabilmesi konusunu, ülkelerin enerji stratejilerinde hayati bir unsur haline getiriyor. Kömür, petrol ve doğal gaz gibi fosil enerji kaynaklarının yanı sıra, asfaltit de dikkate alınması gereken önemli bir yer altı kaynağıdır. Dünya genelinde Çin, Amerika Birleşik Devletleri, Venezuela, Fransa, İsviçre, Endonezya ve Türkiye gibi çeşitli bölgelerde bulunan asfaltitin üzerine yapılan birçok çalışmada, bu kaynağın ekonomik ve çevresel sürdürülebilirlik açısından önemini giderek daha fazla ortaya koymaktadır (Zhu vd., 2020). Bu bağlamda, asfaltitin karakterizasyonunun belirlenmesi, bu değerli doğal kaynağın etkin bir şekilde değerlendirilmesi için büyük bir önem arz etmektedir.

Asfaltit, kaynak kayaçlardan türeyen ham petrolün yüz milyonlarca yıl süren dönüşümü sonucunda hava ve su ile temas ederek oluşmuş bir enerji kaynağıdır. Termal çatlama, oksidasyon ve bakteriyel etkilerin etkisiyle su ve hafif yağ bileşenleri ortamdan uzaklaştırılırken, geride kalan ağır hidrokarbonlar kararlı özelliklere sahip katı organik maddeyi meydana getirmiştir. Asfaltit, morfolojisi, görünümü, rengi ve oluşum evresine göre dört kategoriye ayrılmaktadır: birincil-ayni seviyeli asfaltit, epijenetik-rezervuar asfaltiti, magmatik metamorfik asfaltit ve yüzeysel-sığ oksidasyon ile gaz kaybına uğramış asfaltit. (Zhu vd., 2020). Asfaltit, yüksek yumuşama noktasına sahip katı bir petrol yakıtı olup, yüksek miktarda sülfür ve uçucu maddeler içermektedir. Söz konusu bu hammadde metamorfoz (başkalaşım) yoluyla oluşan ve esas olarak çok az oksijenli bileşik içeren veya hiç içermeyen hidrokarbonlardan ve kristalize olabilen parafinlerden oluşan katı petrol olarak da tanımlanmaktadır. Genel olarak asfaltik malzemelerin petrolün göçü ve tektonik hareketler sırasında çatlaklarda katılaşması ile oluştuğu düşünülmektedir (Lebkushner, 1969; Bartle vd. 1981; Şengüler, 2008; Kavak vd. 2010).

Asfaltitler, genel olarak sertliği 2 ile 3 arasında, renk olarak parlak veya donuk siyah, özgül ağırlık olarak ise 1,03 ile 1,20 arasında değişim göstermektedir. Isıl değeri ise yaklaşık 10 ile 23 MJ/kg (2,388-5,493 kcal/kg) arasında olup, karbon sülfürdeki (CS_2) çözünürlükleri % 90-100, ergime noktası yaklaşık 200-315 °C arasında değişmektedir. Genel olarak hidrojen ve karbondan oluşmakta ve mineral madde oranı en fazla % 40'a ulaşabilir (Demirci vd., 2019).

Ayrıca, asfaltitler, molibden (Mo), vanadyum (V), nikel (Ni), ve uranyum (U) gibi eser metallerle ilişkili hidrokarbonlar ve polar bileşiklerden oluşmaktadır. Asfaltik damarlar veya asfaltitler kil mineraller, kuvars, albit, ortoklaz, ve pirit gibi siyah şeyller içinde çökelenlere benzer büyük miktarlarda otijenik mineraller içerir. Asfaltitler, yüksek kül seviyelerine sahip oldukları ve Mo, Ni ve Ti gibi metaller açısından zengin oldukları bilinmektedir. Yüksek miktarda petrol içeren Türkiye menşei asfaltitleri, petrol çıkarıldıktan sonra katı yakıt olarak kullanılabilir. Bu kapsamda asfaltitlerin termik santrallerde katı yakıt olarak kullanım olanakları da araştırılmıştır (Saltoğlu vd. 1978; Şengüler, 2008; Kavak vd. 2010).

Türkiye'deki asfaltit yatakları, ilk olarak Lebkushner (1969) tarafından Türkiye Devletinin Doğu Türkiye'de yeni ve verimli katı yakıt yatakları arama çabaları doğrultusunda 1964'ten 1967'ye kadar Türkiye Maden Tetkik ve Arama Enstitüsü adına Şırnak'ın güneyindeki bölgede, araştırmıştır. Bu yataklara şimdiye kadar fazla değer verilmemiştir ancak asfaltit, yüksek kalori değeri sayesinde etkili bir katı yakıt olarak kullanılabilmektedir.

Türkiye'deki toplam asfaltit rezervi yaklaşık 82 milyon ton olup bu miktarın yaklaşık 45 milyon tonu görünür rezerv olarak göze çarpmaktadır (DPT, 2001). Ekonomik açıdan büyük öneme sahip asfaltit yatakları, Şırnak il merkezinin güneyinde ve Silopi ilçesinde yer almaktadır. Şırnak ilinde bulunan asfaltitler, yüksek oranda kül ve kükürt içermelerine rağmen son derece yüksek bir kalorifik değere sahip olma özelliği taşımaktadır. MTA raporlarında söz konusu bu asfaltitlerin kalori değer aralığı 3000 ve 6000 kcal/kg olarak belirtilmektedir. Ayrıca bölgeye ait bu asfaltitlerin toplam nem içeriğinin %1-5,3, kül içeriğinin %33-%45, kükürt içeriğinin %4,1-%6,4, uçucu madde içeriğinin %24-%40, sabit karbon içeriğinin %47-%59 ve hidrojen içeriğinin %3,2-%5,6 olduğu rapor edilmiştir (Demirci vd., 2019). Laboratuvar çalışmaları, asfaltit küllerinde radyoaktif minerallerin yanı sıra bazı nadir minerallere ve elementlere de rastlandığını ortaya koymuştur. Asfaltit, yalnızca ısınma amaçlı bir yakıt olarak değil, aynı zamanda termik santrallerde enerji üretiminde de önemli bir kaynak olarak kullanılmaktadır (Orhun, 1969; Demirci vd., 2019).

Asfaltit kömür ile kıyaslandığında bazı temel farklılıklar arz etmektedir. En belirgin ayrım, asfaltitin jeolojik oluşum sürecine dayanmaktadır. Kömür, bitkisel kalıntıların milyonlarca yıl süren jeolojik baskı ve ısının etkisi ile karbonlaşması sonucunda meydana gelirken (Orem ve Finkelman, 2003); asfaltit, petrol kökenli bir kayaç olup, petrolün hidrostatik basınç, gravitasyon, sıcaklık gibi etkilerle yer kabuğundaki çatlak ve kırıklardan yüzeye doğru hareket etmesi ve bu boşluklarda katılaşması neticesinde meydana gelmektedir (Ayaz vd., 2017; Çakır vd., 2013; İlhan ve Aytekin, 2010). Diğer bir ifadeyle, asfaltit, genellikle petrol kökenli bir kömür-altı fosil yakıtı olarak nitelendirilebilir. Asfaltitler görünüm ve kimyasal özellikler bakımından kömürle hemen hemen benzer özelliklere sahip olduklarından, her ikisi de enerji hammaddesi olarak kullanılmaktadır (Bilgin, 2024).

Asfaltitin fiziksel ve kimyasal özelliklerinin kapsamlı karakterizasyonu, bu doğal kaynağın etkili bir şekilde değerlendirilmesi açısından son derece önem arz etmektedir. Bu süreç, asfaltitin enerji ve ekonomik değerinin anlaşılabilmesi, belirli kullanım alanlarına uygunluğunun tespit edilmesi ve çevresel etkilerinin azaltılması açısından gereklidir. Örneğin, asfaltitin karbon içeriği, kalorifik değeri, kükürt oranı ve kül oluşumu gibi parametrelerin belirlenmesi, enerji santrallerinde çevresel sürdürülebilirlik hedeflerine ulaşmak için kritik bir rol oynamaktadır (Speight, 2015). Ayrıca, bu karakterizasyon çalışmaları, asfaltit bazlı yakıtların farklı sanayi kollarındaki uygulanabilirliğini değerlendirmek amacıyla da büyük önem arz etmektedir.

Karakterizasyonun önemini artıran bir diğer faktör, asfaltit rezervlerinin coğrafi ve niteliksel çeşitliliğidir. Türkiye özelinde incelendiğinde, özellikle Güneydoğu Anadolu Bölgesi'nde yüksek miktarda asfaltit rezervlerinin bulunduğu tespit edilmiştir (Ayaz vd., 2017). Ancak, bu rezervlerin kimyasal ve termal özellikleri farklı bölgelerde değişiklik göstermektedir. Rezerv özelliklerinin doğru bir biçimde analiz edilmemesi, bu kaynağın enerji üretiminde düşük verimlilikle kullanılmasına ve taşınma ile işlenme süreçlerinde ciddi ekonomik kayıplara yol açabilmektedir. Bu bağlamda, asfaltitin karakterizasyonu hem enerji kaynaklarının geliştirilmesi hem de uzun vadeli sürdürülebilir enerji politikalarının oluşturulması açısından stratejik bir ihtiyaç teşkil etmektedir.

Sonuç olarak, asfaltit, kendine özgü yapısal ve kimyasal özellikleriyle önemli bir katı yakıt kaynağıdır. Ancak, bu kaynakların potansiyelinin etkin biçimde değerlendirilebilmesi için hassas ve detaylı karakterizasyon çalışmalarının gerçekleştirilmesi gerekmektedir. Gelişen teknolojiler ve analitik yöntemlerin asfaltit karakterizasyonuna sağladığı yenilikler, bilimsel ve endüstriyel uygulamalar açısından yeni ve değerli bilgiler sunmaktadır. Bu çalışmada, mineral oranlarının belirlenmesinde yaygın olarak kullanılan ve maliyetli olan kantitatif XRD analizlerine alternatif olarak MINSQ yönteminin tercih edilerek çalışmaya özgün nitelik kazandırılmaktadır. Bu yöntem tahmin edilen mineral oranları ile gerçek analiz sonuçları arasındaki farkın en küçük kareler yöntemiyle hesaplanmasına dayanır. MINSQ metodolojisi, yüksek karbon içeren kayaçların mineral yapısının tespiti açısından hem ekonomik hem de pratik olarak önemli faydalar sağlamaktadır. Özellikle asfaltit gibi karmaşık özellikler taşıyan numunelerde, pahalı kantitatif XRD yöntemlerine bir alternatif olarak geliştirilmesi, bu yöntemi literatürde özgün ve yenilikçi bir hale getirmektedir. Bu amaçla; bu çalışmada, Şırnak ili Avgamasya sahasından temin edilen ve literatürdeki yüksek kalorifik değere sahip zon dışında daha kırmızımsı yapıda olan düşük kalorifik değere sahip asfaltit oluşumları incelenmiştir.

MATERYAL VE METOT

Bu çalışmada, Şırnak il sınırı içerisinde faaliyet gösteren Avgamasya asfaltit sahasından temin edilen düşük kalorifik değere sahip asfaltit numunesine karakterizasyon testleri uygulanmıştır. Asfaltit numunesi öncelikle Şırnak Üniversitesi Maden Mühendisliği Bölüm Laboratuvarında bulunan çekiçli kırıcı ile tane boyutu küçültüldükten sonra analiz için öğütme işlemleri havanda (<100 μm) gerçekleştirilmiştir. Numunenin karakterizasyon testlerinden tam analizleri (nem, kül, uçucu madde, sabit karbon, toplam kükürt, piritik, sülfat ve organik kükürt içerikleri), yapısal özelliklerinin belirlenmesi için FTIR (Fourier Dönüşümlü Kızılötesi Spektroskopisi) ve asfaltit külündeki minör (eser) elementler analizleri MTA (Maden Tetkik ve Arama/Ankara) laboratuvarlarında gerçekleştirilmiştir. Asfaltit numunesinin katı bitüm içermesi nedeniyle, masarel tanımlaması ve bileşenlerinin yüzdesel miktarlarının belirlenmesine yönelik petrografik analiz yapılamamaktadır. Bu sebeple, asfaltit numunelerinin mineralojik olarak tanımlanması ve yapıda bulunan minerallerin tespit edilmesi amacıyla XRD (X-ışını difraktometresi, Rigaku MiniFlex 600 ile XRF (X-ışınları Floresans, Rigaku Primus ZSX) analizleri gerçekleştirilmiştir. XRD ve XRF verilerinin değerlendirilmesine yönelik MINSQ hesaplamaları kullanılacaktır.

MINSQ, kayaca ait kimyasal analiz verilerini kullanarak kayaç bünyesindeki minerallerin oranlarını kantitatif olarak tahmin eden, en küçük kareler yöntemi prensibine dayanan ve Microsoft Excel' deki "Çözücü" aracıyla çalışan bir elektronik tablo uygulamasıdır. Kullanımı kolay ve etkileşimli bir şekilde gözlemlenebilen mineraller, uygulama alanına sahiptir. MINSQ, kaya numunelerinin temel kimyasal analizleri aracılığıyla mineral oranlarının hesaplanmasını sağlayan bir hesap tablosu yöntemidir. Litojeokimyasal veri varlığı, zorlu mikroskopik nokta sayımları ve maliyetli kantitatif X-ışınları difraksiyonu (XRD) tekniklerine alternatif oluşturmaktadır (Erkan, 2022; Herrmann ve Berry, 2002). MINSQ yönteminin kullanılmasıyla hesaplanan mineral oranlarının doğruluğunu değerlendirmek için Residual SSQ (kalan kareler toplamı) değeri önemli bir ölçüt olarak öne çıkmaktadır. Bu değer, analiz edilen ve tahmin edilen mineral kompozisyonları arasındaki farkları ölçen bir metrik olarak tanımlanabilir. MINSQ yöntemi, Solver adımlarını kullanarak, tahmin edilen mineral oranları ile gerçek analiz sonuçları arasındaki farkların karelerinin toplamını minimize etmeyi amaçlar. Residual SSQ değerinin 0,5'in altında olması, genellikle kabul edilebilir bir çözüm olarak değerlendirilirken, bu değerin yüksek olması mineral analizleri arasındaki uyumun zayıf olduğunu ve tahmin edilen bileşimin mineral yapısını yeterince yansıtmadığını gösterir (Herrmann ve Berry, 2002).

BULGULAR VE TARTIŞMA

Tablo 1'de asfaltitin yapısal ve kimyasal özelliklerini ortaya koyan kısa analiz ve elemental analiz sonuçları, Tablo 2'de ise XRF analiz sonuçları yer almaktadır. Bu analizler, asfaltitin temel bileşenlerini ve genel kimyasal yapısını ayrıntılı bir şekilde tanımlayarak, malzemenin enerji ve endüstriyel uygulama alanlarındaki potansiyelini değerlendirmek için önemli bilgiler sunmaktadır. Kısa analiz, nem, kül, uçucu madde, sabit karbon oranlarını (ASTM D7582), Alt/üst ısıl değer (ASTM D5865) ölçerken, elemental analiz ise karbon (ASTM D7582), hidrojen (ASTM D5373), kükürt (ASTM D5016), piritik, sülfat, organik kükürt (TS 329 ISO), oksijen (Hesaplanan) bileşimlerini belirlemektedir. Kısa analizler, asfaltitin fiziksel ve yanabilir özellikleri ortaya koymaktadır. Numunenin orijinal ve kuru bazdaki analiz sonuçları birbirine çok yakın olduğundan kuru numune sonuçlarına göre değerlendirme yapılmıştır. Sonuçlar her bir parametre için ayrı ayrı değerlendirildiğinde;

- Nem oranının %6,92 olması, asfaltit içerisindeki su miktarını göstermekte olup bu oranın yüksekliği yanma sırasında enerji kaybına neden olarak enerji verimliliğini olumsuz etkilemektedir.
- Kül oranının %48,41 olması, asfaltitin yanmayan bileşenlerini temsil etmekte olup, oldukça yüksek olan bu değer enerji verimliliğinin düşük olduğunu ve yakıt olarak kullanılması durumunda düşük kalite sınıfta olduğuna işaret etmektedir.
- Uçucu oranının %28,22 olması, yanma sırasında açığa çıkan gaz potansiyelini oraya koymakta olup bu oran orta düzeyde uçuculuğa sahip yakıt olduğunu göstermektedir.
- Sabit karbon oranının %23,37 olması, yakıt olarak değerlendirildiğinde enerjiyi sağlayan katı kısmı temsil etmektedir. Bu değer, uçucu oranı ile birlikte değerlendirildiğinde uzun süreli ve kararlı yanma kapasitesinin orta düzeyde olduğunu ortaya koymaktadır.
- Alt (3583 kcal/kg) ve üst (3683 kcal/kg) ısıl değerlerine bakıldığında, enerji potansiyelinin orta düzeyli bir yakıt gibi (linyit gibi) olduğunu göstermekle birlikte kalorinin düşük olmasının nedeni yüksek kül ve nem içeriğinden kaynaklanmaktadır.
- Numunenin ana enerji sağlayıcısı olan karbon içeriği (%34,2) orta düzeyde bir enerji potansiyeli olduğunu göstermektedir. Ancak, karbon yüzdeki katı yakıtlar için ideal değere göre düşüktür (ör. Yüksek kaliteli kömürlerde bu oran %70-80 arasındadır). Hidrojen içeriği %1,78 ile düşüktür.
- Nitrojen içeriği ise %1,53 olup düşük olması çevresel atıklarının sınırlı olması açısından avantaj oluşturmaktadır.
- Buna karşın, kükürt içeriğinin (%5,52) yüksek olması çevresel açıdan önemli bir dezavantaj oluşturmaktadır. Yüksek kükürt, yanma sırasında sülfür dioksit (SO_2) gazı çıkışına yol açarak asit yağmurlarına ve hava kirliliğine neden olabilir.
- Oksijen oranının (%34,9) yüksek olması yanabilirliği olumsuz etkileyebilir. Yüksek oksijen içeriği, genellikle düşük karbon ve enerji yoğunluğunu ifade eder (Bilgiç, 2014).

Tablo 1. Asfaltit numunesinin kısa ve elemental analiz sonuçları

Kısa analizler	Orijinal Numunede	Kuru Numunede
Nem, %	6,92	-
Kül, %	45,06	48,41
Uçucu madde, %	26,27	28,22
Sabit karbon, %	21,75	23,37
Alt ısıl değer, kcal/kg	3295	3583
Üst ısıl değer, kcal/kg	3428	3683
Elementel analizler		
Karbon, %		34,2
Nitrojen, %		1,53
Hidrojen, %		1,78
Toplam Kükürt, %		5,52
	Piritik Kükürt, %	0,65
	Sülfat Kükürt, %	0,28
	Organik Kükürt, %	4,59
Oksijen, %		34,9

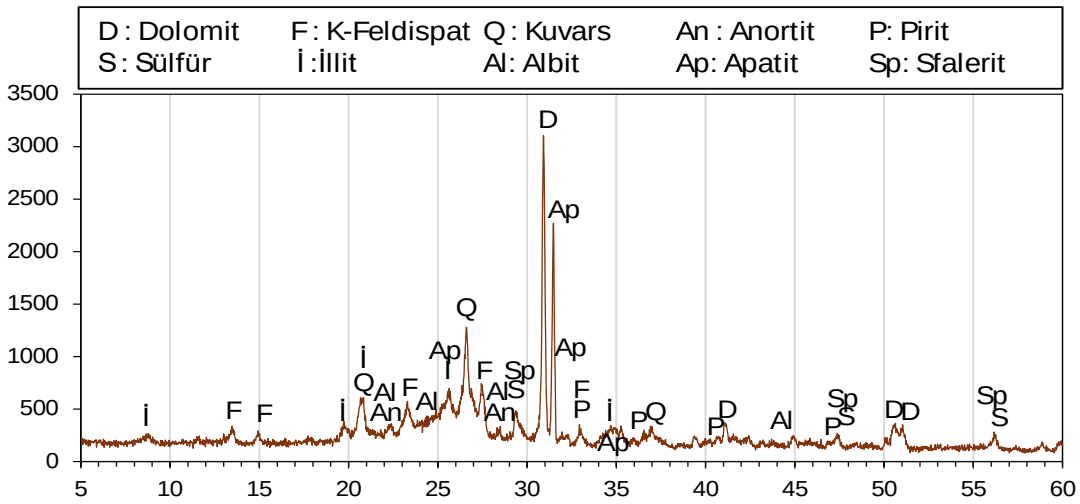
Tablo 2. Asfaltit numunesinin XRF analiz sonuçları

Analiz	İçerik, %	Analiz	İçerik, %	Analiz	İçerik, %
CO_2	72,70	Fe_2O_3	1,20	V_3O_5	0,26
N	0,53	MgO	0,84	ZnO	0,08
SiO_2	9,44	CaO	2,46	MoO_3	0,13
TiO_2	0,18	Na_2O	0,05	SO_3	65,68
Al_2O_3	4,00	P_2O_5	0,29	K_2O	0,96

Asfaltit numunesinin XRF analiz sonuçları (Tablo 2), örnekte oldukça yüksek oranlarda CO_2 (%72,70) ve SO_3 (%65,68) bulunduğunu göstermektedir. Bu da numunenin büyük ölçüde karbonatlı ve sülfatlı mineraller içerdiğini ortaya koyuyor. Buna ek olarak, SiO_2 (%9,44) ve Al_2O_3 (%4,00) gibi ana oksitlerin varlığı, az miktarda kil mineralleri ve silikatların bulunduğunu, Fe_2O_3, MgO, CaO gibi bileşikler ile V ve Mo gibi iz elementlerin ise çeşitli minerallerin ve mikro elementlerin katkısını işaret ettiğini gösteriyor. Bu bileşim, asfaltitin özellikle enerji üretiminde kullanımı esnasında baca gazı arıtma süreçlerinde yüksek sülfat oranı nedeniyle çevresel açıdan dikkatli yaklaşılması gerektiğini, ayrıca silikat ve alümina içeriklerinin kül oluşumu ve süreç kontrolü açısından önemli bir rol oynadığını belirtmektedir.

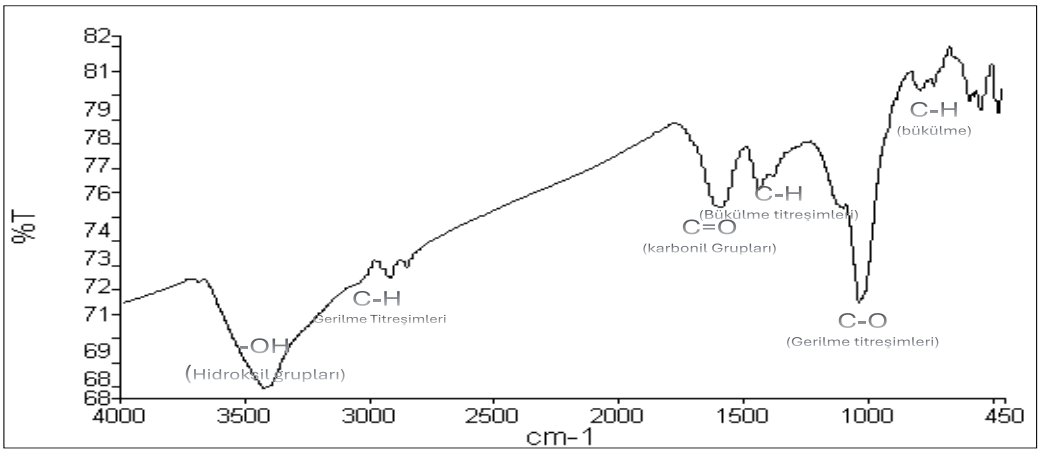
Sonuç olarak, asfaltit numunesinin kısa ve elemental analizlerine göre; ısıl değer ve sabit karbon oranı dikkate alındığında enerji potansiyeli orta düzeyde olsa da yüksek kül ve nem oranı nedeniyle enerji verimliliğinin düşük olması muhtemeldir. Ayrıca, yüksek kükürt içeriği de ciddi dezavantaj oluşturmaktadır. Bu nedenle, yüksek kükürt ve kül içeriğinin düşürülmesine yönelik zenginleştirme proseslerinin araştırılması önem arz etmektedir. Ayrıca, asfaltitit bu özelliklerinin yanı sıra kül yapıcı minerallerin ve yapısal özelliklerinin de ayrıntılı olarak belirlenmesi oldukça önemlidir.

Asfaltitin mineralojik yapısını anlamak hem yanma verimliliğini artırmak hem de işlem koşullarını optimize etmek açısından oldukça önemli bir adımdır. Bu bağlamda, XRD ve FTIR gibi ileri analiz teknikleri, asfaltit içeriğindeki minerallerin tanımlanması ve faz analizinin gerçekleştirilmesi konusunda etkili bir araç olarak ön plana çıkmaktadır. Bu çalışmada, asfaltit numunesinin XRD analizi yapılarak mineralojik özellikleri ortaya konmuş ve kül yapıcı mineraller belirlenmiştir.



Şekil 1. Asfaltit numunesinin XRD grafiği

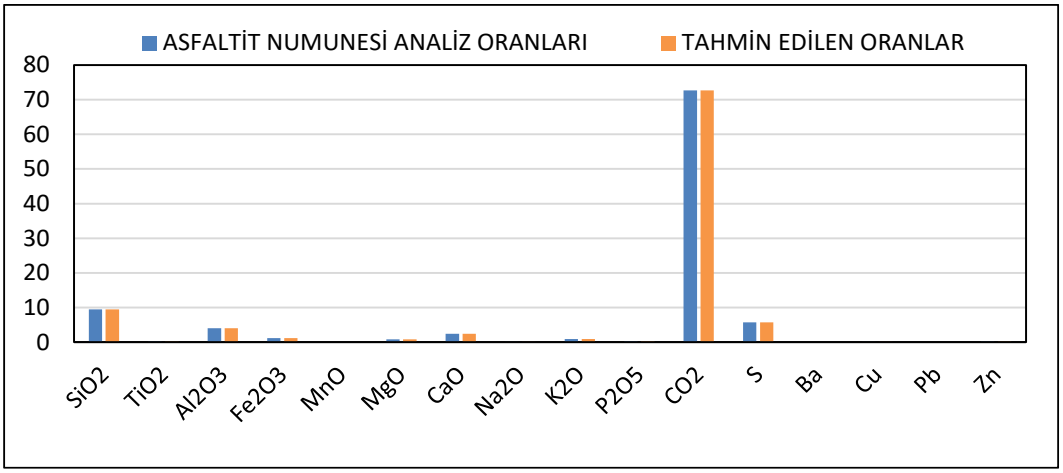
Şekil 1'de X-ışını difraksiyon (XRD) spektrumunda, asfaltit numunesinin mineralojik yapısı detaylı bir şekilde incelenmiştir. Sonuçta, dolomit, feldspat, kuvars, anortit, pirit, sülfür, illit, albit ve apatit mineralleri belirlenmiştir. Genel olarak, bu bulgular asfaltit numunesinin karmaşık bir mineralojik içeriğe sahip olduğunu ve silikatlar, oksitler ile sülfür bazlı matrislerin bulunduğunu ortaya koymaktadır. Yapılan bu analiz, asfaltitin katı yakıt olarak kullanılabilmesi için zenginleştirme koşullarının optimize edilmesi ve bünyesindeki kül yapıcı minerallerin azaltılması açısından önemli veriler sunmaktadır. Ayrıca, elde edilen XRD sonuçları, bu çalışmada belirlenen mineral fazların yanı sıra, önceki araştırmalarda asfaltit örnekleri üzerinde tespit edilen (Bilgin, 2021; 2024; Korkmaz, 2007) kalsit, montmorillonit, reinhardbrunsit, nagaşimalit ve pumpelit gibi çeşitli mineral bileşenlerinin de var olabileceğini göstermektedir. Bu durum, asfaltitin mineral çeşitliliğinin incelenen yer ve örnekleme şartlarına bağlı olarak farklılık gösterebileceğini ortaya koymaktadır. Elde edilen bulgular, daha önceki çalışmalarla kıyaslandığında, çalışmamızda belirlenen mineral türlerinin yanı sıra literatürde yer alan farklı mineral fazlarının da raporlandığını doğrulamaktadır. Bu minerallerin yanı sıra kimyasal analizlerin sonucuna göre çok az oranda rutil ve kalkopirtil gibi minerallerinde bulunduğu söylenebilir.



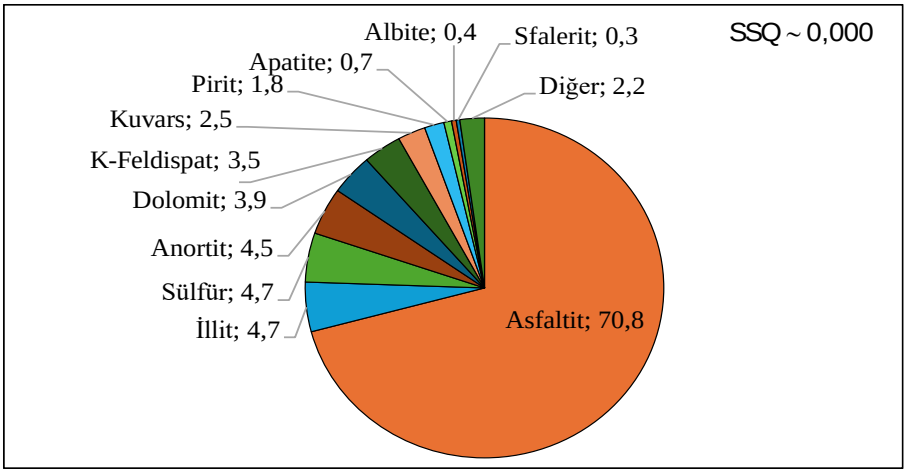
Şekil 2. Asfaltit numunesinin FTIR spektrumu

Şekil 2, FT-IR (Fourier Dönüşümü Kızılötesi Spektroskopisi) analizi sonucunda elde edilen spektrum, asfaltit numunesindeki işlevsel grupları belirlemek için yorumlanmıştır. Grafikteki karakteristik absorpsiyon bantları, malzemenin kimyasal yapısını yansıtmakta ve bu sayede numunenin özellikleri hakkında önemli bilgiler sunmaktadır. 3200–3600 cm^{-1} aralığında yer alan geniş ve güçlü bant, hidroksil (–OH) gruplarına özgü bir absorpsiyon bandıdır. Bu, malzeme yüzeyinde bulunan nem veya

alkol gruplarının varlığını gösterebilir. Genellikle, bu tür bantlar hidrojen bağı yapmış su moleküllerini veya yapısal suyu temsil etmektedir. 2900–3000 cm^{-1} aralığındaki bant ise C–H gerilmesi ile ilişkilidir ve alifatik hidrokarbonların varlığını işaret eder. Özellikle, bu bölgede CH_3 (metil) ve CH_2 (metilen) gruplarına ait titreşimler ortaya çıkar. 1600–1700 cm^{-1} arasındaki bandın varlığı, C=O (karbonil) gruplarını işaret eder. Bu durum, keton, ester veya karboksilik asit gibi bileşenlerin bulunma olasılığını gündeme getirir. 1400–1470 cm^{-1} aralığında görülen bantlar ise C–H bükülme titreşimleri ile ilişkilendirilir ve alifatik zincirlerdeki hidrokarbon yapılarını destekler niteliktedir. 1000–1200 cm^{-1} aralığında gözlemlenen zirveler, C-O bağının gerilme titreşimlerine işaret eder ve alkol, fenol veya ester gruplarının varlığını gösterebilir. 600–900 cm^{-1} arasında görülen tepe, aromatik C–H dış düzlem bükülmeleri ile ilişkilendirilebilir ve aromatik yapıların varlığına dair ipuçları sunar (Başaran vd., 2003; Wang vd., 2021; Wang vd., 2023). Spektrum, asfaltit numunesinin karmaşık bir kimyasal yapıya sahip olduğunu ve alifatik, aromatik ile oksijen içeren grupların bir arada bulunduğunu ortaya koymaktadır. Bu işlevsel grupların varlığı, malzemenin yanabilirlik özelliklerini ve enerji yoğunluğunu etkileyebilecek önemli bir bulgu olarak değerlendirilmektedir.



