INNOVATIVE RESEARCH IN ENGINEERING



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TABLE OF CONTENTS

Chapter 1.....7

Examination of a Lightweighting Methodology Using Lattice Structure: Example Of Brake Pedal *Ahmet DAYANÇ, Feridun KARAKOÇ*

Chapter 2.....23

3D-Printed Bio Applications Using Additive Manufacturing Ahmet DAYANÇ, Melih CANLIDİNÇ, Feridun KARAKOÇ

Chapter 3......39

Strategies for Reducing Carbon Emissions: A Comprehensive Approach *Ali Kemal ÇAKIR*

Chapter 4.....49

Theoretical study of the Azinphos-methyl, Monocrotophos and Omethoate compounds in two phases: Mechanism and DFT study *Bahar EREN, Yelda YALÇIN GÜRKAN*

Chapter 5.....71

The Power of ChatGPT: The Breakthrough Role of the Language Model in Engineering Education *Huseyin COSKUN*

Chapter 6.....101

Optimization of Orthogonal Cutting Parameters of AL 7075-T6 Aluminum Alloy with ANSYS Engin ÜNAL, Faruk KARACA

Chapter 7.....121

Evaluating the Environmental Impacts and Sustainability of Gasoline-Ethanol Blends on Vehicle Exhaust Emissions Beytullah EREN, Idris CESUR

Chapter 8.....133

Evaluation with Spring Management System (SMS) of Springs in the Kumalar Mountain Region (Afyonkarahisar/Turkey) Fatma AKSEVER, Ayşen DAVRAZ, Simge VAROL

Chapter 9.....165

Components and Properties of Dye Sensitive Solar Cells Fatma AYDIN ÜNAL

Chapter 10.....183

Dust Effect on PV Modules: Its Cleaning Methods Hakan DUMRUL, Fatih ARLI, Edip TAŞKESEN

Chapter 11.....201

Design and Control of a Multilevel Inverter for Electric Vehicles Using a Single DC Source Hasan HATAŞ, Mehmet Nuri ALMALI

Chapter 12.....219

Climate Environmental Conditions in Water Buffalo Barns Israfil KOCAMAN, Can Burak SİSMAN

Chapter 13.....239

Hybrid Desiccant Cooling Systems and Solar Assisted Methods Kutbay SEZEN

Chapter 14.....251

Determination of Energy and Exergy Analysis with Artificial Intelligence According to the Environmental Conditions of a Gas Turbine Compressor Mehmet Erhan ŞAHİN, Ahmet ELBİR

Chapter 15.....267

Advancements in Robotic Integration: Navigating Everyday Environments and Enhancing Interaction Through Neural Networks Mücella ÖZBAY KARAKUŞ

Chapter 16.....287

Boxed Medicine Robot Shelving Design Based on Dynamic Storage Allocation In AS/RS Systems Onat Halis TOTUK

Chapter 17......315

Experimental Study of A New Type Natural Ventilation System Onur KAYAPINAR, Oğuz ARSLAN

> Chapter 18......337 QGIS: Open source GIS software and Plugins Selcuk ALBUT

Chapter 19.....357

A Literature Review on Optimal Capital Structure Esmanur PEKER, Sezin ZENGIN FARIASMARTINEZ

Chapter 20......391

Overview of Treatment of Pharmaceutical Industry Wastewater by Photo-Fenton, Ozonation, UV and Electro-Oxidation Methods: Cost, Toxicity, Sustainability Assessment *Ayşe Elif ATEŞ, Sinan ATEŞ*

Chapter 21.....411

A New Vision for Computer Vision: Smart Glasses with Humanoid Robots *Şevval UYANIK*

Chapter 22.....427

An Overview of Common Fracture Parameters for Cracked Structures With Piezoelectric Behavior *Murat SARIBAY*

Chapter 23.....443

Fabrication of Ta₂O₅ Doped Silicate Glasses and Investigation of Their Physical, Structural and Thermal Properties Sadiye ÇETİNKAYA ÇOLAK

Chapter 24.....455

Seismic Assessment of Steel Eccentrically Braced Frames with Short, Intermediate and Long Links Zeynep ÜNSAL ASLAN

Chapter 25.....471

Joint Types and Applications in Rigid Pavements Muhammed TANYILDIZI, İslam GÖKALP

Innovative Research in Engineering

Chapter 1

Examination of a Lightweighting Methodology Using Lattice Structure: Example Of Brake Pedal

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ABSTRACT

This study focuses on the comprehensive design, analysis, and prototyping of a lightweight brake pedal, a critical component in vehicle safety and performance. Initially, the CAD model of a reference brake pedal was transformed into an implicit body. Key stages of the process included defining boundary conditions, forming a 'BCC' type periodic lattice structure, and conducting Finite Element (FE) volume meshing.

The utilization of a lattice structure is a prominent trend in modern engineering, optimizing material use while enhancing structural integrity. In this work, the integration of a 'BCC' type lattice structure led to a weight reduction of approximately 46.4%. The simulation and analysis phase included defining and applying force vector conditions, determining displacement restrictions, and identifying material properties such as Young's modulus, Poisson's ratio, and density. Critical findings, such as maximum displacement and Von Mises values, were obtained, valuable for evaluating the design and manufacturing performance.

The study also touched on the prototyping phase, focusing on 3D printing using PLA material. Details considered in this phase included printing parameters such as speed, temperature, nozzle diameter, infill rate, and cost.

The comprehensive approach in designing the brake pedal provides a valuable example for the automotive industry, demonstrating how engineering principles can be applied at every stage of product development, from design to manufacturing. Moreover, the work serves as an essential reference for future similar projects, showing the potential applications of lattice structures and 3D printing in creating efficient and performance-oriented components. As technology and safety standards in the automotive industry continue to evolve, the insights provided by this study on brake pedal design, analysis, and production offer valuable guidance for professionals, researchers, and academicians in the field.

Keywords: Brake Pedal, Finite Element Analysis, Lattice Structure, Lightweight Design, nTopology

INTRODUCTION

The brake pedal is a component of vital importance for vehicle safety. It plays a critical role in vehicle driving dynamics, enabling the driver to slow down or stop the vehicle through the braking system. The design and production of the brake pedal are of great significance in terms of durability, safety, and performance. In this context, factors such as material selection, design geometry, weight, and strength must be considered (RepairSmith, 2023).

This study comprehensively addresses the design and analysis process of a lightweight brake pedal. Firstly, the CAD model of the reference brake pedal has been transformed into an implicit body (Prasad, 2023). This was followed by processes such as defining boundary conditions, creating a 'BCC' type periodic lattice structure, and forming the Finite Element (FE) volume mesh.

Analysis and simulation are powerful tools in engineering design, used to predetermine material behavior, stresses, displacements, and other critical performance metrics. This study presents the stages of manufacturing and prototyping a lightweight brake pedal step by step (nTopology, 2023).

The use of lattice structures has become a trend in modern engineering, offering advantages in reducing weight and enhancing structural integrity while optimizing material usage. This study provides detailed information on how to integrate a 'BCC' type lattice structure and subsequently create a prototype through three-dimensional printing (McCreight, 2022c).

Especially in the automotive industry, with continuously evolving technology and increasing safety standards, the design and analysis of critical components like the brake pedal are becoming even more important. This study offers a comprehensive view of the design, analysis, and production of a latticestructured brake pedal, and could be a valuable resource for industry professionals, researchers, and academicians.

MATERIALS AND METHODS

The CAD model of the brake pedal is an assembly file. This assembly file in the study consists of two different CAD bodies, the core and the shell. The assembly view of these two different CAD bodies is seen in Figure 1 below.



Figure 1: CAD Model of the Reference Brake Pedal

In the nTopology software, in order to use blocks containing functions, the input types must also be in the types accepted by the function. While it is possible to work directly on CAD data under some conditions, in some cases, it is necessary to convert to an implicit body. For this reason, the two different CAD bodies in the assembly file have been converted into an implicit body to be used as input in different functions (Prasad, 2023). The option "Convert CAD Body to Implicit Body," necessary for conversion, is shown in Figure 2 below.



Figure 2: Conversion of the CAD Model to an Implicit Body

A variable that can be defined from the CAD model is CAD surfaces. These surfaces will be stored as variables to be used as references in defining the

Innovative Research in Engineering

boundary conditions required for structural analysis. Two different surfaces to be defined as variables are shown in Figure 3 below.



Figure 3: Definition of Surfaces Where Boundary Conditions Will Be Applied

To create a lightweight design, the area to be lightened must also be preselected. After the area to be lightened is determined, the entire CAD model of the area to be lightened must be separated to work on the design. Since it has been planned in advance, the assembly file imported into the current study has been transferred to the software to include two different CAD bodies. This makes it easier to work on the core model alone. The body selections here can vary for different parts and different loading scenarios and conditions. In Figure 4 below, the core model and the lattice structure created by referring to this core are seen (McCreight, 2022c).



Figure 4: Reference Volume to Create a Lattice and "Body Centered Cubic" Unit Cell Lattice

After the lattice structure is created, to create the FE mesh needed to prepare the part for analysis as a whole, bringing the bodies that are separate from each other together as a whole would be a practical approach. The separate bodies in implicit form can be joined together with the "Boolean Union" function to provide certain tolerances or radius at the joints (Kratky, 2021). The design of the lightened brake pedal consisting of the outer shell structure surrounding the lattice structure and a single implicit body is seen in Figure 5 below.



Figure 5: Conversion of Shell Structure and Lattice into a Single Implicit Body Before Meshing

As seen in Figure 6, to prepare the pedal design for a structural analysis and to create a high-quality mesh from the implicit body, it is necessary to follow the processing steps where a series of parameters will be adjusted. First, a function that generates a mesh from the implicit body is used, but the mesh and mesh elements that are the output of this function do not meet the mesh metrics suitable for structural analysis. Therefore, a remesh process must be performed. After the remesh function, a volume mesh is created from the reorganized surface mesh, and the Finite Element Mesh is generated by assigning nodes (McCreight, 2021). This mesh structure is the final mesh structure that will be used as input in the model parameter required in the simulation setup.



Figure 6: Creation of FE Volume Mesh from Implicit Body

Innovative Research in Engineering

The final form of the mesh is seen in Figure 7. To ensure that the analysis results are not affected by the mesh and that major differences do not occur in the analysis results as the mesh parameters change, mesh independence must be ensured. For this, errors should not occur in the intermediate steps of the created mesh. The desired quality must be captured in mesh metrics (Prasad, 2022). Additionally, the number of mesh elements must be large enough to ensure mesh independence.



Figure 7: View of the Final Mesh

Another step that must be taken for the setup of the structural analysis is the definition of boundary conditions. The "Force" function block has a series of parameters. One of these parameters allows defining the force vectorially. The other allows the application of the force vector to nodes remaining in the area intersecting with a geometry created by offsetting from an implicit surface derived from a specific CAD surface on the FE Mesh (McCreight, 2022a). The definition of the force boundary condition is shown in Figure 8.



Figure 8: Parameters for Force Boundary Condition

In Figure 9, the vectors shown in yellow represent the force applied to the nodes on the mesh and are seen to be numerous. During the simulation, the force vectors shown below are taken into account. The braking force, having a scalar magnitude of 200 N in the -Z axis direction, has been applied spread over the pedal surface instead of as a point load (McCreight, 2022b).



Figure 9: Application of Force to Pedal Surface

In Figure 10 below, the definition of the boundary condition for the fixed surfaces is provided with the "displacement restraint" function block. Defining Ux, Uy, Uz, Rx, Ry, and Rz parameters as "0" prevents translation and rotation. Also in Figure 11, the image of nodes where rotation and translation are prevented is available (McCreight, 2022b).



Figure 10: Parameters for Displacement Boundary Condition



Figure 11: Displacement Restraint

The material must be selected from the software's library to complete the simulation. If you want to work with a material not in the software's material library, the known properties of this material must be entered. The material can be isotropic or orthotropic. As seen in Figure 12, the simulation will be ready to run when the Young's modulus, Poisson's ratio, and density values are defined (McCreight, 2023).



Figure 12: Parameters of the Material

In nTopology, the FE Model function block accepts both mesh and material information as input. As seen in Figure 13, the "Load Case" parameter accepts a list containing all the boundary conditions as input. In this study, the "Force on Pedal Face" variable and the "Fixed Region" variable are the two different inputs used in the list created for the boundary condition. After all non-optional inputs are provided in the function, "Static Analysis" will run and complete the iterations (nTopology, 2022).



Figure 13: Input of Variables into Simulation Settings

Lastly, a general view of the simulation setup is given in Figure 14.



Figure 14: Completion of Simulation Settings

RESULTS AND DISCUSSION

The analysis results for the brake pedal are given as follows. Displacement is seen in Figure 15. A maximum displacement of 0.53 mm is observed at the farthest point of the brake pedal. When the deformation scale is increased, the observed shape change is consistent with expectations.



Figure 15: Maximum Displacement of 0.53 mm and Minimum Displacement of 0 mm

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Von Mises values are seen in Figure 16. When we look at the color gradient in the part, it is clear that the peak value in the stress is not widespread throughout the piece. This may indicate mesh singularity, and the most dangerous sections can be more easily seen with a new color gradient created by reorganizing the maximum value and narrowing the range. However, without making adjustments, it has been determined that the section with light green color is more risky than other areas.



Figure 16: Maximum Von Mises Value of 57.2 MPa

After the lattice structure was created, a weight gain of 46.4% was seen in Figure 17 when compared to a completely solid model.



Figure 17: Approximate 46% Weight Gain

For the prototype production of the part, the first step is to convert the lattice structure design created from the implicit data type into a format that can be used in a 3D printer. This conversion process can be performed using the "Export Mesh" block in nTopology software. As seen in Figure 18, in this study, the surface mesh of the brake pedal was taken as a reference, and the final geometry was saved in 3MF format.



Figure 18: Exported Mesh

The part, seen in Figure 19, created using PLA material in the Anka Design 3D printer, was completed in 8 hours and weighs 30 grams.



Figure 19: Prototype Production from PLA Material

Other details related to the prototype production process are given in Table 1 below.

Innovative Research in Engineering

Part Height	45 mm
Part Length	150 mm
Part Material	PLA
Print Density	%40
Printing Speed	45 mm/s
Printing Temperature	205 °C
Initial Printing Temperature	215 °C
Nozzle Diameter	0.4 mm
Infill Ratio	% 40
Bed Temperature	60 °C
Layer Height	0.2 mm
Price	75₺

Table 1: Production Parameters and Analysis of Prototype Pedal

CONCLUSION

In this study, a structural analysis and simulation of a lightweight brake pedal have been undertaken. The process began with the CAD model, followed by the creation of an implicit body, the formation of a 'BCC' type lattice structure, and continued with meshing processes. The creation of the volume mesh and Finite Element Mesh, as well as the remeshing process, are crucial steps in preparing the model for simulation.

In the setup of the simulation, procedures such as defining boundary conditions, selecting materials, and determining relevant parameters have been carried out. Additionally, the vectorial definition and application of force, defining displacement boundary conditions, and detailing material properties (such as Young's modulus, Poisson's ratio, and density) have been critical parts of the process. In the analysis results, significant outcomes like maximum displacement and Von Mises values have been obtained. These can be used to assess the performance of the design and production of the part.

A comparison of the 'BCC' type lattice structure design with the solid model has resulted in an approximate weight saving of 46.4%. In the prototype production process, details such as the export process as a ".3MF" file, which is a printable format for 3D printers, material selection (PLA), printing parameters (speed, temperature, nozzle diameter, infill rate, etc.), and cost have been considered.

In conclusion, this study demonstrates how a product can be designed and manufactured through the application of engineering principles at every stage of design, using appropriate software tools. The design and production of the brake pedal can be considered an applicable example, especially in the automotive industry. The conducted analyses and prototype production serve as an important reference for planning and executing similar projects in the future.

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Innovative Research in Engineering

Chapter 2

3D-Printed Bio Applications Using Additive Manufacturing

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ABSTRACT

3D bioprinting technology has made significant progress in tissue engineering and regenerative medicine fields in recent years. This technology uses the precise placement of the correct types of cells on a specific 3dimensional plane to create living tissues and potentially complex organ structures.

Bioprinting is a crucial component of personalized medicine, which has the potential to offer treatments tailored to the specific needs of individual patients. This technology could be a lifesaving solution for patients waiting for organ transplants because the organs needed can be produced from the patient's own cells, which reduces the risk of organ rejection.

However, 3D bioprinting technology is still a young field, and the full implementation of this technology brings significant technical challenges. Issues such as the choice and design of biomaterials, the mechanical and biological stability of printed structures, and the large-scale production of cells required for large-scale organs are problems that have not been fully solved yet.

In the future, overcoming these technological obstacles and unlocking the full potential of bioprinting will have the potential to revolutionize many medical applications of 3D bioprinting technology. The widespread use of this technology carries the potential to provide better outcomes and quality of life for patients, while also significantly reducing the number of patients waiting for organ transplants.

Keywords: 3D Bioprinting, Additive Manufacturing, Personalized Treatment, Organ Transplantation

INTRODUCTION

We always wonder what the next step for humanity will be as futuristic visions of the past start to turn into reality. When it comes to medicine, these steps are long, and clinical and preclinical research can take years. For example, more than 50 years have passed since the first successful heart transplant, and we still need donors today. Heart transplants are still risky and involve complex procedures even after all this time. Artificial organs are the next step beyond this process. 3D bio-organs are a type of artificial organ created using bio-printing technology, where living cells, biological molecules, or various cell components are formed into a predetermined 3D structure for a specific purpose. These structures may have the ability to mimic the function of a specific organ or type of tissue in the human body.

The bio-printing process starts with a patient's own cells. Doctors usually perform a biopsy and grow these cells outside the body. This growth occurs in a bioreactor or a sterile incubator that feeds the cells and maintains their metabolism. The cells are then added to a mixture called bio-ink. This mixture contains water molecules and growth factors that help the cells multiply and differentiate.

The bio-ink is loaded into a 3D bio-printer, and the organ or tissue is created layer by layer. However, making the printed organ work like a human organ is a major challenge. Studies for 3D bio-organ production cover a variety of organs. These include kidneys, eyes, and bladders (Rogers, 2023). In addition, many studies are also focusing on simpler organs like the ear. For instance, in San Antonio, Texas, a doctor has implanted an outer ear produced with a 3D bioprinter using a woman's own cartilage cells. Apart from this, bio-printing studies for more complex organs continue. These organs include the heart, liver, and pancreas. Also, multi-layered skin, bone, muscle structures, blood vessels, retina tissue, and even mini organs have been printed with 3D bio-printers. For example, at the Wake Forest Institute for Regenerative Medicine, scientists have developed a mobile skin bio-printer and plan to take it directly to the patient and print skin on their wounds. In the same institution, bone muscle structures have been printed, which have shown the ability to contract in rodents and regain more than 80% of the muscle function previously lost in a forearm muscle within eight weeks(Barber, 2023).

Although this technology is still in development, it is seen as a significant step towards solving the organ insufficiency problem. 3D bio-printing can reduce the number of patients waiting for organ transplantation and prevent the risk of rejection after organ transplantation. However, significant scientific and ethical issues still need to be resolved for this technology to be fully ready for clinical applications.

Therefore, with the advancement of 3D bio-printer technology, an increasing number of researchers can create functional organoids, but we still seem far from the processes of implanting these organs. According to many experts, while additive manufacturing technologies are maturing in science and many industries and offer significant advantages, their development towards meeting expectations specifically for medical applications is still ongoing.

Bio-Applications: Bone Example

Bones are a part of the vertebrate skeleton consisting of osteoblast and osteoclast cells, along with hard extracellular matrices (such as collagen and hydroxyapatite). Bones have many fundamental functions, including producing red and white blood cells, supporting and protecting organs, storing minerals, and providing the mechanical infrastructure for basic movements. As living beings evolved with complex structures, so did bone structures diversify. This holds true for the human body as well, with human bones displaying complex internal and external structures, as well as varied shapes and sizes. As seen in Figure 1 below, bones can generally be classified into six different structures: long bones, short bones, flat bones, sesamoid bones, sutural bones, and irregular bones (mananatomy.com, 2016).



Figure 1: Types of bones

For example, long bones contain channels through which blood vessels and marrow pass, and the artificial production or repair of these bones can be challenging with conventional production techniques. After trauma, specialized production techniques may be required to replenish missing tissues and tissue losses in these bones. For this purpose, using rapid prototyping techniques through reverse engineering and the development of 3D bio-printers are being explored, especially for how these advancements can be utilized in the diagnosis and treatment of bone traumas and bone diseases.

Based on experiences gained from research, additive manufacturing efforts for the biomedical sector have been effectively implemented in patients for years. Co-Cr, titanium, ceramic-based and other alloys compatible with organic tissue, are customized through additive manufacturing and transformed into products such as dental or hip implants. Thanks to 3D bioprinting technology, anatomically optimal structures can be designed, treatments can be personalized, and thus patient compliance can be enhanced (Seol, Kank, Lee, Atala & Yoo, 2014) (Frejo & Grande, 2019). In this regard, the process of designing personalized implants is being expedited with innovative design methods like nTopology and Materialise 3-Matic (ntopology.com, 2023) (materialise.com, 2023).

Furthermore, 3D bioprinting technology will also reduce unnecessary costs by offering rapid and customizable design and production options. As seen in Figure 2, when there is loss or fragmentary fracture in bone tissue, medical implants that complement or hold the tissue together are being developed as treatment methods (O' Neill,2020) (EOS GmbH, 2015) (Keeffe, 2016).



Figure 2: Porous implants

These are designed to be compatible with bone tissue and have porous structures that support bone growth, and the materials chosen for the production of the implant must be bio-compatible. Materials used to enhance bone growth should be selected based on the optimal combination of parameters such as porosity, maximum and minimum pore sizes, structure, and surface modifications (Farazin, Zhang, Gheisizadeh & Shahbazi, 2023).