Şekil 3. Asfaltit numunesinin MINSQ çıktısı, analiz ve tahmin sonuçlarının kıyaslanması



Şekil 4. Asfaltit numunesinin MINSQ çıktısı, Mineraller ve yüzdeleri

Şekil 3 ve Şekil 4, MINSQ yöntemi kullanılarak hesaplanan mineralojik bileşenlerin oranlarının açıklamaktadır. Şekil 3'te, incelenen asfaltit numunesinin kimyasal bileşimleri ile tahmin edilen mineral kompozisyonları arasındaki karşılaştırmalar yer almaktadır. Sonuçlar numuneye ait analiz sonuçları ile tahmin sonuçlarının tamamıyla uyumlu olduğunu göstermektedir. Bu duruma göre de, SSQ değeri yaklaşık 0,000 olup oldukça yüksek oranda kabul edilebilir bir çözümdür. Bu değerler, analiz edilen kimyasal verilerle tahmin edilen mineral bileşimlerinin istatistiksel olarak neredeyse birebir örtüştüğünü göstermektedir. Buna göre, asfaltit numunesinin de XRD analizlerine göre belirlenmiş olan mineral yüzdelerinin MINSQ ile hesaplamaları; asfaltit (70,8), illit (4,7), sülfür (4,7),

anortit (4,5), dolomit (3,9), K-feldspat (3,5), kuvars (2,5), pirit (1,8), apatit (0,7), albit (0,4) ve sfalerit (0,3) şeklinde hesaplanmıştır. Bu bulgular, MINSQ yönteminin mineral analizi için etkili bir araç olduğunu ve alana özgü mineral bileşenlerine hızlı sonuç sağladığını göstermektedir. Ancak, yöntemin doğruluğu kullanılan mineral kompozisyonlarıyla doğrudan ilişkilidir; bu nedenle, analiz edilen örneklere uygun mineral bileşimlerinin seçilmesi büyük önem taşımaktadır. Yapılan gözlemler, MINSQ yöntemiyle elde edilen tahminlerin genellikle XRD ile belirlenen oranlarla uyumlu olduğunu ortaya koymaktadır. Bu durum, XRD analizi sonuçlarının doğru yorumlanmasının MINSQ sonuçlarının geçerliliğini arttırmak açısından ne kadar önemli olduğunu göstermektedir. MINSQ'nin güvenilirliği, seçilen minerallerin bileşimlerinin analize uygunluğuna bağlıdır. Bu nedenle, gelecekteki ayrıntılı çalışmalarda mineral veri tabanlarının genişletilmesi ve çapraz doğrulama tekniklerinin uygulanması önerilmektedir.

SONUÇLAR

Şırnak ili sınırları içerisinde faaliyet gösteren Avgamasya asfaltit sahasından temin edilen düşük kalorifik değere sahip asfaltit numunesinin üzerinde gerçekleştirilen bu çalışmada kısa ve elementel analizler ile XRD ve XRF analizleri yapılmış olup, çalışmanın özgün yönünü güçlendiren alternatif bir yaklaşım olan MINSQ yöntemiyle mineral oranları tahmin edilmiştir. Asfaltitin sanayide ve enerji üretiminde daha verimli, çevreci ve ekonomik kullanılabilmesi için yapısal ve kimyasal özelliklerinin ayrıntılı şekilde belirlenmesi gerekir. Buda, optimum yakma koşullarının ve doğru zenginleştirme yöntemlerinin seçilmesine imkân tanır. Analizler sonucunda aşağıdaki bulgular elde edilmiştir:

- Kısa ve elemental analizleri sonucunda ısıl (kalorifik) değerler (alt: 3583 kcal/kg; üst 3683 kcal/kg) ve sabit karbon oranı (%23,37) göz önünde bulundurulduğunda enerji potansiyeli açısından orta düzeyde olup, yüksek kül (%48,41) ve nem oranı (%6,92) nedeniyle enerji verimliliğinin düşük olması muhtemeldir. Ayrıca, yüksek kükürt içeriği (%5,52)'de ciddi dezavantaj oluşturmaktadır. Bu nedenle, yüksek kükürt ve kül içeriğinin düşürülmesine yönelik zenginleştirme proseslerinin araştırılması önem arz etmektedir ve gelecekteki çalışmaların konusu olabilir.
- X-ışını difraksiyon (XRD) spektrumunda, dolomit, feldspat, kuvars, anortit, pirit, sülfür, illit, albit ve apatit mineralleri belirlenmiştir. Bu bulgular asfaltit numunesinin karmaşık bir mineralojik içeriğe sahip olduğunu ve silikatlar, oksitler ile sülfür bazlı matrislerin bulunduğunu ortaya koymaktadır.
- Asfaltit numunesinin XRF analiz sonuçları, yüksek miktarda karbonatlı ve sülfatlı mineraller içerdiğini göstermektedir. Bununla birlikte, kil, silikat ve çeşitli iz elementlerine de rastlanmaktadır. Özellikle enerji üretimindeki kullanımı sırasında yüksek sülfat içeriği nedeniyle çevresel etkiler ve süreç kontrolü açısından dikkatli olunması gerektiği anlaşılmaktadır.
- FT-IR spektrumu analizi doğrultusunda ise, asfaltit numunesinin karmaşık bir kimyasal yapıya sahip olduğunu ve alifatik, aromatik ile oksijen içeren grupların (hidroksil ve karbonil) bir arada bulunduğunu ortaya koymaktadır.
- MINSQ yöntemi maliyetli kantitatif XRD tekniklerine alternatif olarak geliştirilmiş olup bu yöntem, tahmin edilen mineral oranları ile deneysel analiz sonuçları arasındaki farkın en küçük kareler yöntemiyle azaltılmasıyla hesaplanmasına dayanır. Çalışmamızda uygulanan MINSQ yöntemi ile elde edilen tahmin sonuçlarının deneysel verilerle yüksek düzeyde uyum gösterdiğini ortaya koymuştur.
- SSQ değeri yaklaşık 0,000 olup oldukça yüksek oranda kabul edilebilir bir çözümdür. Bu durum, analiz edilen kimyasal verilerle tahmin edilen mineral bileşimleri arasında istatistiksel olarak neredeyse tam örtüşme olduğunu göstermektedir. Asfaltit numunesinin de XRD analizlerine göre belirlenmiş olan mineral yüzdelerinin MINSQ ile hesaplamaları; asfaltit (70,8), illit (4,7), sülfür (4,7), anortit (4,5), dolomit (3,9), K-feldspat (3,5), kuvars (2,5), pirit (1,8), apatit (0,7), albit (0,4) ve sfalerit (0,3) şeklinde hesaplanmıştır.

Sonuç olarak; asfaltit numunesinin enerji potansiyeli açısından orta düzeyde olduğu, kül ve kükürt oranlarının yüksek olması nedeniyle enerji veriminin düşebileceği ve çevre açısından dezavantaj

oluşturabileceği belirlenmiştir. Ayrıca; yapılan gözlemler, mineral oranlarının belirlenmesinde alternatif bir yöntem olan MINSQ yöntemiyle elde edilen tahminlerin genellikle XRD ile belirlenen oranlarla uyumlu olduğunu ortaya koyduğu belirlenmiştir. Bu durum, XRD analizi sonuçlarının doğru yorumlanması gerektiğin ne kadar önemli olduğunu göstermektedir.

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MULTI-PURPOSE BUILDING MATERIAL DESIGN WITH OPTIMIZATION OF SUSTAINABLE GEOPOLYMER MIXTURE WITH FIBROUS WASTE TYRE AND SLAG ADDITIVES

LİFLİ ATIK LASTİK VE CÜRUF KATKILI SÜRDÜRÜLEBİLİR GEOPOLİMER KARIŞIMI OPTİMİZASYONU İLE ÇOK AMAÇLI YAPI MALZEMESİ TASARIMI

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ÖZET

Çimentonun üretiminde harcanan enerji ve atmosfere salınan yüksek miktarda karbonun ortaya çıkardığı çevresel olumsuzluklar nedeniyle alternatif yapı malzemelerine yönelim artmıştır. Çimentoya alternatif malzemelerin başında geopolimer üretimi gelmektedir. Geopolimer malzemeler sürdürülebilir malzemelerle elde edilebildiği için iyi bir alternatif oluşturmaktadır. Geopolimer malzemeler puzolanik özelliklere sahip doğal veya yapay malzemelerle elde edilebilmektedir. Bu çalışmada doğal ve endüstriyel faaliyetler sonucu ortaya çıkan yapay puzolanların içerikte kullanıldığı, tamamen atık malzemelerle elde edilmiş geopolimer bir karşımın deneysel çalışmalarla optimizasyonu gerçekleştirilmiştir. Karışım içeriğinde kullanılan malzemelerin optimum oranları araştırılmıştır. Çalışmada elde edilen geopolimer yapı malzemesi ile inşaat sektöründe enerji tasarrufu, düşük karbon ayakizi, sürdürülebilirlik, atıkların geri dönüşümü ve ekolojik olumsuzlukların indirgenmesi gibi faydalar amaçlanmıştır.

Makalemiz kapsamında karışım optimizasyonu gerçekleştirilen geopolimer içeriğinde bağlayıcı olarak öğütülmüş cüruf ve öğütülmüş pomza tercih edilmiştir. Geopolimerizasyon sürecinin tamamlanabilmesi için alkali çözelti oluşumunda sodyum hidroksit kullanılmıştır. Agrega olarak ise mermer sanayisinde atık halde ortaya çıkan küçük çaplardaki ince mermer atıkları değerlendirilmiştir. Bu malzemelere ilave olarak ekonomik ömrünü tamamlamış lifli atık lastik ikamesi ile geopolimer karışımın yüksek süneklik kapasitesine ve düşük birim hacim ağırlığa sahip olabilmesi hedeflenmiştir. Bu kapsamda 24 adet karışım içeriğine sahip numuneler hazırlanmış, bu numunelere basınç ve eğilme testi uygulanmıştır. Deneysel çalışmalar sonucunda 0,72 ton/m^3 birim hacim ağırlığında, ısı geçirgenlik katsayısı 0,47 W/mK olan, 4,4 MPa basınç dayanımı ve 0,93 MPa eğilme dayanımına sahip tamamen atıklardan oluşan bir geopolimer karışıma ulaşılmıştır.

Çalışmamız ile hafif, ısı yalıtım kapasitesi yüksek, sürdürülebilir ve tamamen atık geri dönüşümünden ekonomik bir yapı malzemesi elde edilebilmiştir. Elde edilen malzeme tek başına veya farklı yapı malzemeleri ile kombinasyon yapılarak yapı sektöründe farklı amaçlarla kullanıma

uygun potansiyele sahiptir. Çalışmamız sonucunda elde edilen geopolimer yapı malzemesi ile inşaat sektörünün birçok farklı alt alanında kullanılabilecek geri dönüştürülmüş bileşenlerden oluşan sürdürülebilir inovatif bir yapı malzemesi çözümü geliştirilmiştir. Makalemiz ile bu kapsamda gerçekleştirilen sektör ve akademik çalışmalara katkı sunulabilmesi amaçlanmıştır.

Anahtar Kelimeler: Sürdürülebilirlik, geri dönüşüm, yapı malzemesi, geopolimer, lifli atık lastik, puzolanlar.

ABSTRACT

Due to the environmental impact caused by the energy consumption in cement production and the significant amount of carbon emissions released into the atmosphere, there has been a growing interest in alternative building materials. Geopolymers have emerged as a leading alternative to cement. These materials are considered a sustainable option because they can be derived from natural or artificial materials with pozzolanic properties. This study focuses on the optimization of a geopolymer mixture produced entirely from waste materials, incorporating artificial pozzolans sourced from natural and industrial processes. The study aimed to determine the optimal ratios of the materials used in the mixture. The geopolymer material produced in this research offers several benefits, including energy efficiency, a low carbon footprint, sustainability, waste recycling, and the reduction of ecological impacts in the construction sector.

For the geopolymer mixture, slag and pumice were chosen as binders. Sodium hydroxide was used to create an alkaline solution to facilitate the geopolymerization process. Fine marble waste, produced as a byproduct of the marble industry, was utilized as an aggregate. Additionally, to improve the material's ductility and reduce its unit volume weight, waste tires (which had reached the end of their economic life) were incorporated into the mixture. A total of 24 mixture variations were prepared for the experimental study, and pressure and bending tests were conducted on these samples. The experimental results showed that the geopolymer mixture, consisting entirely of waste materials, achieved a unit volume weight of 0.72 ton/m³, a thermal conductivity coefficient of 0.47 W/mK, a compressive strength of 4.4 MPa, and a bending strength of 0.93 MPa.

The findings of this study suggest that a lightweight, high thermal insulation, sustainable, and cost-effective building material can be created entirely from recycled waste. The material developed in this research has the potential to be used in various applications within the construction sector, either on its own or in combination with other materials. Ultimately, this study contributes to the advancement of sustainable and innovative building materials by utilizing recycled components, offering a promising solution for various sub-sectors of the construction industry.

Keywords: Sustainability, recycling, building material, geopolymer, fibrous waste tire, pozzolans.

A MODEL PROPOSAL FOR THE MULTI-RESOURCE CONSTRAINED, MULTI-OBJECTIVE PARALLEL MACHINE SCHEDULING PROBLEM

ÇOK KAYNAK KISITLI, ÇOK AMAÇLI PARALEL MAKİNE ÇİZELGELEME PROBLEMİ İÇİN BİR MODEL ÖNERİSİ

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ABSTRACT

In this study, a complex scheduling problem frequently encountered in production systems—namely, the multi-resource constrained, multi-objective, single-stage parallel machine scheduling problem—is addressed. In the considered problem, each job consists of a single operation and can be processed simultaneously on multiple machines, depending on the number of molds assigned to that job. Jobs are processed in batches, with the batch size known in advance and varying according to the nature of the job. Each job has a specific due date. It is assumed that operators can operate any machine within the workshop. An operator can handle multiple machines simultaneously, and this number varies depending on the machine type. Throughout the planning horizon, it is assumed that operators remain fixed at their assigned machine or machine group and do not switch positions. In this problem, molds and operators are considered as resource constraints in addition to machines. The objective is to minimize total tardiness and maximize operator efficiency. In this regard, the proposed model goes beyond classical scheduling approaches by simultaneously addressing both resource allocation and task assignment in a multi-objective and realistic framework. A mixed-integer programming model has been developed to represent the problem defined in this study. In future work, metaheuristic algorithms will be developed to solve large-scale instances of the problem.

Keywords: Parallel machine scheduling, multi-objective optimization, resource constraints, operator assignment, production planning

ÖZET

Bu çalışmada, üretim sistemlerinde sıkça karşılaşılan karmaşık çizelgeleme problemlerinden biri olan çok kaynak kısıtlı, çok amaçlı, tek aşamalı paralel makine çizelgeleme problemi ele alınmaktadır. Ele alınan çalışmada her iş tek bir operasyondan oluşmakta ve ilgili işe ait kalıp sayısı kadar makinede aynı anda işlenebilmektedir Her iş partiler halinde işlenmekte ve yapılan işe göre değişen miktarlardaki parti boyutu önceden bilinmektedir. Her işin belirli bir teslim tarihi bulunmaktadır. Atölye içerisinde operatörlerin her makineyi işletebileceği varsayılmaktadır. Bir operatör aynı anda birden fazla makine ile ilgilenebilmekte ve bu sayı makine tipine göre değişmektedir. Planlama ufku boyunca operatörlerin atandıkları makine veya makine grubunda sabit kaldığı ve yerini

değiştirmediği varsayılmaktadır. Makinelerin yanı sıra kalıpların ve operatörlerin de kaynak kısıtı olarak dikkate alındığı bu problemde amaç toplam gecikmenin minimize edilmesi ve operatör verimliliğinin maksimize edilmesidir. Bu yönüyle, önerilen model klasik çizelgeleme yaklaşımlarının ötesine geçerek hem kaynak tahsisini hem de görev atamasını birlikte ele alan çok amaçlı ve gerçekçi bir yapıya sahiptir. Bu çalışma kapsamında tanımlanan bu problemin karma tamsayılı programlama modeli geliştirilmiştir İlerleyen çalışmalarda, problemin büyük ölçekli uygulamalar için çözümüne yönelik metasezgisel algoritmalar geliştirilecektir.

Anahtar Kelimeler: Paralel makine çizelgeleme, çok amaçlı optimizasyon, kaynak kısıtları, operatör atama, üretim planlama

INTRODUCTION

Scheduling problems aim to plan which resources, in what order, and within what time frame jobs will be carried out in production environments. These problems directly affect critical performance criteria such as production efficiency, on-time delivery of products, and effective resource utilization (Sarac & Ozcelik, 2023).

Machine scheduling is one of the fundamental decision-making processes used in many areas such as production planning, project management, service systems, vehicle routing, and logistics. An effective scheduling approach directly contributes to reducing production time, preventing bottlenecks, increasing customer satisfaction, and lowering inventory costs (Takan & Sarac, 2023).

In today's production systems, efficient use of resources and compliance with delivery deadlines are critically important for businesses to remain competitive. In this context, parallel machine scheduling problems aim to ensure that jobs in production environments are planned on appropriate machines in a timely and efficient manner. However, in practical applications, it is often encountered that additional resources such as molds and operators, besides machines, also act as constraints.

Since real-life problems typically exhibit multi-objective characteristics, single-objective solution approaches often fail to produce realistic results. Therefore, multi-objective modeling is important for ensuring realism in scheduling problems (Sarac & Ozcelik, 2023). Furthermore, the presence of not just one but multiple, often conflicting, objectives in real-life applications increases the importance of multi-objective optimization techniques (Demir, 2023). Planning production by balancing multiple objectives enables more effective use of resources and enhances customer satisfaction (Dikmen et al., 2023). Including not only machines but also additional resources such as molds and operators in the planning process ensures that scheduling problems are addressed with more realistic models (Şaştım & Hasgül, 2024).

In the literature, it is often assumed that all machines will be used; however, in some industries, carrying out production with fewer machines reduces energy consumption and increases efficiency. Therefore, optimizing the number of machines to be used provides a significant contribution to production systems (Sarac & Tutumlu, 2022). In recent years, there has been growing interest in production scheduling approaches aimed at improving energy efficiency. Such approaches are critically important for sustainable industrialization and reducing environmental impacts (Jarboui et al., 2024).

In production processes, not only energy efficiency but also the inadequacy of manual planning due to increasing problem scales has become a major issue. Today's large-scale scheduling problems are too complex to be effectively planned manually. Scheduling models and algorithms are essential for increasing productivity, improving quality, and making the best use of available resources (Srinath et al., 2023). Real-world problems often work with variable-sized resources rather than fixed-sized ones, requiring more complex optimization techniques in planning processes. The simultaneous management of jobs with different characteristics and delivery dates pushes the limits of human

planning; thus, the development of efficient and fast scheduling algorithms has become inevitable (Demir, 2024).

This study focuses on multi-resource-constrained, multi-objective, single-stage parallel machine scheduling problems frequently encountered in production environments. This problem structure, which requires the simultaneous planning of mold, operator, and machine resources for each job and aims to balance multiple objectives, goes beyond classical scheduling approaches and more accurately reflects the dynamics of real-world production systems. In this work, a mixed-integer programming model is developed and proposed, aiming to minimize total tardiness while maximizing operator efficiency. This original approach offers an integrated solution structure that simultaneously addresses both resource allocation and task assignment. In the next section, studies from the related literature will be reviewed, and the position and contributions of the developed model within the existing body of knowledge will be detailed.

LITERATURE REVIEW

Parallel machine scheduling problems have long been among the fundamental optimization problems studied to ensure the effective planning of jobs in production systems. In the literature, various modeling and solution approaches have been developed for these problems, taking into account different machine types, resource constraints, sequence-dependent setup times, and multi-objective optimization goals. Especially in recent years, as production environments have become more complex, studies that incorporate not only machines but also additional resources such as operators and molds into the planning process, while balancing multiple objectives, have come to the forefront. This section examines the academic studies conducted on parallel machine scheduling problems; it explains the different problem variations, the methods used, and the limitations of existing studies to clarify the position of the current work within the literature.

Akbar and Irohara (2020) investigated a dual-resource constrained scheduling problem requiring multi-task simultaneous supervision, proposing five different metaheuristic methods to solve a structure that includes job sequencing, machine assignment, and operator allocation. Methods such as tabu search, artificial bee colony, and grey wolf optimization outperformed existing algorithms, while genetic algorithms and bee algorithms offered superior solution quality, particularly for medium- and large-scale problems. The study developed new heuristic techniques that improve both solution speed and quality.

Osman (2021) addressed a scheduling problem in multi-machine production lines, considering sequence-dependent changeover times and limited labor constraints. Three different priority rules and an optimization model were developed to minimize changeover times and maximize labor utilization; the methods were tested on a real industrial dataset, achieving significant improvements in labor utilization rates and changeover durations.

Barak et al. (2021) solved a multi-objective production scheduling problem in flexible manufacturing systems, considering the energy consumption of machines and automated guided vehicles (AGVs). They proposed a modified multi-objective particle swarm optimization (MMOPSO) method to optimize production time and energy consumption. The method demonstrated superiority in both solution quality and speed compared to classical algorithms.

Dunke and Nickel (2022) addressed the dual-resource-constrained job shop scheduling (DRCJSS) problem, which involves worker-machine assignment and job sequencing, under uncertainty and worker productivity variations; by combining mathematical optimization, simulation, and data analysis methods, they introduced an innovative approach to uncertainty management.

Wu et al. (2022) simultaneously tackled parallel machine scheduling and layout problems, and with their developed mixed-integer linear programming model, they optimized both layout costs and

makespan. The model was shown to deliver faster and more effective solutions compared to existing methods.

Munoz et al. (2022) studied scheduling problems in parallel machines with shared and constrained resources in the semiconductor industry; they developed an integer programming model and supporting heuristic methods that accounted for sequence-dependent setups and job release dates. The solution provided more efficient results by narrowing the time horizon.

Saraç and Tutumlu (2022) proposed a multi-objective model for unrelated parallel machine scheduling problems considering sequence- and machine-dependent setup times, which makes decisions on both which machines to use and the sequencing of jobs. They developed genetic algorithm and local search methods, with the genetic algorithm providing higher solution quality and speed for large-scale problems.

Tian et al. (2022) developed a new solution representation and task reordering strategy for the multi-skilled resource-constrained project scheduling problem, aiming to reduce additional time and costs arising from skill switching. The proposed multi-objective evolutionary strategy (MOES) showed superior performance compared to existing methods in tests.

Liu et al. (2023) developed a bi-objective model aimed at generating robust timetables under uncertainties for financially and resource-constrained projects. The ε-constraint method was used for small-scale problems, while a local search-supported NSGA-II was applied for large-scale problems, enabling the integration of project financing and resource planning.

Li et al. (2023) proposed a Pareto-based cooperative search mechanism that optimizes total completion time and energy consumption for the resource-constrained distributed hybrid flow shop scheduling problem. The algorithm was tested in production processes and produced effective results.

Li et al. (2023) addressed the complex product assembly scheduling problem by considering worker skills and transport times, developing a hybrid genetic algorithm that reduced team workload imbalance and total cycle time. The algorithm delivered superior results compared to other methods on real production data.

Shi et al. (2023) developed a model for the dual-resource-constrained flexible job shop scheduling problem that incorporates worker boredom. To optimize production efficiency and worker satisfaction, they proposed a two-stage multi-objective particle swarm optimization algorithm, contributing to the literature by addressing psychological factors.

Chen et al. (2023) developed a lexicographic optimization approach that minimizes total quality loss and total tardiness in the parallel machine scheduling problem. The method was tested on real datasets from the photolithography process and proved effective in improving production quality and scheduling efficiency.

Zou et al. (2023) proposed an adaptive iterative greedy algorithm using destruction and local search strategies for AGV scheduling to optimize energy consumption and production safety. The results showed that the proposed method outperformed existing approaches.

Demir (2023) developed two different lexicographic optimization methods aimed at minimizing total tardiness, total number of washings, and total fixed machine costs in the fabric dyeing process. For the solution, an integer programming model and a lexicographic multi-objective genetic algorithm were proposed; tests showed that while the lexicographic algorithm generally performed successfully, it needed further improvement under heavy workloads and tight delivery conditions.

Wang et al. (2023) addressed the order acceptance and parallel machine scheduling problem considering sequence- and machine-dependent setup times, developing a two-layered logical Benders decomposition method. The model produced effective solutions that maximized total profitability.

Jiang et al. (2023) developed approximation algorithms for the parallel machine scheduling problem in green manufacturing environments. The study presented an optimization model that minimizes

total processing cost and completion time, demonstrating solution efficiency focused on green production.

Wang et al. (2023) proposed a robust optimization model for the unrelated parallel machine scheduling problem under uncertainty, aiming to minimize both the worst-case makespan and the average makespan. A fruit fly optimization algorithm and reinforcement learning-based scenario-guided local search were developed, with the model outperforming existing methods across multi-objective metrics.

Saraç and Özçelik (2023) approached the unrelated parallel machine scheduling problem as a multi-objective problem, considering sequence-dependent setup times. The objectives were to minimize total tardiness and makespan. The developed matheuristic algorithm was compared with the extended ε-constraint method and provided more dominant solutions in shorter time. The study offered solutions to realistic production planning issues.

Dikmen et al. (2023) considered machine setup times and sequence-dependent adjustment times in the unrelated parallel machine scheduling problem. The problem was solved using a mixed-integer programming model and neighborhood search heuristic algorithms, and sensitivity analyses were conducted. The study contributed an innovative approach to enhancing efficiency in production planning processes.

Rolim et al. (2023) addressed the unrelated parallel machine scheduling problem considering a common delivery time constraint. An adaptive large neighborhood search algorithm was developed to minimize total earliness and tardiness costs. The model, tested in semiconductor production processes in the electronics industry, outperformed other methods.

Zhang et al. (2024) focused on a production and maintenance scheduling problem that considers maintenance outsourcing and third-party labor resources in distributed parallel machines. A mixed-integer linear programming model was proposed to minimize total completion time (makespan) and total cost. The developed memetic algorithm was enhanced with an iterative greedy method and local search operators. The algorithm showed 100% better search performance compared to existing methods and achieved the best results in over 85% of the tested instances.

Jartnillaphand and Mardaneh (2025) developed a solution for the parallel machine scheduling problem considering shift continuity and human resources. This new approach, which incorporates shift arrangements, provides efficiency in terms of production continuity and resource utilization. The algorithm offers faster and more effective results compared to traditional methods.

Zakharova and Sakhno (2025) addressed the problem of scheduling parallel jobs under energy constraints with speed scaling. The study developed a genetic algorithm that optimizes energy consumption and showed that this algorithm produced results up to 30% better compared to other methods. The work offers practical solutions for energy-efficient computing processes.

Bezzi et al. (2025) examined a real-world resource-constrained assembly problem and developed a solution aimed at minimizing total completion time. Modeling a three-level assembly process, the study successfully enhanced production efficiency by considering job priorities and resource constraints. This method finds application particularly in off-road vehicle manufacturing.

Uzunoğlu and Tuma (2025) developed machine learning-supported algorithm selection and genetic algorithms for serial batch job scheduling problems. The study accounted for incompatible job families and sequence-dependent setup times. The solution methods were applied particularly in the metalworking industry and achieved results 39.19% better than existing approaches.

Zheng et al. (2025) tackled the scheduling problem in parallel batch processing machines, developing innovative mathematical models to minimize makespan. The study focused on processing capacity constraints and specific restrictions such as job compatibility. Using nonlinear mixed-integer programming techniques, the work finds application particularly in aerospace and semiconductor

manufacturing processes. The developed models provided more efficient solutions compared to existing methods, contributing significantly to the literature.

Speckenmeyer et al. (2025) focused on single-machine scheduling problems with sequence-dependent setup times and developed parallel branch-and-price algorithms to minimize total weighted tardiness. The solution methods were enhanced with parallel computing techniques. These methods significantly reduced solution times for large-scale problems, making an important contribution to the literature.

In particular, many studies have been conducted in the literature on parallel machine scheduling problems. These studies provide important contributions by considering resource constraints, machine compatibilities, multi-objective optimization goals, and the dynamic nature of production environments. Table 1 summarizes the key works that make a direct contribution to the parallel machine scheduling problem. The selected studies guide the literature review by addressing resource constraints, multi-objective optimization goals, and application performance in the context of production planning.

Table 1. Selected Studies on the Parallel Machine Scheduling Problem

Author(s)	Problem	Method	Contribution
Sarac and Ozcelik (2023)	Unrelated parallel machine scheduling	Matheuristic algorithm	Minimization of total tardiness and makespan
Sarac and Tutumlu (2022)	Unrelated parallel machine scheduling	Multi-objective mathematical model, GA	Reduction of machine usage and makespan
Chen et al. (2023)	Parallel machine scheduling	Lexicographic optimization	Minimization of total quality loss and tardiness
Wang et al. (2023)	Parallel machine scheduling	Benders decomposition	Order acceptance and profitability optimization
Jiang et al. (2023)	Parallel machine scheduling (Green production)	Approximation algorithms	Processing cost and makespan optimization in green production
Wu et al. (2022)	Parallel machine and layout scheduling	Mixed-integer programming	Reduction of layout cost and makespan
Munoz et al. (2022)	Parallel machine scheduling	Integer programming + heuristic	Handling of shared resources and sequence-dependent setups
Wang et al. (2023b)	Unrelated parallel machine scheduling	Robust optimization, fruit fly algorithm	Makespan optimization under uncertainty
Demir (2023)	Fabric dyeing scheduling	Lexicographic multi-objective GA	Optimization of total tardiness, number of washings, and machine costs
Dikmen et al. (2023)	Non-identical parallel machine scheduling	Mixed-integer programming	Management of machine setup and sequence-dependent adjustment times
Rolim et al. (2023)	Unrelated parallel machine scheduling	Large neighborhood search	Optimization of earliness and tardiness costs
Zhang et al. (2024)	Distributed parallel machine+ maintenance	Memetic algorithm	Reduction of makespan and costs in maintenance and production scheduling
Jartnillaphand and Mardaneh (2025)	Parallel machine scheduling	Heuristic algorithm	Optimization of shift continuity and resource utilization
Zakharova and Sakhno (2025)	Energy-constrained parallel job scheduling	Genetic algorithm	Achieving energy efficiency
Zou et al. (2023)	AGV scheduling	Adaptive iterative greedy algorithm	Optimization of energy consumption and safety

PROBLEM DEFINITION AND MATHEMATICAL MODEL

This section presents the mathematical model developed for the multi-resource-constrained, multi-objective, single-stage parallel machine scheduling problem frequently encountered in production environments. Unlike classical scheduling problems, the problem structure addressed in this study considers not only machine utilization but also the simultaneous use of additional resources such as molds and operators. In this respect, the proposed model addresses both resource allocation and task assignment in an integrated manner, reflecting the complexity of real-world production systems more accurately.

In this study, each job requires a specific mold and operator resource and can be processed simultaneously in batches on designated machine groups. The batch sizes of the jobs are known in advance, and each job has a specific delivery date. Additionally, an operator has the capacity to manage multiple machines simultaneously, and this capacity varies depending on the machine type. It is assumed that operators work within fixed machine groups throughout the planning horizon and do not switch between machines.

The main objectives of the model are to minimize total tardiness and to maximize operator efficiency. This approach improves both customer delivery performance and the effective utilization of human resources within the production process. In developing the model, simultaneous assignment decisions for jobs, machines, molds, and operators were considered, aiming for a balanced solution within a multi-objective optimization framework.

In this context, the parameters and decision variables used in the study will first be defined, followed by a systematic presentation of the objective functions and model constraints.

Problem Definition

The workshop contains a total of K machines and I jobs that need to be processed. Each job consists of a single operation. Each job iii is processed in batches on one of the m_i identical parallel machine sets, with a processing time of pip_ipi. The batch size bib_ibi for each job is known in advance. Additionally, each job has a predetermined number of molds nin_ini, meaning that each job can only be processed simultaneously on a limited number of machines. All jobs must be completed by their predetermined delivery dates tit_iti to ensure on-time delivery. One of the study's objectives is to minimize total tardiness.

There are L operators working in the workshop. It is assumed that operators are capable of operating all machines. Depending on the machine types, operators can operate multiple machines simultaneously. Machines are grouped and numbered in advance according to the number of machines an operator can manage at the same time. For each machine group, the required number of operators nO_g is predetermined. An example machine layout plan is provided in Figure 1.

Figure 1. Representative Machine Layout Plan

Table 2 presents the required number of operators for the corresponding machine groups. For example, each machine coded 245-T requires one operator, whereas two different machines coded TU-65 can be operated by a single operator, and three different machines coded TU-150 require two operators to operate. The jobs are expected to be assigned to the machines, and the operators are expected to be assigned to the machine groups. The second objective of this study is to process the required jobs throughout the planning horizon using the minimum number of operators.

Table 2. Machine Groups and Required Number of Operators

Machine Group	Number of Machines	Required Number of Operators
TU65	28	1 per 2 machines
TU150	12	2 per 3 machines
245 T	4	1 per machine
400T	6	1 per 2 machines
GRES	3	1 per machine

Mathematical Model

This section presents the mathematical model for the multi-resource-constrained, multi-objective parallel machine scheduling problem addressed in this study. The model is designed to simultaneously determine decisions such as assigning jobs to machines, assigning machines to operators, and assigning molds to machines. Additionally, both minimizing total tardiness and maximizing operator efficiency are addressed within a multi-objective optimization framework.

First, the indices, parameters, and decision variables used in the model are defined; then, the objective functions and constraints guiding the problem's solution are explained in detail. In developing the model, a realistic planning approach was adopted by considering production-specific characteristics, operator-machine matchings, and the batch production structure.

Indices and Sets

To build the model, the indices and sets representing the key elements of the problem jobs, machines, machine groups, and operators are first defined. These indices and sets are used to properly express the decision variables and constraints in the model. Table 3 summarizes all the indices and sets used in this study.

Table 3. Indices and Sets Used in the Model

Symbol	Description
i, j	Job indices (set of jobs)
k	Machine index
g	Machine group index
l	Operator index
Mi	Set of machines available for job i
Mg	Set of machines belonging to machine group g

Parameters

The parameters used in the model are defined to describe the characteristics of the jobs, machine and operator capacities, time constraints of the system, and other operational requirements. Table 4 presents the parameters used in the study along with their descriptions.

Table 4. Parameters Used in the Model

Symbol	Description
p_i	Processing time for one batch of job i (minutes)
b_i	Batch size of job i
s_i	Setup time required for job i
n_i	Number of molds available for job i
t_i	Delivery time of job i
d_i	Total quantity required for job i
nM_i	Number of molds available for job i
nO_g	Number of operators required for machine group g
nM_g	Total number of machines in machine group g
nG	Total number of machine groups in the workshop
τ	Daily working time (minutes)
δ	A constant used to represent large numbers in the model (big M)

Decision Variables

The decision variables defined in the model are formulated to determine the assignment of jobs to machines and operators, the start and end times of jobs, and the usage status of machine and operator groups. Table 5 presents all the decision variables used in the study along with their descriptions.

Table 5. Decision Variables Used in the Model

Variable	Description
x_{ik}	1 if job i is processed on machine k; 0 otherwise
y_{ikl}	1 if job i on machine k is processed by operator l; 0 otherwise
w_{lg}	1 if operator l is assigned to machine group g; 0 otherwise
Z_g	1 if at least one machine in machine group g is active; 0 otherwise
u_{ijk}	1 if job i is processed before job j on the same machine k; 0 otherwise
c_{ik}	Quantity of job i assigned to machine k
sM_{ik}	Start time of processing job i on machine k
cM_i	Completion time of job i
sO_{ikl}	Start time for operator l to process job i on machine k
sS_{ik}	Setup start time for job i on machine k
T_i	Tardiness time of job i
Γ_g	Efficiency of machine group ggg over the planning horizon

Assumptions

To ensure the accuracy of the model and simplify the solution process, several key assumptions have been made. These assumptions have been determined in accordance with the characteristics of the production environment and resource usage, increasing the model's alignment with real-world conditions. The assumptions adopted in this study are presented below:

- Once a job i is assigned to a machine k, the assigned quantity c_{ik} is processed continuously without interruption.
- Each job can be processed simultaneously on as many different machines as the number of molds nM_i available.
- An operator can work on multiple machines simultaneously; however, at most one operator can be actively assigned per machine.
- The number of operators required to operate a machine depends on the machine group, and this ratio is at most ½ (i.e., one operator can supervise two machines).
- Throughout the planning horizon, operators remain fixed within their assigned machine groups; operator changes are not allowed.

Mathematical Model Formulation

This section presents the mathematical formulation of the multi-resource-constrained, multi-objective parallel machine scheduling problem addressed in this study. The model aims to achieve two objectives: minimizing total tardiness and maximizing operator efficiency. The developed decision variables and constraints are designed to realistically reflect the dynamics of the production environment and resource utilization.

Objective Functions

The model includes two main objectives:

- **Obj1:** Minimize total tardiness
- **Obj2:** Minimize the number of operators

The composite objective function is formulated as follows:

$$OBJ = W1 * Obj_1 + W2 * Obj_2$$

$$Obj_1 = Min. \sum_i Ti$$

$$Obj_2 = Min. \sum_g nO_g * Z_g$$

Here, T_i is the tardiness time exceeding the delivery date for job i, and nOg is the number of operators required for the active machine group g. W_1 and W_2 are the corresponding weight coefficients.

Constraints

The constraints included in the model are defined as follows:

Constraint 1 ensures that each job i is assigned to at least one machine:

$$\sum_{k \in M_i} Xik \geq 1 \qquad \forall i \qquad (1)$$

Constraint 2 ensures that each job i is assigned to no more than nM_i different machines, based on the available and predetermined number of molds for that job:

$$\sum_{k \in M_i} Xik \leq nM_i \qquad \forall i \qquad (2)$$

Constraint 3 ensures that each operator l is assigned to at most one machine group g:

$$\sum_g Wlg \leq 1 \qquad \forall l \qquad (3)$$

Constraint 4 enforces that if job iii is not assigned to machine kkk, the variable sM_{ik} is set to zero:

$$sM_{ik} \leq x_{ik} * \delta \qquad \forall i,k \qquad (4)$$

Constraint 5 sequences job pairs iii and jjj assigned to the same machine k:

$$sM_{jk} \geq sM_{ik} + p_i - (1 - u_{ijk}) * \delta \qquad \forall k \in M_i \cap M_j, \forall i,j; i \neq j \qquad (5)$$

Constraint 6 sets the binary variable indicating the processing order between job pairs i and j on machine k:

$$u_{ijk} + u_{jik} = x_{ik} * x_{jk} \qquad \forall i,j,k \qquad (6)$$

Constraints 7, 8, 9, 10 are the linearized form of Constraint 6:

$$\alpha_{ijk} \leq x_{ik} \qquad \forall i,j,k;\ i \neq j \qquad (7)$$

$$\alpha_{ijk} \leq x_{jk} \qquad \forall i,j,k;\ i \neq j \qquad (8)$$

$$\alpha_{ijk} \geq x_{ik} + x_{jk} - 1 \qquad \forall i,j,k;\ i > j \qquad (9)$$

$$u_{ijk} + u_{jik} = \alpha_{ijk} \qquad \forall i,j,k;\ i > j \qquad (10)$$

Constraint 11 calculates the completion time cM_i of each job i:

$$cM_i \geq sM_{ik} + p_i * (c_{ik}/b_i) \qquad \forall i,k \qquad (11)$$

Constraint 12 calculates the tardiness T_i of each job i:

$$T_i \geq cM_i - t_i \qquad \forall i \qquad (12)$$

Constraint 13 ensures that the total number of operators assigned to machine groups does not exceed the available workforce capacity:

$$\sum_l \sum_g w_{lg} \leq L \qquad (13)$$

Constraint 14 enforces that if job i is assigned to machine group g, at least one operator must be assigned to that group:

$$\sum_l w_{lg} = nO_g * Z_g \qquad \forall g \qquad (14)$$

Constraint 15 indicates that if job i is assigned to machine k within machine group g, then the group is active:

$$x_{ik} \leq Z_g \qquad \forall i, g, k \in M_g \qquad (15)$$

Constraint 16 ensures that the total quantity of job i assigned across all machines equals its demand:

$$\sum_k c_{ik} = d_i \qquad \forall i \qquad (16)$$

MODEL CHARACTERISTICS AND DISCUSSION

The multi-resource-constrained, multi-objective parallel machine scheduling model developed in this study goes beyond classical scheduling approaches by comprehensively addressing the realistic constraints encountered in production environments. The model not only considers machine utilization but also integrates the simultaneous management of mold and operator resources, aiming to improve overall resource utilization efficiency. Production-specific applications, such as allowing each job to be processed simultaneously on as many machines as the number of molds available and assigning operators fixedly to machine groups, have been incorporated into the model.

The multi-objective structure of the model enables balancing the often conflicting goals frequently seen in production systems. On the one hand, by minimizing total tardiness, it contributes to customer satisfaction and on-time delivery; on the other hand, by reducing the number of operator resources used, it seeks to enhance efficiency. As a result, the scheduling process achieves a more balanced and effective management of both time and workforce.

While many scheduling studies in the literature focus solely on machine planning, this study simultaneously considers multiple resource constraints, such as mold counts, operator capacities, and batch production. In this respect, the proposed model offers a structure that is closer to the real-world complexity of production environments and increases its potential for practical application. Moreover, modeling the fixed assignment of operators to machine groups and their ability to manage multiple machines simultaneously provides a more flexible and optimized workforce planning compared to classical operator assignment problems.

One of the strengths of the model is its focus on efficient resource use even in very large-scale problems and its flexible design that can adapt to different production scenarios. However, it should be noted that the use of the big-M parameter (δ) in the solution may increase the linear programming solution times for large-scale problems. In this context, future studies are planned to develop specialized solution algorithms and heuristic/metaheuristic methods for large data sizes.

In conclusion, the proposed model contributes to the literature in terms of multi-resource management, multi-objective optimization, and the integration of practical production constraints, and it has the potential to generate positive impacts, especially on critical performance criteria such as operator management, mold utilization optimization, and delivery performance.

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AN INNOVATIVE APPROACH TO PRODUCTION PLANNING: OPTIMIZATION SOLUTIONS IN A DETERGENT FACTORY

ÜRETİM PLANLAMASINDA YENİLİKÇİ BİR YAKLAŞIM: DETERJAN FABRİKASINDA OPTİMİZASYON ÇÖZÜMLERİ

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ÖZET

Bu çalışmada, deterjan üretim fabrikasında üretim planlaması problemine yenilikçi bir optimizasyon yaklaşımı sunulmuştur. Üretim süreçlerinin verimliliğini artırmak ve maliyetleri minimize etmek amacıyla doğrusal programlama yöntemi kullanılarak matematiksel bir model geliştirilmiştir. Çalışma, fabrikadaki üretim verileri ve mesai süresi ile üretim tercihlerini dikkate alarak, optimal üretim planlamasını hedeflemektedir. Modelin çözümü, Lindo programı ile gerçekleştirilmiş ve en uygun üretim planı belirlenmiştir. Bu modelin kullanımıyla, üretim kapasitesinin ve fazla mesai gereksinimlerinin dengelenmesi sağlanarak, üretim maliyetleri ve kar marjları optimize edilmiştir. Sonuçlar, bu yenilikçi yaklaşımın fabrikaların üretim süreçlerinde maliyetleri azaltmak ve verimliliği artırmak için etkili bir çözüm sunduğunu göstermektedir.

Anahtar Kelimeler: Üretim Planlama, Kapasite Planlama, Optimizasyon, Doğrusal Programlama.

ABSTRACT

This study presents an innovative optimization approach to production planning problems in a detergent manufacturing factory. A mathematical model is developed using linear programming to increase production process efficiency and minimize costs. The study focuses on optimal production planning by considering production data and shift preferences, aiming to balance normal and overtime production effectively. The solution of the model is carried out using Lindo software, determining the most optimal production plan. Through this approach, production costs and profit margins are optimized by balancing production capacity and overtime requirements. The results demonstrate that this innovative approach provides an effective solution to reduce costs and increase efficiency in manufacturing processes.

Keywords: Production Planning, Capacity Planning, Optimization, Linear Programming.

UTILIZATION OF SOLAR ENERGY BASED TECHNOLOGIES IN GREENHOUSES

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Abstract

Nowadays, increasing energy costs, environmental concerns and food safety issues have increased the interest in sustainable and renewable energy solutions in agricultural production. The operation of systems such as air conditioning, lighting and irrigation, which have high energy intensity in greenhouse production, makes the integration of renewable energy sources mandatory. This study examines the potential of solar energy-based technologies in greenhouse applications and evaluates the technical and functional aspects of photovoltaic (PV), solar thermal collectors (STC) and hybrid photovoltaic/thermal (PV/T) systems. Although PV panels offer significant advantages in terms of electricity generation, they block sunlight, which can lead to shading problems that can negatively affect plant growth. Therefore, alternative approaches such as semi-transparent PV modules, dynamic systems and concentrator technologies are being developed. PV/T systems have the potential to increase energy efficiency in greenhouses with the capacity to generate both electricity and heat energy. Within the scope of the study, the status, implementation challenges and economic/sustainability of these technologies were evaluated, and the contributions of solar energy use in greenhouse systems in terms of efficiency, cost and environmental benefits were revealed. In conclusion, solar energy technologies offer a strong alternative to reduce energy consumption, increase production efficiency and minimize environmental impacts in greenhouse systems.

Keywords: Solar energy, Greenhouse, Solar thermal, Photovoltaic, PV/T.

Introduction

It is observed that there is a significant increase in energy supply in the world due to developing technologies, global warming caused by CO_2 emissions resulting from the use of fossil fuels and population growth. To meet the energy demand, countries are making significant investments to meet this demand by supporting the orientation of scientists towards alternative energy sources. The shift towards renewable energy sources in the energy sector is very important in terms of meeting the energy demand in the agricultural sector, ensuring food security and sustainable agriculture (Tiwari & Ghosal, 2007). Greenhouse agriculture has an important place in agriculture to meet food demand. The most important factor in greenhouse cultivation is to provide the most suitable atmosphere (temperature, humidity, light, CO_2 ratio) for the development of crops (La Notte et al., 2020; Shamshiri et al., 2018). Providing suitable environmental conditions varies according to the type of greenhouse, the country, region and the tobacco crop to be grown. In hot countries, cooling the greenhouse is very important, while in cold countries, light and heating factors are very important (Mariani et al., 2016; McCartney & Lefsrud, 2018). To bring the ambient conditions in greenhouses to optimum conditions, systems with high energy consumption such as heating, cooling, lighting and irrigation are used. Since the energy needs of these systems are met with energy obtained from fossil energy sources, it is obvious that it may cause economic increase and increase in greenhouse gas emissions (Naghibi et al., 2020; Chai et al., 2012). To prevent the increase in the economy and greenhouse gas emissions, turning to environmentally friendly and sustainable renewable energy

sources in greenhouse cultivation is an important step both in terms of economy and to eliminate global warming (Brooks et al., 2013; Gorjian, et al., 2020; Hassanien et al., 2016). Solar energy, as an environmentally friendly and inexhaustible renewable energy source, is very important in reducing energy costs and greenhouse gas emissions in greenhouse agriculture. Greenhouses are usually built in open areas that do not block solar radiation, and this makes it clear why we should prefer solar energy both for photosynthesis and for the energy needs of greenhouses (McCartney & Lefsrud, 2018). The amount of solar radiation reaching the greenhouses varies depending on factors such as the structure of the covering material of the greenhouses, permeability, dust content of the covered material, etc. (Marucci et al., 2012). The integration of solar energy technologies such as photovoltaic (PV) modules, concentrating photovoltaic (CPV) modules, photovoltaic thermal (PV/T) collectors, concentrating photovoltaic thermal (CPV/T) collectors and solar thermal collectors, or systems with thermal or electrical energy storage in these technologies into greenhouses meets the energy needs of greenhouses in significant amounts (Cossu et al., 2020; Cuce et al., 2016; La Notte et al., 2020). PV modules can be integrated into greenhouses, but in rooftop applications of PV modules, photosynthesis is negatively affected due to the shading effect and plant growth is not as desired. To eliminate this negative effect, different applications have been realized by researchers. These are alternative solutions such as semi-transparent PV modules, organic PV modules, dynamic PV systems and concentrating solar technologies. PV/T and CPV/T systems stand out as alternative energy technologies in terms of meeting an important part of the energy consumption of greenhouses in terms of their ability to generate heat and electricity at the same time. Due to their high electrical and thermal efficiency, PV/T and CPV/T technologies can optimize the relationship between energy demand and crop growth in greenhouses (Allardyce et al., 2017; S. Tiwari et al., 2016; Vadiee & Martin, 2013). In this study, the use of solar energy-based technologies in greenhouse agriculture is comprehensively evaluated from a technical, economic and environmental point of view. In addition, the challenges and areas for improvement in greenhouse applications with PV modules, STC and PV/T collectors were discussed. Economic and environmental evaluations of solar energy technologies used in greenhouse agriculture were made and conclusions and recommendations were made.

The Use of Solar Energy Technologies in Greenhouses

Solar energy technologies are utilized in three different energy types: electrical (PV, CPV), thermal (STC) or electrical and thermal (PV/T, CPV/T) energy. In thermal technologies, solar radiation is converted into thermal energy by flat plate or concentrating solar collectors and used directly or stored in various fields (Mekhilef et al., 2011). In PV systems, solar radiation is directly converted into electrical energy with the help of semiconductor materials (crystalline or organic materials) and used in various fields with different system designs. In PV/T and CPV/T systems, which are formed by combining these two technologies, solar radiation is converted into electrical and thermal energy, saving space and providing economic benefit by increasing the useful energy opportunity. All three technologies are used in agricultural production, especially in greenhouse agriculture, to increase yields, reduce losses and ensure the sustainability of favourable environmental conditions (Mohsenipour et al., 2020). Energy production and storage methods applied in greenhouses vary depending on factors such as the climate of the region where the greenhouse is located, its size and the type of crops grown (Gorjian et al., 2021). Greenhouses are classified as active and passive greenhouses. In passive greenhouses, energy is obtained from solar energy with the greenhouse structure, while in active greenhouses, energy is obtained by integrating solar energy technologies such as STC, PV, CPV, PV/T and CPV/T into greenhouses (Panwar et al., 2011). Figure 1 shows an example of a passive greenhouse application.

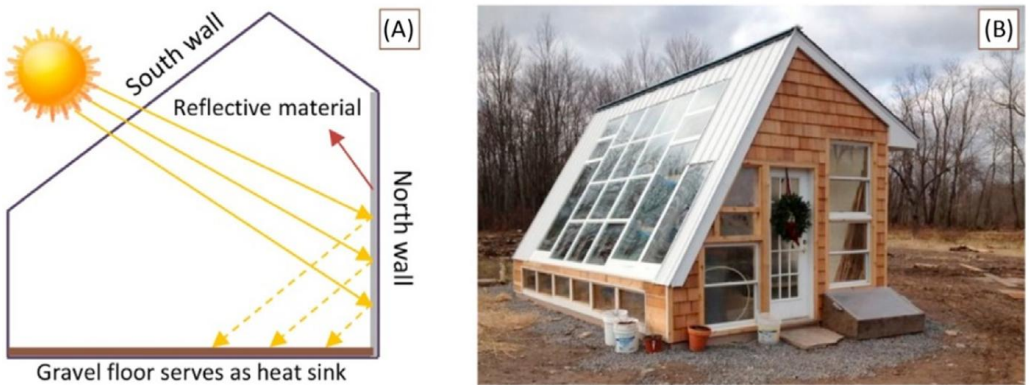

Figure 1. (A) Representative schematic of a classical passive greenhouse; (B) passive greenhouse application (Gorjian et al., 2021)

Storage systems using batteries or thermal energy storage (TES) materials are used in active and passive greenhouses to increase the sustainability of solar energy and crop yields in greenhouses (Du et al., 2021). While passive greenhouses stand out with their low investment costs, active greenhouses can compensate their costs in the long term with the high thermal and electrical performance they provide (Shukla et al., 2016).

Photovoltaic (PV) Systems in Greenhouses

Agriculture is one of the sectors that benefit from solar energy in energy production due to the increase in energy prices and the increase in greenhouse gas emissions due to the use of fossil fuel resources and the possibility of depletion of fossil fuels. The integration of PV technology, one of the most widely used solar energy technologies in these sectors, into greenhouse agriculture has gained importance in recent years (Cossu et al., 2020; Marcelis & Heuvelink, 2019). PV modules are preferred to provide the energy required for heating, cooling, lighting and irrigation systems through on-grid or off-grid systems, either on the roofs of greenhouses or by integrating greenhouses with dynamic systems (Figure 2). The use of PV systems in greenhouses plays an important role in balancing global warming and energy economy factors (Ezzaeri et al., 2018; Marucci & Cappuccini, 2016).

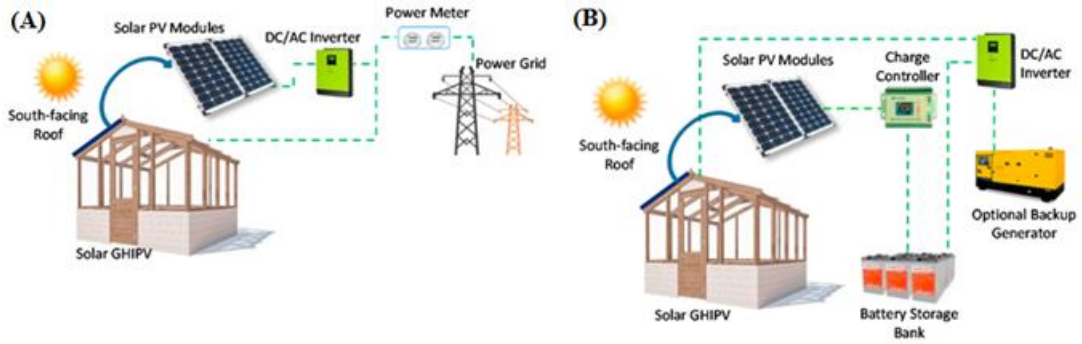

Figure 2. Greenhouse integrated PV systems (A) on grid (B) off grid (Gorjian, et al., 2021)

One of the most important obstacles in the use of PV systems in greenhouses is that opaque PV modules can completely or partially block the photosynthetically active radiation (400-700 nm) coming into the greenhouse, negatively affecting plant growth and thus leading to decreases in crop yields (Ezzaeri et al., 2020). Ezzaeri et al. (2018), in their study, stated that conventional PV modules resulted in yield loss in light-sensitive crops such as tomatoes and peppers because of the excessive use of coverage ratio in rooftop greenhouse application. Bulgari et al. (2015), in their study, stated that significant reductions in lycopene and sugar contents of tomato fruit were observed in greenhouses with 50% PV roofing area. Based on these studies, scientists have concluded that light

transmittance and the ability to provide the optimum conditions necessary for plant growth are very important in the integration of PV systems in greenhouses. For this reason, researchers have mostly turned to translucent PV module technology using polycarbonate or glass modules with PV modules, luminescent PV modules, organic PV modules and dye-sensitized PV cells as alternatives in PV system application studies in greenhouse agriculture applications. In the greenhouse application of semi-transparent PV modules, it has been observed that the modules transmit sunlight at certain wavelengths, allowing both the generation of electrical energy and not interfering with plant photosynthesis and, consequently, plant growth efficiency (Kumar et al., 2022). Buttaro et al. (2016) conducted a study to observe the effects of conventional PV, polycarbonate modules and semi-transparent PV modules on crop yields and reported that in the greenhouse where semi-transparent PV modules were used, crop growth efficiency was maintained and the light distribution in the greenhouse was homogeneous compared to other treatments (Figure 3).

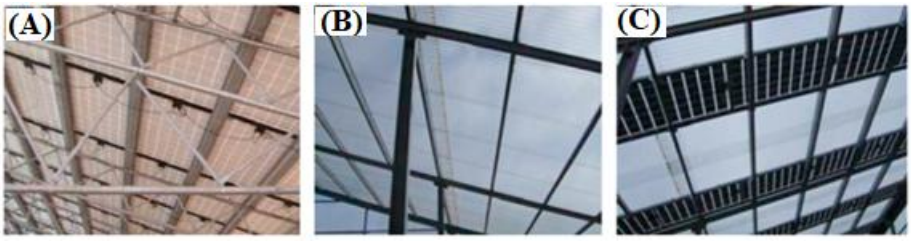

Figure 3. Different greenhouse roof applications. (A) conventional PV module (B) Polycarbonate module (C) translucent PV module (Buttaro et al., 2016)

In another study, Corrado et al. (2016) reported that luminescent solar concentrator (LSC) PV modules provide 37% more electricity generation compared to conventional PV modules and do not have a negative impact on plant growth with homogeneous light distribution (Figure 4).

Figure 4. (A) PV module reference greenhouse application, (B) LSC-PV module greenhouse application (Corrado et al., 2016)

Another solar energy technology used to eliminate the shading effect of PV modules in greenhouse application is organic photovoltaic PV (OPV) module application (La Notte et al., 2020). Due to their transparent and flexible structure, OPV modules do not prevent the photosynthesis of crops by transmitting certain wavelengths of light in sunlight and thus crop growth is not adversely affected. Thus, the desired product yield can be obtained in greenhouse agriculture. However, when OPVs are exposed to high solar radiation, energy efficiency decreases. This situation is undesirable and open to improvement (Magadley et al., 2020; Okada et al., 2017; Shi et al., 2019). Magadley et al. (2020) experimentally investigated the outdoor performance of OPV modules in greenhouse agriculture. They stated that the efficiency of OPV modules decreased under high solar radiation conditions and that they obtained 3 kWh/m^2 of electrical energy at 26% OPV roof coverage rate (Figure 5).

Figure 5. OPV module greenhouse application a) outdoor b) indoor view (Magadley et al., 2020)

PV modules obtained from dye-sensitized solar cells (DSSC), one of the solar energy technologies that are currently tested in the laboratory environment and not used in commercial applications, are preferred in greenhouses. DSCC PV module technology has a transparent and flexible structure like OPVs. The lightweight and flexible structures of DSSC modules provide significant advantages in terms of structural integration, especially in greenhouses with plastic covers and pitched roofs (Roslan et al., 2018). Table 1 summarizes the studies and findings of PV system integrated applications in greenhouses.

Table 1. Studies on PV system applications in greenhouses

Researchers	PV Technology	Application	Key Findings
Yano et al. (2010)	Semi-transparent PV (12.9% coverage)	Roof-integrated, checkerboard layout	Electricity generation and uniform light distribution
Cossu et al. (2014)	Polycrystalline PV (50% coverage)	Partial roof coverage	64% reduction in sunlight; 18% light loss in distant rows
Marucci et al. (2017)	Flexible semi-transparent PV	Curved greenhouse surface	Annual shading kept below 40%
Hassanien & Ming (2017)	Semi-transparent mono-Si PV (20% coverage)	Combination with polyethylene film	35–40% light loss on sunny days; limited shading impact
Colantoni et al. (2018)	Fixed and mobile semi-transparent PV	Roof-mounted	Improved light transmission with mobile systems
Zisis et al. (2019)	Organic PV (22% coverage)	Roof-mounted	20.2% increase in fruit yield and 21.8% increase in plant height for pepper crops

In conclusion, semi-transparent PV modules, LSC technologies and organic PV modules are widely used in rooftop or dynamic applications in greenhouse agriculture as they provide better light-electric balance, better energy production and product quality compared to conventional PV modules. The use of these technologies in greenhouses with appropriate design and integration will play an important role in sustainable energy, economic and environmental future.

Photovoltaic/Thermal (PV/T) Systems in Greenhouses

Increasing the surface temperature of crystalline PV modules decreases the electrical efficiency. Photovoltaic/thermal (PV/T) systems have been developed to increase the efficiency and lifetime of PV modules and to utilize the heat extracted by heat exchangers placed behind the modules, and these systems have gained an important place in solar energy technologies (Shakouri et al., 2020). The classification of PV/T modules is shown in Figure 6.

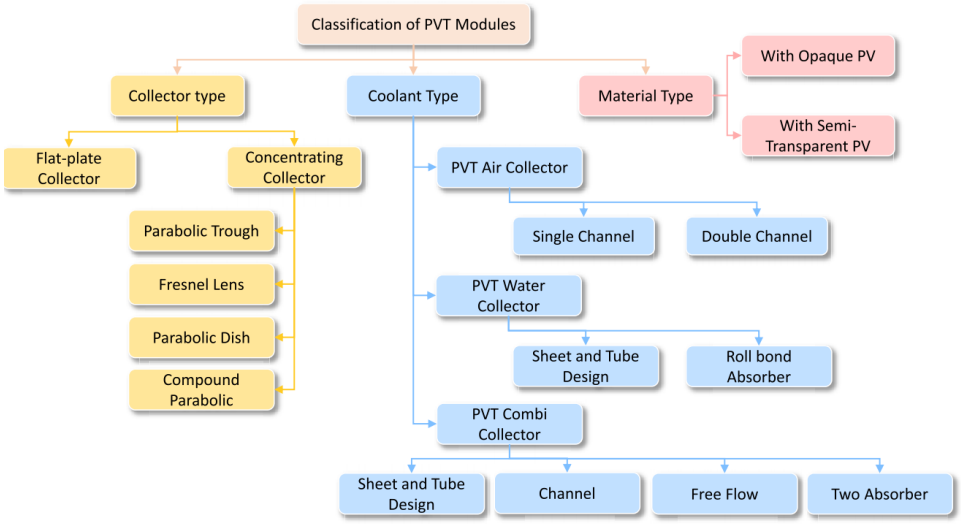

Figure 6. PV/T module types (Gorjian, et al., 2021)

The heat extracted through the fluids used in the thermal modules of PV/T systems is used in areas such as low and medium temperature greenhouse air conditioning. In a flat-roof greenhouse application in India, Nayak & Tiwari (2008) used 9.68 m² PV/T modules to generate 716 kWh of electricity and 21,291 kWh of thermal energy per year. Nayak & Tiwari, (2009) reported that the PV/T system integrated with a ground-air heat exchanger contributed 7-8% to the temperature increase inside the greenhouse during winter months. Mahdavi et al. (2019) stated that the optimum energy balance is achieved in the greenhouse by passing the heat obtained from the fluid passed through PV/T modules through pipes laid on the greenhouse floor. In order to increase the electrical and thermal efficiency obtained from PV/T systems and to use these systems in high temperature applications, concentrator photovoltaic thermal (CPV/T) systems, which are solar energy technologies that allow more utilization of solar radiation by means of Fresnel lenses, parabolic trough, compound parabolic trough concentrators, are preferred in greenhouses (Sharaf & Orhan, 2015; Sonneveld et al., 2010). The types of concentrators used in CPV/T modules are given in Figure 7.

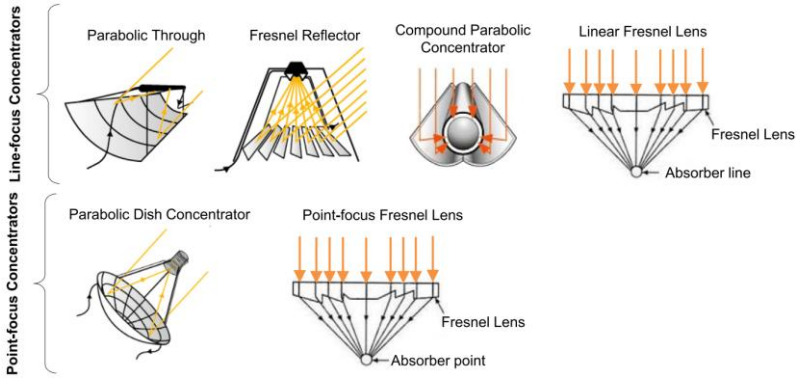

Figure 7. Types of concentrators (Gorjian, et al., 2021)

CPV/T systems provide a great advantage in producing the energy required for greenhouses in regions with low solar radiation. Sonneveld et al. (2010) used selective reflective coating with Fresnel lens on the greenhouse roof. They reported that the shading rate in the greenhouse was 3.3% and 32.5 kWh/m² thermal -18 kWh/m² electrical energy was produced annually. Figure 8 shows examples of greenhouse applications of PVT modules.