Some 3D printed bone repair materials can possess two important features at the same time. Being made of biodegradable polymers, in addition to having channels or pores, provides these structures with different advantages(Bose, Roy & Bandyopadhyay, 2012) (Wank, Rijff & Khang, 2015). Channels are beneficial for the nutrient supply and metabolite elimination required for osteoblast growth, while at the same time, good osteogenic effects and bone formation abilities have been observed at the site of the biodegradable structure (Yeong, Chua & Leong, 2006) (Yang, Leong & Du, 2002) (Ricci, Clark & Murriky, 2012).

As an example of some studies, the 3D printed spine implants shown in Figure 3 below are designed by Amplify Additive. Amplify Additive operates as a contract manufacturer using Electron Beam Melting (EBM) Technology in the production of Orthopedic Implants. This plate has a stochastic cage structure that encourages osseointegration (Molitch-Hou, 2020).



Figure 3: 3D Printed Spine Implant

Additionally, SI-BONE, a leading company in minimally invasive joint surgery, has designed implantable orthopedic products with a new cage structure that encourages osseointegration, as seen in Figure 4 (Stuart, 2023).



Figure 4: Implantable products for minimally invasive joint surgery

Additionally in this process, various polymers (such as hydrogels, solutions, granules, and threads) have been tried to be made suitable for the mechanical properties of the bone. With the help of computer-aided modeling programs, these artificial tissues have been designed in a porous structure and it has been observed that they can be printed. These porous structures have provided a suitable environment for the growth of cells. The use of melt deposition

modeling, extrusion-based, or stereolithography-based printing technologies has formed the basis of these studies.

Bio-Printer Technologies

Bio-printer technologies, as shown in Figure 5 below, are based on three main technologies: droplet-based, laser-based, and extrusion-based (Xie, Gao, Lobo & Webster, 2020).



Figure 5: Bio-printer technologies a) Droplet-based b) Laser-based c) Extrusion-based

Inkjet-based bio-printers, also known as droplet-based bio-printers, spray liquid droplets onto a surface using thermal or acoustic force and create structures layer by layer. In thermal inkjet bio-printing, "bio-ink" droplets are formed by heating the print head electrically and increasing the pressure to push the cells out of the nozzle. Bio-inks contain cells, scaffold materials, and growth factors, and can be placed with precision by controlling droplet size and deposition rate.

Bio-printers can heat up to 300°C, but this is very short-lived, which results in a temperature increase of 4-10 °C in the system and does not cause significant harm to the cells. In piezoelectric inkjet bio-printing, bio-ink droplets are formed by the acoustic wave generated by the piezoelectric crystal inside the print head.

Among the advantages of the inkjet-based bio-printer in organ 3D bioprinting are fast response time, high formation precision, and high efficiency. Acoustic 3D bio-printers can be well controlled by adjusting jet direction, droplet size, and cell viability. Thermal bio-printers can be controlled by adjusting print speed and cost.

However, the inkjet bio-printer has some distinct disadvantages. Bio-inks need to be in a low-viscosity liquid form. This significantly limits the height of

the structures. Low concentration polymeric bio-inks and low cell density (less than 106 cells per milliliter) are required to prevent nozzle clogging and to reduce shear stress applied to the cells.

Another disadvantage is that 3D structures produced with this technology have weak mechanical properties. At present, most researchers in this field are using modified commercial inkjet printer systems to print live cells. This has limited software and hardware development and the complexity of the structures printed. Because of these disadvantages, inkjet-based bioprinting is still in its early stages for large organ 3D bio-printing, while extrusion-based bioprinting is widely used for many research.

Laser-based technology is often also referred to as Laser-Induced Forward Transfer (LIFT) or Laser-Assisted Bioprinting (LAB). Here, a laser is used as an energy source. In this method, a bio-ink layer and an energy-absorbing layer (usually a metal or polymer film) are used together (Koch, Kuhn, Seorg, Gruene, Schlie, Gaebel & Chichkov, 2011). The laser pulse heats the energy-absorbing layer, which creates a pressure wave. This pressure wave is used to push bio-ink droplets towards the receiving substrate underneath the energy-absorbing layer. This method can produce micro cell-loaded 3D structures with polymers of various viscosities (1-300 mPa/s) and provides high resolution (Gruene, Pflaum, Hess, Diamantouros, Schlie, Deiwick & Chichkov, 2011).

One of the major advantages of laser-based bioprinting is high precision and resolution. This allows the cells to be placed exactly in the desired locations, which can aid in the creation of complex cellular structures and even multicellular tissues. Another advantage of laser-assisted bioprinting is the prevention of nozzle clogging issues with cells or polymeric biomaterials.

Also, laser-based bioprinting usually produces very little mechanical stress on the cells, which helps to maintain cell viability and functionality. This can be particularly important for sensitive cell types and tissue structures.

However, the laser-based bioprinting method is generally more costly and technically complex compared to other bioprinting technologies. Also, there is still much research and development needed on the use and optimization of this technology. For example, how to optimize laser parameters (such as wavelength, energy, pulse duration, etc.) and bio-ink properties (such as viscosity, absorption properties, etc.) is still an important and current research topic.

Extrusion-based technology is a special process that uses fluid polymeric solutions or viscous hydrogels as bio-ink. Extrusion bioprinting has the capacity to print thicker, more complex, and higher cell density tissues compared to other printing technologies. These bioprinters usually consist of a three-axis

automatic extrusion system with a liquid-dispensing nozzle. During extrusion processes, cell-loaded bio-inks are deposited in cylindrical filaments to form a bio-structure referencing a CAD model.

Among the advantages of extrusion-based bioprinting in organ 3D bioprinting are high cell densities, large 3D structures, and fast printing speeds. In addition to polymeric solutions or hydrogels, cell aggregates and extracellular matrices (ECMs) can also be used as bio-ink. The viscosity of some polymeric "bio-inks" can decrease as the shear stress of the printing system increases. This can help protect cells and increase the resolution of 3D structures.

A disadvantage of extrusion-based bioprinting could be the limited number of polymeric solutions or hydrogels available that have good biocompatibility and can print large structures in layers.

Bio-Organ Studies: Pancreas Example

The World Health Organization predicts that by 2030, diabetes will be the seventh most common cause of death worldwide as a health problem, and today, more than 40 million people have type-1 diabetes (medizzy.com, 2020). Unfortunately, not every case of diabetes can be managed easily, and hypoglycemia attacks can occur. Moreover, the severity of complications seen in type-1 diabetes is high and damages the eyes, kidney, and heart. For these individuals, pancreatic or islet transplantation could be a solution, but there is a high risk of surgical complications and the possibility of the organ being rejected by the body. Organ transplants are dependent on deceased donors, and the number of patients waiting on the transplant list is increasing day by day. Many scientific teams are being formed worldwide to find a solution to this problem and to search for alternative methods.

One of these teams consists of researchers working at the Research and Science Foundation in Poland, led by Dr. Michał Wszoła. This team was able to produce the world's first 3D bionic pancreas containing special Langerhans pancreatic islets with blood vessels, using a special version of a 3D bio-printer.

It is known that a real pancreas produces pancreatic juice to assist digestion. The pancreas is surrounded by about 1,000,000 pancreatic islets, which resemble small clusters, composed of alpha and beta cells that can produce glucagon and insulin. Diabetes disease damages these Langerhans islets. Therefore, it is clear that these patients do not have cells that can produce insulin and glucagon. The goal in the production of the 3D-bionic pancreas is to create an organ based on alpha and beta cells that can produce glucagon and insulin, to get rid of insulin injections. The 3D-bionic pancreas does not yet

perform its exocrine function like a real pancreas in humans, but it needs to complete some clinical stages in the future to be able to perform this function.

Dr. Wszoła and his team, for the first time in the world, on March 14, 2019, created a fully vascularized prototype of a 3x3x5 cm bionic pancreas using islet cells taken from mice and pigs (Wszoła, Nitarska, Cywoniuk, Gomolka & Klak, 2021). In this study, since the function of the Langerhans islets, which will be responsible for insulin production, was examined, the importance of the organ size remained secondary. The path they will follow in humans is to eliminate the possibility of the organ being rejected by the body by aiming to produce pancreatic cells derived from the patient's own stem cells. After the stem cells are transformed into cells that produce insulin and glucagon, the organ will be printed from the 3D bio-printer and its functionality will be tested before transplantation. To ensure this functionality, it is a requirement for the cells to survive and multiply, but the need for vascularization to meet this in organs such as the pancreas is a major challenge. The transportation of glucose and oxygen to the islet cells can be provided by the organ to be printed having a dense vascular network. Problems related to the vascular system can be solved with a pressure-controlled bio-printer, and the pressure values required for the printing of each different cell type are being researched. Dr. Wszoła and his team saw that the commercially available bio-inks had the negative aspect of isolating the Langerhans islets from the external environment, making it difficult to transfer insulin from these islets outward and oxygen to these islet cells, and decided to develop a special bio-ink due to the cells dying for this reason and the view that commercial bio-inks are not suitable for clinical transplantation. The first bio-ink developed from these mimics the extracellular matrix of Langerhans islets, has good permeability, and its resemblance to natural tissue is high. The second developed bio-ink allows the blood vessels around the Langerhans islets to be made with the bio-printer. The 3D bio-printer regulates the mixture of cells with bio-ink, a composition that ensures the survival of cells, according to the designed model and thanks to computer-aided methods, and prints the blood vessels necessary for the blood to pass through the organ with the secondary print head of the bio-printer. After the current studies are completed on mice, pre-clinical studies to be completed by moving to larger-scale animal models can begin human clinical trials after the results are analyzed, and if everything goes according to the plans, the first bionic pancreas transplantation to a human can be carried out within 3 to 5 years (Listek, 2019).

The 3D bio-printer model used in the research is the "Bio X" model developed by the "Cellink" company, and it is the world's first 3D bio-printer with iPH (intelligent printheads) smart print heads. As product diversity

increases in smart print heads, new opportunities arise and give researchers some freedoms to take this work further. The variety of bio-inks that can be used varies according to the features of smart print heads. In fact, print heads carrying high-resolution cameras provide great benefits in optimizing droplet sizes, filament diameters, and print geometry by monitoring the structure during the printing process. In addition, the "Bio X" is produced as standard with a bio-safety cabinet equipped with built-in UV sterilization and a HEPA filter for cell safety during printing, and can control the finest movements with its motors with $1\mu m$ precision (cellink.com, 2023).

Of course, some parts of all these studies may take a few more years to develop some techniques for the transformation of human stem cells into pancreatic cells, including laboratory studies focused on transforming human stem cells. If it is seen that the body does not reject these cells with positive feedback to be received after these cells are transplanted into the Langerhans islets, the first major step will have been taken towards the maturation process of the technique. There are many people today whose lives are threatened due to pancreatic disease, and new methods and treatments that will give all these people hope for the future continue to be developed at full speed.

DISCUSSION

3D bioprinting technology has several advantages, but it also has some disadvantages. These issues can mainly be grouped into three categories:

Bioprinting Material: Choosing the best printing material is an important factor. Some substances may have biological activity, which can lead to adverse effects between cells and unwanted stem cell differentiation. In addition, existing bioprinting technologies are not reliable in providing the amount of cells needed for some tissue types.

Structure Stability and Mechanical Strength: For a successful transplant process, 3D structures need to have sufficient stability and mechanical strength. When bioprinted tissue engineering (TE) components are transplanted into a living organism, these structures need to provide appropriate cellular nutrition, oxygen transportation, and in vivo vascularization for the survival of the cells.

Printing Speed: The printing speed of complex-scale assemblies using multiple material options can be low. Especially in biofabrication processes, rapid production can be challenging.

Nevertheless, 3D bioprinting technology holds significant potential in many biomedical fields such as organ transplants and tissue regeneration in the future. More research and development of the technology is needed in this field. The development of new methods and the improvement of regulatory processes will
help make this technology more widely available. However, more work is needed to implant organs produced by bioprinting into the real human body. Therefore, the goal for the future is to develop more reliable and functional bioprinting applications.

CONCLUSION

3D bioprinting technology is a technology that provides many benefits in the fields of pharmaceuticals, tissue engineering, and healthcare. Thanks to this technology, it has become possible to create complex structures with improved material quality features over time. However, producing these structures with bioprinting is a challenging process due to the complexity of living body systems, each with a different role. Fortunately, the biomimicry property of materials made with bioprinting technology helps overcome these challenges. Through bioprinting, factors such as cell adhesion, growth factor concentration, and biomaterial dissolution rate can be adjusted. One of the main goals of this technology is to end the constant search for organ donations and enable the printing of a complete organ as needed. Aside from the heart, major organs such as bones, skin, cartilage, and tendons can also be printed with bioprinting. Another advantage of this strategy is that different cell types can be placed in different regions and biocompatible components resemble real cells almost identically. In this way, it is possible to create structures with various functionalities and different physical and chemical properties. With the advancement of bioprinting technology, the lives of many patients in need of organ and tissue transplantation can be positively changed. However, there are still many issues that need to be improved, and more research is needed in this field. This technology is poised to play a significant role in the field of health in the future and requires regulation and supervision to realize its potential. There is still a long way to go for the implantation of organs produced by bioprinting into the real human body, but this technology has the potential to revolutionize the health sector in the future.

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Chapter 3

Strategies for Reducing Carbon Emissions: A Comprehensive Approach

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Abstract

The ever-increasing threat of climate change requires urgent and concerted action to reduce carbon emissions. This requires action projects. In order for action projects to become operational, policies need to be formulated. In this sense, the need for a comprehensive approach that encompasses policy changes, technological developments and social transformations is critical. This paper aims to outline various strategies to effectively tackle carbon emissions while ensuring a sustainable and liveable future for future generations. By integrating these approaches, we can promote a low-carbon economy and protect our planet.

Keywords: Carbon emission, renewable energy, strategies.

1. Introduction

The relentless rise in carbon emissions, primarily due to human activities such as burning fossil fuels, deforestation, and industrial processes, has led to global warming and subsequent climate-related disasters. To mitigate these consequences, we must collectively address the problem through multifaceted measures.

The burning of fossil fuels remains the largest source of carbon emissions worldwide. The combustion of coal, oil, and natural gas for energy production and transportation accounted for approximately 73% of global CO2 emissions [1]. Additionally, deforestation and land-use changes contributed significantly to carbon emissions, releasing carbon stored in vegetation and soils into the atmosphere [2].

Carbon emissions vary significantly across different regions of the world. While some developed countries have made progress in reducing emissions, emerging economies and rapidly industrializing nations have experienced a surge in emissions due to increased energy consumption and economic growth. China, the United States, and the European Union remained the top three emitters, collectively accounting for more than 50% of global CO2 emissions [1].

The continued increase in carbon emissions has profound implications for climate change. Rising CO2 levels trap heat in the atmosphere, leading to global warming and its associated impacts, such as extreme weather events, sea-level rise, and disruptions to ecosystems. The Intergovernmental Panel on Climate Change (IPCC) reports indicate that carbon emissions must be drastically reduced to limit global warming to 1.5°C above pre-industrial levels to avoid the most catastrophic consequences [3].

Global energy-related CO2 emissions grew in 2022 by 0.9%, or 321 million tonnes, reaching a new high of more than 36.8 billion tonnes. The rise in emissions was significantly slower than global economic growth of 3.2%, signalling a return to a decade-long trend that was interrupted in 2021 by the rapid and emissions-intensive economic rebound from the Covid crisis [4].



Figure 1. Global CO2 emissions from energy combustion and industrial processes, 1900-2022 [5].

2. Strategies for Reducing Carbon Emissions

While the overall trend of rising carbon emissions is concerning, there have been positive developments in the adoption of renewable energy sources. Over the past five years, the deployment of solar and wind power has seen significant growth, offering cleaner alternatives to fossil fuels [6]. However, further investments and policy support are needed to accelerate this transition and drive down emissions. What needs to be done in this context is presented in sections, in short summaries.

2.1. Transitioning to Renewable Energy

Shifting from fossil fuels to renewable energy sources is a cornerstone of carbon reduction efforts. Governments, businesses, and individuals can invest in solar, wind, hydro, and geothermal energy to decarbonize the power sector. Policy incentives, tax breaks, and subsidies can encourage the adoption of these sustainable alternatives.

2.2. Energy Efficiency

Enhancing energy efficiency is an effective way to reduce carbon emissions. Implementing stricter building codes, promoting energy-efficient appliances, and encouraging retrofitting of existing infrastructure can substantially curb energy consumption.

2.3. Electrification of Transportation

The transportation sector is a major contributor to carbon emissions. Transitioning to electric vehicles (EVs) and improving public transportation infrastructure can significantly reduce emissions. Governments can incentivize EV adoption, invest in charging infrastructure, and promote cycling and walking as sustainable transportation options.

2.4. Sustainable Land Use

Deforestation and land-use change contribute significantly to carbon emissions. Implementing sustainable land management practices, afforestation, and reforestation initiatives can serve as effective carbon sinks, absorbing atmospheric carbon dioxide.

2.5. Carbon Capture and Storage (CCS)

CCS technologies enable the capture, transportation, and storage of carbon dioxide emissions from industrial processes and power plants. Supporting the development and implementation of CCS can help address hard-to-decarbonize sectors.

2.6. Circular Economy

Promoting a circular economy, where resources are reused, recycled, and waste is minimized, reduces emissions associated with production and disposal processes. Governments can incentivize businesses to adopt circular practices and support research and development in sustainable materials.

2.7. Sustainable Agriculture

Agriculture is a significant emitter of greenhouse gases. Encouraging sustainable farming practices, such as agroforestry, crop rotation, and precision agriculture, can reduce emissions and enhance carbon sequestration in soils.

2.8. Education and Awareness

Raising public awareness about climate change and carbon emissions is essential for fostering individual behavioural changes. Education can drive responsible consumption patterns and motivate citizens to advocate for climatefriendly policies.

2.9. Carbon Pricing

Implementing carbon pricing mechanisms, such as carbon taxes or cap-andtrade systems, provides economic incentives for businesses to reduce their carbon footprint and transition to cleaner technologies.

2.10. International Cooperation

Addressing climate change requires global cooperation. Nations must work together to set ambitious emission reduction targets, share technologies and knowledge, and provide support to developing countries for sustainable development.

2.11. Investing in Research and Development

Continuous investment in research and development is crucial to drive technological innovations that further reduce carbon emissions. Governments and private enterprises should allocate resources to advance clean energy technologies and sustainable solutions.

2.12. Green Investment and Finance

Redirecting financial investments towards green and sustainable projects can accelerate the transition to a low-carbon economy. Governments can create green investment funds and provide incentives for private investors to support clean energy, energy-efficient projects, and sustainable infrastructure.

2.13. Carbon Footprint Tracking and Reporting

Encouraging businesses and individuals to track and report their carbon footprints can raise awareness of their impact on the environment. Carbon footprint tracking tools and certification schemes can help organizations set reduction targets and implement carbon management strategies.

2.14. Public-Private Partnerships

Collaboration between governments, businesses, and non-governmental organizations through public-private partnerships can leverage expertise and resources to develop and implement effective carbon reduction initiatives. These partnerships can enhance innovation and efficiency in tackling climate change.

2.15. Environmental Regulations and Enforcement

Strong environmental regulations and effective enforcement are crucial for holding industries accountable for their emissions. Stricter emission standards, penalties for non-compliance, and monitoring mechanisms are essential to ensure meaningful carbon reduction.

2.16. Community-Based Initiatives

Empowering local communities to participate in carbon reduction efforts fosters a sense of ownership and responsibility. Community-based initiatives, such as tree planting campaigns and localized renewable energy projects, can complement national strategies.

2.17. Climate Resilience and Adaptation

While reducing carbon emissions is vital, it is equally crucial to build resilience against the impacts of climate change. Governments should invest in infrastructure and policies that enhance climate resilience and protect vulnerable communities from extreme weather events.

2.18. Sustainable Consumption and Lifestyle Changes

Encouraging sustainable consumption patterns and lifestyle changes can significantly reduce individual carbon footprints. Education, awareness campaigns, and access to eco-friendly products can influence consumer behaviour towards more sustainable choices.

2.19. Technological Collaboration and Open Innovation

Facilitating technological collaboration and open innovation can accelerate the development and deployment of climate-friendly technologies. Governments and businesses can foster partnerships and open-source initiatives to tackle common challenges collectively.

2.20. Just Transition

Recognizing the social implications of transitioning to a low-carbon economy, governments must ensure a "just transition" for affected communities and workers. Investing in reskilling and retraining programs can support the workforce's shift to green industries.

2.21. Long-Term Planning and Vision

Sustainable carbon reduction requires long-term planning and visionary policymaking. Governments should develop robust climate action plans and set ambitious emission reduction targets aligned with scientific recommendations.

2.22. Continual Monitoring and Evaluation

Regular monitoring and evaluation of carbon reduction strategies are essential to assess their effectiveness and identify areas for improvement. Datadriven insights can inform policymakers and stakeholders in refining their approaches.

3. Conclusion

Reducing carbon emissions is an intricate and multifaceted challenge that demands collective and decisive action. The strategies outlined in this comprehensive approach demonstrate the interconnected nature of tackling climate change. By integrating these efforts, we can create a sustainable future, mitigate the impacts of global warming, and safeguard the wellbeing of both current and future generations. We can achieve this prosperity through the implementation of our strategies to reduce carbon emissions.

All these carbon reduction strategies will have a positive long-term payback. With the implementation of these strategies, it will be possible to achieve the goal of limiting the global temperature level to a maximum of 1.5 °C above the pre-industrial revolution level. Governments, businesses, communities, and individuals must work together to combat climate change and pave the way for a more sustainable and prosperous planet.

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Chapter 4

Theoretical study of the Azinphos-methyl, Monocrotophos and Omethoate compounds in two phases: Mechanism and DFT study

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ABSTRACT

Pesticides can easily evaporate and reach the atmosphere due to their high vapor pressure. They are also easily water-soluble compounds. Therefore, they constitute an important group of air and water pollutants. Organophosphorus pesticides have a short shelf life due to their rapid degradation, but they decompose rapidly, do not cause long-term damage, but these compounds are highly toxic. Therefore, they must be removed from the air and water. Since organophosphorus pesticides are volatile and water-soluble and constitute an environmentally important group of water and air pollutants, in this study, all modeling calculations for Azinphos-methyl (MA), Monocrotophos (MO) and Omethoate (OM) compounds were calculated as DFT/B3LYP/6-31G(d) in the foundation set, it was made both in the gas phase and in the aqueous medium. Geometric optimization was performed with Gauss View 5.0.8 and Gaussian 09 program to calculate the optimized geometries for the studied molecules and to determine the lowest energy state. The aim of this study is to make energy possible reaction calculations for pathways and to determine thermodynamically voluntary reactions, to shed light on the fate of these molecules in nature. Initially, the initial geometries of the reactants were determined in the reactions. Geometric optimizations of reactants, pre-reactions and products were made to identify all possible reaction pathways. In order to determine the possible reaction paths as a result of the calculations, the atoms to which the OH radicals will be added and the hydrogen atoms to be removed were determined and the products were found. Thus, the reaction mechanism was tried to be clarified.