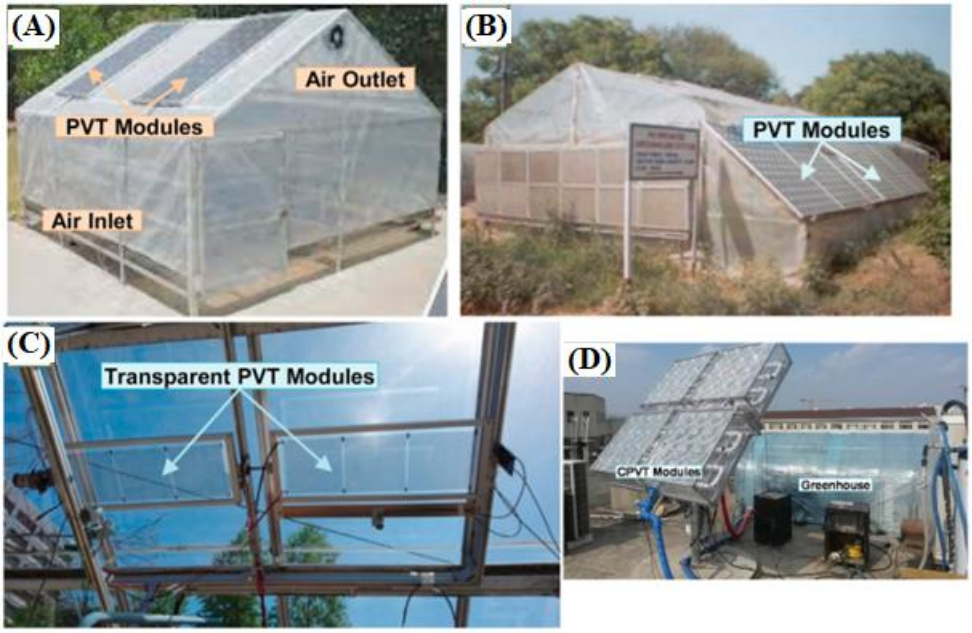

Figure 8. PV/T and CPV/T module greenhouse applications (A) PV/T module, roof (Barnwal & Tiwari, 2011) (B) PV/T module, roof (Nayak & Tiwari, 2008) (C) translucent PV/T with glass module, roof (Zhi Li et al., 2018) (D) Fresnel lens CPV/T, dynamic (Hussain et al., 2016).

Some of the studies on the use of PV/T systems in greenhouses are summarized in Table 2.

Table 2. PV/T system greenhouse application examples.

Researchers	PV/T Technology	Application	Key Findings
Chaysaz et al. (2019)	Flat-Plate PV/T (FP-PVT)	Rooftop / 5.8 m²	59.9% PV/T efficiency under glass cover
Sonneveld et al. (2011)	CPV/T (LFC)	Rooftop / 36 m²	75% solar radiation reduction; 29 kWh/m² electricity and 144 kWh/m² thermal energy annually
Sajid & Bicer (2021)	Flat-Plate PV/T (FP-PVT)	Dynamic / 24 m²	Cost-effective electricity, cooling, and water production
Wu et al. (2020)	CPV/T with parabolic Fresnel lens	Chinese-style greenhouse / 18.2% unplanted area	18% electrical and 45% thermal efficiency achieved

Considering parameters such as energy efficiency depending on the placement angle of PV/T and CPVT modules in greenhouses and light transmittance, which is important in plant growth, depending on the transparency rate of greenhouse roofs, it is concluded that PV/T and CPVT technologies are an important technology in terms of energy efficiency, economy and environmental sustainability in greenhouse applications.

Solar Thermal Collector (STC) Systems in Greenhouses

Solar thermal collectors (STC) are used in different temperature applications by transferring solar radiation to different heat transfer fluids such as air, water or nanofluids through the absorber surface they contain. The energy efficiency of STC systems varies according to the collector type, structure configuration and heat transfer mechanism (Buker & Riffat, 2015). STCs are divided into two main groups: with and without condensers (Figure 9) (Evangelisti et al., 2019).

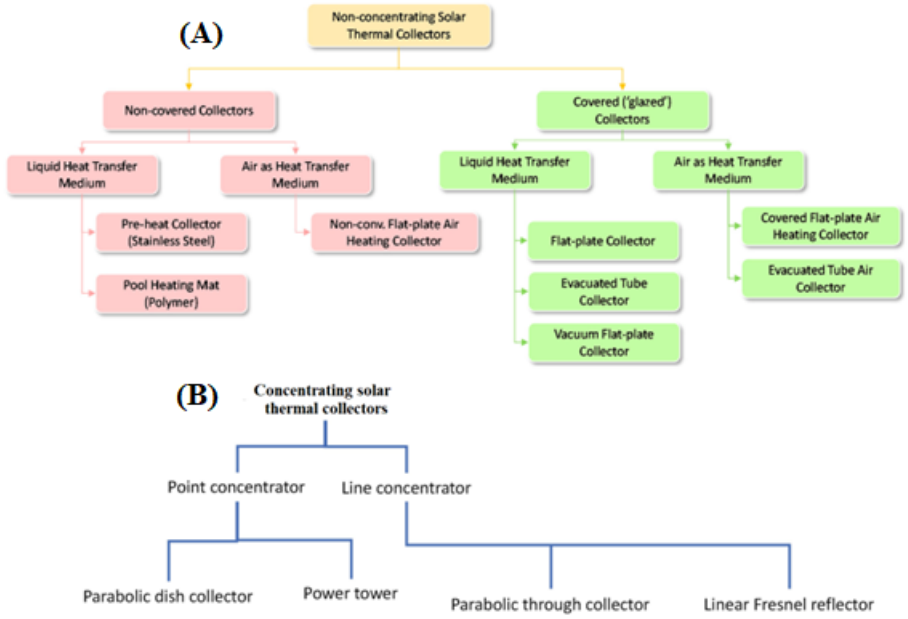

Figure 9. Types of solar thermal collectors (A) without concentrator (B) with concentrator (Evangelisti et al., 2019; Gorjian et al., 2021; Petrovic & Hossain, 2021).

Concentrator STCs are the types of concentrators used in CPV/T technology that focus the solar radiation on a single point or plane, enabling fluid at high temperatures. These temperatures generally range from 50 °C to 1000 °C and are preferred for high temperature applications. Non-concentrator STCs absorb solar radiation directly through the absorber surface, enabling low-temperature fluidization. Fluid temperatures in these systems generally range between 30 °C and 80 °C and are preferred for low temperature applications. Flat plate (FPC) or vacuum tube collectors (ETC) are chosen for low to medium temperature applications such as greenhouse agriculture (usually as dynamic systems or mounted on the north wall of the greenhouse). In north wall applications with FPC, it has been determined that day and night thermal balance is maintained, especially in Chinese greenhouses (Xu et al., 2020). In their study, Hassanien et al. (2018) reported that the internal temperature of the greenhouse was 2-3 °C higher than the reference greenhouse and more than 35% of the thermal energy required for the greenhouse was met by providing the heat obtained from an ETC system to the greenhouse. Concentrator thermal collectors are preferred in greenhouse applications due to their contribution to important indicators such as microclimate conditions, plant growth, product yield, cost and depreciation periods. Fresnel concentrator systems with high thermal-optical efficiency and low cost are generally used in concentrator STCs in greenhouses. In a greenhouse application in South Korea, the thermal performance of spot-focused and plane-focused Fresnel concentrators were comparatively evaluated, and it was found that the thermal efficiency of the system using spot-focused Fresnel was 7-12% higher (Hussain et al., 2015). In an application in Beijing, it was experimentally observed that the Fresnel lens system increased the temperature of the greenhouse soil by about 4 °C and improved the climate inside the greenhouse (Zhiyong Li et al., 2019). In greenhouse agriculture, parabolic trough collectors (PTC) have been used in heating applications and have provided positive effects on crop growth (Grigoriu et al., 2015). Chen et al. (2020) found that in greenhouse experiments with parabolic trough collectors, greenhouse indoor air temperature increased by 1.8 °C and soil temperature increased by 1.5 °C on average during the night. Example studies of different solar collector applications in greenhouses are given in Figure 10.

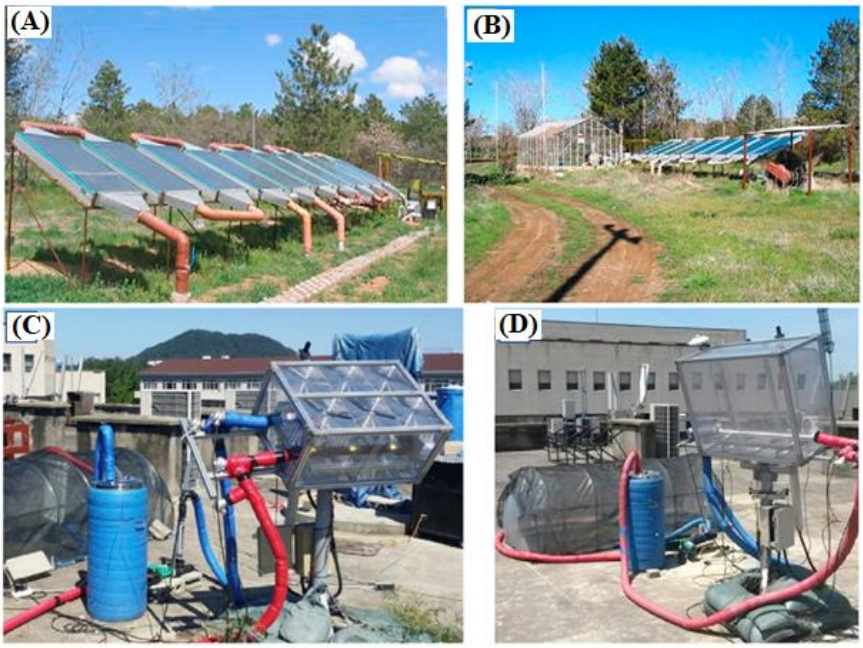

Figure 10. Greenhouse applications with solar thermal collectors (A) and (B) flat plate solar collector (Benli & Durmuş, 2009) (C) spot Fresnel lens (D) linear Fresnel lens (Hussain et al., 2015).

Some of the studies in the literature on the use of solar thermal collector systems in greenhouses are given in Table 3.

Table 3. Studies on greenhouse applications with solar thermal collectors.

Researchers	Collector Technology	Application	Key Findings
Wang et al. (2005)	FPC	Standard greenhouse	Daytime internal temperature exceeded 60°C; 9°C higher than outside in the morning
Kumari et al. (2006)	FPC	Flat-roofed greenhouse	Plant canopy temperature was 12°C higher compared to reference greenhouse
Lazaar et al. (2015)	ETC	Tunnel-type greenhouse	Nighttime temperature increased by 2°C; energy efficiency ranged from 25% to 80%
Semple et al. (2017)	FPC	Commercial greenhouse	64% of annual heating needs met; 7-year payback period
Bazgaou et al. (2021)	FPC	---	55% improvement in crop quality and yield during winter

Studies in the literature show that STCs provide significant thermal, economic and environmental benefits in greenhouse applications. In these applications, FPC and Fresnel concentrator collectors are generally preferred, and these collectors provide very good thermal efficiency and crop growth in greenhouse agriculture in different regions. To ensure continuity in a discontinuous renewable energy type such as solar energy and a continuous application such as greenhouse cultivation, thermal energy storage processes are carried out using phase change materials in solar thermal collector systems and photovoltaic technologies. With thermal energy storage systems, environmental-economic sustainability in greenhouse farming is increased.

Economic and Environmental Evaluation of Solar Energy Technologies in Greenhouses

It can be said that solar energy technologies meet the electrical and thermal energy requirements in greenhouse agriculture by offering economically and environmentally sustainable solutions. However, the continuity of in-greenhouse air conditioning due to processes such as heating, cooling, lighting and irrigation is very important in terms of product development and yield. The lack of continuous solar energy significantly affects the continuous and optimum performance of the systems using these technologies (Xu et al., 2020), especially in winter months and cloudy days due to the decrease in radiation intensity (Gorjian et al., 2020; Hassanien et al., 2018). For this reason, additional energy sources are needed to provide the targeted climatic conditions in the greenhouse. In addition, an efficient energy storage system should be used to ensure the sustainability of solar energy in greenhouse energy applications. With the batteries and phase change materials (PCM) used in electrical and thermal energy storage systems, it is very important to maintain the climate conditions in the greenhouse at an optimum level during sunless days or night hours. In PV and PV/T system rooftop experiments with conventional PV modules, the shading effect caused by the integration of PV modules on the greenhouse roof or walls affects the development of plants in the greenhouse and reduces crop yields (Li et al., 2019). Semi-transparent PV, OPV modules or dynamic monitoring systems are used as solutions (Sonneveld et al., 2011). Considering all these reasons together, it is necessary to develop solar energy technologies used in greenhouses from an economic point of view. The initial costs of components such as PV panels, thermal collectors, energy storage units and monitoring systems directly affect the initial investment decisions for the installation of integrated solar energy systems in greenhouses due to the additional system requirements and the prolonged depreciation period due to the lack of continuous solar energy (Benli & Durmuş, 2009; Sajid & Bicer, 2021). In addition, to keep the climatic conditions in greenhouses under favorable conditions, it is mandatory to carry out cleaning (dusting and contamination of the surfaces of PV modules and STCs), maintenance and repair requirements of the equipment for solar energy systems to work efficiently and provide energy efficiency at the desired capacity. This increases operating costs (Esen & Yuksel, 2013; Gourdo et al., 2019; Xu et al., 2020; Buker & Riffat, 2015). Solar energy systems are very important from an environmental point of view to reduce greenhouse gas emissions released because of the use of fossil fuels and to prevent climate changes due to global warming, and their use in greenhouse farming is becoming widespread as in many areas around the world (Chen et al., 2020; Hassanien et al., 2018). However, the environmental impacts of solar energy system equipment during the production process and at the end of their lifetime should also be taken into account. Waste management and recycling processes of metals used in PV modules and STCs are important for environmental sustainability goals (Grigoriu et al., 2015; M. Li et al., 2020). For these reasons, it is necessary to conduct an integrated environmental impact analysis of all stages from module selection to system design and from energy efficiency to product performance in solar energy systems to be developed for greenhouse applications. Scientists are conducting many experimental and numerical studies on system requirements, optimum system designs and system performances to ensure the economic and environmental sustainability of solar energy systems in greenhouse agriculture. The use of hybrid energy systems and the development of solutions specific to local conditions will make significant contributions to increasing the economic and environmental sustainability of solar energy systems in greenhouses.

Conclusion and Recommendations

In this study, the use of solar energy-based technologies in greenhouses is comprehensively discussed and the application potentials, technical challenges encountered, and environmental-economic sustainability aspects are examined in detail. PV systems meet greenhouse energy needs with electrical energy, STCs with thermal energy, and PV/T and CPV/T systems with electrical and thermal energy production, providing integrated energy solutions. However, the maximum utilization of solar energy in greenhouse applications requires careful optimization of many technical parameters such

as system design, module placement and light transmittance. Regional climate variability, seasonal irradiance fluctuations, high initial investment costs and the need for effective energy storage are among the main factors limiting the continuous and economic operation of the systems. In particular, ensuring the continuity required for in-greenhouse temperature control requires the use of efficient electrical and thermal energy storage systems. Although the use of solar energy systems in greenhouses offers significant environmental and economic advantages in the long term, the high initial investment costs constitute a significant obstacle for small-scale producers. Therefore, establishing financial support mechanisms and incentive programs is of great importance. Solar energy systems reduce dependence on fossil fuels, reduce greenhouse gas emissions and contribute to sustainable agricultural production. However, it is necessary to manage the environmental impacts that may arise during the production and disposal of the systems and to develop strategies for material recycling. As a result, solar energy systems are an important opportunity to meet energy needs in greenhouses in an environmentally friendly and efficient way. The following recommendations can be given to guide future studies in the use of solar energy systems in greenhouse agriculture.

- By optimizing the integration between the greenhouse structure and solar energy systems, both crop and energy efficiency can be increased.
- The use of electrical and thermal hybrid energy storage systems should be expanded to meet energy needs and greenhouse climate conditions.
- The use of low-cost and recyclable materials should be prioritized in solar energy technologies.
- To maximize system efficiency and equipment lifetime, solar energy systems should be regularly maintained and cleaned, and smart energy management systems should be expanded.

In conclusion, solar energy-based solutions in greenhouses offer a strong potential for sustainable agricultural production, and it is envisaged that this potential can be fully utilized if technology, design and management processes are handled with a holistic approach.

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ANALYSIS OF THE MECHANICAL AND ELECTRONIC PROPERTIES OF $XIrI_3$ PEROVSKITE COMPOUNDS

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ÖZET

Perovskit bileşikler, güneş pillerinden LED teknolojilerine, photodedektörlerden çevre teknolojilerine kadar pek çok konuda çalışma alanına sahiptir. Özellikle güneş pilleri ve LEDler gibi yenilenebilir enerji ve ekran teknolojileri alanında çığır açabilirler. Son zamanlarda, metal halide perovskitleri, güneş pili uygulamalarındaki önemli girişleri nedeniyle araştırmacı ağı için inanılmaz bir ilgi çekti. Aslında, bu tür malzemeler ayarlanabilir bant aralığı, geniş emilim spektrumu, yüksek optik emilim ve baskın nokta kusuru gibi ilginç Opto-elektronik özellikler sergilerler. Özellikle kurşun bazlı perovskitlerin toksik etkileri gibi dezavantaja sahip olması, metal perovskitleri ön plana çıkardı. Çalışmamızda $XIrI_3$(X: Sr, Ba, Ra) perovskite bileşiklerin mekanik ve elektronik özelliklerini analiz ettik.Tamamen teorik verilere dayanan çalışmamızı VASP programı ile gerçekleştirdik. VASP programı ilk ilkeler yöntemiyle kuantum mekanik yaklaşımları kullanan çok cisim problemlerini modellemede kullanılan lisanslı bir programdır. Bileşiklerin mekanik olarak test edilmesi bileşiklerin mekanik dayanımı, esnekliği ve kullanım alanı hakkında bilgi edilmesini açısından oldukça önemlidir. Bileşikler kübik yapıya sahip olup, C_{11}, C_{12} ve C_{44} elastik sabitlerine sahiptir. Born kararlılık şartının sağlanmasıyla mekanik parametreler hesaplanmıştır. Elastik sabitler, Bulk modülü, Young modülü, Poisson oranı, Zener anizotropi faktörü, ses hızı, Debye sıcaklığı ve erime sıcaklığı gibi mekanik özellikler elastik sabitler kullanılarak hesaplanmıştır. Malzemenin elektronik özellikleri, malzemenin doğası hakkında bilgi verirken, elektronik özelliklerin bilgisinin doğruluğu, bileşiğin fiziksel özelliklerinin çok hassas olmasına neden olur. Elektronik bant özellikleri, bileşiğin metalik karakterini doğruladı. Ayrıca, durumların toplam ve kısmi yoğunluklarının belirlenmesiyle, atomların ve orbitallerin elektronik özellikleri hakkında daha ayrıntılı bilgiler elde edildi.

Anahtar kelimeler: Perovskit, sünek, metal

ABSTRACT

Perovskite compounds have a wide range of applications, from solar cells to LED technology, photodetectors to environmental technologies. They have the potential to revolutionize renewable energy and display technologies, particularly in solar cells and LEDs. Recently, metal halide perovskites have attracted remarkable attention from the research community due to their significant contributions to solar cell applications. These materials exhibit intriguing optoelectronic properties, such as tunable band gaps, broad absorption spectra, high optical absorption, and dominant point defect characteristics. However, the toxic effects of lead-based perovskites have highlighted the importance of metal-based perovskites as safer alternatives. In this study, we analyzed the mechanical and electronic properties of $XIrI_3$ (X: Sr, Ba, Ra) perovskite compounds. Our research, entirely based on theoretical data, was carried out using the Vienna Ab initio Simulation Package (VASP), a licensed program that employs first-principles methods to model many-body problems using quantum mechanical approaches. Mechanical testing of the compounds is crucial to understanding their mechanical strength, flexibility, and potential application areas. The compounds exhibit a cubic

crystal structure and possess elastic constants C_{11}, C_{12}, and C_{44}. Mechanical parameters were calculated by satisfying the Born stability criteria. Using these elastic constants, various mechanical properties such as bulk modulus, Young's modulus, Poisson's ratio, Zener anisotropy factor, sound velocity, Debye temperature, and melting temperature were determined. Electronic properties provide insights into the material's nature, and the accuracy of electronic property calculations is essential due to their sensitivity to the physical characteristics of the compounds. The electronic band characteristics confirmed the metallic nature of the compounds. Additionally, detailed information on the electronic properties of atoms and orbitals was obtained through the determination of the total and partial density of states.

Keywords: Perovskite, ductile, metal

GİRİŞ

Günümüzde dünya genelinde hızla gelişen teknolojiye paralel olarak, bilim insanları düşük maliyetli, çevre dostu ve yüksek performanslı yeni nesil malzemelerin geliştirilmesine büyük önem vermektedir. Bu bağlamda, malzeme bilimi ve yoğun madde fiziği alanlarında öne çıkan araştırma konularından biri de perovskit yapılı bileşiklerdir. Geniş uygulama potansiyelleri ve çok yönlü fiziksel özellikleri sayesinde perovskitler, son yıllarda bilimsel literatürde yoğun ilgi gören malzemeler arasında yer almaktadır [1–6].

Perovskitler, genel kimyasal formülü ABX_3 ile ifade edilen ve belirli bir kristal simetriye sahip bileşik grubudur. Bu yapıda "A" ve "B" harfleri katyonları, "X" ise bir anyonu temsil eder. Kristal yapı, kübik bir geometri sergiler; burada A katyonları küpün köşelerinde, B katyonu merkezde ve X anyonları ise yüzey merkezlerinde konumlanır [7,8]. Bu karakteristik düzen, perovskit bileşiklerine elektronik, optik ve mekanik özellikler açısından büyük bir esneklik kazandırmaktadır.

Halojenür perovskitler, özellikle fotovoltaik uygulamalarda [9], güneş pilleri [10], piezoelektrik sistemler [11], yarı iletken cihazlar [12–14] ve optoelektronik teknolojiler [15–21] gibi birçok ileri teknoloji alanında umut vaat eden malzemeler olarak değerlendirilmektedir. Sahip oldukları geniş bant aralığı kontrolü, yüksek absorpsiyon katsayısı ve taşınım özellikleri, bu malzemelerin çok amaçlı kullanımını mümkün kılmaktadır. Dolayısıyla, perovskit bileşikler, modern malzeme tasarımı ve uygulamalı fizik çalışmaları açısından oldukça değerli sistemlerdir.

Perovskit malzemelerinin elektronik ve optik özellikleri, yapılarında gerçekleştirilen iyonik veya atomik düzeydeki değişimlerle büyük ölçüde ayarlanabilmektedir. Bu bağlamda, kristal yapının kararlılığı üzerine önemli bir kriter olan Goldschmidt tolerans faktörü, katyon ve anyon yarıçaplarına bağlı olarak değerlendirilir. Yapısal kararlılığın temel göstergesi olan bu faktör, aynı zamanda malzemenin elektronik bant yapısını ve dolayısıyla bant aralığını da etkileyebilmektedir. Nitekim yapılan çalışmalar, daha büyük katyon yarıçaplarına sahip sistemlerin daha yüksek Goldschmidt tolerans faktörü sergileyerek, daha düşük bant aralığı enerjilerine sahip kristal yapılar oluşturabildiğini ortaya koymuştur [22,23].

Bu bağlamda, perovskit yapılı malzemelerin detaylı teorik ve deneysel incelemeleri, yeni nesil elektronik ve optoelektronik aygıtların geliştirilmesine önemli katkılar sunacaktır. Çalışmamızda, bu kapsamda değerlendirilen $XIrI_3$(X: Sr, Ba, Ra) perovskite bileşiklerin elastik ve elektronik özellikleri ilk ilkeler hesaplamalarıyla detaylı şekilde araştırılmıştır.

ARAŞTIRMA VE BULGULAR

Hesaplama Yöntemi

Bu çalışmada gerçekleştirilen tüm teorik hesaplamalar, Yoğunluk Fonksiyonel Teorisi (DFT) çerçevesinde, VASP paket programı kullanılarak yürütülmüştür [6]. Yapısal optimizasyonlar ve elektronik özelliklerin belirlenmesinde, değişim-korelasyon etkilerini tanımlamak amacıyla

Genelleştirilmiş Gradyan Yaklaşımı (GGA) kapsamında Perdew-Burke-Ernzerhof (PBE) fonksiyoneli tercih edilmiştir [7]. Atom çekirdeği ile değerlik elektronları arasındaki etkileşimleri tanımlamak için ise ultrasoft potansiyeller kullanılmıştır [8].

Brillouin bölgesindeki k-uzayı örnekleme işlemi, Monkhorst-Pack şeması uyarınca 15×15×15 boyutunda k nokta ağı ile gerçekleştirilmiştir [9]. Düzlem dalga taban seti için kesme enerjisi 750 eV olarak belirlenmiştir. Yapısal gevşeme kriterleri enerji, kuvvet, yer değiştirme ve stres toleranslarına göre hassas biçimde tanımlanmış ve tüm hesaplamalar bu sınırlar dahilinde tamamlanmıştır.

Ayrıca, bileşiğin elektronik bant yapısı ve yoğunluk durumu (DOS) analizleri de gerçekleştirilerek, enerji seviyeleri ile elektronik geçiş davranışları ayrıntılı olarak incelenmiştir. Bu sayede, $XIrI_3$(X: Sr, Ba, Ra) perovskite bileşikleri yalnızca mekanik değil, aynı zamanda elektronik özellikleri de kapsamlı bir şekilde ortaya konulmuştur.

Mekanik Özellikler

Elastik özellikler, bir malzemenin komşu atomları arasındaki bağların doğası hakkında değerli bilgiler sunan temel fiziksel özelliklerdir. Bu özellikler sayesinde malzemenin esneklik düzeyi, sertliği ve mekanik açıdan ne kadar kararlı olduğu gibi önemli mekanik nitelikleri hakkında fikir edinilebilir. Merkanik özellikler, Tablo 1 de sunulan elastik sabitlerden elde edildi, Bileşik kübik yapıda olduğu için C_{11}, C_{12} ve C_{44} elastik sabitlerine sahiptir ve her üç bileşik için de Born kararlılık kriterlerini sağlamaktadır.

Hacim modülü (bulk modulus), bir malzemenin hacimsel deformasyona karşı gösterdiği direncin ölçüsüdür, Hacim modülü ne kadar büyük olursa bileşik sıkışmaya karşı o kadar dirençlidir. Kayma modülü (shear modulus, G), bir malzemenin paralel düzlemler boyunca uygulanan kuvvetler sonucu oluşan şekil değişimine karşı malzemenin gösterdiği dirençtir. Young modülü ise bir malzemenin uzamaya karşı direncini ifade eder. Young modülü yüksek malzemeler, kuvvet altında daha az uzamaktadırlar. Tablo 1 de yeralan her üç bileşiğin hacim modülü, kayma modülü ve young modülü değerlerinin oldukça küçük olduğu belirlendi, Bu değerlere göre bileşiğin kolayca sıkıştırılabildiği, kolay uzadığı ve kolay şekil alan yumuşak bileşikler olduğu belirlendi.

Materials	C_{11}	C_{12}	C_{44}	B	G	E
$SrIrI_3$	108.3	16.8	6.8	47.3	16.3	43.8
$BaIrI_3$	100.4	18.3	7.9	45.6	16.3	43.6
$RaIrI_3$	92.0	17.5	8.6	42.3	16.2	43.0

Tablo 1. Elastik sabitler, hacim modülü, kayma modülü ve Young modülü değerleri

Malzemenin sünek mi kırılgan mı olduğunu anlamak için B/G Pugh oranı, Poisson oranı ve Caushy basıncı değelerinden anlayabiliriz. B/G Pugh oranı 1.75 den büyük olduğunda, Poisson oranı 0.26 dan büyük olduğunda ve Caushy basıncı pozitif olduğunda bileşik sünek özellik gösterir. Tablo 2 deki verilerden bileşiklerin sünek karakterli oldu belirlendi.

Hv oranı malzemenin sertlik oranını verir ve bu sabitte elastik özelliklerden hesaplanır. Tablo 2 deki verilerden bileşiklerin oldukça yumuşak oldukları görüldü.

Tablo 2. B/G oranı, Poisson oranı, Caushy basıncı ve Hv değerleri

Materials	B/G	v	C'	Hv
$SrIrI_3$	2.906	0.345	10.0	1.8
$BaIrI_3$	2.801	0.340	10.4	1.8
$RaIrI_3$	2.617	0.330	8.9	1.8

Debye sıcaklığı (θ_D), katı hal fiziğinde bir kristal örgüsündeki titreşim modlarının (fononların) enerjisel dağılımını karakterize eden temel bir termodinamik parametredir. Malzemenin Debye sıcaklığı ne kadar yüksekse, o malzemenin atomik bağları o kadar güçlüdür. En düşük Debye sıcaklığı $RaIrI_3$ bileşiğine aitken, en yüksek değer $SrIrI_3$ bileşiğindedir. Genel olarak bileşiklerin Debye sıcaklığının orta düzeyde olduğu söylenebilir. Bu durum düşük sıcaklıkta özgül ısının klasik sınıra (Dulong-Petit değeri) daha erken ulaşacağını, fonon katkılı ısı iletkenliğinin çok yüksek olmadığını ve Atomlar arası bağ kuvvetlerinin orta düzeyde olduğunu gösterir.

Erime sıcaklığı, bir katı malzemenin kristal yapısının, uygulanan ısı enerjisi sonucunda bozularak sıvı hale geçtiği sıcaklık noktasıdır. Bu sıcaklıkta, katı ve sıvı fazlar termodinamik dengededir ve bu geçiş sırasında malzemenin sıcaklığı sabit kalırken, ona verilen enerji faz dönüşümüne harcanır. Bileşiklerin erime sıcaklıkları oldukça yüksektir, yüksek sıcaklık uygulamaları için uygun bileşiklerdir.

Ayrıca bileşiklerin ses hızları da belirlendi ve Tablo 3 de sunuldu.

Materials	θ_D(K)	Tm±300(K)	V_l(m/s)	Vt(m/s)	Vm(m/s)
$SrIrI_3$	163.4	1193.053	3230	1569	1763
$BaIrI_3$	158.0	1146.364	3110	1530	1718
$RaIrI_3$	149.0	1096.72	2895	1457	1634

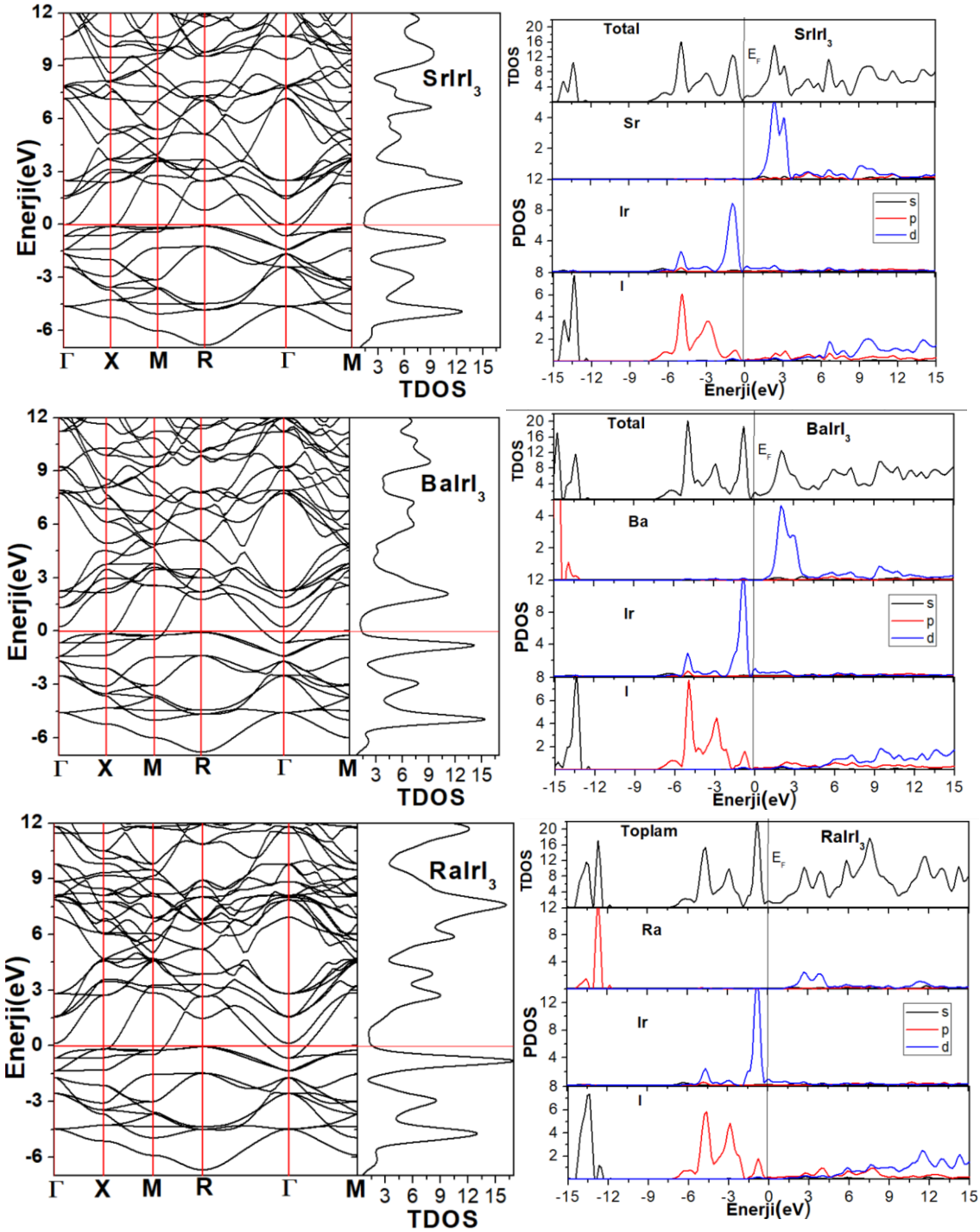
Tablo 3. Debye sıcaklığı, Erime sıcaklığı, ses hızları

Elektronik Özellikler

$XIrI_3$(X: Sr, Ba, Ra) perovskit bileşiklerin elektronik özellikleri analiz edildi. Çalışılan bileşiklerin elektronik bant yapısı, Brillouin bölgesindeki XRMGR yönelimi boyunca incelenmiş ve Şekil 1'de sunulmuştur. Hesaplamalarda Fermi enerji düzeyi referans olarak 0 eV kabul edilmiştir. Bant yapısının analizi, değerlik bandının en yüksek noktaları ile iletim bandının en düşük noktalarının örtüştüğünü ortaya koymaktadır; bu da bant aralığının bulunmadığını göstermektedir. Bu özellik, $XIrI_3$ (X: Sr, Ba, Ra) perovskit bileşiklerinin metalik karakterde olduğunu ortaya koyar. Şeklin sağ tarafında gösterilen toplam elektronik durum yoğunluğu (DOS) grafikleri, Sr'dan Ra'ya doğru gidildikçe DOS değerlerinde bir artış olduğunu göstermektedir. Fermi seviyesindeki durum yoğunluğu (DOS_x) sıfırdan büyük olup bu da metalik davranışın bir göstergesidir [24]. $SrIrI_3$, $BaIrI_3$ ve $RaIrI_3$ bileşikleri için DOS_x değerleri sırasıyla 1.34, 1.17 ve 1.24 olarak hesaplanmıştır. Literatürde, Fermi seviyesinde düşük DOS değerlerinin yapısal kararlılıkla ilişkilendirildiği bildirilmektedir [25].

Atomların bant yapısına olan katkılarını daha ayrıntılı şekilde incelemek amacıyla, kısmi (PDOS) ve toplam (TDOS) elektronik durum yoğunluğu verileri Şekil 1'de sunulmuştur. Bu analiz, enerji bant

yapısının iki ana bölgeye ayrıldığını göstermektedir: değerlik bandı ve iletim bandı. Değerlik bandına, özellikle Fermi seviyesine yakın bölgede, Ir atomlarının d orbitalleri ile I atomlarının p orbitalleri arasındaki hibritleşmiş durumların baskın katkı sağladığı gözlemlenmektedir. Ayrıca, Sr, Ba ve Ra elementlerinin d orbitallerinden gelen katkılar da iletim bandında önemli rol oynamaktadır.



Şekil 1. $XIrI_3$ (X: Sr, Ba, Ra) perovskit bileşiklerin elektronik bant yapısı ve toplam yoğunluğu

SONUÇLAR VE TARTIŞMA

Bu çalışmada $XIrI_3$ (X: Sr, Ba, Ra) perovskit bileşiklerinin elastik ve elektronik özellikleri detaylı şekilde incelenmiştir. Elastik sabitler, bileşiklerin mekanik olarak kararlı ve yumuşak bir yapıya sahip olduğunu göstermiştir. Elastik sabitlerden belirlenen, B/G oranı, Poisson oranı ve Caushy basıncı

değerleri sünek karakteri doğrulamıştır. Debye ve erime sıcaklıkları, orta düzeyde bağ kuvvetleri ve yüksek sıcaklık dayanımı ortaya koymuştur. Elektronik bant yapıları ve DOS analizleri, bu bileşiklerin metalik özellik taşıdığını açıkça göstermektedir. Elde edilen veriler, $XIrI_3$ bileşiklerinin çeşitli yapısal ve elektronik uygulamalar için potansiyel adaylar olduğunu göstermektedir.

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ANALYSIS OF SOME STRUCTURAL PROPERTIES OF THE YZn INTERMETALLIC COMPOUND UNDER PRESSURE

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ÖZET

İntermetalik bileşikler, korozyona dirençli olmaları, sünek yapıları, yüksek çekme mukavemeti ve yüksek sıcaklıklardaki uygulamaları ile endüstriyel uygulamalarda dikkat çekmiştir. Çalışmamızda, YZn intermetalik bileşiğinin basınç altında yapısal elastik, anizotropik ve elektronik özellikleri analiz edildi. Sunulan çalışmamız CASTEP koduyla gerçekleştirilmiş olup, DFT yaklaşımı hesaplanmıştır. Brillouin bölgesi için Monkhorst Pack ağı 10x10x10 k tercih edilmiş ve 350 eV düzlem dalga kesme enerjisi kullanılmıştır. Değişim-korelasyon potansiyelleri genelleştirilmiş gradyan yaklaşımı (GGA) dahilinde alınmıştır. YZn intermetalik bileşiği, CsCl tipi (B2)kübik bir yapıya sahiptir. Öncelikle bileşiğin geometrik optimizasyonu gerçekleştirildi ve ardından yapısal parametreleri hesaplandı. Yapısal sabitlerden örgü sabiti, hacim modülü, hacim modülünün birinci türevi gibi parametreler elde edildi. YZn'nin elastik sabitleri stress-strain yöntemi kullanılarak elde edilir. Elastik parametrelerden elastik özellikler young modülü, hacim modülü, kayma modülü G/B oranı, Caushy basıncı ve poisson oranı gibi parametreler belirlendi. Kübik B2 kristal yapısına sahip bileşiğin elastik sabitleri, mekanik stabilite kriterlerini sağladığını ortaya koymaktadır. Ayrıca, hesaplanan Bulk, Shear ve Young modülleri, bileşiğin görece düşük sertliğe sahip olduğunu ve yumuşak bir malzeme karakteri sergilediğini göstermektedir. Poisson oranı dikkate alındığında ise, bileşiğin sünek bir mekanik davranış sergilediği sonucuna ulaşılmıştır. Mekanik özelliklerin üç boyutlu olarak değerlendirilmesi için ELATE programı tercih edildi. Ayrıca elektronik özelliklerin belirlenmesiyle iletkenlik durumu, bant yapıları, bağ yapıları ve yük yoğunluğu incelenmiştir. Çalışmamızda elde edilen verilerimiz mevcut literatür bilgisiyle uyum içindedir. Valans bandı ile iletkenlik bandının Fermi seviyesine yakın örtüşmesi YZn'nin metalik olduğunu göstermektedir.

Anahtar kelimeler: İntermetalik, sünek, metal

ABSTRACT

Intermetallic compounds have attracted attention in industrial applications due to their corrosion resistance, ductile nature, high tensile strength, and applicability at elevated temperatures. In our study, the structural, elastic, anisotropic, and electronic properties of the YZn intermetallic compound under pressure were analyzed. The presented work was performed using the CASTEP code, and the calculations were carried out within the framework of density functional theory (DFT). A Monkhorst-Pack k-point grid of 10×10×10 was chosen for the Brillouin zone sampling, and a plane wave cutoff energy of 350 eV was employed. The exchange-correlation potentials were considered within the generalized gradient approximation (GGA). The YZn intermetallic compound exhibits a cubic structure of the CsCl-type (B2). First, the geometric optimization of the compound was performed, and then the structural parameters were calculated. Among the structural constants, parameters such as lattice constant, bulk modulus, and the first derivative of the bulk modulus were obtained. The elastic constants of YZn were determined using the stress-strain method. From the elastic parameters, mechanical properties such as Young's modulus, bulk modulus, shear modulus, G/B ratio, Cauchy pressure, and Poisson's ratio were evaluated. Based on these elastic parameters, it was determined that the cubic B2 structure of the compound is mechanically stable. Additionally, the softness of the

compound was assessed based on the bulk, shear, and volume moduli. According to the Poisson's ratio, the compound exhibits a ductile nature. For a three-dimensional evaluation of mechanical properties, the ELATE program was utilized. Furthermore, the electronic properties were examined to assess the conductivity state, band structures, bonding characteristics, and charge density. The data obtained in our study are consistent with the existing literature. The overlap between the valence band and the conduction band near the Fermi level confirms the metallic nature of YZn.

Keywords: Intermetallic, ductile, metal

GİRİŞ

İntermetalik bileşiklerin farklı alanlardaki geniş uygulama potansiyeli, bu malzemelere olan üretim talebinde kayda değer bir artışa yol açmıştır. Bu bileşikler, hem deneysel hem de teorik yaklaşımlarla kapsamlı biçimde araştırılmaktadır. Elektronikten mekanik sistemlere kadar uzanan geniş kullanım alanları sayesinde, intermetalik bileşikler özellikle malzeme bilimi uzmanlarının dikkatini çekmektedir. Yüksek sıcaklık dayanımı, termal kararlılık, süneklik, yüksek çekme mukavemeti ve korozyon direnci gibi üstün fiziksel ve kimyasal özellikleri, bu ilginin temel nedenleri arasındadır [1][2].

İntermetalik bileşikler, iki ya da daha fazla metal elementin bir araya gelmesiyle oluşur ve ortaya çıkan faz, bileşiği oluşturan saf metallerden tamamen farklı bir yapıya sahiptir [3]. Bu malzemeler, güçlü atomlar arası bağ yapıları sayesinde süper alaşımlara kıyasla daha yüksek mekanik dayanım sergilemektedir. Bununla birlikte, bağ yapılarının metalik karakterini koruması, seramik malzemelere göre daha düşük kırılganlık göstermelerine olanak tanımaktadır. Bir maddenin sünek olması, yani kolayca kırılmak yerine şekil değiştirebilme özelliği, hem üretim süreçlerinde hem de ürünün güvenli kullanımında büyük önem taşır. Örneğin gaz türbini kanatları veya protezler gibi karmaşık yapılar ile balta başları ya da otomobil çamurlukları gibi daha basit araçlar, işlevsel ve güvenilir olabilmek için sünek yapıda olmalıdır [4].

Son yıllarda keşfedilen ve doğuştan sünek özellikler sergileyen bazı intermetalik bileşiklerin, B2 tipi (CsCl benzeri) kristal yapıya sahip oldukları ve genellikle nadir toprak elementleri (RE) ile geç geçiş metalleri (TM) içerdikleri belirlenmiştir. Yitriyum (Y) temelli YX (X = Cd, In, Au, Hg ve Tl) bileşikleri, B2 kristal yapısında başarıyla sentezlenmiş olup, bu yapıların yapısal özellikleri Inadelli ve Palenzona tarafından kapsamlı şekilde derlenmiştir [5]. Ayrıca, Chouhan ve çalışma arkadaşları, söz konusu YX bileşiklerinin yapısal, elektronik, elastik ve termal özelliklerini kuramsal yöntemlerle detaylı biçimde incelemiştir [5].

Biz de bu çalışmada, literatüre katkı sağlamak amacıyla YZn intermetalik bileşiğinin yüksek basınç altında gösterdiği yapısal, elastik ve elektronik özellikleri teorik olarak analiz edildi.

ARAŞTIRMA VE BULGULAR

Hesaplama Yöntemi

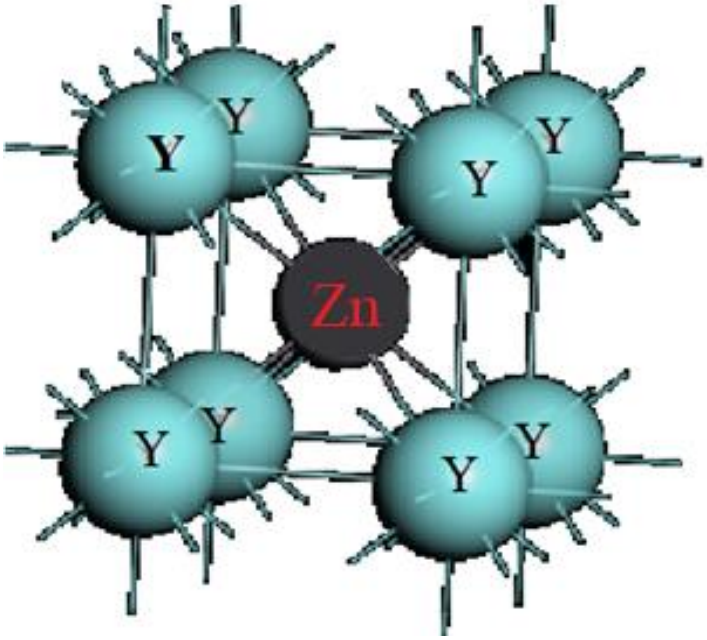
Bu çalışmada gerçekleştirilen tüm teorik hesaplamalar, Yoğunluk Fonksiyonel Teorisi (DFT) çerçevesinde, CASTEP paket programı kullanılarak yürütülmüştür [6]. Yapısal optimizasyonlar ve elektronik özelliklerin belirlenmesinde, değişim-korelasyon etkilerini tanımlamak amacıyla Genelleştirilmiş Gradyan Yaklaşımı (GGA) kapsamında Perdew-Burke-Ernzerhof (PBE) fonksiyoneli tercih edilmiştir [7]. Atom çekirdeği ile değerlik elektronları arasındaki etkileşimleri tanımlamak için ise ultrasoft potansiyeller kullanılmıştır [8].

Brillouin bölgesindeki k-uzayı örnekleme işlemi, Monkhorst-Pack şeması uyarınca 10×10×10 boyutunda k nokta ağı ile gerçekleştirilmiştir [9]. Düzlem dalga taban seti için kesme enerjisi 350 eV olarak belirlenmiştir. Yapısal gevşeme kriterleri enerji, kuvvet, yer değiştirme ve stres toleranslarına göre hassas biçimde tanımlanmış ve tüm hesaplamalar bu sınırlar dahilinde tamamlanmıştır.

Ayrıca, bileşiğin elektronik bant yapısı ve yoğunluk durumu (DOS) analizleri de gerçekleştirilerek, enerji seviyeleri ile elektronik geçiş davranışları ayrıntılı olarak incelenmiştir. Bu sayede, YZn bileşiğinin yalnızca mekanik değil, aynı zamanda elektronik özellikleri de kapsamlı bir şekilde ortaya konulmuştur.

Yapısal Özellikler

YZn bileşiği, 221 numaralı (Pm-3m) uzay grubuna ait olan ve CsCl tipi (B2 fazı) kristal yapısında kristalleşen bir intermetalik bileşiktir. Bu kristal yapı, birbiriyle iç içe geçmiş iki alt kafesten meydana gelir; bunlardan biri katyonlara, diğeri ise anyonlara aittir. Bu düzende, bir iyon küpün merkez noktasını işgal ederken, diğer iyonlar köşe noktalarında konumlanır ve merkezi iyonu sekiz koordinatla çevreler. Bu yapı sayesinde birim hücre içerisinde itriyum (Y) atomu Wyckoff 1a (0, 0, 0) konumunda yer alırken, çinko (Zn) atomu ise Wyckoff 1b (0.5, 0.5, 0.5) pozisyonunu işgal eder. Bu düzenleme, Şekil 1'de de şematik olarak sunulmuştur.



Şekil 1: YZn bileşiğinin birim hücresi

Tablo 1: YZn bileşiğinin yapısal parametreleri

Basınç(GPa)	Örgü sabiti (Å)	Hacim (Å^3)	Yoğunluk (g/cm^3)	Bulk modül (GPa)
0	3.603	46.795	5.474	71.187
5	3.522	43.713	5.86	79.671
10	3.46	41.449	6.18	108.226
15	3.41	39.66	6.459	132.261
20	3.367	38.174	6.711	142.592
25	3.329	36.904	6.942	161.681
30	3.296	35.81	7.154	176.587

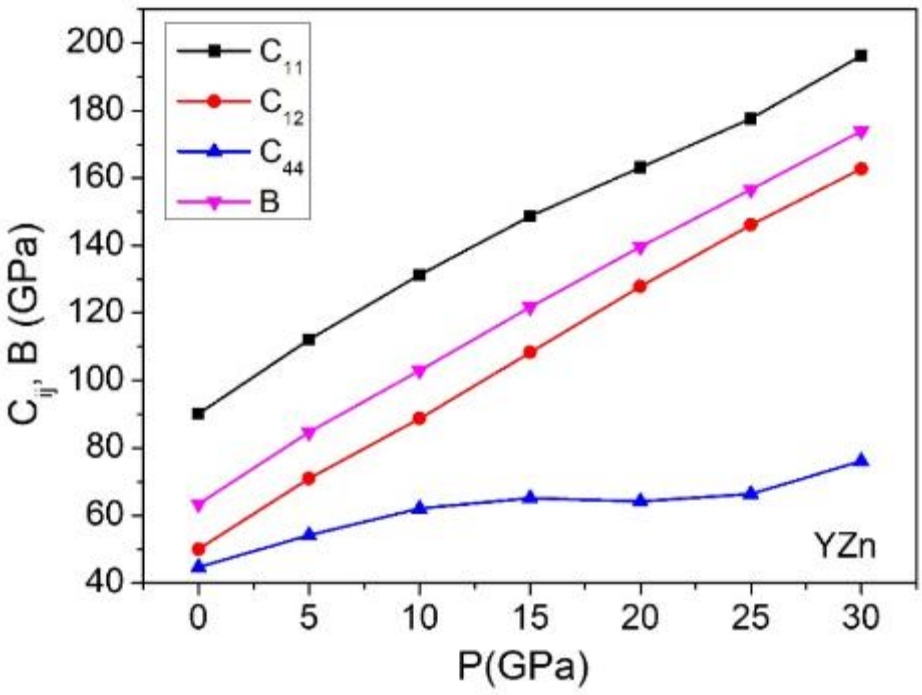
YZn bileşiğine ait örgü parametresi (a, Å), birim hücre hacmi (Å³), yoğunluk (g/cm³) ve hacim modülü (Bulk modülü, B, GPa) hesaplanmış ve elde edilen sonuçlar Tablo 1'de verilmiştir. Yapılan

hesaplamalar sonucunda örgü sabiti 3.603 Å olarak bulunmuştur. Bu değer, literatürde yer alan deneysel ve teorik sonuçlarla oldukça iyi bir uyum içindedir [5].

Çalışmada, YZn bileşiğinin yüksek basınç altındaki davranışları incelendiğinden, yapısal optimizasyon işlemleri 0 ile 30 GPa aralığında, 5 GPa'lık artışlarla tekrarlanmıştır. Bu basınç aralıklarına ait hesaplamaların sonuçları da Tablo 1'de detaylı olarak sunulmuştur. Uygulanan basınç arttıkça hacimde gözlemlenen azalma, yoğunluk ve hacim modülünde belirgin bir artışa neden olmuştur. Bulk modülündeki bu artış, bileşiğin sıkıştırma karşısındaki sertliğinin yükseldiğini göstermektedir. Benzer bir eğilim, literatürde NiBe intermetalik bileşiği için de rapor edilmiştir [10].

Elastik özellikler, atomlar arasındaki bağ kuvvetlerini ve malzemenin mekanik özelliklerini anlamada kritik bir rol oynar. Bu özellikler, özellikle bir malzemenin esneklik, sertlik ve mekanik kararlılığı gibi temel davranışlarını belirlemede önem taşır. B2 tipi kübik kristal yapısına sahip olan YZn bileşiğinin ikinci mertebeden elastik sabitleri, gerilme-gerinim (stress-strain) yöntemi [11] kullanılarak hesaplanmıştır. Kübik kristal simetrisine sahip sistemlerde yalnızca üç bağımsız elastik sabit bulunur: C_{11}, C_{12} ve C_{44}.

YZn bileşiği için hesaplanan bu elastik sabitlerin tamamı Born mekanik kararlılık kriterlerini sağlamaktadır. Bu kriterler şu şekilde özetlenebilir: $C_{11} + C_{12} > 0$, $C_{44} > 0$ ve $C_{11} - C_{12} > 0$. Ayrıca, intermetalik bileşiklerin kararlı olması için $C_{12} < B < C_{11}$ koşulunu da karşılaması beklenir [12]. Bu koşulların tümü YZn bileşiği için sağlanmıştır. Söz konusu kararlılık durumunun farklı basınçlar altındaki davranışı ise Şekil 2'de grafiksel olarak verilmiştir.



Şekil 2. YZn bileşiğinin Cij(GPa) ve B(GPa) nin basınçla değişimi

YZn bileşiği, yapılan elastik hesaplamalar doğrultusunda mekanik açıdan kararlı bir yapı sergilemektedir. Bulk (hacim) modülü ile shear (kayma) modülü değerlerinin düşük olması, bu malzemenin dış etkilere karşı kolaylıkla sıkıştırılabilir olduğunu ortaya koymaktadır. Uygulanan basınç arttıkça, her iki modül değerinde de belirgin bir artış gözlenmiş, bu da malzemenin basınç altında daha az sıkıştırılabilir hale geldiğini göstermiştir.

Young modülü, bir malzemedeki atomlar arası bağ kuvvetinin bir göstergesi olup, sertlik ile doğrudan ilişkilidir. YZn bileşiği için elde edilen Young modülü değerlerinin görece düşük olması, bileşiğin sert olmayan, daha esnek bir yapıya sahip olduğunu düşündürmektedir.

Poisson oranı, bir malzemenin sünekliğini değerlendirmede yaygın olarak kullanılan bir parametredir. Bu oranın 0.26'nın üzerinde olması, malzemenin sünek karakter taşıdığını göstermektedir [13]. YZn bileşiği için hesaplanan Poisson oranı da bu eşik değerin üzerinde bulunmuş ve basınç arttıkça bileşiğin bu sünek yapısını koruduğu gözlemlenmiştir.

Tablo 2. YZn bileşiğinin farklı basınçlarda hesaplanan mekanik parametreleri

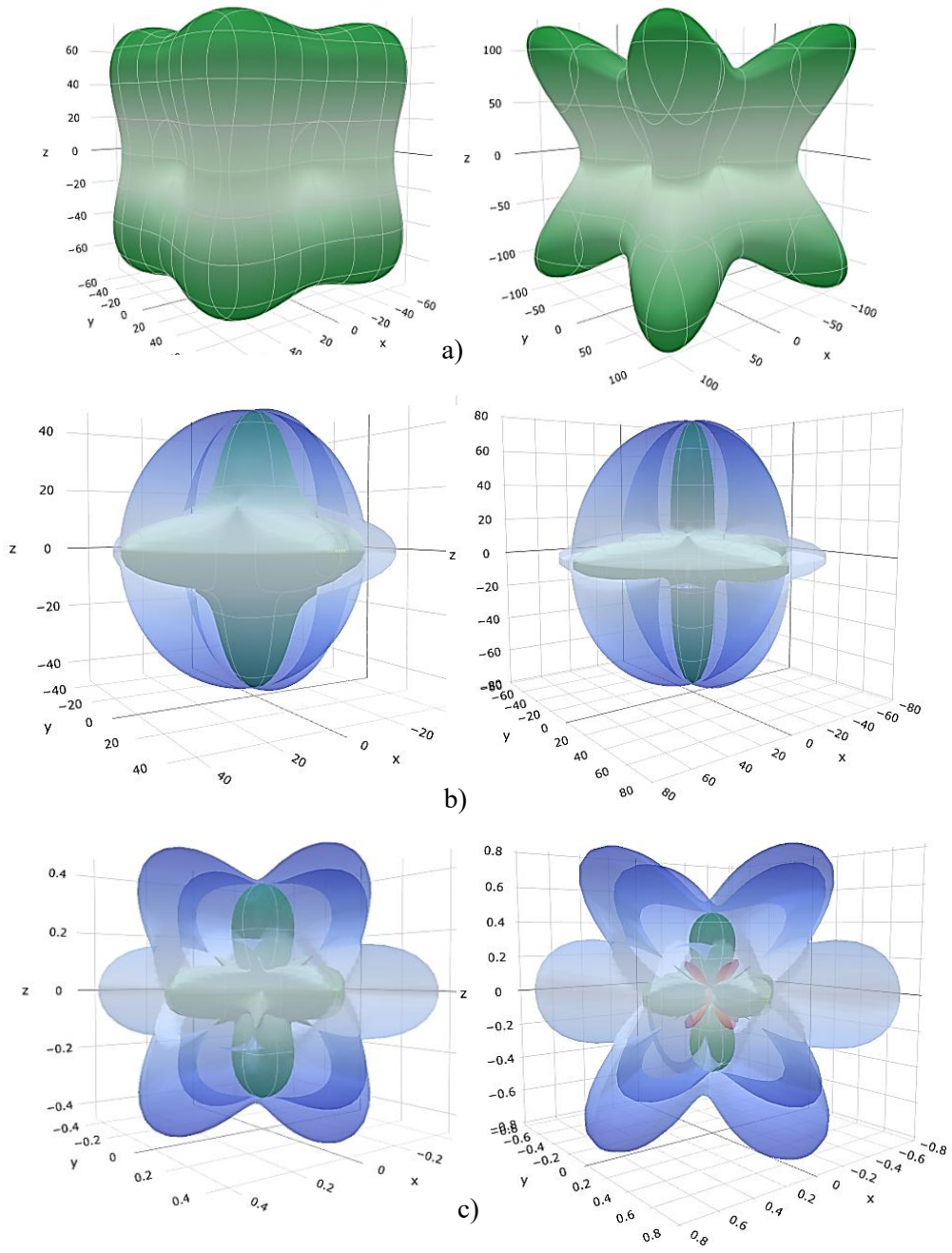
Basınç(GP)	C_{11}	C_{12}	C_{44}	B	E	G	λ
0	90.192	50.024	44.681	63.413	83.091	32.416	0.281
5	112.145	70.963	54.113	84.691	96.290	36.738	0.310
10	131.257	88.744	62.059	102.915	75.967	40.421	0.326
15	148.636	108.322	65.152	121.760	110.070	40.786	0.349
20	163.067	127.904	64.191	139.625	105.402	38.350	0.374
25	177.613	146.104	66.349	156.607	104.382	37.577	0.388
30	196.268	162.673	76.094	173.871	116.513	41.962	0.388

Bir malzemenin elastik anizotropisini incelemek amacıyla, Young modülü (E), kayma modülü (G) ve Poisson oranı (ν) değerlerinin yön bağımlılığı ELAM kodu [36] kullanılarak YZn bileşiği için hesaplanmıştır (Bkz. Tablo 3). Tablo 3'te sunulan veriler, artan basınç değerlerinin anizotropide bir artışa yol açtığını ortaya koymaktadır.

Tablo 3. Mekanik özelliklerin minimum ve maksimum değerleri.

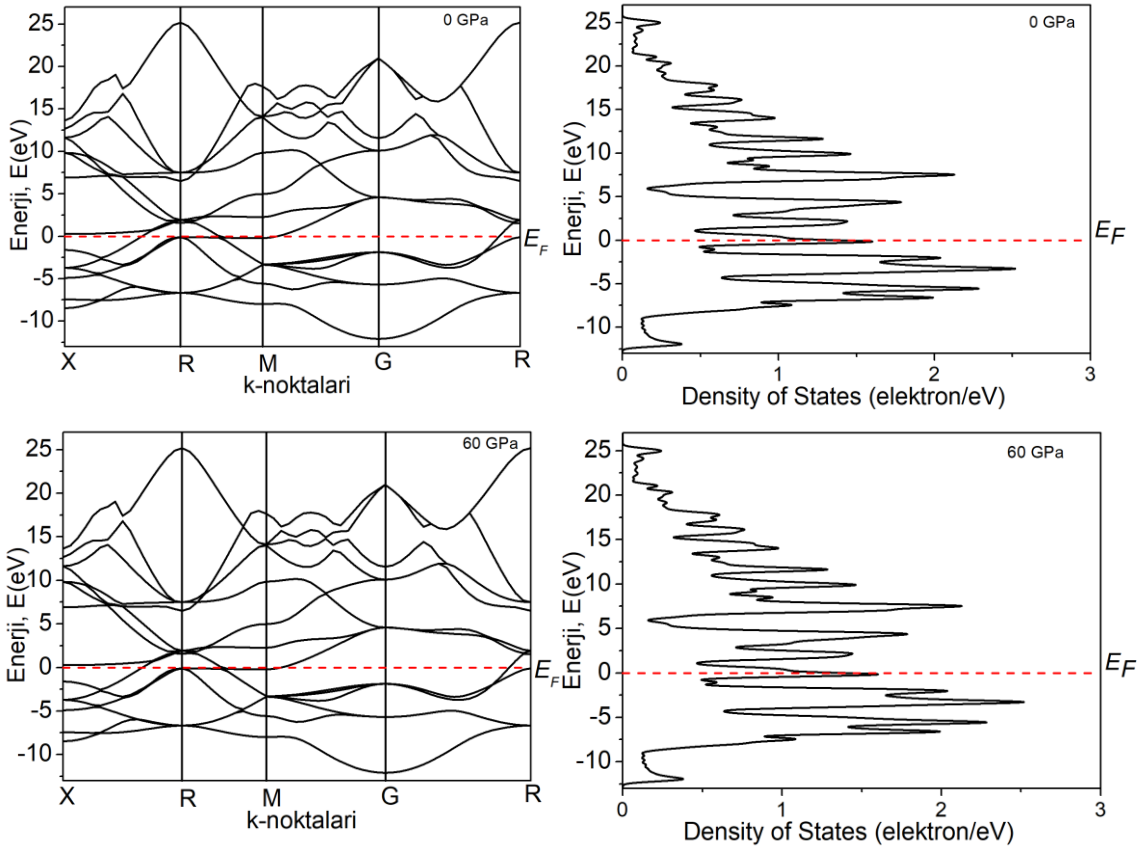
P	E(GPa)			G(GPa)			λ		
	E_{min}	E_{max}	A	G_{min}	G_{max}	A	λ_{min}	λ_{max}	A
0	54.5	108.55	1.992	20.084	44.682	2.225	-0.026	0.569	∞
15	57.309	165.87	2.894	20.157	65.152	3.232	-0.136	0.827	∞
30	48.821	199.22	4.081	16.798	76.798	4.530	-0.260	1.044	∞

Şekil 3 de ELAM kodu kullanılarak YZn bileşiğinin Young modülü (E), kayma modülü (G) ve Poisson oranı (ν) nın üç boyutlu olarak çizilmiş anizotropi şekilleri verilmiştir. Şekillerdeki küresellikten sapma anizotropinin varlığının göstergesidir. Şekil 3 deki şekillerin sol tarafı 0 GPa basıncı, sağ tarafı ise 60 GPa basıncı göstermektedir. Basıncın artışıyla anizotropinin artışı şekilerde de görülmektedir.