Keywords: Azinphos Methyl, Monocrotophos, Omethoate, DFT, reaction pathways

INTRODUCTION

While pesticides are used as veterinary medication for pets and as insecticider at homes in order to fight with pests, and in agriculture, they are also widely used for the preservation of stored food, against forest pests, and for killing vector microorganisms. Besides, due to their being extremely volatile and water-soluble, they are a significant source of danger. Pesticides are known as volatile organic matters. As a result of uncontrolled and extensive use of pesticides, the pesticides themselves or their transformed products accumulate in soil, air, water, and food. The increasing need for pesticides due to the increase in the world population, and these matters having highly toxic features, their amount in nature should be monitored. Pesticides lead to acute and chronic poisoning, cancer, allergic reactions, damage in the nervous system, learning difficulties and memory loss, as well as to disorders in enzyme balance, damage and mutation in intracellular DNA molecules (Dolapsakis et al., 2001:1531; Sarabia et al., 2009:938; Wagner,1989).

Organophosphorus compounds are widely used as pesticides, and these matters react with atmospheric radicals by reaching the atmosphere. These compounds undergo photolysis and react with the OH radical, and this reaction is the most dominant one among dissipation reactions. The permanence of organophosphorus pesticides in nature is short due to their fast decay. These pesticides fragmentise rapidly, thus do not cause long term damage; however, these compounds are highly poisonous. Along with killing not targeted insects, these pesticides give harm to both human and nature. In addition, since they do not have a stable structure, they are applied at frequent intervals. Therefore they are considered to be overcosting (Aschmann et al., 2010; Goodman et al., 1988:281; Goodman et al., 1988:578; Aschmann et al., 2005:11827; Atkinson and Arey., 2003:4605; Aschmann et al., 2005:2282; Aschmann and Atkinson, 2006:13029; Atkinson et al., 1988:273).

The toxicity of these pesticides at a wide scope is effective on the nervous system of mammals. They are usually at liquid form at room temperature, and at gaseous state they are effective on skin, respiratory system and on the cornea of the eye. Exposure to organophosphorus pesticides may lead to paralysis, or even death. The variety of symptoms occurring as a result of exposure is depended on the mode of transmission and the specific characteristic of the pesticide. These pesticides also cause behavioural or psychological changes. These can be exemplified as hazardous changes such as, insomnia tension, exhaustion, nervousness, depression, and loss of memory, etc. The water- and fat-solubility of these pesticides, their appropriate size and electric loads, as well as their molecular geometry and their having a stable leaving group, provides these

pesticides to reach their target without decay. In this study, the molecules to be studied as organophosphorus pesticides are, in order: Azinphos-methyl (MA), Monocrotophos (MO), Omethoate (OM). In Figure 1, both optimized images, two-dimensional images, molecular formulas, and abbreviations and names to be used from now on are given respectively. When dissolved in neutral, acidic, or soft alkaline water, Azinphos methyl, herein after referred to as MA, is at very stable state. However, in an environment above pH 11, it can be hydrolysed rapidly into benzamide, anthranilic acid, and other chemicals. Sunlight and microorganisms in natural water can be used in order to provide a faster decay in MA. Thus, its half-life can be shortened from a couple of months to a couple of days. There are basic pathways for biological degradation or loss through vaporization under normal conditions. Vaporized MA becomes exposed to excessive UV light, and undergoes photodissociation. If it is not exposed to UV light and bioactivity, it reaches half-life in one year. Appearing as colorless crystals with a slight ester odor, MO is a reddish-brown solid as a commercial product. It is used as a rapid-acting insecticide with both systemic and contact effects against a wide variety of pests in cotton, sugar cane, tobacco, potatoes, peanuts, tomatoes and ornamental plants, and it is very toxic. OM, a toxic organophosphorus pesticide in liquid form, is used as insecticide and acaricide. Colorless to yellowish oily liquid has a mercaptan-like odor and is readily soluble in water and is extremely dangerous (Sanderson et al., 2007:210; Rahimi and Abdollahi, 2007:115; Toy and Walsh, 1987; Luis et al., 2015).

In this study, by conducting conformation analysis of MA, OM and MO, which are organophosphorus pesticides, the most appropriate conformers with the lowest energy and the most stable ones were determined. The geometric optimizations of the molecule and its molecular properties were determined at B3LYP/6-31G(d) level of DFT study (Gaussian 09, 2009). As a result of the quantum chemical calculations, load densities, energy values, and geometric parameters for selected molecules and various fragments of these molecules were determined. Since organophosphorus pesticides are volatile, water-soluble, significant in terms of environment, and constitutes an important group of water and air pollutants, all modelling calculations carried out in this study were realized at both gas-phase and at aqueous media within water as a solvent.

The selected molecules are organic compounds. Organic contaminants are known to exist in water at very low concentrations according to recent studies. Therefore, it is vital to purify drinking water from organic contaminants. Solar light on earth helps water systems like lakes, rivers, etc. to be purified naturally. Large organic molecules are degraded into smaller basic molecules through sunbeams, and finally form carbondioxide, water, and other small molecules (Verschueren, 1996; Matthews and Al-Ekabi, 1993:121; Eren and Yalcin Gurkan, 2017:277).

OH radical acts like an electrophile in its reaction with any organic molecule, and therefore readily attaches the unsaturated bonds, while O radical is a nucleophile, and thus does not attach these bonds. If there is an aliphatic side chain readily bound to an aromatic molecule, radical H attacks O, whereas OH radical preferentially attaches the aromatic ring, which can result in the formation of various products when pH reaches a range in which O radical is the reactant, rather than OH radical. Organic compounds react with OH radical by undergoing photolysis, and this reaction is the most dominant reaction among dissipation reactions in the atmosphere. Biomolecules, which are hydroxyl scavengers at various speeds, are specific detectors for hydroxyl radical due to their ability of hydroxylation. Moreover, the repulsion of existent substituents, and the electron withdrawal lead to the position of the attack to the ring. The attack of any hydroxyl radical to an aromatic compound leads to a hydroxylated product to be formed, and these newly formed products may be much more harmful that their original product in the beginning of the process, thus it is essential that these products be monitored (Eren and Yalcın Gürkan, 2015: 849; Eren and Yalcin Gurkan, 2017:277; Buxton et al., 1998:513; Anbar and Neta, 1967:493; Halliwell et al.,998:59).

This study was conducted in order to find out whether being named MA, OM and MO molecules, would be fragmented in the nature under the formation of CO₂, H₂O and other small molecules. In this study, the kinetics of the degradation reaction path of molecules with OH radical was analysed theoretically through the density functional theory (DFT) method. Theoretical calculations were carried out at DFT/B3LYP/631G(d) level in gas-phase (Gaussian 09, 2009; Verschueren, 1996; Matthews and Al-Ekabi,1993:121; Eren and Yalcin Gurkan, 2017:277; Buxton et al.,1988:513; Anbar and Neta, 1967:493; Halliwell et al., 1999:59; Hatipoglu et al., 2010:59).

COMPUTATIONAL SET-UP AND METHODOLOGY Computational models

Mean bond distances and geometric parameters of the closed ring were used to form molecule models. Tetrahedral angles were used for the sp3-hybridized carbon and oxygen atoms and 120° for the sp2-hybridized carbon atoms was used in the computational modelling. The aromatic ring was left planar, excluding the position of attack. Since there was an alteration in the hybridization state of the carbon at the addition centre from sp2 to sp3, the attacking OH radical was estimated to form a tetrahedral angle with the C–H bond (Atkins and Friedman, 1997; Atkins, 1998; Eren and Yalcın Gürkan, 2015: 849).

Molecular orbital calculations

In photocatalytic degradation reactions of molecules, it is possible that products more harmful than those in the original material could be formed. For this reason, it is crucial to apprehend the nature of the primary intermediate products before conducting а photocatalytic degradation reaction experimentally. Calculations carried out by quantum mechanical methods provide the most reliable and precise information. Hence, due to the yield produced being the same, photocatalytic degradation reactions of molecules and its hydroxy derivatives were based on the direct reaction of these molecules with OH radical. With this aim, the kinetics of the reactions of molecules with OH radical was theoretically analysed. The study was initiated with molecules and then exposed to reaction with OH radical and the reaction yields were modelled in gas-phase. Experimental results in the scientific literature revealed that OH radical detaches a hydrogen atom from saturated hydrocarbons, and OH radical is added to unsaturated hydrocarbons and materials with this structure. Therefore, possible reaction paths for the analysed reactions were calculated. In this study, primarily the conformation analyses of the MA, OM and MO were conducted, and the conformers with the lowest energy, or in other words, the most stable ones were determined. Geometric optimizations of the molecule were carried out at DFT/ B3LYP/6-31G(d) level. As a result of the quantum chemical calculations, the geometric parameters, energy, enthalpy, and Gibbs-free energy, and also load density, and mulliken loads in gas-phase were determined (Atkins and Friedman, 1997; Atkins, 1998; Eren and Yalcın Gürkan, 2015: 849; Gaussian 09, 2009; Eren and Yalcin Gurkan, 2017:277).

Kinetic data treatment

The objective of this study was to provide a model revealing the outcome of reactions of photocatalytic degradation. Every structure was calculated in terms of thermodynamic and electronic features and vibration frequencies by using the gained optimum geometric parameters. Consequently, based on the quantum mechanical calculation results, energy, enthalpy and Gibbs-free energy of every reaction was calculated at room temperature at gas-phase. For every fragment, GaussView 5.0.8. was used to draw the optimized geometric structures, and the Gaussian 09 programme packet was used for the calculations (Gaussian 09, 2009).

Methodology

The investigated reaction system was composed of OH radical, which are open-shell species. It is known that open-shell molecules cause severe problems in quantum mechanical calculations. The self-consistent field method (SCF) calculation will proceed for an open-shell case in the same way as for a closed-shell case. Nevertheless, because of two sets of equations having to be dealt with, at each iteration, the program has to consider, either simultaneously or successively, the closed-shell and the open-shell equations. In this respect, the computational burden could be two-times larger for an open shell than that for a closed-shell. Another point raised in connection with the optimization of the SCF process for open-shell molecules is the relative intricacy of the sequence of calculations for the closed-shell Hamiltonian and the open-shell Hamiltonian (Mierzejewska, et al., 2012:2727; Diercksen et al., 1974:4).

DFT methods, taking the electron correlation into account, use the precise electron density to calculate molecular properties and energies. Spin contamination does not affect them and hence, for calculations involving open-shell systems, they become favourable. DFT calculations were made by the hybrid B3LYP functional combining the HF and Becke exchange terms with the Lee–Yang–Parr correlation functional. In such calculations, it is the 6-31G(d) basis set that is used (Gaussian 09, 2009).

RESULTS AND DISCUSSION



(OM) Omethoate: C5H12NO4PS

Şekil 1: Optimized images of the three molecules studied, two-dimensional images, abbreviations and names to be used from now on, and molecular formulas

MA	Bond length(A ^o)	MA	Bond angle(°)	Mulliken atomic
	0 ()			charges
O ₂₂ -C ₂₃	1.44396	$O_{22}P_{20}S_{31}$	118.63706	O ₁₂ -0.515513
O ₂₁ -C ₂₆	1.44509	$O_{21}P_{20}S_{31}$	116.91646	N ₁₃ -0.358044
P20-O22	1.62111	O22P20S19	100.81072	N ₁₄ -0.003126
P20-S31	1.93989	O21P20S19	107.18704	N ₁₅ -0.357954
P20-O21	1.62479	$C_{16}S_{19}P_{20}$	101.33611	S ₁₉ 0.013051
S ₁₉ -P ₂₀	2.10567	$C_9N_{15}C_{16}$	119.76423	P ₂₀ 0.760437
C16-S19	1.86833	$N_{14}N_{15}C_{16}$	113.75495	O ₂₁ -0.519080
N15-C16	1.44770	N13N14N15	120.02978	O ₂₂ -0.510278
N14-N15	1.37929	O12C9N15	121.43047	S ₃₁ -0.343658
N ₁₃ -N ₁₅	1.26326			
MO	Bond length(A ^o)	МО	Bond angle(°)	Mulliken atomic
				charges
C10-O4	1.44140	$C_{10}O_4P_1$	118.30500	P ₁ 1.242307
O4-P1	1.60690	$O_2P_1O_5$	116.85219	O ₂ -0.547047
O5-P1	1.60542	$C_6O_5P_1$	120.58288	O ₃ -0.562352
O ₅ -C ₆	1.45107	$C_2P_1O_3$	112.21985	O ₄ -0.518473
P ₁ -O ₂	1.47582	$O_5P_1O_2$	116.85219	O ₅ -0.542616
P1-O3	1.62194	O ₃ C ₁₄ C ₁₉	118.50298	C ₁₉ -0.118998
O3-C14	1.39935	O ₃ C ₁₄ C ₁₅	115.28194	O ₂₂ -0.523794
C14-C15	1.49727	$C_{15}C_{14}C_{19}$	126.14844	N ₂₃ -0.228292
C25-N23	1.45353	$C_{14}C_{19}C_{21}$	125.90799	
C ₂₁ -N ₂₃	1.36056	C21N23C25	129.07187	
C21-C19	1.49965	N23C21C19	119.25749	
		O22C21N23	121.50747	
ОМ	Bond length(A ^o)	ОМ	Bond angle(°)	Mulliken atomic
				charges
C9-O3	1.43913	$C_9O_3P_1$	122.88143	P ₁ 1.066158
O3-P1	1.60261	$O_3P_1O_2$	113.12618	O ₂ -0.538403
O4-P1	1.61607	$O_3P_1O_4$	101.12144	O ₃ -0.488061
O ₂ -P ₁	1.47995	P1O4C5	119.36948	O ₄ -0.538549
O ₄ -C ₅	1.44122	$O_2 P_1 S_{13}$	113.69425	S ₁₃ -0.124480
S ₁₃ -P ₁	2.12191	$O_4 P_1 S_{13}$	101.57776	C ₁₄ -0.067697
S13-C14	1.85548	$P_1S_{13}C_{14}$	100.02862	O ₁₈ -0.502420
C17-C14	1.53457	$S_{13}C_{14}C_{17}$	115.20111	N ₁₉ -0.232727
C17-N19	1.35877	C14C17N19	116.81084	
C21-N19	1.45164	C17N19C21	122.46353	

 Table 1: Bond lengths, bond angles and Mulliiken atomic charges of MA,

 MO and OM molecules

The starting molecules of MA, MO and OM in Figure 1 and the data in Table 1 are important for predicting where the molecule will break first. The important data in Table 1 are separated from the others in bold. The numbers under each atom in Figure 1 agree with the numbers under atoms in Table 1.

Although the longest bond, the widest bond angle is predicted to break first, the energy values and surroundings of the electronegative atoms are observed and a decision is made as a whole. It should not be forgotten that the double bonded or closed ring structures are more stable than the others, and if there is to be fragmentation, the rupture from these stable structures will be in the last stage.

Table 2: Gibbs-free energy, enthalpy, and Energy values (Au) for the gasesphase and aqueous mediaof the degraded fragments of the MA molecule andMulliken loads of studied fragments.

	Gas phase(Au)	Aqueous		Gas phase(Au)	Aqueous
		media(Au)			media(Au)
	ΔE=-1915.722205	-1915.736781		-1876.453425	-1876.461885
MA	∆H=-1915.721261	-1915.735837	M1	-1876.452481	-1876.460941
	ΔG=-1915.791682	-1915.807274		-1876.517822	-1876.528743
	-1837.180245	-1837.198950		-1801.201413	-1801.216529
M2	-1837.179301	-1837.198006	M3	-1801.200469	-1801.215585
	-1837.240095	-1837.258974		-1801.264611	-1801.279842
	-1761.928877	-1761.943260		-1686.683444	-1686.699731
M4	-1761.927933	-1761.942316	M5	-1686.682500	-1686.698787
	-1761.987736	-1762.002328		-1686.739728	-1686.755963
	-509.076789	-509.086953		-1407.829390	-1407.838979
M61	-509.075844	-509.086009	M62	-1407.828446	-1407.838035
	-509.116824	-509.126984		-1407.880171	-1407.890609
	-548.361826	-548.370610	M72	-1368.544830	-1368.553796
M71	-548.360882	-548.369666		-1368.543886	-1368.552852
	-548.404074	-548.412879		-1368.591211	-1368.600871
	-946.544270	-946.554145	M82	-970.339691	-970.348214
M81	-946.543325	-946.553201		-970.338747	-970.347270
	-946.591727	-946.601853		-970.382562	-970.391140
	-931.066361	-931.076303		-891.791295	-891.803309
M91	-931.065417	-931.075359	M92	-891.790351	-891.802365
	-931.104718	-931.115078		-891.825684	-891.837649
	-510.210569	-510.223390		-510.248705	-510.260389
M10	-510.209625	-510.222446	M11	-510.247761	-510.259445
	-510.255565	-510.268715		-510.292837	-510.304692
					100.00.00.00.00
	-454.883952	-454.893828		-400.815511	-400.826265
M12	-454.883008	-454.892884	M13	-400.814566	-400.825320
	-454.925516	-454.935459		-400.855162	-400.866194
	-396.899245	-396.909078		-345.456929	-345.463012
M14	-396.898301	-396.908134	M15	-345.455985	-345.462068
	-396.939495	-396.949639		-345.493735	-345.499854
	-341.574786	-341.574786		-232.143528	-232.146212
M16	-341.573842	-341.573842	M17	-232.142584	-232.145268
	-341.611521	-341.611521		-232.175374	-232.178062
		1	1	1	1

The energy values for all possible reaction pathways for each fragment were calculated in both the gas phase and the water phase. Every fragment that may occur as a result of the interaction of the main molecule with the OH radical is

included in the study. The reason why the energy values are given in atomic mass units (Au) is that the digits after the comma are very close to each other when converting to the SI unit.

	Mulliken		Mulliken atomic		Mulliken atomic	
	atomic		charges		charges	
	charges					
	O ₁₂ -0.515513		O ₁₂ -0.561690		O ₁₂ -0.562131	
MA	N ₁₃ -0.358044	M1	N ₁₃ -0.350780	M2	N ₁₃ -0.349829	
	N ₁₄ -0.003126		N ₁₄ -0.001986		N ₁₄ -0.001975	
	N ₁₅ -0.357954		N ₁₅ -0.341351		N15 -0.342061	
	S ₁₉ 0.013051		S ₁₉ 0.005037		S ₁₉ -0.008853	
	P ₂₀ 0.760437		P ₂₀ 0.732364		P ₂₀ 0.715743	
	O ₂₁ -0.519080		O ₂₁ -0.187614		O ₂₁ -0.169519	
	O ₂₂ -0.510278		O ₂₂ -0.494371		O ₂₂ -0.174496	
	S ₃₁ -0.343658		S ₂₇ -0.343266		S ₂₃ -0.345728	
	O ₁₂ -0.514852		O ₁₂ -0.520316		O ₁₂ -0.526350	
M3	N ₁₃ -0.356490	M4	N ₁₃ -0.357564	M5	N13 -0.355606	
	N ₁₄ -0.002664		N ₁₄ -0.006323		N_{14} -0.004440	
	N ₁₅ -0.357095		N ₁₅ -0.334853		N15 -0.331233	
	C ₁₆ 0.153533		S ₁₉ 0.013396		S ₁₉ 0.027907	
	S ₁₉ 0.008971		P ₂₀ 0.548839		P ₂₀ 0.321823	
	P ₂₀ 0.522807		O ₂₁ -0.196917		S ₂₁ -0.305679	
	O ₂₁ -0.503418		S ₂₂ -0.324307			
	S ₂₆ -0.315610					
	C ₅ -0.001880		S4 -0.006802		C5 -0.002923	
M61	O ₁₂ -0.502186	M62	P ₅ 0.764184	M71	O ₁₂ -0.514735	
	N ₁₃ -0.363869		O ₆ -0.518702		N ₁₃ -0.368853	
	N ₁₄ 0.006169		O7 -0.508209		N ₁₄ -0.012947	
	N ₁₅ -0.136830		S ₁₆ -0.352087		N15 -0.355586	
	S1 -0.029583		O ₁₂ -0.522931		P1 0.765206	
M72	P ₂ 0.730397	M81	N ₁₃ -0.363545	M82	O ₂ -0.507973	
	O ₃ -0.501879		N ₁₄ -0.007355		O ₃ -0.486596	
	O ₄ -0.491319		N ₁₅ -0.329204		S ₁₂ -0.386325	
	S ₁₃ -0.339476		S ₁₉ 0.073548			
	P ₁ 0.761518		P ₁ 0.744055			
M91	O ₂ -0.199559	M92	O ₂ -0.178908			
	O ₃ -0.485670		O ₃ -0.178935			
	S ₈ -0.389815		S ₄ -0.386212			

 Table 3: Mulliken atomic charges of the MA molecule and its fragments

Mulliken atomic charges of electronegative atoms of all fragments are given in Table 3.

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Figure 2: Fragmentation path of MA and its fragments Optimized by DFT method. (Blue, nitrogen; red, oxygen; yellow, sulphur; grey, carbon; orange, phosphorus; white, hydrogen)



Figure 3: Two-dimensional view of the possible degradation pathways of the MA molecule

It is aimed to make the degradation mechanism more understandable by giving together three-dimensional images optimized by DFT method in Figure 2. and two-dimensional images in Figure 3.

Table 4: Energy, enthalpy and gibbs free energy values of MO and OM molecules in atomic mass units in gas phase

MO	Gaz Fazı			OM	Gaz Fazı		
	(E,H,G⁰)				(E,H,G ⁰)		
	-1047.217557		-1007.942226		-1292.813152		-1253.537258
MO	-1047.216612	MO2	-1007.941282	OM	-1292.812208	OM1	-1253.536314
	-1047.281561		-1008.002231		-1292.875879		-1253.593091
	-1007.944345		-1007.924726		-1253.531853		-1045.582978
MO1	-1007.943401	MO3	-1007.923781	OM2	-1253.530909	OM3	-1045.582033
	-1008.004282		-1007.985870		-1253.590231		-1045.627955
	-968.684705		-968.652244		-1178.285878		-1214.264713
MO21	-968.683760	MO31	-968.651299	OM11	-1178.284934		-1214.263769
	-968.738898	-	-968.711366		-1178.342033	OM12	-1214.318337
	-968.648624		-968.672442		-1214.256862		-1006.307409
MO11	-968.647680	MO12	-968.671498	OM21	-1214.255918	OM31	-1006.306465
	-968.706830		-968.727271		-1214.308366		-1006.348702
1.000	-932.692811		-890.100751	0.412	-1139.004549	0.414	-1139.016116
MO22	-932.691867	MO32	-890.099807	OM13	-1139.003605	OM14	-1139.015172
	-932.749242		-890.151995		-1139.056430		-1139.06/624
	020 200555		002 422000		1174.002(00		0(7.02114(
MO12	-929.398555	MOD	-893.432800	01/22	-11/4.983608	01/22	-967.031146
MOIS	-929.397011	MO25	-893.431830	OMIZZ	-11/4.982004	01/152	-907.050202
	-929.44/999		-893.484943		-11/3.032070		-907.009139
	-814 851865		-818 163583		-1024 481714		-1063 763104
M033	-814 850921	MO24	-818 162639	OM15	-1024.481714	OM16	-1063 762160
11055	-814 899497	111021	-818 215403	011110	-1024 526326	0.000	-1063 811817
	011.099197		010.215 105		1021.520520		1005.011017
	-739.597949		-400.980853		-1099.734703		-1024.481714
MO34	-739.597005	MO25	-400.979909	OM23	-1099.733758	OM18	-1024.480770
	-739.642871		-401.024937		-1099.781798		-1024.526326
	-322.418129				-646.596564		-607.315151
MO35	-322.417184			OM17	-646.595619	OM19	-607.314207
	-322.456366				-646.637109		-607.351644



Figure 4: Two-dimensional view of the possible degradation pathways of the MO molecule



Figure 5: Two-dimensional view of the possible degradation pathways of the OM molecule

CONCLUSIONS

Of these three organophosphate pesticide molecules, only the full description is given for MA to explain how the degradation reaction of an organic molecule is written, but the data for all molecules are shared with the readers.

When mulliken atomic charges of MA molecule in Table 1 were analysed, the electronegativity rank was found out to be O_{12} , O_{21} , O_{22} , N_{13} , N_{15} , S_{31} , N_{15} , N_{14} respectively. Although O_{12} is the most electronegative atom, it has a stable structure due to the double bond it makes with the C atom at the top of the closed ring. It can be predicted that fragmentation will not begin here. P_{20} was surrounded by three electronegative atoms, namely O_{21} , O_{22} and S_{31} . The mulliken atomic charges of the most electronegative ones, which were O_{21} and O_{22} , were determined as -0.519080 and -0.510278 respectively. The most stable, or in other words, the fragments with low energy were estimated to occur through the separation of the atoms close to them. Thus, when energy (ΔE), enthalpy (ΔH) and Gibbs free(ΔG) energy values of MA molecule again in Table 2 were analysed, it was determined that the values of all fragments in gas and aqueous phase were negative. Fragmentation occurred spontaneously with OH radical and continued likewise. MA was determined to have -1915.722205 Au energy value.

M1, which was the most stable fragment, was obtained by the fragmentation of the separation of C_{26} (or C_{23}) from O_{21} (or O_{22}), and its energy value was determined as -1876.453425 Au. The second most stable fragment, which was M2, was obtained through both methyl groups bound to O_{21} and O_{22} being separated, and this proved our estimation that separations started around electronegative atoms. Energy value of M2 was calculated as -1837.180245 Au. The third most stable fragment, which was M3, was obtained through the separation of O_{21} and O_{22} from both P_{20} - O_{21} and P_{20} - O_{22} bonds at the same time, and the energy value was found out to be -1801.201413 Au. When Table 1 findings for each fragment were investigated, they provided information about the fragmentation process of the molecule. In Figure 2,3, starting from the lowest electrochemical values in Table 2, mechanism paths for fragmentation of MA were recommended.

Optimized figures of various fragments of MA molecule were given in Figure 2. In some of these figures a number of stable molecules were investigated in terms of bond lengths and bond angles, which were given in Table 1. When bond lengths of MA were investigated, it was found out that bond length of S19-P20 was 2.10567 A°, which was the longest bond length. This bond length provided estimation for the site of formation of M_{82} fragment. It was anticipated that C_{16} - S_{19} bond length 1.86833 Ao led to the formation of M72 fragment, and that N_{15} - C_{16} bond length 1.44770 A° and $C_9N_{15}C_{16}$ bond angle 119.76423° led to the formation of M62 fragment in Table 3. In order to prevent any incompleteness, all fragments, which were fragmented from around different atoms of MA molecule, were investigated in terms of their optimized figure, electrochemical values, bond lengths and angles, and the most stable fragments were chosen accordingly.

The probable stable fragmentation pathway of MA molecule is given in Figure 2,3. In these probable pathways, fragmentation process was carried out from different electronegative parts of the molecule, and thermochemical values in each fragmentation were calculated. In these possible fragmentation pathways, MA molecule was fragmented into its smallest fragment; thus, the fate of MA in nature was determined for further experimental studies.

When the energy data obtained for each fragment of MO and OM in Table 4 and the bond lengths, bond angles and electronegative atoms in Table 1 are examined, information about the fragmentation paths of the molecules has been provided. Starting from the lowest electrochemical values, the mechanism pathways for the degradation fragmentation of pesticides are suggested in figure 4,5. For the avoidance of doubt, all fragments fragmented around their different atoms for each pesticide were investigated for their optimized shape. The most voluntary fragments were selected accordingly. The possible fragmentation paths of the molecules were determined, and the fragmentation process was carried out from different electronegative parts of the molecule in these possible paths.

RESULTS AND DISCUSSION

As a chemical structure, organophosphorous pesticides are esters of phosphorous acid. Usually, two ester groups, methoxy or ethoxy are attached to the phosphorous atom. The third ester group may be aliphatic, homocyclic, or heterocyclic structures, and are attached to the ester atom by an ester or thioester bond. This weak bond increases the electrophilic property of the phosphorous atom, and gives it an electron affinity property. OPs are majorly affected by chemical reactions such as hydrolysis and oxidation. As seen in Figure 1, those with P=0 feature (MO and OM) hydrolyze more easily and therefore their persistence is lower than those with P=S feature (MA). However, those with P=0 (MO and OM) have higher water solubility (Eren and Yalçın Gürkan, 2021:463; Eren, and Gürkan, 2022:224).

As seen in Figure 1, the MA molecule enters the thiophosphates group with the P=S bond, and although the OM molecule has the P=O bond, it is classified in the thiophosphate group due to the 1S and 3O atoms in its structure. All OPs have different R groups but each has 2 methoxy ends. Knowing the chemical structure of a molecule gives us a preliminary information about the decomposition reaction. Writing the degradation mechanism of a molecule is possible when the energy values, bond lengths and bond angles, the existence of atoms surrounding electronegative atoms are considered as a whole. Mulliken atomic charges of all fragments are given in Table 3 for researchers who want to self-test.

Although the different molecular weights do not allow us to make a general comparison, when the three studied molecules are compared in terms of energy values, they can be ranked starting from the lowest energy with units MA -1915.72 Au, OM -1292.81 Au, MO -1047.22 Au. In the degradation reactions of which we predict the fate of these molecules in nature, the molecule that first reacts with OH radicals is MA, namely Azinphos-methyl. Because it is the molecule with the lowest energy, that is, the most voluntary reaction.

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Chapter 5

The Power of ChatGPT: The Breakthrough Role of the Language Model in Engineering Education

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ABSTRACT

This study has investigated how ChatGPT can be used in engineering education. Suggestions on using ChatGPT for different engineering processes covering all engineering disciplines are presented under the headings within the scope of studies in the literature. Within the scope of these suggestions, scenarios were created for electrical, software, computer, material and industrial engineering. These scenarios were taught to ChatGPT via prompts, and answers were obtained. The quality of the answers was evaluated within the scope of studies and lecture notes related to the related engineering field. As a result, it is predicted that ChatGPT can be used as a guide and assistant within the scope of different engineering education approaches.

Keywords: chatgpt, engineering education, prompt, use case, artificial intelligence

INTRODUCTION: What is the ChatGPT and Engineering Education?

Technology continues to reshape how we learn and teach in the rapidly evolving landscape of education. One remarkable innovation that has captured the attention of educators and learners alike is ChatGPT, an advanced artificial intelligence language model developed by OpenAI.

1.1. What is the ChatGPT?

ChatGPT is an advanced artificial intelligence (AI) language model developed by OpenAI based on the GPT-3.5 architecture. It is designed to generate human-like text and engage in interactive conversations with users. It is part of the GPT (Generative Pre-trained Transformer) family of models and is trained on diverse internet text to understand and generate natural language (OpenAI, 2023). ChatGPT, like other models in the GPT family, operates based on a transformer architecture. The basic working architecture of ChatGPT is given in Figure 1.



Figure 1 ChatGPT basic working architecture

1. Input Encoding: When a message or question is inputted to ChatGPT, it gets tokenized into smaller units called tokens. These tokens can be words, subwords, or characters. Using an embedding matrix, Each token is converted into a unique numerical representation.

2. Self-Attention Mechanism: The heart of the transformer architecture is the self-attention mechanism. It allows the model to weigh the importance of each word/token in relation to others in the same sentence. This creates a context where the model understands the interdependencies between words.

3. Multi-Head Attention: The self-attention mechanism is applied multiple times in parallel, each time with different learned weights. These multiple "heads" capture different aspects of relationships between tokens, enabling the model to consider various contextual perspectives.

4. Positional Encoding: Since the transformer architecture lacks inherent token order knowledge, positional encodings are added to the embeddings. These encodings provide information about the position of each token in the sequence.

5. Encoder Layers: The tokens and their positional encodings pass through several layers of self-attention and feed-forward neural networks. These layers refine the token representations by aggregating contextual information from the entire sequence.

6. Decoding: For generating responses, the process is similar. The model takes the tokenized input, adds positional encodings, and passes it through multiple decoder layers. During decoding, the model generates tokens one by one while considering the context and previous tokens it has generated.

7. Probability Distribution: At each step of decoding, the model produces a probability distribution over the vocabulary for the next token. Sampling techniques, such as "greedy decoding" or "beam search," are used to select the next token based on this distribution.

8. Output Generation: The selected token is appended to the previously generated tokens, and the process repeats for subsequent tokens until an appropriate stopping condition is met (e.g., reaching a maximum length or generating an end-of-sentence token).

This process of encoding, self-attention, decoding, and output generation allows ChatGPT to generate contextually relevant and coherent text responses based on the input it receives.

Apart from this architecture, ChatGPT has some prominent features (OpenAI, 2023);

Capabilities: ChatGPT can perform various tasks, including answering questions, providing explanations, offering suggestions, generating text, giving recommendations, and engaging in conversations on various topics. It can be fine-tuned for specific applications, making it a versatile tool for different domains.

Training Data: ChatGPT is trained on a large and diverse dataset that includes text from books, articles, websites, and other sources. The training data

encompasses a broad array of subjects, allowing ChatGPT to generate coherent and contextually relevant responses across various topics.

Language Understanding: ChatGPT uses a variant of transformer architecture, which excels at understanding and generating natural language. It processes input text in context, enabling it to comprehend the nuances of user queries and generate coherent and contextually appropriate responses.

Limitations: While ChatGPT is highly advanced, it does have limitations. It might occasionally generate incorrect or nonsensical responses. It can also be sensitive to input phrasing, sometimes giving different responses to slight rephrasing. Additionally, it might produce biased or inappropriate content, despite efforts to reduce such occurrences.

Applications: ChatGPT has applications in various fields, including customer support, content generation, code writing assistance, tutoring, language translation, creative writing, and more. Its interactive conversational abilities make it worthwhile for tasks that involve human-like interaction.

Its applications span various domains. Some examples of application areas in the engineering discipline can be given as follows;

- ChatGPT can serve as a virtual assistant for engineers, helping them with tasks like answering technical queries, providing design suggestions, offering troubleshooting advice, and aiding in decision-making.
- ChatGPT can help engineers write code snippets, debug programs, and provide explanations for coding concepts, thereby enhancing software development processes.
- ChatGPT can aid in setting up simulations, interpreting results, and providing insights into engineering analysis, assisting in fields like structural analysis, fluid dynamics, and more.
- Language models can facilitate knowledge sharing within engineering teams, providing on-the-job training, answering questions, and explaining concepts to newcomers.
- Engineers can utilize ChatGPT to extract insights from data, interpret graphs and charts, and even assist in creating visualizations to communicate findings effectively.
- ChatGPT can assist in designing and troubleshooting IoT devices and embedded systems, aiding engineers in developing and deploying connected devices.

- Engineers working on renewable energy projects can benefit from ChatGPT's insights into solar panel efficiency, wind turbine design, and sustainable energy solutions.
- Engineers can use ChatGPT to discuss concepts related to robotics, automation, control systems, and artificial intelligence for creating advanced autonomous systems.
- ChatGPT can offer insights into environmental impact assessments, waste management strategies, pollution control, and sustainable infrastructure development.
- In medical devices and equipment, ChatGPT can assist in designing, troubleshooting, and understanding complex biomedical systems.

1.2. Engineering Education

Engineering education refers to imparting knowledge, skills, and competencies related to engineering principles, practices, and problem-solving techniques to individuals pursuing a career in engineering (Case & Light, 2011; Goncher et al., 2023). It encompasses various teaching and learning methods to prepare students to become competent and innovative engineers. Engineering education approaches encompass a variety of strategies, methods, and pedagogical philosophies used to effectively teach engineering concepts and skills (Zuraidah et al., 2015). These approaches have evolved to adapt to changing technological advancements, industry demands, and educational research. There are student-centred, instructor-centred, and hybrid approaches in engineering education, given in Figure 2 (Burrows, 2019; O'Neill & McMahon, 2005). These student-centred approaches foster a learner-focused environment, enhancing motivation, engagement, and the development of skills that are crucial for success in the field of engineering. While lecturer-centred approaches can effectively convey information, they may lack the engagement and interactivity necessary to promote deeper understanding and critical thinking (Sabah & Du, 2018; Trinidad, 2019; Zuraidah et al., 2015).



Figure 2 Engineering education approaches

Modern educational trends often encourage a balance between lecturercentred and student-centred approaches to create more dynamic and effective learning environments (Budiman et al., 2021; GP et al., 2021). Effective assessment methods, including formative and summative assessments and timely and constructive feedback, play a crucial role in enhancing learning outcomes. As engineering educators strive to prepare students for the challenges of an increasingly complex and interconnected world, integrating ChatGPT into the classroom presents a transformative opportunity. This study delves into the various ways ChatGPT can revolutionize engineering education, enhancing student learning, fostering critical thinking, and propelling the field into the digital age.

1. USAGE AREAS OF CHATGPT IN ENGINEERING EDUCATION

integrating engineering education, advanced technology In has revolutionized how students learn, and educators teach. While ChatGPT's applications span various domains, its potential in engineering education is particularly promising. ChatGPT has numerous applications in engineering education, as it can provide assistance, guidance, and support to students and educators (Hwang & Chang, 2021; Okonkwo & Ade-Ibijola, 2021). With its ability to understand and generate human-like text, ChatGPT has found diverse applications across various domains within engineering education. From simplifying complex concepts to aiding in problem-solving, code assistance, and project planning, ChatGPT is a versatile virtual assistant enhancing student learning experiences and educators' instructional capabilities (Pavlik, 2023).

This section explores the multifaceted usage areas where ChatGPT can significantly contribute to fostering a deeper understanding of engineering principles and nurturing the next generation of skilled engineers. The engineering education subject map where ChatGPT can be used, prepared in this context, is presented in Figure 3.



Figure 3 Engineering education subject map

1.1. Concept Explanation

ChatGPT can explain complex engineering concepts in simpler terms, helping students grasp fundamental ideas more effectively (Dahlkemper et al., 2023; Ling et al., 2023). Five specific examples of how ChatGPT can be utilized for concept explanation in engineering education can be explain as follows;

Fluid Dynamics Concepts: Students studying fluid dynamics often encounter intricate principles and equations. ChatGPT can break down concepts like Bernoulli's principle, Reynolds number, and laminar vs turbulent flow, providing intuitive explanations and addressing real-time queries.

Circuit Analysis Fundamentals: ChatGPT can assist students in understanding fundamental circuit analysis concepts, such as Ohm's law, Kirchhoff's laws, and various circuit elements. It can explain how to analyze circuits step by step and clarify common misconceptions.

Thermodynamics and Heat Transfer: Complex concepts in thermodynamics, such as the laws of thermodynamics, heat engines, and heat transfer mechanisms, can be challenging. ChatGPT can simplify these concepts, offer relatable examples, and answer questions to enhance understanding.

Structural Engineering Principles: When learning about structural analysis, students grapple with topics like stress, strain, and material properties.

ChatGPT can elucidate the differences between tension and compression, explain Hooke's law, and provide insights into the behavior of various materials under load.

Control Systems Basics: Concepts in control systems, like feedback loops, transfer functions, and stability analysis, can be abstract. ChatGPT can provide concrete examples from everyday life, such as thermostat control or cruise control, to make these concepts more relatable and comprehensible.

In each of these instances, ChatGPT serves as a personalized tutor, adapting to the student's pace of learning and offering explanations that cater to their level of understanding. This enhances learning by demystifying complex engineering concepts and fostering a deeper appreciation for the subject matter.

1.2. Problem Solving

Students can interact with ChatGPT to receive step-by-step solutions and explanations for engineering problems, aiding in their understanding and problem-solving skills (Flannery, 2023; Liang et al., 2023)

Mechanical Engineering Calculations: Students often encounter complex mechanical engineering problems involving forces, moments, and equilibrium. ChatGPT can guide them through these problems step by step, explaining the relevant principles and equations to arrive at the correct solutions.

Electrical Circuit Analysis: ChatGPT can assist students in solving intricate electrical circuit problems involving resistors, capacitors, and inductors. It can provide detailed calculations, help with node and mesh analysis, and explain techniques like Thevenin's and Norton's theorems.

Programming and Algorithm Challenges: In software engineering courses, students might struggle with coding challenges and algorithmic problems. ChatGPT can offer code snippets, explain programming concepts, and provide strategies for optimizing algorithms and debugging code.

Numerical Methods and Simulations: Students studying numerical methods can benefit from ChatGPT's guidance in solving equations numerically, performing iterative calculations, and understanding methods like Newton-Raphson or finite difference approximations.

Thermodynamics Problem Sets: ChatGPT can provide solutions to thermodynamics problems involving energy transfers, work calculations, and

efficiency analysis. It can explain the application of relevant thermodynamic laws and guide students through complex energy balance scenarios.

ChatGPT serves as an interactive problem-solving assistant in these instances, helping students develop critical thinking skills, gain confidence in tackling complex engineering challenges, and reinforce their understanding of theoretical concepts through practical application.

1.3. Code Assistance

For software engineering disciplines, ChatGPT can assist students in understanding coding concepts, debugging code, and suggesting improvements (Ahmad et al., 2023; Daun, 2023).

Debugging Support: Students learning programming can encounter errors and bugs in their code. ChatGPT can analyze code snippets, identify common errors, and suggest fixes, helping students learn the debugging process.

Syntax Explanation: ChatGPT can provide explanations for programming language syntax, clarifying concepts like loops, conditionals, data types, and function definitions and assisting students in writing accurate code.

Algorithm Implementation: For engineering algorithms like sorting, searching, or optimization, ChatGPT can guide students through implementing these algorithms in code and explain their underlying logic.

Data Structures Usage: ChatGPT can guide using data structures like arrays, linked lists, stacks, and queues. It can explain when to use specific structures and help students write code that effectively utilizes them.

Version Control and Collaboration: ChatGPT can introduce version control concepts (e.g., Git) and explain collaborative coding practices. It can assist students in managing repositories, branching, merging, and resolving conflicts.

Debugging Methodology: Beyond simple error fixing, ChatGPT can teach students systematic debugging approaches, including strategies for isolating issues, using debugging tools, and tracing code execution.

Optimization Techniques: ChatGPT can provide insights into code optimization, discussing topics like time complexity analysis, algorithmic efficiency, and best practices for writing performant code.

Through these code assistance examples, ChatGPT helps engineering students with syntax and error correction and developing a deeper understanding of programming concepts, problem-solving strategies, and efficient coding practices, all of which are crucial skills for successful engineers.

1.4. Design and CAD Support

ChatGPT can provide guidance in engineering design principles, use of Computer-Aided Design (CAD) tools, and offer suggestions for design improvement (Handa et al., 2023; Nelson et al., 2023).

Design Principles Explanation: Students can consult ChatGPT for explanations of fundamental design principles like symmetry, balance, proportion, and hierarchy, enhancing their understanding of aesthetic and functional considerations.

3D Modeling Techniques: ChatGPT can guide students through techniques for creating 3D models, including extrusion, lofting, revolving, and sweep, while explaining their applications in various engineering disciplines.

Assembly and Mechanism Design: Students can receive assistance in designing complex assemblies and mechanisms and learning how to create moving parts, constraints, and interlocking components using CAD software.

Parametric Design Concepts: ChatGPT can explain parametric design concepts, helping students understand how to create models that adapt to changes in dimensions, allowing for rapid design iterations.

Simulation Setup: For engineering simulations, ChatGPT can explain how to set up simulations within CAD software, define boundary conditions, and interpret results, enhancing students' ability to analyze designs virtually.