Şekil 3. a) Young modülü, b) Kayma modülü ve c) Poisson oranı sol taraf 0 GPa ve sağ taraf 60 GPa

YZn intermetalik bileşiğinin elektronik özellikleri de analiz edilmiştir. YZn bileşiğine ait elektronik enerji bant yapısı, Brillouin bölgesinin yüksek simetri doğrultusu olan X-R-M-G-R yönlerinde Şekil 4'te sunulmuştur. Fermi seviyesi 0 eV referans alınarak yerleştirilmiştir. Bant yapısında, değerlik bandının en üst noktaları ile iletim bandının en alt noktaları birbirine çakışacak şekilde yer almakta, aralarında bir bant aralığı bulunmamaktadır. Bu durum, YZn bileşiğinin metalik karakter taşıdığını göstermektedir. Sağ panelde ise, bileşiğe ait elektronik yoğunluk durumu (DOS) değerleri verilmiştir. Uygulanan basınca rağmen bileşik, metalik özelliğini muhafaza etmiştir.



Şekil 4. YZn bileşiğinin elektronik bant yapısı grafiği

SONUÇ VE TARTIŞMA

YZn bileşiğinin yapısal, elastik ve elektronik özellikleri, DFT tabanlı ilk prensipler hesaplamalarıyla CASTEP yazılımı kullanılarak ayrıntılı bir şekilde incelenmiştir. Çalışmanın tamamen teorik temellere dayanması nedeniyle ilk olarak geometrik optimizasyon işlemi gerçekleştirilmiş ve yapısal parametreler elde edilmiştir. Optimizasyon sonucunda kafes sabiti 3.603 Å olarak hesaplanmıştır ve bu değer, literatürde bildirilen deneysel ve teorik verilerle tutarlılık göstermektedir. Elde edilen elastik sabitler, bileşiğin kübik B2 kristal yapısı altında mekanik kararlılığa sahip olduğunu ortaya koymuştur. Ayrıca, Bulk, Shear ve Young modüllerine ait hesaplamalar, bileşiğin nispeten yumuşak bir yapıda olduğunu göstermektedir. Poisson oranı dikkate alındığında ise, YZn bileşiğinin sünek özellik taşıdığı sonucuna varılmıştır. Elektronik bant yapısı ve yoğunluk durumu analizleri sonucunda, bu bileşiğin metalik karakter sergilediği belirlenmiştir.

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IMPACT OF CLIMATE CHANGE ON WATER RESOURCES IN NORTHEASTERN ALGERIA

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Abstract

The aim of this research is to assess the effects of climate change on social, economic, industrial, agricultural and aquatic systems, with particular emphasis on rainfall diversity and its consequences for water resources. By analyzing precipitation data from sixteen climate stations located in northeastern Algeria, this research aims to accurately determine the cold and dry seasons caused by climate. The results will be used to develop effective adaptation strategies for resource management in the context of climate degradation, ensuring sustainable management in a changing climat.

Key-words: Adaptation strategies, climate change, dry seasons, rainfall variability, wet seasons.

EXAMINING THE ANTICORROSION EFFICACY OF A GUANIDINE DERIVATIVE IN ACIDIC MEDIUM FOR MILD STEEL PROTECTION

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Abstract

In a novel twist bridging biochemistry and surface science, this study investigates the anticorrosion efficiency of a guanidine derivative as a green corrosion inhibitor for mild steel in acidic media. The compound, structurally inspired by naturally occurring biomolecules, is characterized by a high nitrogen content and a guanidino functional group, both of which enhance its adsorption capabilities on metallic surfaces. Its molecular architecture promotes the formation of a dense and adherent protective film, minimizing metal dissolution and surface degradation in harsh environments. Electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization (PP) were employed at 298K to evaluate the inhibitory performance in 1 M HCl solution. Results demonstrated a marked decrease in corrosion current density and a significant increase in charge transfer resistance, indicating the formation of an effective barrier layer. The highest inhibition efficiency exceeded 90% at optimal concentrations, highlighting the compound's potential as a robust corrosion inhibitor. Surface characterization using scanning electron microscopy (SEM) further confirmed the preservation of steel morphology in the presence of the inhibitor, compared to the severely corroded blank sample. These findings not only support the use of guanidine-based compounds in corrosion protection but also emphasize the promise of bioinspired molecular design for environmentally friendly industrial applications. The study provides a foundation for the development of sustainable alternatives to conventional, often toxic, corrosion inhibitors used in aggressive environments.

Keywords: Guanidine derivative, Corrosion inhibition, Mild steel, Acidic media, Electrochemical Impedance Spectroscopy, Potentiodynamic Polarization.

INTEGRATIVE MORPHOLOGICAL AND MOLECULAR CHARACTERIZATION OF GILL MONOGENEANS IN WILD AND FARMED *SPARUS AURATA* FROM TUNISIA

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Abstract

The expansion of marine aquaculture has raised significant environmental concerns, affecting wild fish populations and facilitating pathogen transmission between farmed and wild fish. This study investigates the presence and genetic identification of gill monogenean parasites in gilthead seabream (*Sparus aurata* Linnaeus, 1758) from various sites in Tunisia. Unlike previous studies that focused solely on either morphological or molecular identification, this research integrates both approaches for a more comprehensive assessment. Morphological analysis identified two distinct species belonging to different subclasses: *Lamellodiscus echeneis* (Wagener, 1857) within Monopisthocotylea and *Sparicotyle chrysophrii* (Van Beneden & Hesse, 1863) Mamaev, 1984 within Polyopisthocotylea. Infection prevalence was assessed in both wild and farmed seabream populations. *L. echeneis* was detected in 92.3% of wild seabream and 91.1% of cage-reared seabream, while *S. chrysophrii* showed a prevalence of 45% in wild seabream and 45.61% in farmed seabream. Molecular characterization was conducted using nuclear ITS rDNA markers and a partial mitochondrial cytochrome oxidase subunit I (COI) sequence for *L. echeneis*, along with large subunit 28S and COI sequences for *S. chrysophrii*. Phylogenetic analyses (NJ, ML, and BI) clustered *L. echeneis* samples from different locations into a single, well-supported clade. Similarly, *S. chrysophrii* sequences exhibited high genetic conservation, forming a distinct clade. These findings confirm the widespread presence of these monogenean species in the studied regions. This study enhances epidemiological knowledge of *L. echeneis* and *S. chrysophrii* in *S. aurata*, providing accurate molecular characterization based on nuclear and mitochondrial markers. The results contribute to future research on monogenean parasites in Tunisia and other economically significant aquaculture species.

Keywords: Sparus aurata / Infection prevalence / Molecular characterization / L. echeneis / S. chrysophrii.

COMPREHENSIVE STUDY ON THE EXTRACTION OF CELLULOSE FROM PLANT SOURCES AND ITS APPLICATION IN ADSORPTION OF POLLUTANTS: A DETAILED INVESTIGATION USING DENSITY FUNCTIONAL THEORY (DFT) SIMULATIONS AND BOX-BEHNKEN DESIGN (BBD) OPTIMIZATION FOR ADSORPTION EFFICIENCY

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Abstract

The extraction of cellulose from plant sources has garnered significant attention due to its potential applications in various environmental and industrial processes. In this study, cellulose was extracted from natural plant materials using an eco-friendly method to create an efficient adsorbent for the removal of pollutants from aqueous solutions. The adsorption process was optimized using the Box-Behnken design (BBD), a statistical approach that allowed the evaluation of critical factors such as contact time, pH, and adsorbent dosage. Furthermore, a Density Functional Theory (DFT) approach was employed to understand the interaction mechanisms at the molecular level, providing insights into the adsorption process's thermodynamic and kinetic parameters. The results indicated that the cellulose adsorbent demonstrated high efficiency in removing contaminants, with the optimized conditions yielding the highest adsorption capacity. The integration of experimental data with DFT simulations and BBD optimization offers a comprehensive understanding of the adsorption process, making it a promising approach for designing sustainable materials for environmental remediation..

Keys words: Cellulose extraction, plant sources, adsorption, pollutants, Density Functional Theory (DFT), Box-Behnken Design (BBD), optimization.

NEW CHALLENGES FOR INSURANCE COMPANIES IN THE AREAS OF ANTI-MONEY LAUNDERING, FIGHT AGAINST TERRORISM AND PROLIFERATION FINANCING AS WELL AS COMPLIANCE WITH FINANCIAL SANCTIONS (LEGAL AND INFORMATION TECHNOLOGY PERSPECTIVE)

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Abstract

Anti-money laundering, as well as the fight against terrorism and proliferation financing, likewise, financial sanction rules had been introduced gradually with the aim to pursue not only ethical principles but also had been considered beneficial to both local (national) and global economies. Nevertheless, in case any government or just few governments lift the application of any of the strict rules, the free rider pattern occurs. Global non-compliance of any company, though legally justified by local legal provisions, is likely to distort the level playing field among companies between financial sectors as well as cross borders. In our study we introduce the related new-born policy stance (USA) and focus on how providers of life-insurance products with savings elements in both EU and Hungary are likely to be affected. It is worth mentioning that according to World Bank non-life insurance products should also be taken into account. Our study adopts a mixed methodological approach: we examine FATF recommendations, IAIS principles, EU legislation as well as industry standards, industry advocacy guidelines, organisational self-regulation features and information technology achievements in compliance of insurance companies, incuding the data protection challenges. The results show us the firm need for strict international regulation, yet recognising and allowing for mild local-national specificities, in addition to the need for uniformity of standards. Our research contributes to the academic discourse on globally unified provisions related to anti-money laundering, fight against terrorism and proliferation financing as well as financial sanctions, with no actual exclusion from statutory enforcement.

B3LYP-BASED QUANTUM CHEMICAL INVESTIGATION OF STRUCTURAL, VIBRATIONAL, SPECTROSCOPIC, AND REACTIVITY PROPERTIES OF 3-(P-FLUOROPHENYL)-1H-PYRAZOLE-4-CARBALDEHYDE

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Abstract

3-(p-Fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule is a key intermediate in drug synthesis, valued for its anti-inflammatory, antimicrobial, and anticancer potential. Its fluorinated and aldehyde-functionalized structure enables applications in medicinal chemistry, material science, and coordination chemistry, offering enhanced stability, reactivity, and electronic properties. Thus, the molecule should extensively be examined experimentally and especially theoretically in detail. On this basis, the ground-state molecular properties, including optimized molecular geometries, vibrational spectra, corresponding vibrational mode assignments as well as ^{1}H and ^{13}C NMR chemical shifts of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde (C10H7FN2O) were systematically explored using density functional theory (DFT) and Hartree Fock (HF) with the B3LYP functional and 6-31++G(d,p) basis set. Additionally, UV–visible absorption spectra, thermodynamic parameters, and atomic charge distributions were computed to control the possible intra-molecular charge transfer regions, electron donating groups, lone pairs, π bonds conjugations, and electron engagement in bonds for the title molecule. Normal coordinate analysis was applied to scaled DFT force fields to interpret the theoretical vibrational results. It was found that the calculated vibrational frequencies exhibited strong correlation with available experimental data, validating the robustness of the computational approach for structural characterization. Furthermore, we analyzed the frontier molecular orbitals, molecular electrostatic potentials (MEP and ESP), and global reactivity descriptors (electronegativity, chemical hardness, softness, electrophilicity index, and energy band gap) to assess the potential of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde for intermolecular interactions and metallic bonding.

Keywords: 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde; DFT; HF; B3LYP; MEP.

Introduction

Pyrazole derivatives represent a class of five-membered heterocyclic compounds containing two adjacent nitrogen atoms within the ring framework, which exhibit a wide array of biological, antifungal, antimicrobial, pharmaceutical, and agrochemical activities [1–3]. Among them, 1H-pyrazole-based aldehydes have garnered significant attention due to their reactive formyl group at the 4-position, enabling facile derivatization and incorporation into more complex molecular frameworks

[4]. The functionalization of pyrazole scaffolds with electron-withdrawing or electron-donating substituents has been demonstrated to modulate their physicochemical properties, binding affinities, and biological efficacy [5].

In particular, the incorporation of halogenated aromatic groups—such as fluorophenyl moieties—into heterocyclic systems has emerged as a key strategy in modern medicinal chemistry. Fluorine substitution, owing to its high electronegativity and unique steric and electronic characteristics, can significantly influence the metabolic stability, lipophilicity, and bioavailability of the resulting compounds [6,7]. The para-fluorophenyl group, in particular, has been associated with enhanced pharmacokinetic profiles and increased target specificity in various drug candidates [8].

The compound (p-Fluorophenyl)-1H-pyrazole-4-carbaldehyde represents a structurally intriguing hybrid of a bioactive pyrazole core and a para-substituted fluorinated aromatic aldehyde moiety. This dual functionality positions the molecule as a versatile synthetic intermediate and a potential pharmacophore in the design of novel therapeutics, including anti-inflammatory, antimicrobial, anticancer, and central nervous system (CNS)-active agents [9,10]. Moreover, the formyl group offers a strategic handle for further functionalization through Schiff base formation, cyclization reactions, or transition-metal-catalyzed coupling protocols [11].

Despite its synthetic potential and anticipated reactivity, detailed studies on the structural, spectroscopic, and electronic properties of (p-Fluorophenyl)-1H-pyrazole-4-carbaldehyde remain limited in the current literature. Thus, comprehensive investigations encompassing its synthesis, molecular characterization, and potential reactivity are warranted. In this work, we report the synthesis and spectroscopic analysis of (p-Fluorophenyl)-1H-pyrazole-4-carbaldehyde, including FT-IR, NMR, and UV-Vis studies, along with theoretical investigations using density functional theory (DFT) to elucidate its optimized geometry, electronic structure, and frontier molecular orbitals.

As well known, in recent years, theoretical investigations have emerged as indispensable tools for the comprehensive characterization of organic molecules, particularly those with potential functional and industrial relevance. These approaches provide critical insights into a wide range of physicochemical properties, encompassing molecular geometry, thermodynamic stability, electronic structure, optical behavior, vibrational spectra, and electrochemical characteristics. Key descriptors such as charge distribution, dipole moment, frontier molecular orbitals, and intramolecular charge transfer (ICT) regions are effectively predicted using quantum chemical methods. By leveraging these theoretical frameworks, researchers are able not only to deepen their fundamental understanding of molecular behavior but also to anticipate experimental outcomes in a time- and cost-efficient manner. The present study addresses these knowledge gaps by performing an extensive theoretical investigation of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde using DFT methods. The B3LYP functional, comprising Becke's three-parameter hybrid exchange functional and the correlation functional of Lee, Yang, and Parr, is employed alongside the 6-31G++(d,p) basis set to ensure computational accuracy and efficiency. The calculated results are rigorously compared with available experimental data from the SDBS (53392) spectral database, yielding strong agreement and thus affirming the reliability of the adopted theoretical approaches.

This study also delves into the analysis of UV-visible absorption spectra, thermodynamic parameters, and $^{1}H/^{13}C$ nuclear magnetic resonance (NMR) chemical shifts to obtain a holistic picture of the molecule's properties. The atomic charge distributions and dipole moment values are explored to identify key ICT pathways and assess the potential for intermolecular interactions and mc bonding behavior. Visual analyses of electronic descriptors such as HOMO, LUMO, MEP, and ESP maps further elucidate reactivity patterns, energy band gaps, electronegativity, electrophilicity, chemical hardness, and molecular softness.

The insights obtained from this comprehensive theoretical exploration not only bridge the gap between experimental and computational studies but also lay the groundwork for future investigations into the physicochemical behavior of halogenated aromatic compounds. Ultimately, the findings

underscore the potential of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde for applications in chemistry, materials science, pharmacology, and industrial chemistry, thereby supporting its integration into functional device architectures or molecular design strategies. All in all, the findings aim to contribute foundational knowledge toward the rational design of pyrazole-based compounds with tunable biological or material properties.

Computational Details

In the present study, an in-depth computational investigation of the 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde whose optimized molecular structure is illustrated in Fig. 1 has been carried out for the first time. The study systematically explores a range of molecular and electronic properties employing advanced quantum chemical method. All calculations were executed using the Gaussian 09 suite of programs [12,13], utilizing density functional theory (DFT) approach. Specifically, the B3LYP functional with combining Becke's three-parameter hybrid exchange with the Lee–Yang–Parr correlation functional is applied in conjunction with the 6-31++G(d,p) basis set [14–17].

The computational protocol encompasses the evaluation of several fundamental and derived molecular descriptors. These include total dipole moment components (μ, μ_x, μ_y, μ_z), atomic charge distributions, intramolecular charge transfer (ICT) regions, and thermodynamic parameters calculated at standard room temperature (300 K). Electronic absorption characteristics were simulated through ZINDO to generate UV–visible spectra, while nuclear magnetic resonance (NMR) spectra including both ^{13}C and ^{1}H are computed using the Gauge-Independent Atomic Orbital (GIAO) method to predict chemical shifts.

These theoretical insights contribute to a comprehensive understanding of the molecular behavior of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule, serving as a foundational reference for future experimental and theoretical studies targeting this class of compounds. The calculated data are systematically compared with available experimental findings to validate the reliability and predictive capacity of the chosen computational methodologies.

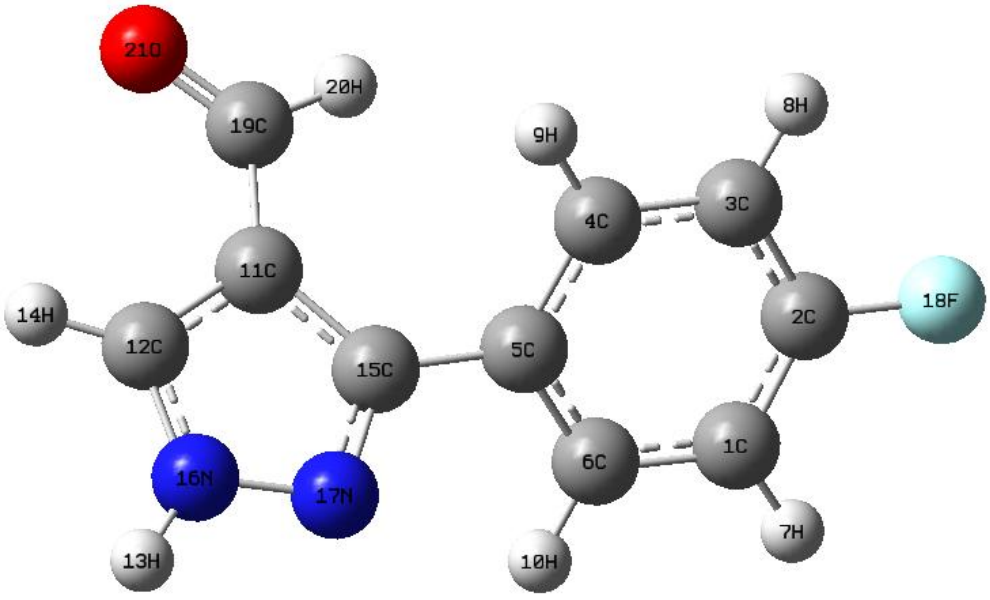

Fig. 1. Image of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule.

Results and discussion

Uv–vis Spectra for 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde

The electronic transitions in the 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde can be classified based on the nature of the involved molecular orbitals and their spatial localization within the organic framework. Among the most prominent types of electronic excitations are the π → π* transitions, which involve electron promotion from a bonding π orbital to an anti-bonding π* orbital, and the n → π* transitions, which involve excitation from a lone pair orbital (typically localized on heteroatoms) to an anti-bonding π* orbital. In general, π → π* transitions are characterized by higher oscillator strengths due to their greater probability and symmetry-allowed nature, whereas n → π* transitions are typically weaker and less intense due to their forbidden or partially allowed transition nature.

To accurately characterize these transitions in 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde, ZINDO calculations were under vacuum conditions. This computational approach enables the prediction of electronic absorption spectra, including excitation energies (wavelengths, λ_{max}), oscillator strengths (f), configuration interaction coefficients, and the nature of the involved singlet states. The calculated λ_{max} values provide insight into the energies required for electron promotion, while the oscillator strength values offer a quantitative measure of the intensity of each transition.

Table 1. Theoretical electronic absorption spectra parameters

Cl-expansion coefficient

Excitations	Energy (eV)	Singlet-A	Wavelength (nm)	Oscillator strength (f)	Translations
Excited State 1					
31→36		0.37534			HOMO→HOMO+5
31→41		-0.13711			HOMO→HOMO+10
34→36		-0.11650			LUMO+2→LUMO+4
35→36		0.48748			LUMO+3→LUMO+4
35→37	2.7075	-0.22668	457.93	0.0158	LUMO+3→LUMO+5
Excited State 2					
31→36		0.47837			HOMO→HOMO+5
31→41		-0.16640			HOMO→HOMO+10
34→36		-0.18164			LUMO+2→LUMO+4
35→36		-0.33006			LUMO+3→LUMO+4
35→37	2.8478	0.25238	435.36	0.0000	LUMO+3→LUMO+5
Excited State 3					
35→36	3.1950	0.32755			LUMO+3→LUMO+4
35→37		0.58037	388.05		LUMO+3→LUMO+5
35→39		0.10142		0.1071	LUMO+3→LUMO+7

A summary of these theoretical electronic transition parameters, including the associated singlet excited states, is presented in Table 1. The analysis reveals that the key electronic transitions occur between frontier molecular orbitals such as the highest occupied molecular orbital (HOMO), the HOMO-1, and the lowest unoccupied molecular orbital (LUMO), as well as the LUMO+1. For example, the first excited state is primarily associated with transitions from HOMO-1 to LUMO and from HOMO-1 to LUMO+1. These transitions correspond to low-energy excitations and are responsible for the visible absorption features observed in the UV-visible spectrum.

Numerically, the calculated absorption maxima (λ_{max}) are 457.93 nm for the first excited state, 435.36 nm for the second, and 388.05 nm for the third. The absorption band near 388 nm can be attributed to a strong $\pi \rightarrow \pi^*$ transition arising from the aromatic C=C moieties within the benzene ring structure. The peak at 435.36 nm similarly results from overlapping $\pi \rightarrow \pi^*$ transitions influenced by the extended conjugation and electronic delocalization within the aromatic system. The relatively weak absorption peak observed around 457.93 nm is indicative of an $n \rightarrow \pi^*$ transition, likely originating from lone pair electrons on the nitrogen atom (from the amine group) or bromine atoms interacting with the π^* system of the ring, as these atoms introduce localized non-bonding electron density.

Furthermore, the computed oscillator strengths for these transitions are 0.0158 for the first excited state, 0.0000 for the second, and 0.1071 for the third. These values indicate that while the second excited state transition (435.36 nm) exhibits a moderately allowed transition ($\pi \rightarrow \pi^*$), the first and third are significantly less intense, consistent with the characteristics of $n \rightarrow \pi^*$ transitions or symmetry-forbidden excitations. The combination of these theoretical findings provides a robust understanding of the optical properties and electronic structure of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde, thereby offering insights into its potential utility in optoelectronic and photochemical applications.

NMR Spectra Analyses

NMR spectroscopy remains one of the most powerful and widely used analytical techniques for the structural elucidation and identification of organic molecules. Specifically, ^{1}H and ^{13}C NMR provide valuable insights into the electronic environment surrounding hydrogen and carbon atoms, respectively, enabling detailed characterization of molecular frameworks. The accuracy of theoretical NMR chemical shift predictions relies significantly on the computational method employed, particularly in terms of the treatment of electron correlation and basis set quality.

In this study, the Gauge-Independent Atomic Orbital (GIAO) method was utilized to calculate the ^{1}H and ^{13}C NMR chemical shifts of the 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde. The theoretical calculations are performed using both the HF and DFT methods, specifically the B3LYP hybrid functional in combination with the 6-31+G(d,p) basis set. In addition, a more extensive basis set, B3LYP/6-311+G(d,p), is applied to the optimized molecular structure to enhance accuracy. The calculated NMR parameters are then compared with available experimental data to evaluate the reliability of the computational approach.

The results, summarized in Table 2, demonstrate a strong correlation between theoretical predictions and experimental observations. For ^{1}H NMR, the isotropic chemical shifts calculated via B3LYP/6-311+G(d,p) range from 6.8415 to 11.3991 ppm, which align well with the experimentally observed shifts in the range of 7.333 to 13.76 ppm. This close agreement underscores the effectiveness of the B3LYP method in accounting for electron correlation effects, which are often underestimated in HF-based calculations. The slightly broader theoretical range may be attributed to subtle conformational dynamics and solvent effects not explicitly included in the vacuum-phase simulations. At the HF/6-31G(d) GIAO, ^{1}H NMR chemical shifts are calculated to be in a range of 7.557-12.1146 ppm.

For the ^{13}C NMR chemical shifts, relative to the tetramethylsilane (TMS) reference standard, the calculated values span from 103.586 ppm to 187.457 ppm at B3LYP/6-311+G(2d,p) GIAO. In HF/6-31G(d) GIAO and CH4 HF/6-31G(d) GIAO, the ^{13}C NMR chemical shifts are calculated from 121.106 ppm to 204.977 ppm and 120.21 ppm to 204.092 ppm, respectively. Experimentally, the corresponding ^{13}C chemical shifts are reported between 115.30 and 184.61 ppm. While the computed range slightly overestimates the experimental values, the trend and relative ordering of carbon environments are accurately captured. The discrepancies can be primarily attributed to the neglect of solvent-induced shielding and anisotropic magnetic susceptibility effects in the theoretical model.

Furthermore, the chemical environments of the nitrogen and fluorine atoms, which significantly influence local electron density and magnetic shielding, are also included in the analysis. These values, presented in Table 2, offer additional evidence of the predictive capability of the GIAO method within the B3LYP framework. The presence of electronegative fluorine atoms exerts a de-shielding effect on adjacent nuclei, particularly evident in the downfield shift of the nearby hydrogen and carbon signals. Similarly, the lone pair electrons on the nitrogen atom contribute to localized shielding variations, subtly influencing the neighboring proton and carbon shifts.

In conclusion, the theoretical NMR analysis conducted using the GIAO method and B3LYP/6-311+G(d,p) level of theory provides a robust and reliable means for interpreting and complementing experimental NMR spectra. The good agreement between computed and experimental chemical shifts validates the use of the quantum mechanical method for accurately modeling the magnetic properties of organic molecules. This synergy between theory and experiment enhances our understanding of the electronic structure of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde and serves as a foundation for future applications in structural prediction, reactivity profiling, and molecular design in both academic and industrial contexts.

Table 2. Experimental and theoretical chemical shifts for 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule.

Atoms	TMS HF/6-31G(d) GIAO	TMS B3LYP/6-311+G(2d,p) GIAO	CH4 HF/6-31G(d) GIAO	Exp.
C_{15}	204.977	187.457	204.092	184.61
C_{19}	188,988	171.429	188,113	163.72
C_2	171.032	153.513	170.147	161.27
C_{12}	160.668	143.149	159.783	149.34
C_5	139,854	122.334	138.969	137.89
C_6	133,418	115.899	132.533	130.69
C_4	131.828	114.308	130.943	127.22
C_{11}	127.937	110.417	127.051	119.70
C_1	121.196	103.676	120.31	115.52
C_3	121.106	103.586	120.21	115.30
H_{13}	12.1146	11.3991		13.76
H_{20}	10.9441	10.2286		
H_{14}	10.368	9.6525		9.898
H_{10}	8.7979	8.0824		8.46
H_7	7.9773	7.2618		7.918
H_8	7.9084	7.1929		
H_9	7.557	6.8415		7.333

Thermodynamic Properties

A detailed thermodynamic investigation of the 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule has been conducted using DFT methodology employing the B3LYP functional in conjunction with the 6-31++G(d,p) basis set. The computed thermodynamic parameters include total electronic energy, zero-point vibrational energy (ZPVE), rotational constants, thermal energies, entropies, heat capacities at constant volume, and dipole moments (μ, μ_x, μ_y, μ_z). These values are

summarized in Table 3, offering a comprehensive view of the molecule's behavior across translational, rotational, and vibrational modes.

Table 3. Total energies (a.u.), Zero-point correction (a.u./Particle), zero-point vibrational energies (kcal mol^{-1}), entropies (cal $mol^{-1}K^{-1}$), thermal energies (kcal mol^{-1}), rotational constants (GHz), heat capacities (cal $mol^{-1}K^{-1}$), and dipole moment (Debye).

Parameter	DFT
Total Energy	-669.86178973
Zero-point vibrational Energy	96.35986
Rotational Constant	1.48608
	0.38231
	0.31534
Zero-point correction	0.153559
Thermal correction to Energy	0.164560
Thermal correction to Enthalpy	0.165504
Thermal correction to Gibbs Free Energy	0.115605
Entropy	
Total	105.022
Translational	41.632
Rotational	31.862
Vibrational	31.527
Heat capacity	
Total	42.146
Translational	2.981
Rotational	2.981
Vibrational	36.185
Thermal energy	
Total	103.263
Translational	0.889
Rotational	0.889
Vibrational	101.485
Total dipole moment	3.2978
μ_x	-1.4433
μ_y	-2.9452
μ_z	0.3436

According to the results, the total entropy (S°) of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde is calculated to be approximately 105.022 cal.$mol^{-1}K^{-1}$ using the B3LYP theory, indicating a moderate level of molecular disorder and thermal accessibility at standard temperature. The calculated total electronic energy is -669.86178973 atomic units (a.u.) at the B3LYP level. Similarly, the zero-point vibrational energies are obtained as 96.35986 a.u.

The heat capacity (C_v), an indicator of the energy required to raise the temperature of the molecule, is calculated as 42.146 cal.$mol^{-1}K^{-1}$ under DFT method. The value reflects the degrees of freedom involved in molecular motion and provides insight into the thermodynamic stability and energy distribution within the molecular system.

Another crucial aspect of the thermodynamic analysis is the dipole moment, a vector quantity that reflects the separation of positive and negative charges within a molecule. This parameter is pivotal for understanding various physical and chemical behaviors, including dielectric properties, solubility, reactivity, and interactions with biological systems or electromagnetic fields. In the present study, the

dipole moment is computed as 3.2978 Debye, indicating a moderately polar structure arising from asymmetric electron density distribution, especially due to the presence of electronegative fluorine and nitrogenous atoms.

The magnitude of the dipole moment has important implications beyond molecular polarity. It significantly influences intermolecular forces such as van der Waals interactions and dipole–dipole attractions. Consequently, molecules with higher dipole moments tend to exhibit stronger interactions in both biological and materials science contexts. For example, dipole–dipole forces play a fundamental role in molecular recognition processes involving enzyme active sites, which are sensitive to both electrostatic potential and spatial orientation of incoming ligands [18].

Furthermore, the thermodynamic and dipole-related findings present here are of considerable relevance for the design and engineering of functional materials. In particular, these insights can be leveraged in the development of molecular semiconductors, optoelectronic devices, and composite materials, where thermal stability, electronic polarization, and vibrational characteristics play central roles.

In summary, the thermodynamic and electronic parameters derived from B3LYP theoretical framework provide a coherent and detailed portrait of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde's molecular behavior, offering valuable predictive tools for its application in fields such as molecular electronics, spectroscopy, pharmacology, and materials science.

Atomic charge distributions

In this investigation, the atomic charge distributions of the 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule are systematically examined through Mulliken population analysis [19–22], a method that provides qualitative insights into the electronic structure by partitioning the electron density among atoms in a molecule. Calculations were performed using DFT with the B3LYP theory at 6-31++G(d,p) basis set. The computed Mulliken charges for each atomic center are reported in Table 4.