Sketching Techniques: ChatGPT can explain various sketching techniques used in CAD, such as isometric, oblique, and orthographic projections, helping students effectively communicate their design ideas on paper.

Design Validation and Testing: ChatGPT can guide students through concepts of design validation and testing, explaining methods like simulation, physical testing, and failure analysis to ensure design robustness.

1.5. Project Planning

Students can consult ChatGPT for project management advice, task scheduling, and resource allocation strategies (Skibniewski et al., 2023; Weng, 2023).

Work Breakdown Structure (WBS): ChatGPT can help students understand how to create a WBS, breaking down complex engineering projects into smaller tasks and subtasks for better organization and resource allocation.

Gantt Chart Creation: ChatGPT can guide students through the process of creating Gantt charts, explaining how to set up timelines, allocate tasks, and visualize project dependencies.

Risk Management Planning: Students can receive insights from ChatGPT on identifying potential project risks, assessing their impact and likelihood, and developing mitigation strategies to ensure project success.

Cost Estimation Techniques: ChatGPT can explain various cost estimation methods, including bottom-up, top-down, and analogous estimating, aiding students in creating accurate project budgets.

Through these examples, ChatGPT assists engineering students in developing essential project management skills, enabling them to effectively plan, execute, and monitor engineering projects from inception to completion.

1.6. Mathematical Concepts

ChatGPT can explain mathematical equations, theorems, and formulas relevant to engineering disciplines, helping students improve their mathematical understanding (Fraiwan & Khasawneh, 2023; Johal, 2023).

Eigenvalues and Eigenvectors: ChatGPT can provide insights into eigenvalues and eigenvectors, explaining their importance in systems of differential equations, stability analysis, and vibration analysis.

Probability and Statistics: Students can receive explanations of probability distributions, statistical measures, hypothesis testing, and regression analysis

from ChatGPT, helping them apply statistical methods in engineering data analysis.

Partial Differential Equations (PDEs): ChatGPT can assist students in understanding PDEs, discussing classification, methods of solution, and their role in describing physical phenomena like heat transfer and wave propagation.

Taylor Series and Approximations: Students can learn about Taylor series expansions, the Maclaurin series, and their applications in approximating functions with assistance from ChatGPT.

Linear Algebra Applications: ChatGPT can explain linear algebra applications like solving systems of linear equations, image compression using singular value decomposition (SVD), and least squares regression.

Numerical Integration Techniques: Students can receive guidance from ChatGPT on numerical integration methods such as Simpson's and trapezoidal rules and their significance in solving engineering problems.

Control Systems Mathematics: ChatGPT can assist in explaining Laplace transforms, transfer functions, and state-space representations used in control systems analysis and design.

Probability Distributions in Engineering: Students can learn about probability distributions such as normal, exponential, and Poisson distributions and their relevance in modeling real-world uncertainties.

Optimization and Linear Programming: ChatGPT can discuss optimization concepts, including linear programming, integer programming, and the simplex method, aiding students in solving engineering optimization problems.

Vector Analysis: ChatGPT can provide explanations for vector operations like addition, subtraction, dot product, and cross product, helping students understand their geometric and algebraic interpretations.

Matrix Algebra: Students can receive guidance from ChatGPT on matrix operations, such as multiplication, inversion, and determinants, along with practical applications in solving systems of linear equations.

Differential Equations: ChatGPT can explain various types of differential equations (ordinary and partial), discussing methods for solving them and their significance in modeling engineering phenomena.

Complex Numbers: Students can learn about complex numbers, their representation, arithmetic operations, and applications in electrical engineering and signal processing with assistance from ChatGPT.

Fourier Transform: ChatGPT can elucidate the Fourier transform, detailing its role in signal analysis, frequency domain representation, and its relevance in disciplines like telecommunications.

Calculus Concepts: Students can receive explanations of calculus concepts such as differentiation, integration, and applications like optimization and rate of change from ChatGPT.

In each of these instances, ChatGPT serves as a virtual math tutor, breaking down complex mathematical ideas into understandable explanations, fostering a deeper comprehension of essential mathematical concepts in engineering.

1.7. Technical Writing

ChatGPT can assist engineering students in crafting technical reports, essays, and documentation, providing guidance on structure, content, and terminology (Huang & Tan, 2023; Zheng & Zhan, 2023).

Report Structure and Organization: ChatGPT can provide guidance on structuring engineering reports, explaining the importance of sections like abstract, introduction, methodology, results, and conclusion.

Clarity and Conciseness: Students can receive tips from ChatGPT on writing clearly and concisely, avoiding jargon, and ensuring that their technical writing is easily understandable by both technical and non-technical audiences.

Citation and Referencing: ChatGPT can explain different citation styles (APA, IEEE, etc.), teaching students how to cite sources and references within their technical documents properly.

Proofreading and Grammar: ChatGPT can help students with grammar and proofreading, offering suggestions to improve sentence structure, punctuation, and overall writing quality in their engineering documentation.

By providing technical writing support, ChatGPT helps engineering students develop essential communication skills required for accurately conveying complex concepts and ideas in the engineering field.

1.8. Research Assistance

ChatGPT can aid in literature review, suggest relevant research papers, and summarise their contents for advanced engineering studies.

Literature Review: Students can consult ChatGPT for guidance in conducting literature reviews, identifying relevant research papers, and summarizing key findings and methodologies.

Research Topic Exploration: ChatGPT can help students brainstorm research topics within their engineering discipline, suggesting recent trends, gaps in existing knowledge, and potential areas for investigation.

Research Proposal Writing: ChatGPT can assist students in crafting research proposals, explaining the components of a strong proposal, such as research objectives, methodologies, and anticipated outcomes.

ChatGPT empowers engineering students to engage in effective academic inquiry, develop research skills, and produce well-structured and evidence-based research projects by offering research assistance.

1.9. Career Guidance

ChatGPT can provide insights into various engineering career paths, industry trends, and skills in demand, helping students make informed decisions.

Career Path Exploration: Students can consult ChatGPT to explore different engineering career paths, such as civil engineering, mechanical engineering, software engineering, and more, understanding the roles and responsibilities associated with each.

Industry Trends and Emerging Technologies: ChatGPT can provide insights into current industry trends, emerging technologies (e.g., AI, renewable energy), and growth areas within the engineering field.

Networking Strategies: ChatGPT can discuss strategies for building a professional network, attending conferences, using online platforms, and connecting with peers and industry professionals.

Resume and Portfolio Building: Students can receive guidance on crafting effective resumes, cover letters, and portfolios that showcase their skills, experiences, and accomplishments.

Interview Preparation: ChatGPT can assist students in preparing for engineering job interviews, offering tips on common interview questions, technical assessments, and strategies for presenting their qualifications. By providing career guidance, ChatGPT empowers engineering students to make informed decisions about their professional paths, helping them align their skills, interests, and goals with the dynamic landscape of the engineering industry.

Simulation and Modeling

ChatGPT can explain simulation techniques, modeling approaches, and how to interpret results, enhancing students' understanding of complex systems (Alneyadi & Wardat, 2023; Santos, 2023; Susnjak, 2023).

Finite Element Analysis (FEA) Principles: ChatGPT can explain the basics of FEA, discussing concepts like discretization, element types, mesh generation, and boundary conditions used in simulating structural behavior.

Fluid Dynamics Simulations: Students can interact with ChatGPT to learn about computational fluid dynamics (CFD), discussing how to set up simulations for fluid flow, heat transfer, and turbulence analysis.

Electromagnetic Field Simulations: ChatGPT can provide insights into electromagnetic field simulations, explaining how software tools like FEMM or COMSOL are used to analyze and optimize magnetic field designs.

Thermal and Heat Transfer Modeling: Students can engage ChatGPT to understand principles of thermal modeling, including conduction, convection, and radiation, and how simulation tools assist in designing efficient heat management systems.

Multi-Body Dynamics Simulations: ChatGPT can discuss the principles of multi-body dynamics, explaining how simulation software helps engineers analyze the motion and interaction of interconnected mechanical components.

Modeling Environmental Impact: Students can explore with ChatGPT how simulation and modeling tools are used to assess the environmental impact of engineering projects, including considerations like emissions, noise, and pollution.

Heat Transfer Interactive Simulation: ChatGPT can provide interactive simulations of heat transfer scenarios. Students can input materials, geometries, and temperature differentials and observe how heat is transferred through conduction, convection, and radiation. These interactive demonstrations empower engineering students to visualize and comprehend complex engineering phenomena, enhancing their understanding and intuition for different concepts.

Circuit Simulation: Students can engage with ChatGPT to virtually simulate electronic circuits. They can input circuit components and parameters, and ChatGPT can provide real-time responses, showing how the circuit behaves under different conditions.

Structural Analysis of Complex Systems: ChatGPT can discuss how simulation tools aid in analyzing complex structures such as bridges, dams, or aerospace components, ensuring safety and reliability.

Validation and Verification Techniques: ChatGPT can explain techniques for validating and verifying simulation models, discussing the importance of comparing results with experimental data to ensure accuracy.

ChatGPT facilitates a deeper understanding of simulation and modeling techniques through these discussions, enabling engineering students to apply these tools effectively to real-world scenarios.

2. CHATGPT USE CASES IN ENGINEERING EDUCATION

Within the scope of usage areas of ChatGPT, this section delves into the diverse and impactful use cases of ChatGPT, highlighting its role in enhancing comprehension, skill development, and collaborative learning within the dynamic landscape of engineering education. To use ChatGPT, you can create a free membership on openai.com (OpenAI 2023). After you become a member, you will see the screenshot in Figure 6.

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			ChatGPT	
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Figure 4 ChatGPT home page screen

You can generate responses according to the prompt content by typing the prompts into the prompt box in Figure 4. An example prompt and response are given in Figure 5. You can use response feedback to feed ChatGPT, aim to more accurate response according to your prompt.



Figure 5 An example response

You can use the response generator if you do not like the given answer or want it to be changed. Chatgpt is used with commands and directions defined as prompt. Simple prompt structure and example are given in Figure 6.



Figure 6 Simple prompt structure and example

Especially in Context and Task structure, "Generate...", "Tell me about...", "Imagine that...", "Act as if..." statements can be used to get more detailed and creative feedback. Some of the uses mentioned in Chapter 2 are exemplified for the application of prompts for different engineering disciplines. The outputs obtained were evaluated according to expert opinions.

Electronical Engineering

Scenario-1: As an electronics engineering student, you want to simulate a circuit in power electronics. You need to design a step-down switching power supply. For this, you are asked to create a circuit simulation.

Prompt:

Act as if you are an electronics engineer specializing in power electronics. I want you to design a step-down switching power supply for this topic. The power supply must operate at a voltage of 0-12 volts and a current of 1 ampere. Is the information I have given sufficient?

The response of ChatGPT is given in Figure 7.



Figure 7 Response of scenario-1

Software Engineering

Scenario-2: As a software engineering student you are using laravel library. You want to save the license plate number, model, color information you get from the vehicle registration form to the database with the Tinker shell structure using the model named Vehicle. For this, you need to create web.php and template pages.

Prompt:

Imagine that you're a software engineer specializing in Laravel.

I want you to write the codes that save the license plate number, model, color information you get from the vehicle registration form using laravel into the database through the model named Vehicle.

I want you to write web.php and template codes separately.

Is the information I have given sufficient?

The response of ChatGPT is given in Figure 8



Figure 8 Response of scenario-2

Computer Engineering

Scenario-3: You are a graduate student who wishes to join a research team working on a human-computer interaction. You've been asked to research the equipment needed to set up a human-computer interaction lab.

Prompt:

As a researcher who wants to work on human-computer interaction, I want you to list what should be in the Human-computer interaction lab. How would you specifically say these devices along with the make and model? Is the information I have given sufficient?

The response of ChatGPT is given in Figure 9.



Figure 9 Response of scenario-3

Material Sciences Engineering

Scenario-4: As a final year materials engineering undergraduate, you are a student searching for graduation paper ideas. Your consultant teacher asked you to design a sensor that can detect temperature that can be used in wearable materials and stated that you can use the 3D printer in the laboratory.

Prompt:

Act as if you are designing a system that can detect body temperature that could be used in wearables. For this, I want you to design a sensor with conductive properties in a flexible structure. You should be able to produce this material using a 3D printer. Is the information I have given sufficient to design this sensor?

The response of ChatGPT is given in Figure 10.

Certainly, I can help you design a muscle movement sensor for wearables. Given yo	our 🗆 🖒
requirements, here's a more detailed breakdown of the design process:	
Step 1: Sensor Type and Functionality	
You want a sensor to detect muscle movements. To achieve this, an electromyogra	iphy
(EMG) sensor is commonly used. EMG sensors detect the electrical activity genera	ated by
muscle contractions.	
Step 2: Conductive Material Selection	
For the conductive material, consider using a combination of a flexible polymer and	đ
conductive particles. A thermoplastic polyurethane (TPU) matrix infused with grap	ohene or
silver nanoparticles could provide the required flexibility and conductivity.	
Step 3: Sensor Design and Structure	
Design a sensor pattern that consists of multiple electrodes. The electrodes should	d be
strategically placed to capture muscle activity from different muscle groups. The p	oattern
can be a series of interlocking loops or a grid structure. This design allows the sense	sor to pick
up different muscle contractions.	
Step 4: 3D Printing Considerations	
Choose a 3D printer that can handle flexible materials like TPU. The printer should	have a
high enough resolution to accurately reproduce the fine details of the electrode pa	ittern.
Experiment with different printing settings to find the optimal balance between flex	xibility,
conductivity, and resolution.	
Step 5: Integration with Wearable	
Design the sensor with attachment points that allow it to be easily integrated into v	wearable
devices, such as arm bands or clothing. Consider creating a pocket or pouch to ho	use the
sensor securely while ensuring it remains in close contact with the skin.	© Regenerate

Figure 10 Response of scenario-4

Industrial Engineering

Scenario-5: As an industrial engineering undergraduate, you need to research real-life examples of Poisson distributions and real-life examples that cannot be explained by Poisson distributions for your probability course.

Prompt:

Imagine that you are writing a thesis for industrial engineering applications.

Describe 3 examples of real-life industry applications of Poisson distributions.

Also describe 2 real-life examples that cannot be explained by Poisson distributions and explain why they cannot be explained by Poisson distributions.

You can use an academic language when writing these.

Is the information I have provided sufficient for you to do what I want?

The response of ChatGPT is given in Figure 11.



Figure 11 Response of scenario-5

3. EVALUATION AND DISCUSS

When we evaluate the scenarios, prompts and answers, it is seen that ChatGPT offers us the design stages for Scenario-1. Some users may expect a direct circuit drawing, but it is important to present the design steps in order to encourage the student's practice. Otherwise, presenting only a direct circuit drawing may negatively affect the student's learning process. Although we do not specify the laravel version in software engineering for scenario-2, it seems that ChatGPT offers us application codes for the latest version. In this case, it shows that ChatGPT is following the current versions. When the codes are applied according to the newest version, it has been observed that only a few minor changes are needed in web.php to work. For scenario-3, the human-computer interaction laboratory has been examined and it has been observed that the devices and models offered by ChatGPt are used in many laboratories (Masaryk Uni. HCI Lab, n.d.; METU HCI R&A Lab., n.d.; Oswego Uni. HCI Lab, n.d.). For scenario-4, a more specific situation in the field of materials

engineering was taught and the answer that ChatGPT presented under the headings was searched in the literature and it was observed that similar approaches were made (Al-Rubaiai et al., 2019; Guo et al., 2021; Mousavi et al., 2020; Yang et al., 2018).In Scenario-5, an answer was requested on two different topics related to Poisson distributions, which is a very detailed topic for industrial engineering. The ChatGPT answer was searched in the lecture notes of the relevant subject, and it was observed that there were similar contents.

4. CONCLUSION

In this study, how ChatGPT can be used within the scope of student, instructor-centered and hybrid approaches in the field of engineering education was investigated within the scope of studies in the literature. Sample scenarios were produced within the scope of different engineering disciplines and their answers were discussed. It has been observed that the answers produced by ChatGPT produce correct results, although incomplete. In this context, it is thought that ChatGPT can guide students in their self-learning processes or contribute positively to their problem-solving processes.

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Chapter 6

Optimization of Orthogonal Cutting Parameters of AL 7075-T6 Aluminum Alloy with ANSYS

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ABSTRACT

In this study, ANSYS software was used to analyze the cutting temperature and stresses resulting from orthogonal cutting of Al 7075-T6 alloy and investigate how they are influenced by three levels of cutting speed, chip thickness and tool rake angle. The factor levels were optimized using the Taguchi L9 orthogonal array. The Taguchi analysis, which adopted the smaller is better approach, was performed in Minitab 15 software. Thus, it was observed that the lowest levels of the analysis parameters gave the optimum results for cutting temperature and stress. In addition, the effect ratios of the factors on cutting temperature and stress were determined as cutting speed, chip thickness, and rake angle in descending order. The results of this study can help improve the material processing efficiency and quality in machines using orthogonal cutting operations.

Keywords: ANSYS, Al 7075-T6 alloy, Taguchi, cutting temperature, cutting stress.

INTRODUCTION

With the combination of industrialization and modern technology, the demand for processed materials has increased, and traditional machines have struggled to meet this demand. To address this need, Computer Numerical Control (CNC) machines were invented. CNC machines perform the same operations as traditional machines but at a much faster pace, reducing the processing time of materials and successfully meeting the needs of the industry. However, traditional machines still maintain their popularity in the industry despite their slower processing times. One of the main reasons for this is the high quality of the processed material, even though the processing time is longer. The material processing on these machines is theoretically formulated using the orthogonal cutting method. Based on this formulation, certain parameters have emerged for material processing on machines, such as the tool approach angle, chip thickness, and cutting speed, which have a significant impact on material deformation (Çelik & Fidan, 2022; B. Li, 2012).

In machines like lathes, mills, drills, and broaches, the most important soughtafter features after material processing are the deformations that occur on the material and surface quality. These features are influenced by the parameters resulting from the orthogonal cutting method. Therefore, cutting parameters play a crucial role in deformation and surface quality (El-Tamimi & El-Hossainy, 2008).

The numerical modeling of the orthogonal cutting method in a digital environment is achieved through the finite element method. The finite element method essentially divides a large system into smaller components called finite elements, by discretizing the space where the equation is solved into small regions. This formulation of the boundary value problem results in an algebraic equation system. This system is then solved using variable methods such as Rayleigh-Ritz or Galerkin methods. In these methods, the results are obtained in terms of basic functions, which means that these functions are used to interpolate the actual solution. The orthogonal cutting process is simulated in a numerical environment using the ANSYS program through this method. In this modeling, cutting parameters are entered as data into the program, and their effects are observed through graphs in the simulation. By varying these parameters using ANSYS, simulations were performed, and their effects on deformation zones were examined (Karaca, 2017; Ünal & Yalçın, 2023).

It is assumed that cutting speed, considered as one of the cutting parameters, has a negative effect on the deformation zone. A high cutting speed, exceeding the optimal value at which the cutting tool advances on the material, is predicted to cause damages in the deformation zone due to frictional heat. The tool approach angle affects the material's cutting speed and chip thickness. It is believed that a rake angle greater than 60 degrees will cause deformation on the workpiece, disrupt the chip formation, and decrease the cutting speed. These hypotheses were investigated for their accuracy by performing simulations in a numerical environment using the finite element method and varying the parameters (Mamundi Azaath et al., 2021).

In machining methods involving chip removal, particularly orthogonal cutting, turning, and milling, numerous studies have been conducted on cutting parameters and their effects on cutting forces and surface roughness. In these studies, surface roughness has been predominantly investigated and examined using the Taguchi method. The following studies have been conducted (Anggoro et al., 2022; Gurugubelli et al., 2022; Kolluru et al., 2021; Maneesh et al., 2023)

Based on the literature review, it was observed that the deformation zones of a workpiece were not investigated using the finite element method. In this study, ANSYS software was used to analyze the deformation zones and stresses resulting from orthogonal cutting and investigate the influence of cutting parameters on the deformation zones.

Chip Formation

Among the methods used for the production of a product from raw material, machining is one of the most important. In machining, excess material on the workpiece, in the desired dimensions and geometries specified in the technical drawing, is removed in the form of chips by using suitable machine tools or cutting tools.

The common factor in chip removal is the formation of chips. Chips are formed as a result of plastic deformation of the main material. These stresses cause a surface layer, called the chip, to separate from the workpiece and slide off the cutting surface, exceeding the flow limit of the material. The surface between the cutting tool, which is in contact with the material, and the material experiences high temperatures and stresses. When the stresses exceed the yield point of the material, a specific surface layer, known as the chip, separates from the workpiece and slides off along the cutting surface (ÖZTÜRK, 2016). The cross-sectional view of chip formation is shown in Figure 1.



Figure 1: The cross-sectional view of chip formation (Groover, 2011)

The form and proper breaking of chips are crucial factors in the machining process. Good chip formation and breaking ensure that the workpiece is machined accurately in the desired dimensions and geometries. Additionally, proper chip breaking allows the cutting tool to operate efficiently and for an extended period.

The form of chips is dependent on the plastic deformation of the material during the machining process. The shape of the chip is formed as a result of the material undergoing plastic deformation and the generation of stresses when the cutting tool comes into contact with the material. A good chip form ensures that the chips are efficiently removed in the desired sizes and shapes.

Proper chip breaking refers to the chip ability to break and separate smoothly. This occurs when the surface layer of the material, where the chip is formed, surpasses the yield point and separates from the workpiece, sliding along the cutting surface. Smooth chip breaking ensures that the chips are formed and removed in the desired direction and timing, while also influencing the surface quality of the workpiece.

The form and proper breaking of chips are influenced by various factors such as machining parameters, cutting tool geometry, and material properties. Parameters such as cutting speed, feed rate, depth of cut, tool material, and cutting tool geometry can affect chip formation and breaking. Therefore, selecting the appropriate cutting parameters and utilizing suitable cutting tool geometries are essential in the machining process.

The stages of chip formation are shown in Figure 2. In this case, the cutting tool first approaches the workpiece and plunges into the workpiece until the pass to be removed. After the plunging process is realized, the cutting tool starts to advance and thus the cutting process begins. With the advancement of the cutting tool, chip formation begins and after a certain progress, the chip breaks off and leaves the workpiece.



Figure 2: The stages of chip formation (Suresh et al., 2013)

There are two commonly used cutting methods for the analysis of the shear: Orthogonal (Figure 3a) and Oblique cutting (Figure 3b). Since perpendicular cutting exhibits a two-dimensional problem behavior rather than a threedimensional problem, it is a widely used method in experimental and theoretical studies in finding the equations constituting cutting mechanics. The depth of cut, which is removed by the cutter effect, is generally known as the uniform chip thickness and is usually taken as a constant for practical cutting operations and work done (Gurbuz et al., 2011; Gürbüz et al., 2012).



Figure 3: a) Orthogonal cutting b) Oblique cutting (Adeyinka, 2020)

Chip removal is explained by the planar section taken at the chip formed area at the cutting edge. In Figure 4, which shows the chip formation plane and the parameters, ϕ in the chip formation plane is the shear angle; α is the free margin angle; β is the wedge angle; where *a* is the depth of cut and *a'* is the chip thickness (Gurbuz et al., 2011).


Figure 4: The chip formation plane and the parameters (Groover, 2011)

Stacking factor (λ) caused by the shear angle effect is obtained from the triangles ABC and BCD in Figure 4. The chip shear angle (ϕ) has an important role in chip removal and is used to calculate the chip stacking factor. Accordingly, if those given in Equation 2 are substituted in Equation 1, the stacking factor is;

$$\lambda = \frac{a'}{a} \tag{1}$$

$$\sin\phi = \frac{a}{h} \gg a = h \sin\phi$$
 (2a)

$$\cos\left(\phi - \gamma\right) = \frac{a'}{h} \gg a' = h\cos(\phi - \gamma) \tag{2b}$$

calculated.

The parameter that has a significant effect on the distribution of the cutting forces acting on the cutter in the chip removal process and the chip flow is the chip-tool contact length (Figure 5). This parameter is directly related to the shear angle and the main shear zone. Various studies have been carried out by many researchers in the literature to determine the chip-tool contact length. The Equation 3 of chip-tool contact length (l_c) is given below.

$$l_c = 2.\lambda.\alpha \tag{3}$$



Figure 5: The rake angle, wedge angle and free angle during cutting (Artozoul et al., 2014)

The chip tool contact length given in Equation 3 has been verified by various experimental studies. Since the position of the shear surface can be determined by the shear angle. The following Equation 4 can be written for the shear angle (Groover, 2011; Gurbuz et al., 2011; Gürbüz et al., 2012).

$$tan\phi = \frac{cos\gamma}{\lambda - sin\gamma} \tag{4}$$

Factors Affecting Chip Removal

To achieve high production efficiency, it is essential to ensure optimal machining conditions during the manufacturing process. In chip removal operations, the cutting parameters, namely cutting speed (V), feed rate (f), and depth of cut (a), have a significant impact on tool life and the amount of material removed. For a cutting tool to remove a certain amount of material from the surface of a workpiece, it needs to penetrate into the material as a cutting tool. Therefore, the cutting tool used as a tool must be harder and more durable than the workpiece material. Additionally, the cutting tool must have a specific tool geometry and certain cutting conditions to allow for the occurrence of cutting by applying sufficient force to the tool. In turning operations, which represent chip removal most effectively and accurately, single-point cutting is considered. Similarly, in other machine tools, similar events are simplified and presented (Sürücüler, 2010).

MATERIAL AND METHOD

In this research, the chip removal process, which is one of the fundamental methods of machining, specifically orthogonal cutting, was modeled using the

finite element method in the ANSYS program to investigate the deformation regions resulting from different cutting parameters.

In order to prepare the orthogonal cutting analysis in the ANSYS program, the levels of cutting parameters need to be determined. The cutting parameters for orthogonal cutting are as follows:

- Cutting speed
- Depth of cut •
- Chip angle •

For each parameter, three different levels have been determined. These levels are given in Table 1.

Table 1: Cutting Parameters							
Parameters	Symbol	Level 1	Level 2	Level 3			
Cutting speed (m/min)	V	300	450	600			
Depth of cut (mm)	а	0,5	1	2			
Chip angle (°)	heta	12	16	20			

The material selected for the workpiece is Aluminum Al 7075-T6. The mechanical properties of the material are provided in Table 2.

Properties					
Density (g/cm ³)	2.804				
Specific Heat Constant Pressure (mJ/kg·°C)	8.48e+05				
Initial Yield Stress Y (MPa)	420				
Maximum Yield Stress Ymax (MPa)	810				
Hardening Constant B	965				
Hardening Exponent n	0.1				
Derivative dG/dP G'P	1.741				
Derivative dG/dT G'T (MPa/°C)	-16.45				
Derivative dY/dP Y'P	0.02738				
Melting Temperature Tmelt (°C)	946.85				
Shear Modulus (MPa)	26700				

Table 2: AL7075-T6 Mechanical Properties

The cutting tool material selected for this study is high-speed steel (HSS). The mechanical properties of the tool material are presented in Table 3.

Properties	
Density (g/cm ³)	8.16
Rockwell hardness (HRc)	62
Elastic Modulus (GPa)	207
Yield Strength (MPa)	3250

Table 3: High-Speed Steel (HSS) Tool Steel Mechanical Properties

The dimensions of the workpiece are 4x5x30 mm and cutting tool are specified in Figure 6.



Figure 6: Schematic view of cutting tool and workpiece.

Analyses were conducted using ANSYS Workbench (Figure 7). In this case, the Explicit Dynamics section is utilized to simulate the orthogonal cutting process. A total of 9 solutions were performed.



Figure 7: Results of ANSYS Workbench model design

In determining the boundary conditions, a cartesian coordinate system was used. The workpiece is fixed along the x, y, and z axes. The contact surfaces selected are the front and bottom surfaces of the cutting tool, and the front, side, and top surfaces of the workpiece. Friction between the parts was considered, and a friction coefficient of 0.4 was assumed. The motion of the cutting tool was applied along the x-axis. The mesh size was set to 1 mm. In the analysis settings,

the time step was set to 0.001 seconds, and the total number of cycles was set to 100,000. As the cutting tool removes material while moving, a material removal feature was enabled for the analysis.

Orthogonal cutting parameters are affected by many factors that must be considered in order to achieve optimum targets. By choosing the appropriate optimization method for this, it becomes easier to obtain an optimized set of cutting parameters for better results. Taguchi methodology was used to determine the optimum cutting parameters affecting the machining process. The Taguchi methodology allows the practitioner to be optimized with several numerical studies that provide a clear understanding of the various effects of factors (Abhishek et al., 2015; Özek & Ünal, 2011; Saglam et al., 2007). L9 orthogonal array is preferred for Taguchi parameter design. Numerical analysis data were analyzed methodically using the S/N ratio. The S/N ratio analysis provides an optimized combination of process parameters, while providing information on the process temperature and its contribution to von Mises stresses.

RESULTS

In this research, the ANSYS program was used to analyze the effects of cutting parameters on the deformation zones in the modeling of orthogonal cutting process using M2 high-speed steel (HSS) tool steel with different cutting tool angles, cutting velocities and chip thicknesses on Al 7075-T6 material with a bar profile. The necessary analysis settings were configured, and the solution was obtained. Design of experiment with Taguchi L9 array and analysis results of temperature and stress are indicated in Table 4.

Cutting speed	Chip	Rake angle	Stress (MPa)	Cutting
(m/min)	thickness	(°)		temperature
	(mm)			(°C)
300	0.5	12	490.77	250.87
300	1.0	16	797.41	392.49
300	2.0	20	724.00	454.92
450	0.5	16	724.17	428.87
450	1.0	20	750.09	421.87
450	2.0	12	764.25	433.81
600	0.5	20	752.63	433.88
600	1.0	12	746.66	505.93
600	2.0	16	758.73	512.54

Table 4: Design of experiment with Taguchi L9 array

Figure 8 represents the graph and S/N response chart for temperature and Figure 9 represents the graph and S/N response chart for stress. The higher the S/N value, the less the performance characteristics will deviate from the target value. (Mohapatra et al., 2023). Figures 8 and 9 present the response plot of whole cutting parameters based on S/N analysis, taking the smaller is better approach for lower cutting temperature and stress, respectively. The line between each level represents the influence of the cutting parameters on the output. Based on this inference, as can be mentioned from the S/N graphs, the first level values of cutting speed, chip thickness and rake angle present the optimum values for the cutting temperature.



Figure 8: Main Effects Plot for SN ratios of temperature variations



Figure 9: Main Effects Plot for SN ratios of von Mises stress variations

As seen in Figure 8, the most effective parameter on the cutting temperature is the cutting speed. Many factors can change with the increase in cutting speed, and many of these factors can interact with each other. To explain the expression in question, let's explain how cutting speed affects temperature and chip formation (Saglam et al., 2007; Ullen et al., 2020). Increasing cutting speed can lead to increased heat generation due to friction and deformation in the cutting

zone. While some of this heat is transferred to the material as energy, some of it is accumulated in the cutting zone. In this case, the temperature in the cutting zone increases. An increase in temperature can cause changes in the material structure. Especially in metal materials, high temperatures can change the mechanical properties of the material, affect the surface quality and increase wear (Ünal, 2016; Ünal & Karaca, 2017). An increase in the amount of chips can affect the temperature rise during the cutting process. A greater amount of chip thickness can often result in more heat being generated and a faster temperature rise. Good cutting process planning and parameter optimization can help control unwanted temperature rise (Singh et al., 2019).

When the situation of the rake angle in Figure 8 is analyzed, while the rake angle increased from 12° to 16°, the cutting temperature also increased. However, when increasing from 16° to 20°, the cutting temperature started to decrease. The 16° rake angle represents the breaking point at the selected parameter levels. However, larger rake angles can mean lower friction and less heat generation. The effects of the cutting process with increasing cutting speed are quite complex and can affect the behavior of the material in many ways (Cao et al., 2023; Weng et al., 2023). Increasing the depth of cut is another parameter that increases the process temperature. The increase in temperature can lead to an increase in the plastic deformation of the material and thus an increase in stresses (Figueiredo et al., 2022). This situation is also observed in the S/N graph in Figure 8. As the chip thickness increases, the cutting temperature increases.

Increasing shear rate can often increase von Mises stresses in the shear zone. Increasing the cutting speed can cause the material to deform rapidly by the cutting tool. This rapid deformation may require the material to withstand greater stresses. When the state of the cutting speed in Figure 9 is examined, the amount of stress shows a continuous increasing trend with increasing cutting speed. On the other hand, high cutting speed can cause the material to heat up and cool down as it is cut. Rapid heating and cooling can lead to the build-up of thermal stresses. These thermal stresses can affect von Mises stresses. Increasing stresses in the shear zone can have a number of effects on the material (G. Li et al., 2022). Since the cutting tool tip angles especially rake angle affect the applied cutting force, they also directly change the stresses in the cutting zone (Celik & Fidan, 2022; B. Li, 2012). With the increase in rake angle, the stress firstly increased and then decreased (Figure 9). Because the high rake angle changed the plastic deformation rate in the yield region. The effect of depth of cut on stresses increase. More chips mean more material is cut and deformed. This can cause increased stresses in the cutting zone because the amount of chip is directly related to the amount of deformation of the material (Aykut et al., 2007).

Therefore, in Figure 9, an increase in stress was observed with increasing chip thickness.

CONCLUSIONS

In the present analysis study, the orthogonal cutting process with the cutting tool was modeled in ANSYS software and the effect of cutting parameters on the deformation zones was optimized by the Taguchi method.

As a result, the following conclusions can be inferred.

• As the cutting speed increases, both the cutting temperature and the stresses in the cutting zone increase.

• While the cutting temperature increased when the chip thickness increased, a more significant change was observed in the stresses in the cutting zone.

• Increasing the rake angle increased the cutting temperature and stresses similarly.

• It has been observed that there is a very good agreement between the results obtained from the model and the literature.

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Chapter 7

Evaluating the Environmental Impacts and Sustainability of Gasoline-Ethanol Blends on Vehicle Exhaust Emissions

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ABSTRACT

This study investigates how adding ethanol to a gasoline-powered engine affects exhaust emissions at various speeds. The results show that increasing ethanol content leads to a reduction in nitrogen oxides (NOX), hydrocarbons (HC), and carbon monoxide (CO) emissions. Including ethanol in gasoline, blends demonstrate its potential to improve the environmental performance of internal combustion engines by reducing harmful exhaust emissions. The findings highlight the importance of ethanol as a sustainable fuel option and support its adoption to mitigate air pollution, enhance air quality, and minimize associated health risks. Further research is needed to fully understand ethanol usage's complete environmental implications and sustainability. The study emphasizes the significance of continued research, development, and collaboration among policymakers, researchers, and stakeholders to promote alternative fuels like ethanol and foster a cleaner and more sustainable future for the transportation sector.

Keywords : I Alternative Fuels, Environmental Impacts, Exhaust Emissions, Gasoline–Ethanol Blends, Sustainability.

INTRODUCTION

The use of fossil fuels in vehicles significantly impacts the environment, which is a pressing concern. Bringing gasoline and diesel in cars releases a large amount of greenhouse gases and pollutants into the air. This contributes to climate change and air pollution, which have severe consequences for ecosystems, human health, and the overall well-being of the planet. It is crucial to understand the adverse effects of using fossil fuels in vehicles and find alternative solutions to reduce environmental harm and create sustainable transportation systems. The growing concerns over environmental impacts and the limited availability of fossil fuels have increased interest in alternative fuels and their potential benefits for sustainability (Martins et al., 2019:964). Alternative fuels play a crucial role in addressing the challenges posed by conventional fossil fuels. With depleting oil reserves and mounting concerns about greenhouse gas emissions, exploring alternative fuel options has become crucial (Liu et al., 2007:1070, Sangeeta et al., 2014:697). The energy crisis arising from the limited availability and depletion of fossil fuel resources has made the use of alternative energy sources imperative. Various alternative fuel types, including hydrogen, methanol, ethanol, LPG, and different vegetable oils, have been employed in vehicles, with some still being utilized (Eyidogan et al., 2013:499). One promising opportunity is the utilization of gasoline-ethanol blends, which offer a viable alternative to traditional gasoline fuels. These blends have gained significant attention due to their potential to reduce exhaust emissions and mitigate the environmental impacts of combustion engines (Chen at al., 2012:120, Costa and Sodre, 2010:287, Bayraktar, 2005:1733, Shahinsha, 2023, Thakur et al., 91). Traditional gasoline fuels are known to emit significant amounts of pollutants, such as hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx), which have detrimental effects on air quality and human health. In contrast, ethanol, a renewable biofuel derived from biomass sources, possesses properties that enable more complete combustion, resulting in reduced emissions of these pollutants. The utilization of gasoline-ethanol blends can, therefore, contribute to the reduction of harmful exhaust emissions and alleviate the environmental impacts associated with combustion engines (Thakur et al., 2016:91, Barbir et al., 1990:739, Bastian-Pinto et al., 2009:411).

Al-Hasan examined the effects of ethanol-gasoline blends on engine performance and exhaust emissions. The results showed that blending ethanol with unleaded gasoline improved power, efficiency, and fuel consumption, while reducing emissions of CO and HC. The study concluded that a 20% ethanol blend yielded the best overall results (Al-Hasan, 2003:1547). Mohammed et al., investigated the impact of ethanol-gasoline blends on SI engine performance and emissions. The study found that increasing ethanol concentration improved power, fuel consumption, and thermal efficiency, but had a negative effect on volumetric efficiency. Ethanol blends also led to a reduction in harmful exhaust gases. The research concluded that ethanol addition enhanced various parameters except for lower heating value (Mohammed et al., 2021:100891). Mohamad et al., conducted a review on the effects of ethanol-gasoline fuel blends on the exhaust emissions and characteristics of SI engines. Researchers found that blending ethanol with gasoline resulted in improved combustion efficiency, enhanced engine performance, and reduced emissions of CO and NOx (Mohamad et al., 2018:29).

Sustainability is a crucial aspect of alternative fuels and their utilization. The pursuit of sustainable energy solutions involves not only environmental considerations but also social and economic aspects. Gasoline-ethanol blends align with this goal by offering a renewable fuel option that can reduce dependence on fossil fuels, mitigate climate change, and promote the development of sustainable energy infrastructure. Furthermore, the production and use of ethanol derived from sustainable biomass sources can contribute to rural development and create new economic opportunities (Stancin et al., 2020:109927, Kumar et al., 2020).

The primary objective of this study is to analyze the effects of ethanol addition to a gasoline-powered engine on exhaust emissions at different engine speeds. By blending ethanol with gasoline in varying ratios, we aim to evaluate the environmental implications and potential benefits of utilizing ethanol as an alternative fuel in internal combustion engines. This study will provide valuable insights into the emission reduction capabilities of ethanol and contribute to ongoing efforts to achieve sustainable transportation.

In the following sections, we will present a detailed methodology, discuss the experimental setup, give the obtained results, and provide a comprehensive analysis of the findings. Finally, we will discuss the broader implications, limitations, and recommendations for future research in this field.

MATERIALS AND METHOD

The experiments utilized the experimental setup depicted in Figure 1. A Lombaridini brand dual-cylinder, spark-ignition, electronically fuel-injected, water-cooled engine was employed for the tests. The experiments were carried out under full load conditions at six different engine speeds: 1400, 1800, 2200, 2600, 3000, and 3400 rpm. To achieve the full load conditions, an electric motor dynamometer was employed. The engine was allowed to stabilize to determine the exhaust emissions emitted by the engine in the experimental study. Exhaust measurements were taken once the engine reached a steady state.

An MRU Delta 1600L brand emission measurement device was used in the experiments to measure exhaust emissions from the engines. This device quantifies the CO value as a percentage and measures the HC and NOx emission values in parts per million (ppm).



Figure 1: Experimental setup

Ethanol-gasoline blends were prepared by mass for the experiments. The ethanol used in the experiments is industrial grade with a purity of 99.9%. The experiments used blends of 10% ethanol and 90% gasoline (E10) and 20% ethanol and 80% gasoline (E20).

To compare the experimental results of using standard 100% gasoline (STD) and ethanol-blended fuels at different ratios in the engines, the engine was operated under the same conditions.

RESULTS AND DISCUSSION

This study aimed to examine the impact of ethanol addition to a gasolinepowered engine on emissions at different engine speeds. Experimental measurements were conducted, and the collected data are summarized below.

Figure 2 presents the HC emission values emitted from the engine when using a fuel mixture of standard fuel (STD) and ethanol. The figure shows that when ethanol is used as a fuel in the engine, reductions are observed at all engine speeds compared to the STD motor fuel. The maximum reduction amount is achieved in the E10 fuel mixture at 2200 rpm, which is 6%. The decrease in HC emissions is attributed to the different chemical and physical properties of alcohol compared to gasoline fuel. Due to its higher oxygen content and faster combustion rate compared to gasoline, ethanol enhances combustion efficiency. Due to ethanol's high combustion rate, the rapid reaction of hydrogen (H) and carbon (C) atoms with air leads to their combustion without being transformed into HC emissions. The high flame speed within the cylinder also results in a shorter combustion duration, reducing heat loss from the cylinder walls. These factors contribute to the reduction in HC emissions.



Figure 2: The HC emissions for different engine speeds

Figure 3 presents the NOx emission values emitted from the engine when using a fuel mixture of standard fuel (STD) and ethanol. It is observed that when using ethanol-gasoline blends in the engine, reductions in NOx emissions are detected across all engine speeds and blend ratios. The E10 fuel mixture exhibits a maximum decrease of 9% at 1400 rpm, while using the E20 fuel mixture results in a maximum reduction of 18% at 1400 rpm. The decrease in NOx emissions

can be attributed to the higher latent heat of vaporization of ethanol. During vaporization, ethanol absorbs more heat from the surroundings, decreasing adiabatic flame temperature. The lowered temperatures contribute to the reduction in NOx emissions.



Figure 3: The NOx emissions for different engine speeds

Figure 4 illustrates the CO emission values emitted from the engine when using a fuel mixture of standard fuel (STD) and ethanol. It is observed that when E10 and E20 fuel mixtures are used in the engine, reductions in CO emissions are detected. The improvements in CO emissions can be attributed to the enhanced combustion efficiency of ethanol-blended fuel. The higher oxygen content and faster combustion rate of ethanol contribute to the acceleration and efficiency of combustion reactions. The high flame speed within the cylinder leads to a shorter combustion duration. The fuel's carbon (C) particles are believed to complete their combustion without being converted into CO due to the high combustion rate.



Figure 4: The CO emissions for different engine speeds

Overall, the addition of ethanol to the gasoline fuel blend demonstrated a significant impact on emissions at different engine speeds. The results indicate that increasing the ethanol content led to a general reduction in NOX, HC, and CO emissions. This finding suggests that utilizing ethanol as an additive in gasoline engines can reduce harmful exhaust emissions, thus improving the environmental performance of internal combustion engines. Further research is warranted to explore the optimal ethanol-gasoline blend ratios for achieving the most significant emission reductions without compromising engine performance.

The environmental evaluation of the ethanol addition to a gasoline-powered engine at different engine speeds reveals several significant findings.

Firstly, reducing NOX emissions with ethanol is a significant benefit. NOX emissions contribute to air pollution and are associated with smog formation and air quality deterioration. The observed decrease in NOX emissions across all engine speeds indicates that adding ethanol can mitigate these harmful pollutants.

Secondly, reducing HC emissions with ethanol blending is another positive outcome. HC emissions contribute to ground-level ozone formation and are associated with respiratory issues. The reduction in HC emissions observed in this study suggests that ethanol addition can help alleviate the adverse effects of these emissions on human health and the environment.

Lastly, the findings demonstrate decreased CO emissions with ethanol in the fuel blend. CO is a toxic gas that can have detrimental effects on human health, particularly when inhaled in high concentrations. The reduction in CO emissions signifies a potential improvement in air quality and a decrease in the associated health risks.