The analysis revealed significant variation in the Mulliken charges across the molecule, reflecting the influence of molecular geometry, bonding environment, and electron delocalization. At the B3LYP/6-31++G(d,p) level, carbon atoms exhibited a wide range of charge values, spanning from -0.987046 to 1.156780 atomic units (a.u.), indicative of strong π-electron conjugation and localized charge disparities within the aromatic ring system. The nitrogen atoms, bearing a lone pair of electrons, demonstrate both negative and positive Mulliken charge values: -0.305626 a.u. (for N_{16}) and 0.010403 a.u. (for N_{17}) under B3LYP method. The negative values reflect the high electronegativity and lone-pair electron density of the nitrogen atom, which contributes significantly to intramolecular charge transfer (ICT) processes. Fluorine atom, as expected due to their electron-withdrawing nature and polarizability, exhibits negative charge value at DFT level of theory. The Mulliken charge is found to be -0.324165 a.u. Moreover, hydrogen atoms, typically associated with partial positive charges due to their single bonding to more electronegative atoms, show Mulliken charge values ranging from 0.123734 a.u. (for H_{20}) to 0.344326 a.u (for H_{13} atom). This variability arises from their diverse bonding environments and the influence of lone pairs on adjacent atoms, which can perturb the local electron density.

Table 4: The Mulliken charges across the molecule

Label	DFT(B3LYP/6-31+(d,p))
C_{15}	-0.452801
C_{19}	-0.231735
C_{2}	-0.544734
C_{12}	0.326990
C_{5}	1.156780
C_{6}	-0.512986
C_{4}	-0.987046
C_{11}	-0.033966
C_{1}	0.512406
C_{3}	0.510053
H_{13}	0.344326
H_{20}	0.123734
H_{14}	0.191311
H_{10}	0.154183
H_{7}	0.150451
H_{8}	0.154542
H_{9}	0.147591
O_{21}	-0.389712
N_{16}	-0.305626
N_{17}	0.010403
F_{18}	-0.324165

To sum up, the Mulliken charge analysis underscores the key electronic features of the 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule, such as the presence of electron-rich and electron-deficient regions, the impact of substituent groups, and the nature of intramolecular charge distribution. These findings are essential for understanding the compound's reactivity, spectroscopic behavior, and potential for interaction with external fields or molecular receptors.

Molecular Features of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde

This section provides an in-depth analysis of the frontier molecular orbitals (FMOs) of the 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule, with particular emphasis on the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO). These orbitals are fundamental to understanding the electronic structure, optical properties, and chemical reactivity of organic compounds. The HOMO represents the outermost orbital containing electrons and primarily functions as an electron donor, while the LUMO denotes the lowest energy orbital that is vacant and capable of accepting electrons, thereby acting as an electron acceptor.

According to molecular orbital theory, the interactions between HOMO and LUMO are directly linked to intramolecular electronic transitions, particularly $\pi \rightarrow \pi^*$ transitions. These transitions critically influence the optoelectronic behavior of the molecule [23, 24]. The energy level of the HOMO is correlated with the ionization potential, indicating how readily the molecule can donate electrons. Conversely, the LUMO energy level is associated with the electron affinity, reflecting the molecule's capacity to accept electrons.

A key parameter derived from these orbitals is the energy gap (ΔE) between the HOMO and LUMO. This band gap is of substantial importance, as it provides insight into the electronic excitation potential, molecular stability, and chemical reactivity. Molecules with a narrow HOMO–LUMO gap tend to exhibit higher chemical reactivity and greater susceptibility to electronic excitation, whereas a broader band gap signifies increased molecular stability and reduced reactivity [25],

In addition to its role in molecular reactivity, the HOMO–LUMO gap is a decisive factor in determining the efficiency and functionality of materials in semiconductor applications. Particularly in the context of organic electronics, the band gap directly influences charge transport mechanisms, energy absorption, and overall device performance. It has been widely acknowledged that tuning the ΔE parameter is vital for optimizing energy efficiency and functional properties in organic semiconductors and composite materials. In the present study, the three-dimensional visualizations of the HOMO and LUMO orbitals are illustrated in Fig. 2, providing a spatial representation of the electron density distribution in both orbitals.

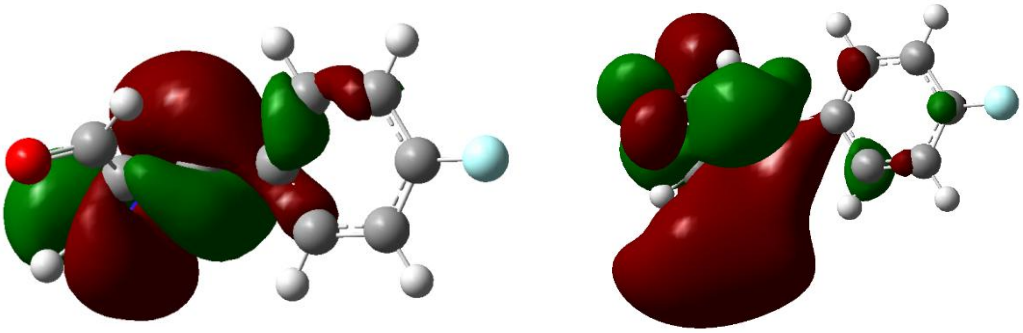

Fig. 2. 3D plots of a-) HOMO and b-) LUMO of the title compound. (Red/green regions reveal the positive/negative phases.

These visualizations help identify regions of electron donation and acceptance, contributing to a more comprehensive understanding of charge transfer pathways within the molecule. It is shown that the HOMO is predominantly delocalized across the molecular framework; however, a notable absence of orbital density is observed between atoms 19 and 21. Additionally, the contribution of the benzene ring to the HOMO distribution appears minimal, indicating limited electron delocalization in this region. In contrast, the LUMO reveals a broader spatial distribution of electron-accepting character across the molecule, except for the benzene ring and the fluorine-substituted site, which show negligible orbital involvement. This suggests that electronic excitation or charge transfer processes are less likely to engage these particular regions. Accordingly, the frontier molecular orbital analysis underscores the electronic nature and reactive potential of the 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule, offering valuable insights for its potential application in electronic, photonic, and materials science domains.

Conclusions

In the present study, we conduct a comprehensive quantum chemical investigation of the ground-state molecular properties of 3-(p-fluorophenyl)-1H-pyrazole-4-carbaldehyde molecule. Calculations are performed using DFT employing the B3LYP functional combined with the 6-31++G(d,p) basis set. Theoretical predictions included thermodynamic parameters, ^{1}H and ^{13}C NMR chemical shifts, and UV–Visible absorption spectra. The computations are further extended to analyze atomic charge distributions, with a focus on identifying ICT regions, electron-donating groups, non-bonding lone pairs, and π-bond conjugations, all of which contribute significantly to the compound's electronic behavior and reactivity.

To deepen the understanding of the electronic structure, FMO analysis was carried out. The spatial distribution and energy characteristics of the HOMO and LUMO were analyzed to assess the compound's potential for intermolecular interactions, metallic bonding, and electronic transitions. This information is essential for predicting the molecule's reactivity, stability, and potential for application in electronic devices, optical materials, and biologically active frameworks.

In conclusion, the theoretical findings strongly correlate with existing experimental observations, underscoring the effectiveness DFT approaches in the structural and electronic characterization of this pharmaceutically relevant compound. The insights gained lay the foundation for future studies and functional modifications aimed at optimizing the compound for targeted biomedical and industrial applications.

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ALTERATION OF ELECTRICAL FEATURES OF BI-2212 CRYSTAL STRUCTURE WITH BARIUM ACETATE

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ABSTRACT

Although there are several studies on barium or barium oxide ions added Bi-based ceramic superconductor materials such as Bi-2212 and Bi-2223 superconducting phases in the literature, a study with barium acetate ($Ba(C_2H_3O_2)_2$) has not been done yet. In this study, the crucial effects of barium acetate addition on the characteristic dc electrical properties of bulk Bi-2212 ceramic superconductors has been investigated in detail instead of addition of barium ions or barium oxide. In other words, it is thought that the chemical salt of barium(II) and acetic acid makes a positive contribution to the electrical properties of the ceramic structure due to the advantages including superior stability and coordination structure. However, the experimental electrical measurements performed using the four-probe method in the temperature range of 15 K-100 K display that the characteristic electrical conductivity behavior is found to decrease regularly depending on the increase in the $Ba(C_2H_3O_2)_2$ impurity additions in the Bi-2212 crystal structure. This is because the $Ba(C_2H_3O_2)_2$ material leads to the revival of fundamental microstructural problems such as metallic connections between the adjacent layers, inter-grain/intra-grain interactions, crack-initiating flaws, permanent lattice strains, irreversible impurity scattering, and permanent irreversible deformations in the ceramic matrix. We also determine key electrical characteristics including normal state temperature resistivity at 300 K (ρ_{300K}), residual resistivity ratios (RRR), residual resistivity (called ρ_{res}), ρ_{norm}, ρ_{85K}, and $\Delta\rho$ with the aid of electrical curves. Experimental results indicate a consistent decrease in all characteristic direct current electrical properties with increasing additive content. The computed results reveal a degradation in crystal structure integrity and interlayer metallic connectivity, attributed to increased lattice strain and enhanced impurity scattering effects. Consequently, the $Ba(C_2H_3O_2)_2$ impurity addition to crystal system is not considered a favorable strategy for improving the electrical conductivity and associated transport properties of the Bi-2212 system in prospective application areas.

Keywords: Bi-2212 ceramics; Barium acetate; Electrical resistivity; Microstructural problems.

Introduction

Bismuth-based cuprate superconductors have been the subject of intensive scientific research, especially in the field of materials engineering, since the discovery of high-temperature superconductivity [1]. Scientists are constantly working on increasing the transition temperature, critical current density, and critical field transport properties. Scientists have been focusing on the first two families of bismuth-based cuprate superconductors, which have 3 main members (Bi-2223, Bi-2212, and Bi-2201) in their family [2–4]. Moreover, the $Bi_{2.0}Sr_{2.0}Ca_{1.0}Cu_{2.0}O_y$ (Bi-2212) phase has attracted special attention due to its relatively high superconducting transition temperature ($T_c \sim 85$ K), distinct layered crystal structure, and promising potential for practical applications in superconducting magnets, electronic devices, and power systems. At the same time Bi-2212 exhibits superior thermodynamic stability and higher critical temperatures compared to many other high-temperature superconductors. It demonstrates an impressive current-carrying capacity of approximately 10^7 A/cm^2 and can sustain magnetic fields exceeding 100 T at temperatures around 35 K, while also offering reduced energy losses. Additionally, the unique ceramic structure of Bi-2212, characterized by weak van der Waals bonding between BiO planes, facilitates mechanical flexibility, enabling easy deformation during processing. This property is particularly advantageous for the fabrication of long-length superconducting cables and tape castings, with lengths exceeding one kilometer [5–8]. Structurally, Bi-2212 belongs to the cuprate family, which is characterized by a perovskite-like arrangement of CuO_2 planes separated by Bi–O and Sr–O layers, where superconductivity originates primarily within the CuO_2 planes via complex electron-pairing mechanisms [9–11]. The intrinsic anisotropy, oxygen stoichiometry, and sensitivity to structural modifications of the Bi-2212 phase provide a flexible platform to study the interplay between superconductivity, crystal chemistry, and microstructural properties. Various external interventions, such as chemical doping, ion substitution, and thermal treatments, have been extensively investigated to optimize the electrical, flux-pinning, superconducting properties, mechanical performance, and microstructural stability of Bi-2212 ceramics [12–16]. In particular, ion substitutions at Bi, Sr, or Ca sites can significantly affect the electrical, superconductivity, carrier concentration, phase purity, grain connectivity, and flux-pinning behavior, and thus affect the superconducting transition temperature and critical current density. Understanding and controlling the relationship between structural, mechanical and superconducting properties of Bi-2212 is important for its integration into technological applications that require high performance under mechanical stress and magnetic fields [18, 19]. Therefore, comprehensive studies focusing on the correlation between structural improvements, mechanical strength and electrical and especially superconducting functionality are crucial to advance the fundamental knowledge and practical utility of Bi-2212-based materials. In this context, the present work systematically investigates the effects of compositional modifications on the electrical properties of Bi-2212 superconductors, aiming to enhance their performance and reliability for future applications. However, temperature-dependent electrical resistivity measurements indicate that chemical salt of barium(II) and acetic acid incorporation adversely impacts the metallic behavior of the crystal structure by reducing the hole carrier concentration and weakening electron-phonon interactions, ultimately leading to increased structural disorder.

Fabrication, Processing, and Electrical Characterization of Barium Acetate-added Bi-2212 Superconducting Cuprates

In this work, bulk $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ superconducting ceramics were fabricated by incorporating varying amounts of barium acetate (x = 0.00 to 0.10) through the conventional solid-state reaction method. All thermal treatments, including heating and cooling, were performed under ambient air conditions without the use of protective atmospheres. High-purity precursors (≥99.99%) including $Ba(C_2H_3O_2)_2$, $SrCO_3$, CuO, Bi_2O_3, and $CaCO_3$ powders, were utilized to achieve the desired stoichiometric ratios for the Bi-2212 superconducting phase.

For each composition, 1.8 grams of the raw materials were accurately weighed and initially mixed by grinding in porcelain crucibles for 8 hours in air to achieve preliminary homogenization and particle size reduction. To further refine the mixture, the powders were ground for an additional 30 minutes in an agate mortar without using any liquid medium, facilitating better interatomic interactions.

The blended powders were then calcined at 800 °C for 36 hours inside a programmable furnace, maintaining a heating/cooling rate of 5 °C/min. The purpose of the calcination step was to promote phase formation and minimize the presence of secondary phases. After calcination, the powders were pressed into rectangular rods with dimensions of 20 × 5 × 16 mm^3 under ambient pressure, aiding in the enhancement of grain connectivity and densification during subsequent processing.

Sintering was conducted at 850 °C for 36 hours in air to achieve final consolidation of the ceramic samples. The resulting $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ superconducting ceramics were designated as BiBaC-0, BiBaC-1, BiBaC-2, BiBaC-2, BiBaC-3, BiBaC-4, and BiBaC-5, corresponding to barium acetate content addition levels of x = 0.00, 0.03, 0.05, 0.07, 0.09, and 0.13, respectively.

The electrical resistivity behavior of the samples was assessed via the standard four-probe technique in a cryogenic environment, employing a constant direct current of 5 mA over a temperature range of 10 K to 95 K. Based on the resistivity profiles, important electrical parameters were extracted, including the residual resistivity ratio (RRR), resistivity at 300 K (ρ_{300K}), residual resistivity (ρ_{res}), normalized resistivity (ρ_{norm}), resistivity at 87 K (ρ_{87K}), and resistivity change ($\Delta\rho$), to study the microstructural impact of barium acetate content addition on the Bi-2212 crystal system.

The results indicated a consistent decline in key direct current electrical properties with increasing barium acetate content concentration. A comprehensive analysis and interpretation of these trends are provided in the subsequent sections.

Results and discussion

Effects of Barium Acetate Addition on Electrical Resistivity, Metallic Behavior, and Critical Transport Mechanisms in Bi-2212 Superconducting

This work presents a detailed analysis of how barium acetate content concentration influences the electrical transport properties and key resistive parameters of $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ materials. Samples with varying sodium doping concentrations (x = 0.00, 0.03, 0.05, 0.07, 0.09, and 0.13) were synthesized to assess their viability for advanced technological sectors, including power grids, cryogenic cooling systems, magnetic levitation platforms, high-efficiency generators, electric propulsion systems, and other emerging energy applications. Electrical resistivity measurements were performed using the standard four-probe method under a constant direct current of 5 mA, covering a temperature window between 10 K and 95 K. The resulting temperature-dependent resistivity profiles (Figure 1) offer comprehensive insights into the charge transport dynamics of the $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ materials.

From the resistivity data, crucial electrical parameters such as RRR, ρ_{300K}, ρ_{res}, ρ_{norm}, ρ_{87K}, and $\Delta\rho$ were extracted and analyzed to understand the influence of $Ba(C_2H_3O_2)_2$ impurity addition level on the electronic structure and microstructural integrity of the Bi-2212 phase.

All samples exhibit conventional metallic behavior above their respective superconducting transition temperatures, in line with the expected electronic density of states near the Fermi level. However, a progressive suppression of metallic characteristics is clearly observed with increasing sodium content [20].

This deterioration is linked to the interference of sodium impurities with the electron-phonon coupling strength, which is crucial for the formation of Cooper pairs in high-temperature superconductors [21]. Furthermore, the longitudinal transport relaxation time (where $1/\tau$ is proportional to temperature), a

hallmark of metallic conductivity associated with spin-charge separation phenomena, also shows significant degradation [22].

Overall, the introduction of $Ba(C_2H_3O_2)_2$ impurity addition amount not only hampers the superconducting transition but also disrupts the metallic conduction pathways, undermining the performance of Bi-2212 ceramics for advanced engineering applications. The experimental findings and theoretical calculations emphasize the detrimental effects of barium acetate content concentration and highlight the need for careful dopant selection when optimizing Bi-2212 materials for critical technologies such as renewable energy systems and superconducting power transmission.

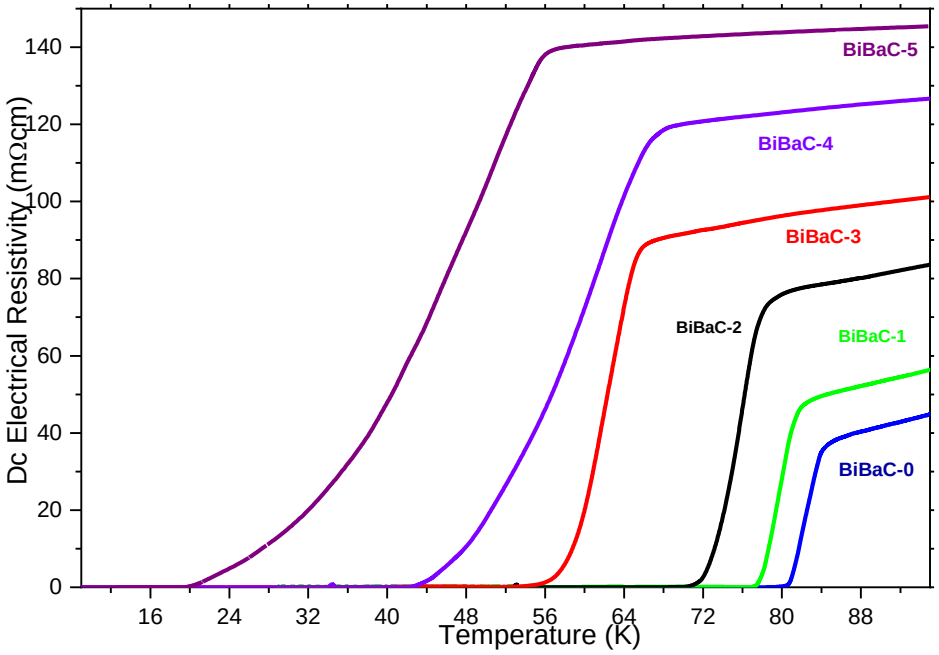

Fig. 1 Change of DC electrical resistivity measurement results against different environment temperatures for the different $Ba(C_2H_3O_2)_2$ added Bi-2212 superconductors

Influence of Barium Acetate ***Incorporation on Hole Carrier Concentration in Bi-2212 Superconductors***

Secondly, we examine extensively influence of barium acetate content concentration on hole carrier concentration in solidified Bi-2212 superconductors with the aid of DC electrical curves.

The metallic character of the bulk $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ superconducting system is predominantly dictated by variations in the hole carrier density within the σ-antibonding planes [23]. Experimental analysis reveals that increasing the $Ba(C_2H_3O_2)_2$ chemical concentration systematically deteriorates the metallic behavior of Bi-2212 ceramics. This decline is attributed to the progressive formation of microstructural defects, such as grain boundary misorientations, local dislocations, internal stresses, microvoids, pores, residual impurities, and disruptions in intergranular coupling across superconducting planes.

These structural imperfections critically impede the mobility of hole carriers, thereby degrading the intrinsic electrical conductivity and basic superconducting performance of the Bi-2212 material. As depicted in Fig. 1, the BiBaC-0 sample exhibits the highest hole carrier concentration and the strongest metallic bonding across both intra-grain and inter-grain regions, resulting in superior electrical conductivity and optimized superconducting properties. Similar observations have been reported in prior studies [24].

Conversely, a progressive weakening of metallic bonding is observed with increasing of barium acetate content concentration level. This degradation stems from multiple interrelated factors, including the disruption of electron-phonon interactions essential for Cooper pair formation, the

suppression of antiferromagnetic spin fluctuations, the reduction in mobile hole density, and the overall deterioration of crystalline order [25].

Collectively, the findings underscore the adverse impact of barium acetate content concentration amount on the fundamental electronic and transport properties of Bi-2212 cuprate superconductors, thereby constraining their potential for deployment in high-performance industrial, technological, and large-scale superconducting applications.

Table 1. General electrical resistivity parameters: ρ_{87K}, ρ_{300K}, ρ_{norm}, *RRR*, ρ_{res}, and $\Delta\rho$ values for $Bi_{2.1}(Na_x)Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ ceramic cuprate structures

Samples	ρ_{300K} *(m.Ωcm)*	ρ_{res} *(m.Ωcm)*	*RRR* (ρ_{300K}/ρ_{87K})	$\Delta\rho$ $(\rho_{300K}-\rho_{87K})$ *(m.Ωcm)*	ρ_{norm} $(\rho_{87}/\Delta\rho)$	ρ_{87K} *(m.Ωcm)*
BiBaC-0	151.86	1.42	3.792707293	111.82	0.358075478	40.04
BiBaC-1	166.12	6.76	3.202004626	114.24	0.454131653	51.88
BiBaC-2	177.28	41.98	2.211576846	97.12	0.825370675	80.16
BiBaC-3	187.32	66.44	1.888687235	88.14	1.125255276	99.18
BiBaC-4	186.58	105.48	1.488353542	61.22	2.047696831	125.36
BiBaC-5	182.16	129.46	1.254372676	36.94	3.931239848	145.22

Effect of Barium Acetate Impurity Incorporation on the DC Electrical Resistivity of Bulk Bi-2212 Superconductors

The influence of barium acetate content concentration amount on the fundamental dc electrical resistivity parameters of bulk $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ superconducting was systematically analyzed through the resistivity curves shown in Fig. 1. Key electrical parameters; namely, RRR, ρ_{300K}, ρ_{res}, ρ_{norm}, ρ_{87K}, and $\Delta\rho$ were assessed in detail and summarized in Table 1. The results clearly demonstrate a strong correlation between barium acetate content concentration and the degradation of electrical transport properties.

One of the primary observations concerns the variation in ρ_{300K}. The BaBiC-0 superconductor exhibited a ρ_{300K} value of 151.86 mΩ.cm, whereas $Ba(C_2H_3O_2)_2$-added specimens, namely BaBiC-1, BaBiC-2, BaBiC-3, BaBiC-4, and BaBiC-5, showed values of approximately 166.12, 177.28, 187.32, 186.58, and 186.12 mΩ.cm, respectively. Similarly, an examination of ρ_{res}, derived according to Matthiessen's rule [26], indicates a pronounced and systematic increase with sodium addition, reflecting a growing presence of structural imperfections, including grain boundary defects, microvoids, lattice distortions, and stress fields [27].

Moroever, ρ_{res} values especially escalated from 1.42 mΩ.cm in the BaBiC-0 superconductor to 129.46 mΩ.cm in BaBiC-5, with intermediate values of 6.76, 41.98, 66.44, and 105.48 mΩ.cm corresponding to the BaBiC-1 through BaBiC-4 superconductors, respectively. This significant increase confirms that barium acetate impurities introduce substantial crystalline disorder, severely impeding charge carrier mobility and thus deteriorating the material's superconducting and electrical performance. Especially, the barium acetate including chemical salt of barium(II) and acetic acid gives more damage the conducting properties of Bi-2212 superconductor as compared to the other addition chemicals.

Further analysis of the ρ_{87K} parameter, a critical indicator of impurity scattering, revealed a similar trend. The BaBiC-0 superconductor demonstrated the lowest ρ_{87K} (40.04 mΩ.cm), while the value progressively increased with $Ba(C_2H_3O_2)_2$ addition level, reaching 145.22 mΩ.cm for BaBiC-5. This steady rise highlights enhanced impurity scattering caused by microstructural defects such as dislocations, stress concentrators, and grain boundary disruptions [28].

At the same time, RRR which reflects structural quality and electronic transport efficiency, also showed a significant decline with increasing $Ba(C_2H_3O_2)_2$ chemical addition concentration. RRR decreased from 3.793 in the solidified BaBiC-0 sample to 1.2543 for BaBiC-5 compound. Intermediate compositions exhibited RRR values of 3.202, 2.212, 1.889, and 1.488, confirming a continuous loss of crystalline integrity and increased carrier scattering [29]. A lower RRR value directly corresponds to poorer electrical and mechanical properties, underscoring the detrimental effect of sodium incorporation.

In addition, the Δρ parameter further illustrated the structural degradation. The BaBiC-0 superconductor exhibited the highest Δρ (111.82 mΩ.cm), indicative of minimal defect density and superior lattice coherence. In contrast, Δρ values decreased progressively to 36.94 mΩ.cm for BaBiC-5 workpiece, with intermediate reductions corresponding to the other $Ba(C_2H_3O_2)_2$ chemical added-Bi-2212 superconductors. This decline points to increased lattice disorder and microstructural irregularities resulting from sodium incorporation.

The normalized resistivity (ρ_{norm}), another marker of structural and electronic degradation, also increased significantly with $Ba(C_2H_3O_2)_2$ addition content level. While the BaBiC-0 sample had a ρ_{norm} of 0.3581, BaBiC-5 (including the highest $Ba(C_2H_3O_2)_2$ addition) exhibited a markedly higher value of 3.9312. The progressive increase (ten times increase) across intermediate doping levels reflects escalating lattice strain, impurity concentration, and electron scattering mechanisms.

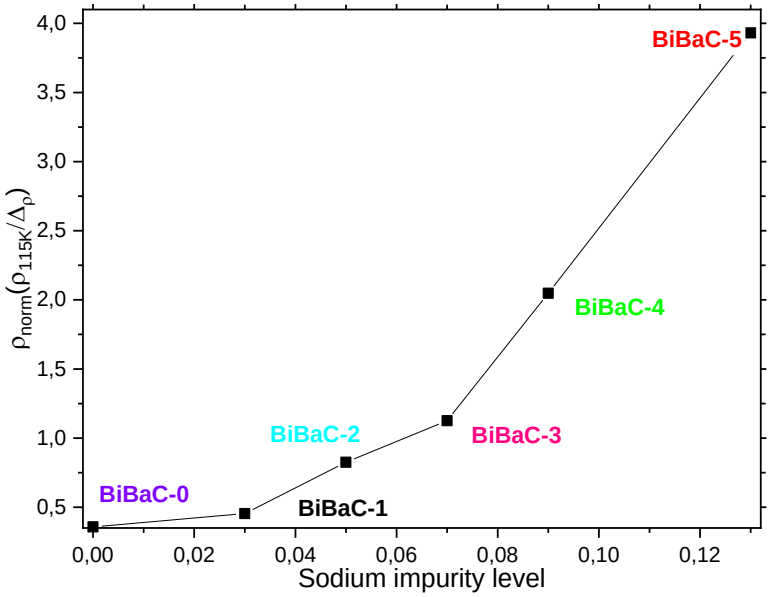

Fig. 2. Variations of microstructural problems in different $Ba(C_2H_3O_2)_2$ added Bi-2212 superconductors

The effects of $Ba(C_2H_3O_2)_2$ addition level on the microstructure and electrical properties of Bi-2212 ceramics are further illustrated graphically. Figure 2 highlights the evolution of microstructural defects as a function of barium acetate impurity level, while Fig. 3 depicts the corresponding decline in material quality. As evident from Fig. 2, impurities of barium acetate addition induce a substantial increase in grain misorientations, microvoid formation, lattice strain, and intergranular connectivity problems. Consequently, these defects severely impair charge carrier transport, leading to enhanced resistivity and diminished superconducting efficiency.

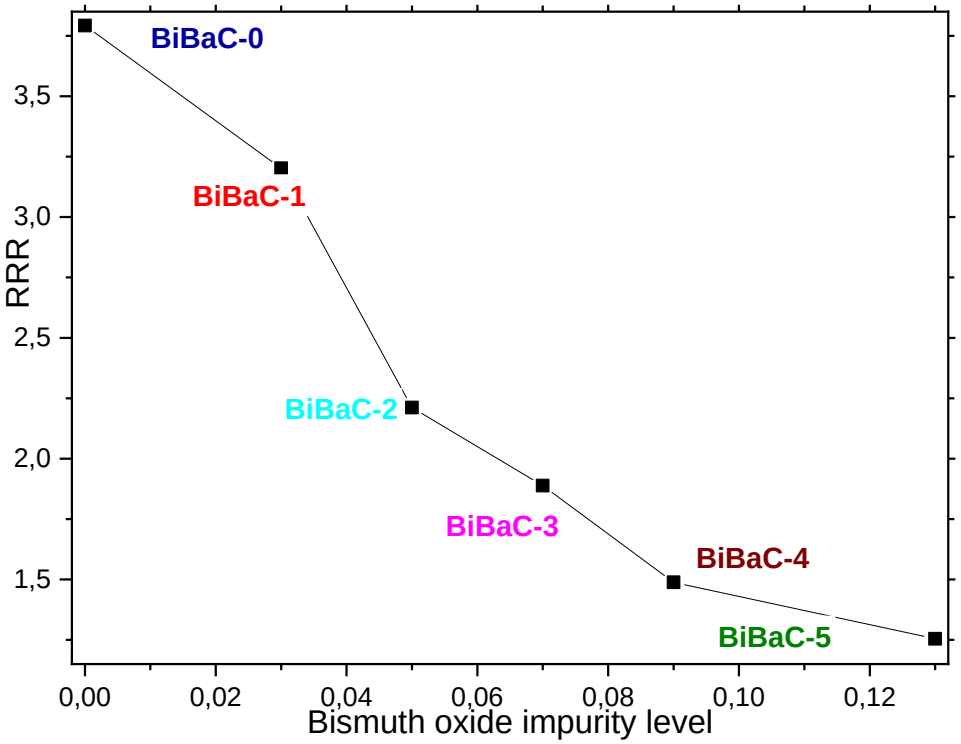

Fig. 3. Variation of material qualities in different $Ba(C_2H_3O_2)_2$ added Bi-2212 superconductors

Figure 3 reinforces these findings by showing a systematic degradation of the overall material quality with increasing sodium content. As sodium impurity levels rise, both structural integrity and electrical performance of the Bi-2212 ceramics deteriorate, rendering highly doped samples unsuitable for advanced superconducting applications.

In summary, the $Ba(C_2H_3O_2)_2$-added bulk Bi-2212 superconductor exhibited the best structural and electronic characteristics, positioning it as a promising candidate for advanced superconducting technologies. Conversely, the BaBiC-5 material with the chemical salt of barium(II) and acetic acid chemicals, characterized by the highest electrical resistivity and lowest RRR, clearly illustrates the adverse effects of $Ba(C_2H_3O_2)_2$ impurities, emphasizing the critical importance of minimizing dopant concentrations to optimize the material for heavy industrial and engineering applications.

Conclusion

This study explores the viability of employing bulk $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ superconducting systems by examining their dc electrical resistivity behavior. For the first time, comprehensive resistivity measurements were performed over the temperature range from 10K to 95K to assess their potential for technological applications. Detailed evaluation of the temperature-dependent resistivity profiles enabled the extraction of key electrical parameters, including ρ_{300K}, *RRR*, ρ_{115K}, ρ_{res}, ρ_{norm}, and $\Delta\rho$ parameters. The values provide critical insights into the structural coherence, electronic transport properties, and the overall suitability of Bi-2212 ceramics for applications in heavy industry, advanced engineering, and large-scale technological systems. The experimental findings unequivocally demonstrate that sodium incorporation adversely affects both the crystallographic order and the electronic properties of the $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ superconducting matrix. Increasing $Ba(C_2H_3O_2)_2$ impurity concentration level systematically deteriorates the material quality, evidenced by the proliferation of microstructural defects, enhanced charge carrier scattering, and suppressed superconducting performance. Thus, stringent control of barium acetate impurity levels is imperative to retain high electrical conductivity and preserve the structural integrity of Bi-2212 ceramics for practical applications.