The results indicate that adding ethanol to gasoline can yield positive environmental benefits by reducing NOX, HC, and CO emissions. These findings support the adoption of ethanol as an alternative fuel component to mitigate the environmental impact of internal combustion engines. However, further investigations are necessary to evaluate the long-term effects of ethanol usage, including factors such as the life cycle assessment, potential greenhouse gas emissions, and the sustainability of ethanol production.

CONCLUSION

This study comprehensively analyzes the effects of ethanol addition to gasoline-powered engines regarding exhaust emissions and environmental benefits. The findings of this research contribute to the existing body of knowledge on alternative fuels and their potential to mitigate environmental pollution and promote sustainability in the transportation sector.

The results of the study demonstrate that the inclusion of ethanol in gasoline blends leads to a significant reduction in emissions of nitrogen oxides (NOx), hydrocarbons (HC), and carbon monoxide (CO) across various engine speeds. Reducing exhaust emissions is crucial in addressing air pollution, improving air quality, and minimizing health risks for human populations and ecosystems.

The findings of this study underscore the importance of continued research and development in the field of alternative fuels. By exploring and implementing sustainable fuel solutions like ethanol blends, we can pave the way for a greener, more sustainable future for the transportation sector. Policymakers, researchers, and stakeholders must collaborate to promote the adoption of alternative fuels, develop supportive policies, and invest in the necessary infrastructure to facilitate their widespread use.

In conclusion, this study provides valuable insights into the environmental impacts and sustainability of gasoline-ethanol blends on vehicle exhaust emissions. The findings underscore the potential of these blends to significantly reduce emissions and promote a more sustainable approach to transportation. Continued research and policy efforts are crucial to optimize the use of gasolineethanol blends further and accelerate their adoption, leading to a greener and more environmentally friendly future for the automotive industry.

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Chapter 8

Evaluation with Spring Management System (SMS) of Springs in the Kumalar Mountain Region (Afyonkarahisar/Turkey)

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ABSTRACT

Population growth and overexploitation of groundwater are one of the biggest sustainability challenges of the last century. Therefore, the importance of sustainable use and management of water resources is increasing day by day. The investigation area located in the in the Aegean Region and covers an area of 350 km². Cretaceous -Triassic aged limestones-dolomites, Neogene-Plio Quaternary aged pyroclastic rocks and uncemented terrestrial clasts are the dominant rocks of the investigation area. There are many natural springs discharged from aquitard medium in the study area. These springs are used for drinking, irrigation and domestic usage etc. The Spring Management System was used to determine the potential, quantity, quality and to ensure their sustainability of the springs in the study area. In this study, a total of 38 spring water samples were collected for wet and dry seasons. The hydrochemical facies of spring waters were determined as CaMgHCO₃, CaHCO₃, CaNaHCO₃, CaMgSO₄, and CaNaSO₄. Differences in water types are due to the rock-water interaction. Trace element concentration values of springs as Al, As, Fe, Ni and Mn exceed limits of drinking water standards of TS266 (2005), WHO (2011) and EPA (2009). In addition, the springs in the study area are within the absolute protection zone. For this reason, suggestions were made for the sustainable use and protection of springs in the study area with the Spring Management System.

Keywords: Kumalar Mountain (Afyonkarahisar) region, natural springs, Spring Management System (SMS), sustainability

INTRODUCTION

Natural springs are important for the use of groundwater and in water supply for human consumption. Springs are a direct reflection of the state of groundwater in the aquifers that feed them, and when managed properly, can meet the increasing demands of societies in long-term. In order to create a viable spring management plan, it is necessary to determine the hydrogeological characteristics of the spring recharge area, the recharge-discharge characteristics of it, the hydrological conditions controlling the amount of water and the factors affecting the water chemistry. The long-term sustainable water management strategies are: to minimize net losses of water from the hydrologic system; to encourage effective and efficient water use, to focus on protecting the quality and quantity of groundwater, to provide quality of surface water and groundwater and ensure the fair allocation of water for human use (Brune, 1975:15; Kresic, 2009:549; Kresic, 2010:17; Kresic and Stevanovic 2010:13-16). In order to realize these strategies, an appropriate water resources management system should be developed. The system should provide the most suitable and reliable water with effective and safe planning and management.

As observed in many regions in our country and in the world, most of the springs are unfortunately not utilized for appropriate purposes and conditions. Especially in rural areas where there is not enough water source in terms of drinking water, all research on water management is of great importance. There are many natural springs around the Kumalar Mountain, which was chosen as the study area. These springs are used, without any management in place, for domestic and agricultural purposes. In this study, it is aimed to make the necessary studies for optimum utilization and sustainable usage of the natural springs around Kumalar Mountain (Afyonkarahisar). With the data obtained within the scope of the study, a spring management system was created for the study area and necessary precautions and suggestions were made.

Study Area

Kumalar Mountain is located in the Aegean Region and the Inner Western Anatolian part of Turkey. The study area covers an area of approximately 350 km² within latitudes 38°15'N to 38°40'N and longitudes 30°10'E to 30°40'E (Figure 1). The study area includes Sandiklı and Şuhut districts of Afyonkarahisar province. Kumalar Mountain (2250 m) is the highest peak in the study area. Kumalar Mountain is a mountain mass of 50-60 km long and 30-35 km wide, extending in the north-south direction by separating the Sandiklı and Şuhut basins. The study area extends from the Kumalar Mountain to the Sandiklı plain in the west and to the Şuhut plain in the east. In addition, there are 24 settlement areas in the study area.

METHODOLOGY

Sampling and Analyses

A total of 38 spring water samples were collected during the wet season (September-2017) and dry season (April-2018). The samples were collected using 100 ml sterile polyethylene bottles and decreased to pH<2 (for cation analysis). The collected samples were stored in a cooler, and labelled accordingly with coordinates. Determination of sample coordinates were collected with a GPS (Global Positioning System). The in-situ measurements such as pH, electrical conductivity (EC- μ S/cm), discharge temperature (T-°C) and total dissolved solids (TDS-mg/l) were made using portable multiparameter device. Cations (Ca²⁺, Mg²⁺, Na⁺, K⁺), anions (Cl⁻, SO4²⁻, HCO3²⁻) and nitrogen derivatives (NO3⁻, NO2⁻, NH4⁺) were analyzed using standard methods of APHA (2012) in the Water Chemistry Laboratories of Hacettepe University. Trace element (Al, As, B, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, U, Zn) analyzes of water samples were made ICP-MS instrument in the Canada Bureau Veritas Mineral Laboratories.



Figure 1: Hydrogeological map of the study area

Spring Management System (SMS)

With the spring management system (SMS), the potential, quantity and quality of natural flowing springs are determined and improvement and development studies are carried out for sustainability. Today and in the future, the efficient use of our water resources depends on the correct planning of water resource management systems. In natural flowing water springs, utilization of springs is minimized due to factors such as the lack of storage and the inability to control the flow depending on the physical and topographic conditions of the region where the spring is located. Considering that the need for water is increasing, spring management plans should be made to meet the increasing water demand. The SMS is of great importance for the sustainable use of water springs.

Creation of Spring Management System (SMS) in the study area

In the study area, the inputs were created in order to enable us to obtain the necessary parameters for SMS. The created inputs enabled us to determine the hydrogeological, hydrological, hydrogeochemical properties of each spring and to determine the purposes of usage.

- 1. The inputs of Spring Management System (SMS)
- 2. Where are the discharge locations of springs?
- 3. What are the aquifer units that feed the springs?
- 4. What are the types of springs (fault, contact, karst, crack, etc.) according to their discharge locations?
- 5. What are the monthly flow rates of springs?
- 6. Are there water bodies such as stream, lake, etc. fed by springs?
- 7. Are there different receiving bodies?
- 8. What are hydrogeochemical properties of springs and are seasonal changes observed?
- 9. What are the current usage purposes of springs?
- 10. Is it compatible with water quality and current usage purposes?
- 11. How the current situation (hydrogeological, hydrological etc.) should be improved for sustainable use?
- 12. What should be done to protect, improve and develop springs?

The Spring Management System (SMS) process

The SMS is formed from the processes of utilization, quality and sustainability of natural springs (Figure 2). The utilization process includes the determination of the potential of springs, the amount of water used and the amount of water left unused. At the quality process, evaluations were made for drinking, irrigation and domestic purposes, which are usage areas of springs in the study area. In the sustainability process, investigations were made on the improvement and development of springs and suggestions were presented.

Utilization: One of the important parameters controlling the utilization of spring waters is its amount or potential. This information will be helpful, "how much of the available water can be used" and "what is the remaining amount of water" at the spring?

The potential of springs: In this study, monthly flow measurements were made with the method of containers with a certain volume during 1 years to determine the water potential of the springs. A hydrological database has been created the obtaining of gauging flow data from natural springs. By evaluating

the measurement results, the annual amount of water discharged from each spring has been determined.

The amount of water used: The current uses of all springs in the study area have been determined by field studies. The suitability for current use in terms of quantity has been evaluated.

The quantity of water remaining after use: In order to determine the usability of any spring other than existing uses, it is necessary to determine the amount of water remaining after use. Utilization possibilities are evaluated by taking into account factors such as the amount of water remaining from use, needed purposes, quality and regional characteristics.

Quality: Water quality is another important factor controlling the availability of spring waters. Water quality assessments are made using different standards and diagrams according to their intended use.

Drinking water quality: Some of the springs in the study area are used for drinking water purposes. In addition, there are springs recommended for drinking water use in field studies. The chemical analysis results of the spring waters were examined for drinking water use. The standards of Turkey Regulation on Water Intended for Human Consumption (TS266, 2005; ITASHY, 2013), World Health Organization (WHO, 2011) and Environmental Protection Agency (EPA, 2009) were used to evaluate the use as drinking water.

Irrigation water quality: The methods (different diagrams and classifications) are used to investigate the suitability of irrigation water quality in the study area.

Domestic water quality: Water resources in the region are also used in domestic and animal husbandry. The use for these needs is mostly related to the amount of water. Quality assessments for drinking water purposes are also valid for this section.

Sustainability: Water is the most basic and indispensable need of life and individual. The maintenance of almost all vital activities depends on water. Water scarcity is becoming an increasingly prominent and pervasive problem; water quality is deteriorating rapidly in almost every country. Sustainability for water resources is the ability to meet people's water needs for many years. Sustainable water use can be achieved by developing and improving existing water resources. For this reason, methods such as SMS are needed.

Improvement of the springs: Efforts to improve springs are carried out in relation to quality and quantity. Improvement of springs in terms of quantity is possible with spring catchment studies. Some of the springs have catchment structure in the study area. In terms of quality, improvement is to control the

factors that adversely affect the quality in the current situation and to create protection areas for the protection of quality in the long term.

Development of the springs: Measures and proposal packages are created by conducting researches to increase the quantity and quality of springs with all the studies carried out.



Figure 2: Spring Management System (SMS) scheme

RESULT AND DISCUSSION

Geological and Hydrogeological Setting

Autochthonous, allochthonous and cover rocks are dominant in the study area. The autochthonous units have a narrow spread in the study area and the units are in the Middle Triassic-Middle Eocene age range. Generally, the autochthonous units are represented by carbonate sandstone, siltstone, claystone, clayey limestone, sandy clayey limestone, conglomerate, sandstone, shale, marl, spilitic pillow lava and flysch series. The allochthonous units spread to the southwest and southeast of the study area. These units are composed of sandstone, chert, limestone, dolomitic and cherty limestone, pelagic limestone and serpentine intercalated volcanite. Cover rocks and Plio-Quaternary terrestrial clastic rocks are showed a very widely spread in the study area. The cover rocks are formed from conglomerate, claystone, siltstone, limestone, marl and volcanic rocks (basalt, andesite and trachyte etc.). The Plio-Quaternary aged rocks are consisting of old slope debris and fluvial deposits, clay, silt, sand and gravel levels (Balci, 2011a:19, b; Ocal and Goktas 2011:7; Ocal, et al., 2011:4).

The lithological units were classified as porous aquifer, karstic aquifer, aquitard and aquifuge mediums in the study area. The Plio-Quaternary deposits consist of current sediments such as unconsolidated gravel, sand, silt, clay, and clayey gravel, sandy clay, and sandy clayey gravel levels. Due to the lithological units it contains, the unit has a porous structure and has a good aquifer feature. The porous aquifer is located in the Sandıklı and Şuhut plains

and numerous wells have been drilled on the aquifer. The units are important groundwater reservoirs and are the main drinking, domestic and irrigation water sources for the region. Carbonate rocks consisting of limestones in the study area were defined as karst aquifers. Limestone can contain groundwater with their secondary porosity that develops due to their melting gaps, faulted structure, intersecting cracks and discontinuities. Limestones were cut in the boreholes drilled in Akın village in the east of the study area. The yields of these wells vary between 15 and 30.27 l/s (Aksever et al., 2021:8). The semipermeable units are described as Aquitard Medium-I and the slightly permeable units and defined as Aquitard Medium-II. The units with semi-permeable properties consist of conglomerate, sandstone, shale and sandy, clayey limestone. Fractured and faulted structures developing in these units increase permeability. However, the shale and clayey layers within the unit form an impermeable level. The Aquitard Medium-II consists of trachy-andesites and basalts. Cooling cracks in andesite and basalt and secondary porosity due to tectonic events caused an increase in permeability. Some units in the study area do not contain groundwater due to their lithological properties. The units are impermeable, and they show the characteristics of an aquifuge medium (Figure 1).

Application of the spring management system (SMS) Utilization of springs

In this study, 19 springs were determined to represent the study area. 7 of these springs are located in the west of the study area, 1 of them is on the summit of Kumalar Mountain, which is separates Sandıklı from Suhut districts, and the remaining 11 springs are located in the villages of Suhut district. The springs are shows distribution in Sandıklı, Dutağacı, Bektas, Kargın, Akın, Başören, Kavaklı, Aydın, Yıprak, Balçıkhisar, Kayabelen, Bademli and Kulak locations in the study area. These springs are Esegöz, Dutağacı, Karalaröreni, Asmakaya, Çamurluk, Karakaya, Akın, Kumalardağı, Karlıbahçe, Kavaklı, Harman, Sanlı, Torun, Sıtma, Deveyatağı, Güldede, Dedecik, Bademli and Zafer (Figure 1). Asmakaya, Akın, Torun, Devetağı, Kumalardağı and Zafer springs have catchment structure. Local people benefit from these spring water for drinking water and domestic purposes (Table 1). Asmakaya spring is the only drinking water source of Bektaş village. Torun spring is also the only drinking water source of Yıprak village. Other resources are generally used in animal husbandry and irrigation. Almost all of the resources are used as uncontrolled.

Potential and amount of springs

In order to determine the potential of the springs in the study area, regular flow measurements were made every month periodically for 12 months (September 2017-September 2018). Asmakaya, Karalaröreni and Torun springs have high flow rates in the study area (Table 1). Flow measurements of the Karalaröreni spring could only be measured for 2 months. This spring has remained within the Bektaş Pond reservoir since November-2017 and no flow measurements could be made. Due to the different activities carried out by the local government around the Asmakaya spring, the spring discharge location was closed and flow measurements could only be made for 8 months. The flow rates of all spring waters decreased in the dry period and increased in the rainy period. This shows that the spring water discharges are directly related to the amount of rainfall. Despite the seasonal fluctuations in all of the springs, the same flow rates were measured in 2017 and 2018 in September, which is considered to be the beginning of the water year. This shows that the recharge conditions have not changed in 2017-2018 years.

The flow rates of the springs in the study area vary between 0.01 and 2.66 l/s. Dutağacı, Kavaklı Esegöz, Kumalardağı, Çamurluk and Dedecik springs discharge from the rocks containing high alkali such as dacite, rhyolite, andesite, basalt etc. The annual average discharges of springs were determined as 0.05, 0.02, 1.22, 0.09, 0.03 and 0.03 l/s, respectively. Karalaröreni, Asmakaya, Karlıbahçe, Harman and Sanlı springs discharge from volcanic rocks and clastic limestones. The average annual flow rates of springs are 0.16, 0.07 and 0.23 l/s respectively, except for Karalaröreni and Asmakaya springs. The Akın spring discharges from the limestones and the annual average flow rate of the spring is 0.30 l/s. Torun and Sıtma springs discharge from volcanic rocks and limestones. The annual average flow rates of the springs are 2.10 and 0.48 l/s. Güldede spring is discharged from a lithological unit which are contained sandstone, claystone, siltstone and limestone. Annual average flow of the spring 0.23 l/s. The Bademli spring discharges from the formation consisting of sandstone and serpentine, and its annual average flow rate was measured as 0.13 l/s. Karakaya and Zafer springs are discharged from the lithological units consisting of limestones, dolomitic limestone and cherty limestone levels and their annual average flow rates were determined as 0.20 and 0.18, respectively (Aksever, et al., 2021:8; Table 1).

Most of the spring waters are discharged in relation to volcanic units (tuff, andesite, dacite etc.), clastic sedimentary rocks (sandstone, conglomerate, siltstone, claystone) and limestones. Due to volcanic units and limestones have low primary porosity, groundwater movement is controlled only by fracture
distributions and fault lines. For this reason, discharge flows of springs are higher in regions where secondary porosity (faults, fractures, and fissures) develops due to tectonic events. The hydrogeological features of these units and the small feeding areas have caused the spring flow rates to be low.

No	Location	Spring	Average yield l/s	Time month	Spring location lithology	Usage purposes	
1	Sandıklı	Esegöz	1.22	12	high alkali such as dacite, rhyolite, andesite, basalt etc.	Irrigation, livestock	
2	Dutağacı	Dutağacı	0.05	12	high alkali such as dacite, rhyolite, andesite, basalt etc.	Irrigation, livestock	
3	Bektaş	Karalaröreni	2.5	2	volcanic rocks and limestones	Irrigation, livestock	
4	Bektaş	Asmakaya	2.66	8	volcanic rocks and limestones	Drinking, domestic	
5	Bektaş	Çamurluk	0.03	12	high alkali such as dacite, rhyolite, andesite, basalt etc.	Irrigation, livestock	
6	Kargın	Karakaya	0.20	12	limestones, dolomitic limestone and cherty limestone	Irrigation, livestock	
7	Akın	Akın	0.30	12	limestones, dolomitic limestone and cherty limestone	Drinking,	
8	Sandıklı- Şuhut	Kumalardağı	0.09	12	high alkali such as dacite, rhyolite, andesite, basalt etc.	Drinking, domestic	
9	Başören	Karlıbahçe	0.16	12	volcanic rocks and clastic limestones	Livestock	
10	Kavaklı	Kavaklı	0.02	12	high alkali such as dacite, rhyolite, andesite, basalt etc.	Livestock	
11	Aydın	Harman	0.07	12	volcanic rocks and clastic limestones	Irrigation, livestock	
12	Aydın	Sanlı	0.23	12	volcanic rocks and clastic limestones	Livestock	
13	Yıprak	Torun	2.10	12	volcanic rocks and limestones	Drinking	
14	Yıprak	Sıtma	0.48	12	volcanic rocks and clastic limestones	Livestock	
15	Balçıkhisar	Deveyatağı	0.15	12	high alkali such as dacite, rhyolite, andesite, basalt etc.	Drinking, domestic	
16	Balçıkhisar	Güldede	0.23	12	sandstone, claystone, siltstone and limestone.	Irrigation, livestock	
17	Kayabelen	Dedecik	0.03	12	high alkali such as dacite, rhyolite, andesite, basalt etc.	Irrigation, livestock	
18	Bademli	Bademli	0.13	12	sandstone and serpentine	Irrigation, livestock	
19	Kulak	Zafer	0.18	12	limestones, dolomitic limestone and cherty limestone	Drinking, domestic	

Table 1: Average yield and usage of springs in the study area

Hydrogeochemistry and quality of springs

Total 38 water samples were collected in the study area for two seasons (September 2017 and April 2018). Major ion $(Ca^{2+},Mg^{2+}, Na^{+}, K^{+} \text{ and } HCO_{3}^{-}, SO_{4}^{2-}, Cl^{-})$ and trace element (Al, As, B, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, U, Zn) analyzes of water samples were made.

Hydrogeochemical facies

The major ion contents of waters were $Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$ and HCO_{3}^{-} $>SO_4^2 > Cl^-$ (Table 2). The chemical composition of water samples is plotted in a Piper (1944) diagram (Figure 3). This diagram is widely used for the determination of hydrochemical facies according to the chemical properties of water samples. According to this diagram, the sum of alkaline earth elements is greater than the sum of alkaline elements $(Ca^{+2}+Mg^{2+}>Na^{+}+K^{+})$ in 52% of spring waters. Dutağacı (2), Akın (7), Kavaklı (10) and Dedecik (17) springs water samples are "non-carbonate waters with a hardness of more than 50%", Sanlı (12) spring water sample is "mixed water with none of the ions exceeding 50%" and all remaining springs water samples are "waters with a carbonate hardness of more than 50%". According to the Piper diagrams for September-2017 and April-2018 periods, the spring waters have same water type. The spring waters are divided into 5 different water types. Spring water samples 1 and 2 are "CaMgSO₄", 3, 5, 8, 9 and 15 samples have "CaMgHCO₃", 4, 6, 7, 13, 16, 18 and 19 samples have "CaHCO3", 11, 12 and 14 samples have "CaNaHCO₃", 10 and 17 samples have "CaNaSO₄" water type (Table 2, Figure 3).

The Gibbs (1970) diagram was also used for the hydrogeochemical facies evaluation of the spring waters. In this diagram, it was determined that all of the water samples were in the "water-rock interaction zone" in both seasons (Figure 4). The water types of the spring waters were controlled by water rock interaction.

Base ion exchange

The ion exchange between the groundwater and its host environment during residence or travel can be understood by studying the chloroalkaline indices (CAI-I and CAI-II) (Schoeller, 1965, 1967). The chloro-alkaline indices I and II were calculated from the following equations [1] and [2].

$$CAI-I = [Cl-(Na+K)]/Cl$$
[1]

$$CAI-II = [C1-(Na+K)]/(SO_4+HCO_3+CO_3+NO_3)$$
[2]

(All values are expressed in meq/l).