Acknowledgment

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ROLE OF BARIUM ACETATE IMPURITY ON SUPERCONDUCTING TRANSITION PROPERTIES OF BI-2212 CUPRATES

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Abstract

In this study, we investigated the changes in the potential usage of $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_{\gamma}$ (Bi-2212) ceramic structures in heavy industry, advanced engineering and large-scale technological application areas depending on the different addition levels of barium acetate ($Ba(C_2H_3O_2)_2$). On this basis, we firstly synthesized the $Ba(C_2H_3O_2)_2$ added Bi-2212 superconductors via conventional solid-state reaction in ambient air and make electrical measurements in the temperatures between 15 K and 100 K using the four-probe method. The obtained electrical resistivity curves were used to determine the fundamental superconducting transitions such as offset (T_c^{offset}) critical, onset critical (T_c^{onset}) transition temperatures and related transition temperature width evaluated from the formula of $\Delta T_c = T_c^{onset} - T_c^{offset}$. Consequently, the purpose of this study is only to determine the change of the impurity addition amounts directly on the superconducting transition temperatures. The experimental findings revealed a progressive degradation of superconducting behavior with increasing $Ba(C_2H_3O_2)_2$ content levels, attributed to the detrimental effects of barium acetate impurities on key microscopic features, including electron-phonon couplings, superconducting volume fraction, hybridization processes, wavefunction overlap, mobile hole concentration, superconducting phase stability, hole trap energies, bipolarons, and super electron cluster formations through the Bi-2212 crystal system. At the same time, the existence of $Ba(C_2H_3O_2)_2$ impurities in the cuprate superconducting system was obtained to degrade seriously crystal quality based on a pronounced increase in defect formations, permanent lattice strains, impurity scattering, stress localization regions, and grain misalignments along the Bi-2212 structure. In this respect, the excess $Ba(C_2H_3O_2)_2$ impurity added Bi-2212 superconductors possessed relatively lower T_c^{offset} and T_c^{onset} but higher ΔT_c numerical parameters. These results conclusively demonstrated that $Ba(C_2H_3O_2)_2$ impurity addition is an ineffective strategy for enhancing the fundamental superconducting performances of the bulk Bi-2212 superconducting system.

Keywords: Superconducting transitions; Bi-2212 superconductors; Barium acetate; Electron-phonon couplings.

Introduction

The continuous demand for advanced superconducting materials capable of operating under extreme conditions has driven extensive research into high-temperature superconductors (HTS). Among the various families of HTS compounds, the $Bi_2Sr_2Ca_{n-1}Cu_nO_{4+2n+x}$ (BSCCO) family has garnered particular attention due to its outstanding material properties [1, 2]. Within this family, $Bi_2Sr_2Ca_1Cu_2O_{8+x}$ (Bi-2212) stands out as a highly promising candidate for technological and industrial applications owing to its high critical temperature (Tc ~ 85–95 K), superior phase stability, and relatively simple fabrication process compared to other cuprate superconductors [3–6]. The layered perovskite structure, with weak van der Waals coupling between Bi-O layers, contributes to remarkable anisotropic properties of the Bi-2212 superconductor, facilitating high current-carrying capacities along the Cu-O_2 planes.

Bi-2212 superconductors offer several critical advantages that make them highly attractive for heavy industry technologies, future engineering systems, and large-scale energy infrastructures. These include their exceptional chemical stability, strong flux pinning capabilities, resilience against oxygen loss at elevated temperatures (~850°C), and compatibility with various cooling technologies, such as those utilizing liquid nitrogen and cryocoolers [7–10]. Furthermore, Bi-2212 superconductors can conduct engineering-level direct currents without electrical resistance and maintain high performance under the influence of strong external magnetic fields, making them especially useful for applications like high-field magnets, superconducting power cables, fault current limiters, transformers, magnetic levitation transport systems, and fusion reactors [11–17].

Another vital attribute of Bi-2212 is its relatively cost-effective synthesis route, the use of non-toxic starting materials, and its scalability into multi-filamentary wire and tape forms, allowing integration into complex device architectures. Compared to other superconducting materials such as YBCO and MgB_2, the Bi-2212 offers enhanced manufacturability, improved material purity, and greater flexibility for use in practical applications. At cryogenic temperatures, Bi-2212 exhibits high critical current densities (J_c) and low hysteresis losses, even when subjected to strong magnetic fields, maintaining superconductivity where many other materials fail [11–13]. The remarkable properties collectively position Bi-2212 at the forefront of superconducting material development for next-generation engineering and technological applications.

Nevertheless, the performance of Bi-2212 ceramics is strongly influenced by chemical composition, doping levels, and microstructural integrity. Even slight deviations from the optimal stoichiometry or the incorporation of foreign impurity ions can profoundly affect the superconducting behavior. In particular, chemical salt of barium(II) and acetic acid doping seems to attract research interest due to its potential impact on electronic transport mechanisms, charge carrier density, electron-phonon coupling, and lattice stability. While controlled doping is often employed to tailor the electrical and structural properties of superconductors, unintentional or excessive doping can lead to increased structural disorder, enhanced electron scattering, weakening of inter-grain coupling, and deterioration of superconducting coherence.

In this context, the present study systematically investigates the effect of barium acetate content incorporation on basic superconducting properties (onset critical transition temperature, offset critical transition temperature, and broadening of the transition widths) to offer crucial insights into the structural integrity, charge carrier dynamics, degree of impurity scattering, and superconducting transition quality of the Bi-2212 material. Our findings reveal that the addition of $Ba(C_2H_3O_2)_2$ chemical into the Bi-2212 matrix systematically degrades the superconducting performance. The presence of sodium impurities results in an increase in structural defects such as grain boundary disruptions, microvoids, lattice distortions, and impurity phases, which, in turn, enhance electron scattering, lower charge carrier mobility, and weaken inter-grain coupling. Consequently, the superconducting phase coherence is suppressed, leading to a significant reduction in critical current density and fundamental electrical performance [18–20].

The study clearly demonstrates that maintaining minimal impurity levels is critical for preserving the optimal electrical conductivity, structural quality, and high-temperature superconducting properties of Bi-2212 ceramics. These insights are crucial for guiding the future synthesis strategies and materials engineering approaches aimed at optimizing Bi-2212 for use in heavy industry, advanced engineering systems, and large-scale technological deployments such as renewable energy integration, magnet-based medical systems, and cryogenic energy storage technologies.

Fabrication, Processing, and Electrical Evaluation of Barium Acetate-Modified Bi-2212 Superconducting Ceramics

In this study, the influence of barium acetate incorporation on the superconducting and electrical properties of $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_{\gamma}$ ceramic superconductors was systematically investigated. Bulk samples were synthesized by introducing varying concentrations of barium acetate $Ba(C_2H_3O_2)_2$, with doping levels ranging from x = 0.00 to 0.13, employing the conventional solid-state reaction route. All thermal treatments, including calcination and sintering, were carried out in ambient atmospheric conditions, without the use of controlled or inert gas environments, thus reflecting realistic processing scenarios for scalable fabrication. $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_{\gamma}$ materials.

High-purity (≥99.99%) precursor powders such as Bi_2O_3, $SrCO_3$, $CaCO_3$, CuO, and $Ba(C_2H_3O_2)_2$ were used in accordance with stoichiometric ratios to form the Bi-2212 superconducting phase. For each composition, 1.8 g of the powder mixture was initially homogenized by mechanical grinding in porcelain crucibles for 8 hours in air, followed by an additional 30 minutes of fine grinding in an agate mortar to further reduce particle size and enhance homogeneity at the atomic level.

The homogenized powders were subjected to a calcination process at 800 °C for 36 hours in a programmable muffle furnace, with controlled heating and cooling rates set to 5 °C/min. This step was crucial for initiating phase development and reducing undesirable secondary phase formation. Post-calcination, the powders were pressed into rectangular bar-shaped compacts ($20 \times 5 \times 16$ mm³) under uniaxial pressure. The green compacts were subsequently sintered at 850 °C for 36 hours in air to achieve microstructural densification and to facilitate the growth of well-connected superconducting grains.

The resulting barium acetate-modified Bi-2212 ceramics were labeled BiBaC-0, BiBaC-1, BiBaC-2, BiBaC-3, BiBaC-4, and BiBaC-5, corresponding to barium acetate addition levels of x = 0.00, 0.03, 0.05, 0.07, 0.09, and 0.13, respectively. These labels were used consistently throughout the study for comparative analysis.

Electrical characterization of the synthesized samples was conducted using the standard four-probe technique under cryogenic conditions. A constant direct current of 5 mA was applied across the samples, and temperature-dependent electrical resistivity measurements were recorded over a range of 10 K to 95 K. From these measurements, several critical electrical parameters were extracted to assess the impact of barium acetate doping on charge transport behavior and structural coherence. At the outset, it is important to clarify that this investigation encompasses both the fundamental electrical resistivity behavior and the intrinsic superconducting properties of the studied Bi-2212-based materials.

The present analysis emphasizes the effect of $Ba(C_2H_3O_2)_2$ impurity concentration on superconducting transition properties, specifically the onset and offset critical temperatures (T_c^{onset} and T_c^{offset}), and the corresponding transition widths ($\Delta T_c = T_c^{onset} - T_c^{offset}$) of $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_{\gamma}$ materials. The data clearly demonstrate a pronounced degradation in all critical superconducting parameters with increasing barium acetate impurity content in the crystal system of Bi-2212 phase. This decline is attributed to a combination of interrelated structural and electronic mechanisms, including enhanced microstructural disorder, grain misalignment, increased density of microvoids and stress concentrators, and weakened inter-grain coupling.

On a microscopic scale, $Ba(C_2H_3O_2)_2$ incorparation is understood to weaken the pairing binding energy, hinder bipolaron formation, and induce detrimental modifications to the Bi–O spacer layers. Furthermore, the barium acetate disrupts Cu–O orbital hybridization, exacerbates the hole-filling effect, reduces the density of mobile hole carriers, and suppresses the electron–phonon coupling strength, all of which collectively degrade superconducting performance.

In summary, a systematic and concentration-dependent suppression of superconductivity is observed with increasing barium acetate impurity levels. These findings provide critical insight into the interplay between chemical doping and superconducting phase stability in Bi-2212 cuprates, and a more comprehensive interpretation is presented in the following sections.

Results and discussion

This investigation provides valuable insight into the fundamental mechanisms underpinning superconductivity in cuprate ceramics by exploring the effects of barium acetate content concentration into the Bi-2212 matrix. Bulk $Ba(C_2H_3O_2)_2$ added $Bi_{2.1}Sr_{2.0}Ca_{1.1}Cu_{2.0}O_\gamma$ ceramic superconductors were synthesized with varying sodium doping levels (x = 0.00–0.13) via the conventional ceramic processing route. To evaluate the effect of the barium acetate incorporation on superconductivity, detailed experimental studies were conducted using a cryogenic measurement system in conjunction with the standard four-probe technique. Electrical resistivity data were acquired under a constant direct current of 5 mA across a temperature range spanning from 10 K to 95 K.

Figure 1 illustrates the temperature-dependent DC electrical resistivity behavior of the synthesized samples over the range of 10 K to 95 K. Although the general electrical response remains within the metallic regime, significant modifications in both resistivity magnitude and changing trend are evident with increasing barium acetate content level. The observed variations confirm the sensitive influence of $Ba(C_2H_3O_2)_2$ incorporation on the electrical transport characteristics of the Bi-2212 system.

According to the liquid model, the monotonic increase in DC resistivity with temperature confirms the metallic nature of the samples, related to an intrinsic trait linked to strong electron–phonon coupling within the Bi-2212 lattice [21, 22]. This metallic behavior is also attributed to the distribution of electronic density of states in the layered perovskite structure of Bi-2212 [23–25]. However, a progressive decline in metallic character is observed with increasing barium acetate content level, signifying the degradation of crystallinity and intergranular coherence.

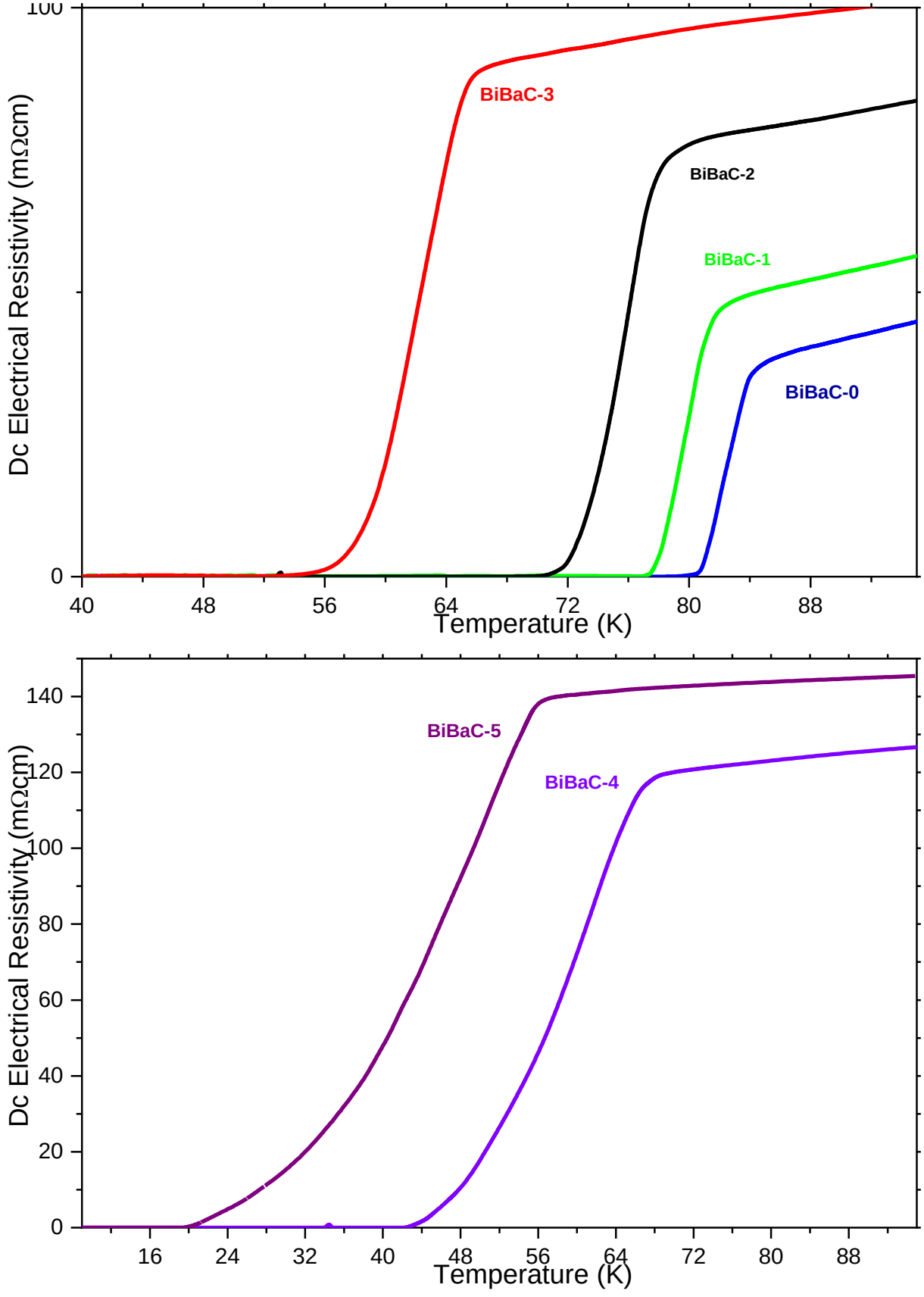

Figure 1 DC electrical resistivity results over temperatures for different $Ba(C_2H_3O_2)_2$ added Bi-2212 superconductors.

The deterioration is primarily attributed to the sodium-induced amplification of microstructural disorders, including grain misorientation, lattice imperfections, impurity scattering, microvoids, and local stress concentrations. Barium acetate incorporation in the Bi-2212 system also enhances lattice strain through the formation of secondary impurity phases, thereby disrupting grain boundary integrity and intergranular electrical pathways. These structural faults directly reduce the mobile charge carrier density and weaken the superconducting coupling at grain boundaries, impeding efficient charge transport throughout the superconducting matrix.

At the atomic scale, $Ba(C_2H_3O_2)_2$ incorporation addition interferes with key superconducting mechanisms: it modulates the Bi–O insulating layers, diminishes the pair-binding energy of Cooper pairs, alters orbital hybridization, reduces the density of mobile hole carriers, enhances the hole-filling mechanism, and suppresses electron–phonon interactions. These disruptions collectively lead to a substantial decline in superconducting performance metrics [26, 27].

Detailed resistivity measurements reveal clear trends in the superconducting transition parameters; namely, the onset and offset critical temperatures (T_c^{onset} and T_c^{offset}), and the corresponding transition widths ($\Delta T_c = T_c^{onset} - T_c^{offset}$).

Table 1 Onset (T_c^{onset}) and offset (T_c^{offset}) critical transition temperatures, and transition width ($\Delta T_c = T_c^{onset} - T_c^{offset}$) parameters.

Superconductors	T_c^{offset} ***(K)***	T_c^{onset} ***(K)***	ΔT_c ***(K)***
BiBaC-0	80.52	84.04	3.52
BiBaC-2	77.48	82.10	4.62
BiBaC-3	71.12	78.36	7.24
BiBaC-4	55.58	65.24	9.66
BiBaC-5	42.72	66.84	24.12
BiBaC-6	20.06	55.34	35.28

As summarized in Table 1, T_c^{onset} and particularly T_c^{offset} exhibit a significant downward trend with increasing $Ba(C_2H_3O_2)_2$ incorporation addition content. For instance, the BiBaC-0 sample (x = 0.00) shows T_c^{onset} and T_c^{offset} values of 84.04 K and 80.52 K, respectively, with a narrow ΔT_c of 3.52 K. By contrast, the heavily added BiBaC-5 sample (x = 0.13) presents markedly reduced values of 55.34 K (T_c^{onset}) and 20.06 K (T_c^{offset}), with a dramatically widened ΔT_c of 35.28 K, as presented in Table 1. It is obvious that the presence of chemical salt of barium(II) and acetic acid totally damages the fundamental superconducting quantities. Intermediate samples follow the expected progressive trend. BiBaC-1 (x = 0.03) exhibits T_c^{onset} = 82.10 K and T_c^{offset} = 77.48 K (ΔT_c = 4.62 K), while BiBaC-2 (x = 0.05) presents T_c^{onset} = 78.36 K and T_c^{offset} = 71.12 K (ΔT_c = 7.24 K). Further deterioration is observed in BiBaC-3 and BiBaC-4, with T_c^{offset} values decreasing to 55.58 K and 42.72 K, and corresponding ΔT_c values of 9.66 K and 24.12 K, respectively. These findings are visualized in Fig. 2, highlighting the correlation between sodium doping and superconducting degradation.

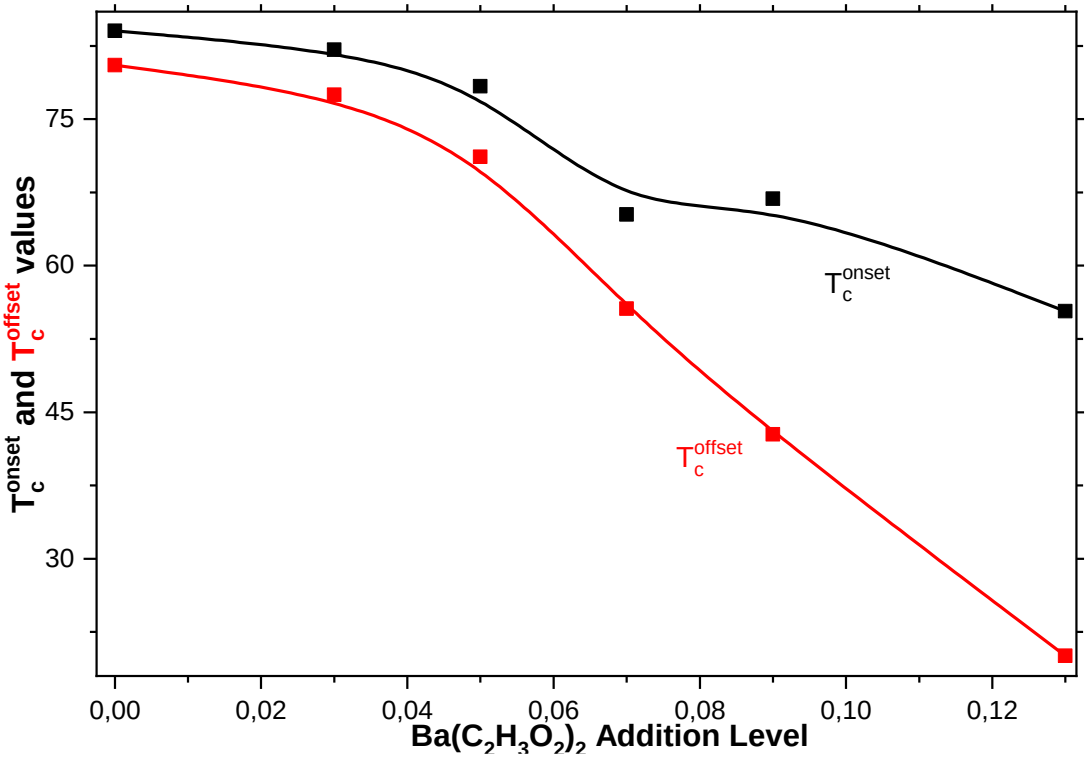

Fig. 2 Change of onset T_c^{onset} and offset T_c^{offset} critical transition temperatures for different $Ba(C_2H_3O_2)_2$ added Bi-2212 superconductors

The significant broadening of the superconducting ΔT_c is indicative of reduced phase homogeneity and deteriorated interparticle superconducting coherence. It is well-established that ΔT_c reflects the strength of electron–phonon coupling and phase volume fractions, and its expansion with barium acetate content level strongly suggests structural and electronic disorder [28, 29].

In conclusion, barium acetate content level exerts a profoundly detrimental effect on the superconducting properties of Bi-2212 cuprate ceramics. The incorporation of barium acetate content disrupts both the structural order and electronic coherence of the superconducting phase, resulting in marked reductions in critical temperature parameters and overall superconducting efficiency. The findings emphasize the necessity of strict compositional control in the development of high-performance ceramic superconductors and provide a comprehensive understanding of impurity-induced degradation mechanisms within cuprate systems.

Conclusion

This study presents a thorough investigation into the evolution of superconducting characteristics and related parameters such as crystalline structural integrity, and interlayer coupling strength within bulk $Ba(C_2H_3O_2)_2$ added Bi-2212 superconductors as a function of sodium ion incorporation. The superconducting samples were synthesized via the conventional solid-state ceramic route, ensuring phase reproducibility and stoichiometric consistency. Electrical characterizations were carried out through standard four-probe DC resistivity measurements conducted over a cryogenic temperature range of 10 K to 95 K.

The experimental results demonstrate a clear and systematic deterioration in both superconducting transition parameters and structural coherence with increasing barium acetate content level. These degradations are interpreted in the context of emerging microstructural disorders and diminished charge transport capabilities induced by impurity doping. Particularly, barium acetate content addition

is found to intensify the presence of intrinsic microstructural defects, including grain boundary misorientations, lattice strain, dislocation networks, local compositional inhomogeneities, impurity-induced scattering centers, stress concentration zones, and microvoid formation within the Bi-2212 matrix. Such factors are known to obstruct intergranular electron mobility and disrupt phase coherence across superconducting domains.

Quantitative analyses reveal that the BiBaC-0 sample exhibits (x = 0.00) exhibits the highest T_c^{onset} of 84.04 K and T_c^{offset} of 80.52 K superconducting transition temperatures. In contrast, the BiBaC-5 sample (x = 0.13) displays significantly reduced transition temperatures of 55.34 K (T_c^{onset}) and 20.06 K (T_c^{offset}), indicating a substantial loss in superconducting phase volume and electron–phonon interaction efficiency. The continuous decline in T_c values and concurrent broadening of the superconducting transition width with increasing $Ba(C_2H_3O_2)_2$ impurity content highlight the fragility of the superconducting state in the presence of structural disorder and chemical nonuniformity. Similarly, the presence of the chemical salt of barium(II) and acetic acid seriously impair the basic superconducting quantities of Bi-2212 superconductor.

The suppression of superconducting performance is closely associated with weakened interlayer coupling mechanisms within the Bi-2212 structure. Barium acetate impurity addition perturbs the layered perovskite arrangement by altering the electronic environment of the Bi–O spacer layers, modulating the local potential landscape, and disrupting orbital hybridization. These effects collectively diminish the binding energy required for Cooper pair formation and reduce the likelihood of bipolaron creation, which is an essential component of high-temperature superconductivity in cuprates. Additionally, the sodium-induced degradation lowers the concentration of mobile hole carriers, which are vital for sustaining superconducting currents across the Cu–O planes.

The observed results also raise critical concerns regarding the structural resilience of the Bi-2212 system under dopant-induced stress. The increase in barium acetate content imposes mechanical and electronic strain on the lattice, which leads to reduced grain connectivity and fragmentation of superconducting pathways. This compromises not only the macroscopic current-carrying capability but also the reproducibility and reliability of these materials in real-world applications.

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SYNTHESIS, CHARACTERIZATION AND BIOLOGICAL ACTIVITY OF NI(II), CU(II), CO(II) AND MN(II) COMPLEXES OF 3,5-DICHLORO-2-HYDROXYBENZALDEHYDE BASED LIGAND

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ABSTRACT

The Schiff base 2-(((4-bromophenyl)imino)methyl)-4,5-dichlorophenol was prepared by reacting 4-bromoaniline with 3,5-dichloro-2-hydroxybenzaldehyde in a methanol solution under reflux. The complexes (**1-4**) were synthesized by treating Schiff base with MCL_2; (M=Ni(II), Cu (II), Co(II) and Mn(II)) under reflux. All the complexes and ligands were found to be non-electrolyte in nature. The structure of the Schiff base and its complexes were characterized by UV-Vis, FT-IR, and ^{1}H NMR spectroscopy. This characterization revealed the presence of the azomethine group (HC=N) in the ligand and also provided evidence of the bonding of this azomethine nitrogen with the metal (II) atom. The -OH stretching vibration appeared in the FT-IR spectra of the ligand while disappear in the spectra of complexes and the appearance of new stretching vibrations *v*(M-O) and *v*(M-N) indicate that metal oxygen and metal nitrogen bonds are formed. The formation of bands indicates the coordination of M(II) occurs through this site thus 4-coordinated and 6-coordinated geometry in the solid state is proposed. The synthesized complexes display intense bands in 200-500 nm, which may be assigned to π - π^*, n - π^* transition in the spectra. Intra ligand and charge transfer transitions observed in the spectra of metal complexes. The antibacterial activities of the synthesized Schiff base and its complexes were determined against different strains of bacteria *Bacillus subtiliius* and *Escherichia coli*. These complexes were found to be more active towards the strains of bacteria as compared to the ligand.

Keywords: Schiff base, Transition metal complexes, Spectroscopic characterization, Antibacterial activity

ACCESS CONTROL AS TECHNOLOGICAL GATEWAY TO DATA SECURITY: AN INTRINSIC STUDY OF CLOUD COMPUTING DEVELOPMENT

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Abstract

The advent of technology has brought countless innovations alongside with modernization. Cloud computing technology has made vivid attempts to find solutions to the ever changing needs of cloud users but the issues of trust have held back its users by challenges such as data security. Access control attempts to moderate the accessibility to resources/services made by cloud users based on authentication, authorization attributes to subjects, objects attributes as well as system attributes in conformation to set policies. The mechanism behind Access control aims at either granting or denying access to specific data for security purpose against unauthorized users. This paper identified some measures that can be used to support trustful development and security of cloud computing technology. The paper further discussed some of the aspects that weigh most in the users' trust in cloud computing technology and also described how access control can help to gain user's trust for guaranteed data security. In order to gather relevant information for the paper discussion, questions were drafted and administered to respondents using online Google form. The responses collected were collated and subjected to reliability analysis. Conclusively, recommendations were made to cloud vendors and users on how to best optimize the use of cloud computing technology so as to ensure the availability, integrity and confidentiality of data.

Keywords: Access Control, Technological Gateway, Data Security, Cloud Computing System.

QUALITATIVE AND QUANTITATIVE ANALYSIS OF AMINO ACID CONTENT ACACIA POLYACANTHA LEAVES

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ABSTRACT

This research aimed to investigate the qualitative and quantitative composition of amino acids present in Acacia polyacantha leaves. Acacia polyacantha, also known as the White Thorn or Senegalia polyacantha, the analysis was carried out using HPLC technique, Eight of the amino acids compounds found in the leaves are essential and seven are non-essential. Histidine was found to be the lowest amino acid in the leave while Proline was found to be the highest amino acids in the leave of acacia polyacantha. This research will help us to improve our understanding of the nutritional value of this plant and may encourage its use as a food and fodder source. The results of this study could also be useful in other areas research, such as the development of new food and pharmaceutical products. This study is expected to make a significant contribution to our knowledge of Acacia polyacantha leaves and their potential uses.

Keywords: Acacia polyacantha leaves, Qualitative analysis and Quantitative analysis of amino acids content.

SYNTHESIS, CHARACTERIZATION AND ANTIBACTERIAL ACTIVITY OF SOME SELECTED TRANSACTION METAL COMPLEXES USING SCHIFF BASE DERIVED FROM 3-NITROBENZALDEHYDE AND ISO-LEUCINE

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Abstract

A series of metal (II) complexes (Cr(III), Fe(III), Co(II), and Ni(II)) have been successfully synthesized from Schiff base ligand derived from 3-nitrobenzaldehyde and Amino acid (iso-leucine). The compounds were characterized using FTIR and UV analytical techniques. The IR spectrum of the Schiff base shows a band at 1699cm-1 which confirmed the presence of azomithine group (C=N), all the complexes shows a down shift band from that of the Schiff base which confirmed the occurrence of the complexation with the metal ions (Cr, Fe, Co and Ni). Antimicrobial screening of the Schiff base and it's metal complexes were investigated against two types of bacteria (staphylococcus aureus and salmonella typhi). From the results obtained, the Concentration of the compounds range from 1000mg/ml to 125mg/ml. Fe(III) complex shows the highest zone of inhibition at a concentration of 1000mg/ml in staphylococcus aureus. And the lowest zone of inhibition obtained at a concentration of 125mg/ml against all the two types of bacteria. This indicates that, the higher the Concentration of the compounds, the more their activity against staphylococcus aureus used as gram negative and salmonella typhi as gram positive.

Keywords: Synthesis, characterization and antibacterial screening**.**

CHEMICAL SYNTHESIS, CHARACTERIZATION AND INVITRO ANTIBACTERIAL STUDIES OF IRONOXIDE NANOPARTICLES

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ABSTRACTS

In the past decade, nanomaterials have attracted much attention due to their physical properties and technological applications. In this work, iron oxide nanoparticles were first synthesized via a simple co-precipitation method Using Ferrous sulphate (iron (IIi) Sulphate) and Ferric chloride (iron (III) chloride) as precursor and ammonia solution as precipitator. The samples were then characterized by X-ray diffraction (XRD) and Scanning electron microscope and Fourier transform infrared spectroscopy (FTIR). XRD pattern showed that the iron oxide nanoparticles exhibited Fe2O3(hematite) structure in nanocrystals. The Fe2O3 nano-powders with uniform size were prepared when the samples calcined at 300 °C, and the lowest particle size was found to be 30 nm by XRD technique. The surface morphological studies from SEM depicted sphere-like shaped particles without formation of clusters by increasing annealing temperature. The EDS spectrum showed peaks of iron and oxygen free of impurity with many elements. The antibacterial activity of chemically synthesized IONPs was assessed against pathogenic bacteria of Staphylococcus aureus and Salmonella typhi, as higher antibacterial activity was observed in staphylococcus aureus (Gram positive bacteria) taking ciprofloxacin as the control. No activity detected in Saureus at lower concentrations. By altering the concentrations, an increase of the antibacterial activity was observed in both S.aureus and salmonella typhi.

Keywords: Nano particles, nanomaterials, x- ray diffraction, SEM, salmonella typhi.

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