If CAI-I and CAI-II have both positive values, it implies that there is equilibrium between the two chloro-alkaline indices and the ion exchange process occurring between Mg^{2+} and Ca^{2+} in the host rock and Na^+ and K^+ in

water cationic exchange. But if both indices are negative, then there is disequilibrium between the indices and the ion exchange process is a reverse ion exchange (Schoeller, 1965). The CAI-I values were calculated between - 7.05 and -1.65 and the CAI-II values between -0.32 and -0.03 in the water samples taken from the spring waters in the study area in the April-2018 (Table 2). CAI values are negative in the samples and there is reverse ion exchange in the spring waters, it shows the exchange of Mg^{2+} and Ca^{2+} in water and Na^+ and K^+ ions in the aquifer.



Figure 3: Piper diagram



Figure 4: Gibbs diagram

]	Ion exchange			
No	Spring	Cations	Anions	Water Type	CAI-I	CAI-II
1	Esegöz	Ca2+>Mg2+>Na+>K+	SO42->HCO3->Cl-	CaMgSO ₄	-5.28	-0.09
2	Dutağacı	$Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$	SO42->HCO3->Cl-	$CaMgSO_4$	-4.32	-0.17
3	Karalaröreni	$Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$	HCO3 >SO42 >Cl	CaMgHCO ₃	-3.3	-0.14
4	Asmakaya	Ca2+>Mg2+>Na+>K+	HCO3 >Cl >SO42-	CaHCO ₃	-3.4	-0.1
5	Çamurluk	$Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$	HCO3 ⁻ >Cl ⁻ >SO4 ²⁻	CaMgHCO ₃	-4.13	-0.13
6	Karakaya	Ca2+>Na+>Mg2+>K+	HCO3 >SO42 ->Cl	CaHCO ₃	-1.74	-0.04
7	Akın	Ca2+>Mg2+>Na+>K+	HCO3 ⁻ >SO4 ²⁻ >Cl ⁻	CaHCO ₃	-4	-0.06
8	Kumalardağı	Ca2+>Mg2+>Na+>K+	HCO3 ^{->} SO4 ²⁻ >Cl ⁻	CaMgHCO ₃	-4.42	-0.18
9	Karlıbahçe	$Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$	HCO3 >SO42 ->Cl	CaMgHCO ₃	-6.64	-0.23
10	Kavaklı	$Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$	SO42->HCO3->Cl-	$CaNaSO_4$	-6.75	-0.32
11	Harman	Ca2+>Na+>Mg2+>K+	HCO3 >SO42 ->Cl	CaNaHCO ₃	-3.53	-0.21
12	Sanlı	Ca2+>Na+>Mg2+>K+	HCO3 >SO42 ->Cl	CaNaHCO ₃	-6.96	-0.3
13	Torun	$Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$	HCO3 >SO42 ->Cl	CaHCO ₃	-5.78	-0.26
14	Sıtma	$Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$	HCO3 >SO42 ->Cl	CaNaHCO ₃	-7.05	-0.26
15	Deveyatağı	$Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$	HCO3 >SO42 ->Cl	CaMgHCO ₃	-6.78	-0.2
16	Güldede	Ca2+>Mg2+>Na+>K+	HCO3 ^{->} SO4 ²⁻ >Cl ⁻	CaHCO ₃	-1.65	-0.03
17	Dedecik	$Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$	SO42->HCO3->Cl-	$CaNaSO_4$	-4.56	-0.3
18	Bademli	$Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$	HCO3 ⁻ >Cl>SO4 ²⁻	CaHCO ₃	-5.94	-0.13
19	Zafer	$Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$	HCO3 -> SO42 -> Cl-	CaHCO ₃	-2.19	-0.04

Physico-chemical parameters

The pH values of the samples were between 4.46-8.00 and 6.22-7.91 in the wet and dry season respectively, indicating alkaline nature of groundwater samples (Table 3). All pH values are within the permissible limit (6.5–8.5) of National Primary Drinking Water Regulations (EPA, 2009). The temperature,

total hardness and electrical conductivity (EC) values of the spring waters were not exceeds the WHO (2011), TS266 (2005) and EPA (2009) permissible limits. (Table 3).

Drinkability of the spring waters

The suitability of the sampled springs as drinking water supplies has been evaluated by comparing the chemical analyses against the regulation and limits outlined in TS266 (2005) and WHO (2011). All major physiochemical properties, anion, cation and nitrogenous compound concentrations were within the acceptable limits for drinking water (Table 3).

In this study, trace element contents of spring waters were evaluated for drinking water usage. Generally, trace element concentrations except for aluminum (Al), arsenic (As), iron (Fe) nickel (Ni) and manganese (Mn) do not exceed the limit values of WHO (2011), TS266 (2005) and EPA (2009). Al contents of the spring water samples range from 2 to 3428 μ g/l (wet season) and from 1 to 2971 μ g/l (dry season) (Table 3, Figure 5). In both periods, the highest Al contents were determined in the Dutağacı village. According to TS266 (2005) and EPA (2009) standards, the limit value of Al is 200 μ g/l. Al contents of Esegöz (1) and Dutağacı (2) springs exceeded the limit values of drinking water standards. Esegöz and Dutağacı springs are discharged from volcanic rocks. Al increases are related to the feldspar, kaolin and mica minerals which are found in volcanic origin units (Eriksson 1981).

Arsenic values of the spring waters varied from 5.5 to 42 μ g/l in the wet season. According to TS266 (2005), WHO (2011) and EPA (2009) drinking water standards, the limit value of As is 10 μ g/l. Except for the spring samples 1, 2, 8, 15, 16, 18 and 19, As in 63% of the waters exceeded the drinking water limit value (Table 3, Figure 5). As values range between 4.1 and 39.1 μ g/l in the dry season. The extreme values of As were determined in other spring waters except for 7 (1, 2, 6, 8, 13, 15, 19) samples (Table 3, Figure 5). In the study area, volcanic rocks crop out in large areas. The arsenic level in groundwater is 1-2 μ g/l on average, excluding volcanic rocks and places where sulfide minerals are stored (Sahinci 1991). Sediments which are derived from volcanic rocks generally have higher arsenic concentrations (Saldivar and Soto 2009). The increase of As concentration of water samples associated with arsenic containing cover rocks of volcanic origin.

The Fe concentration of spring waters varies between $<10-4138 \ \mu g/l$ and $<10-3575 \ \mu g/l$ in wet season and dry season, respectively (Table 3). The permissible limit is 300 $\mu g/l$ according to EPA (2009) standards, but it is 200 $\mu g/l$ according to Turkish drinking water standards (TS266, 2005). Fe

concentrations of Sanlı (12) (4138 μ g/l, 3575 μ g/l) and Dedecik (17) (3343 μ g/l, 3261) springs exceed the drinking water limit value in both periods (Table 3, Figure 5). The smell of sulfur is felt in the discharge area of the Sanlı spring and yellow sediments are also observed on the spring water. The increase in Fe content of spring waters is water-rock interaction.

In general, the Mn concentration of spring water samples varies between 0.33-1288.37 μ g/l in wet season and between 0.4-1326.28 μ g/l in dry season. According to WHO (2011), TS266 (2005) and EPA (2009) drinking water standards, the limit value of manganese is 400 μ g/l, 50 μ g/l and 50 μ g/l, respectively. High manganese concentrations were determined in Esegöz spring (312.6 μ g/l- wet season), Dutağacı (1288.37 μ g/l, 1326.28 μ g/l) and Sanlı (510.83 μ g/l, 500.17 μ g/l) springs in both periods (Table 3, Figure 5). The increases of Mn concentrations in these springs water are originated from geogenic origin.

The Ni concentrations of the spring waters are between <0.2-86.5 μ g/l and 0.2-81.2 μ g/l in both periods. The Ni contents of the spring waters are within the permissible limit of WHO (2011) with 70 μ g/l and TS266 (2005) with 20 μ g/l, except for Dutağacı spring. The Ni contents of the Dutağacı spring are 86.5 μ g/l and 81.2 μ g/l in wet and dry season, respectively. The increase of Ni in the spring is due to the rock-water interaction (Table 3, Figure 5).

Irrigation usability of springs

The springs in the study area for observed drinking water quality are suitable. Also, parameters of the spring waters were compared to relevant standards on the basis that they are agricultural use (covering irrigation and livestock requirements). These assessments were made according to the widely used US Salinity Laboratory (USSL) diagram (Richards 1954), Wilcox (1955) diagram and sodium adsorption ratio (SAR) value. Electrical conductivity (EC), percentage sodium (Na%), and SAR of spring waters have been used in these diagrams for evaluations.

The SAR values of the spring water samples varied between 0.06-0.89 and 0.05-0.84 in wet and dry season, respectively (Table 3). According to the SAR values, the spring waters are in the class of "very good irrigation water". The sodium percentage values of the spring water samples were changed between 3.55 and 32.40 in wet season and changed between 2.42 and 28.42 in dry season (Table 3). The highest SAR value belongs to the Kavaklı spring (10) in both periods and the spring is suitable for irrigation water usage.

In the US Salinity Laboratory (USSL) diagram, the spring waters fall in category C_1S_1 and C_2S_1 . According to the diagram, it is divided into classes

according to salinity and sodium values which are important for irrigation water. C_1S_1 , C2S1, C_3S_1 classes are used in all kinds of irrigation; while C_4S_1 , C_3S_2 classes can be used in some special conditions, C_4S_2 , C_4S_3 classes are defined as unusable in irrigation (Sahinci 1991). Samples 3, 4, 5, 8, 9, 11, 12, 13, 14, 15 (wet season) and 3, 5, 6, 8, 9, 12, 14, 15, 17 (dry season) are in the " C_1S_1 " class and these waters are "less salty, low sodium water can be used as irrigation water suitable for all kinds of agriculture, except for plants sensitive to sodium". Samples 1, 2, 6, 7, 10, 16, 17, 18, 19 (wet season) and 1, 2, 3, 4, 7, 10, 11, 13, 16, 18, 19 (dry season) are in the " C_2S_1 " class and these waters are "*medium salty, low sodium water can be used as -suitable irrigation water for plants that need moderate salt*" (Figure 6). According to Wilcox (1955) diagram, the spring waters in the study area were in "*excellent to good usable*" water class for irrigation in the both periods (Figure 7).

Parame	Uni						Dri	Drinking Water				
ters	ts	Wet Season (September 2017)				Dr	y Season	:	Standards			
					Stand				Stand		TS26	EPA
		Mini	Maxi	Mea	ard	Mini	Maxi	Mea	ard		6	(200
		mum	mum	n	Devia	mum	mum	n	Devia	WHO	(2005	9)
					tion				tion	(2011))	
Physical Parameter												
рН		4.46	8.00	6.94	0.89	6.22	7.91	7.31	0.52	6.5- 8.5	6.5- 9.5	6.5- 8.5
Temper ature (T)	°C	10.30	23.20	17.37	4.16	10.10	19.30	13.30	2.06			
Electric al Conduc tivity (EC)	μs/ cm	80.00	510.00	255.2 6	132.6 4	90.00	770.00	316.8 4	165.0 3		650- 2500	
Total Dissolve d Solids (TDS)	mg /l	40.00	250.00	124.7 4	64.50	40.00	380.00	156.3 2	80.91	600- 1000		500
Total Hardne ss (TH)	°F	3.19	28.64	11.58	7.69	2.63	27.44	11.80	7.42			
Chemical Parameters												
Na ⁺	mg /l	2.20	21.22	7.45	5.96	2.01	21.93	26.08	5.94	200	200	
K ⁺	mg /l	0.41	6.91	3.22	1.81	0.45	9.99	153.8 4	2.39	3000		
Mg ²⁺	mg /l	1.18	17.16	5.38	3.97	1.71	13.77	5.66	3.30			
Ca ²	mg /l	8.88	103.25	37.52	28.60	7.65	96.73	37.96	26.99			
Cl	mg /l	0.78	5.96	2.43	1.28	0.65	6.47	26.34	1.57	250	250	250
SO4 ²⁻	mg /l	1.65	207.01	36.96	60.57	1.70	214.59	71.74	62.52	500	250	250
HCO3 ²⁻	mg /l	17.60	317.20	109.7 6	96.64	10.89	272.32	104.3 4	89.52			
Irrigation	<u>Wat</u>	er Paran	<u>ieters</u>									
Na%	%	3.55	32.40	18.17	10.14	2.42	28.42	13.75	7.68			
Sodium		0.06	0.89	0.34	0.24	0.05	0.84	0.36	0.23			
Adsorpt												
ion												
Ratio (SAD)												
Nitragon Compounds												
ranogen	ma	ounus										10
NO ₃ -	/l	0.00	18.70	2.83	4.15	0.00	21.84	3.33	4.78	50	50	10
NO ₂ -	mg /l	0.00	0.01	0.00	0.00	0.00	0.08	0.00	0.02	3	0.5	1

Table 3: Results of analysis of springs in the study area

NH4 ⁺	mg /l	0.00	0.51	0.10	0.17	0.00	0.50	0.05	0.13	-	0.5	
Trace Elements (* exceeding the limit value)												
Al	μg/ l	2.00	3428.0 0*	207.3 7*	781.9 1	1.00	2971.0 0*	213.1 1*	712.1 9	-	200	50- 200
As	μg/ l	5.50	42.00*	13.70 *	8.53	4.10	39.10*	13.23 *	7.85	10	10	10
В	μg/ l	6.00	49.00	19.88	11.60	7.00	44.00	17	10.53	2400	1000	
Ba	μg/ l	1.44	114.80	22.76	28.42	1.49	99.48	22.25	24.25	700	-	2000
Cd	μg/ l	0.11	0.78	0.45	0.47	0.07	0.84	0.45	0.54	3	5	5
Cr	μg/ l	0.60	3.40	1.54	0.81	0.80	4.10	1.66	0.97	50	50	
Cu	μg/ l	0.20	70.70	4.46	16.06	0.20	73.10	4.78	16.57	2000	2000	1300
Fe	μg/ l	20.00	4138.0 0*	1537. 60*	2031. 38	30.00	3575.0 0*	1422. 20*	1825. 71	-	200	300
Hg	μg/ l	0.00	0.00	< 0.10	< 0.10	0.00	0.00	0.00	< 0.10	6	1	2
Mn	μg/ l	0.33	1288.3 7*	129.3 4	316.3 5	0.25	1326.2 8*	125.5 0	320.3 3	400	50	50
Ni	μg/ l	0.20	86.50*	20.67	30.70	0.20	81.20*	16.40	27.46	70	20	
Pb	μg/ l	0.20	0.20	0.20	<0.2	0.20	0.90	0.53	0.35	10	25	15
Se	μg/ l	0.50	10.40	5.45	7.00	0.60	8.70	4.65	5.73	40	10	50
U	μg/ l	0.04	9.96	2.22	2.76	0.03	10.62	2.52	3.33	30	-	30
Zn	μg/ l	0.90	180.50	18.21	41.41	6.20	205.50	55.96	42.81	-	-	5000



Figure 5: Trace element distribution maps of the study area (Wet Season-September 2017)



Figure 6: US Salinity Laboratory (USSL) diagram



Figure 7: Wilcox diagram

Pollution sources

The determination of the pollution parameters of the spring waters is very important in terms of its domestic usage quality. For this reason, the effects of

existing solid-liquid wastes, agricultural and heavy metal pollutions on springs in the study area were investigated in detail. So, analysis of nitrogen compounds $(NO_3^-, NO_2^- \text{ and } NH_4^+)$ were made to determine agricultural effects. In addition, trace elements analyses were also evaluated (Table 3).

Impact of solid and liquid wastes on springs: The chemical and trace element analysis results of the samples taken from the water springs in the study area were evaluated in the above sections. In these evaluations, the negative effects of anthropogenic factors such as domestic wastewater, septic tank, sewage and animal shelters (barn, poultry, etc.) leachate, solid-liquid wastes from industrial and mines were not detected on the spring waters which are located near the settlement areas. Other springs which are far from the settlement areas are discharged at high altitudes, so it is not possible to have the effect of solid and liquid waste.

Impact of agricultural pollution on springs: The people in the study area live on agriculture and animal husbandry activities. Irrigated farming activities are carried out in 90% of the region. Crops such as potatoes, sugar beet, corn, barley and wheat are grown in the region that require excessive irrigation. Nitrogen derivatives are one of the most widespread groundwater contaminants in the agricultural areas. The nitrate, nitrite and ammonium concentrations of the spring waters were between 0.00-18.70 mg/l, 0.00-0.01mg/l and 0.00-0.51 mg/l in the wet season, respectively. In the dry season, these values were varied between 0.00-21.84 mg/l, 0.00 mg/l and 0.00-0.50 mg/l, respectively (Table 3). The maximum permissible level of nitrate is given to be 50 mg/l in TS266 (2005) and WHO (2011) standards. However, if nitrate concentration is over 10 mg/l, it is indicated that groundwater is affected by anthropogenic factors. The highest nitrate contents were detected in the Bademli spring in both periods. This spring is close to the alluvial environment where agricultural activities are intense. The nitrate increase observed in this spring is related to agricultural activities. The water springs in the region are generally far from agricultural areas. For this reason, nitrogen derivatives values indicating agricultural pollution are low.

In this study, a pollution map was prepared by showing all analysis results of water springs together (Figure 8). It has been determined that only Al, As, Mn, Fe and Ni elements exceed the limit values in some of the spring waters in the study area. However, it is seen that the As content is above the limit values in most of the springs. When the pollutant sources in the study area were examined, it was determined that the heavy metal pollution detected in the water springs was not caused by anthropogenic factors. The high heavy metal contents are due to the rock-water interaction, that is, they are of geogenic

origin. The heavy metal contents of the Kumalardağı (8), Devetağı (15), Güldede (16), Bademli (18), Zafer (19) springs in wet season with Esegöz (1), Karakaya (6), Kumalardağı (8), Torun (13), Devetağı (15), Zafer (19) springs in dry season were determined suitable for the drinking water standards.



Figure 8: Pollution distribution map of the study area

-Sustainability of springs in the study area Improvement of the springs

Aquifers and springs which drinking water is supplied should be protected in terms of quality and quantity, and protection areas should be determined in order to prevent their pollution and deterioration. For this reason, regulations have been established for the determination of protected areas in our country. Quality protection of water resources is even more important, especially in groundwater, which is the main supplier for drinking water (Foster et al., 2002:9). Spring protection zones are sub-areas of groundwater and surface water basins where each spring or spring system is likely to have adverse effects from human activities that supply water to the springs. Protected areas for groundwater resources should be defined according to the geological and hydrogeological characteristics of the basin and water consumption types (Pochon et al., 2008:1269).

In our country, protection areas have been determined in order to protect the current situation of aquifers and resources from which drinking water is supplied, in terms of quality and quantity, and to prevent pollution and deterioration. In the Official Gazette dated 10 October 2012 and numbered 28437 described three protection zones to protect the quality and capacity of the drinking groundwater resources. These are: (1) The absolute protection zone (2) The 1st degree protection zone, (3) The 2nd degree protection zone.

(1) The absolute protection zone comprises the spring areas. An absolute protection zone is declared for the sources with an annual average flow rate of less than 50 l/s. Also, in order to protect wells, springs, catchments and similar structures which are used for drinking water supply, no structures or activities are allowed within 50 meters in the absolute protection area.

(2) The 1st degree protection zone is the area between the limit of the distance equal to the distance that the water infiltrating the aquifer from the surface of the recharge area must travel in 50 (fifty) days until it reaches the groundwater operation facility and the limit of the absolute protection zone. Also, various pollutants such as heavy metals and toxic substances, radioactive substances, chemicals used in agricultural struggle and protection, bituminous substances and detergents do not generally lose their harmful effects even if they remain underground for a very long time. In addition to the general protection measures, special conditions are determined with the studies to be carried out in the regions where such pollutants are present.

(3) The 2nd degree protection zone is determined starting from the outer boundary of the first degree protection area, taking into account the boundary of the source's recharge area and the boundary of the aquifer. The second degree protection zone can be extended up to the surface water drainage area at most. In case of recharge from the side basin, the aquifer providing the recharge can be included in the protection zone.

Some of the water springs in the study area are located on the mountain slopes and some of them are located in and around the settlement areas. Considering the residents that live in the spring catchment, protection areas at different protection levels were determined around the spring. These protection areas were created by considering the protection, potential, quality and usage areas of the springs and hydrogeological characteristics of the region. These protection areas were separated as absolute, 1st degree and 2nd degree and protected zones were mapped (Figure 9). The absolute protection zone comprises the all springs in the study area. The first degree protection zone was determined according to the spread and orientation of the developed crack systems and aquifer units within the recharge area of the springs of the study area. While determining this limit, the distances to the settlement centers were taken into consideration. The second degree protection zone was created by taking into account the recharge area boundary of the spring and the drainage areas.



Figure 9: Protection zones map of the study area

Development of the springs

Although there are many springs in the study area, most of them are used for local and limited purposes. These restrictions are directly related to the low flow rates of the springs. When all the researches carried out in the study are evaluated together, it is seen that there are important problems in terms of quantity and quality of spring waters. The most important springs in the study area are Asmakaya and Torun springs which are used for drinking water purposes. Asmakaya spring is used as a drinking water source in the Bektaş village and Torun spring is used as a drinking water source in the Yıprak village. However, it is observed that As contents of these spring waters exceeded the drinking water limit value (10 μ g/l) (Table 3). As contents of the Asmakaya spring was measured as 17.3 μ g/l in September-2017 and 16.6 μ g/l in April-2018. In the Torun spring, it is 10.2 μ g/l in September -2017 and 9.7 μ g/l in April-2018.

In the April samples representing the wet season, Asmakaya and Torun springs have a lower As content. The closest resource to the Bektaş village that can be used in drinking water quality is the Kumalardağı spring, which discharges from the high elevations. The results of the physical and chemical analysis of the spring show that it is suitable for drinking water usage. Also, its flow rate is higher than other springs in the region. As the Kumalardağı spring water can be used as a drinking water source of Bektaş village alone, it can also be recommended to be used by mixing it with the Asmakaya spring water. In case of mixing the spring waters, the As content of the mixing water will fall below the limit value. In this regard, it is necessary to establish planning and especially monitoring programs for the As contents of these waters.

In the Torun spring, it was determined that the As content decreased due to the increase in the amount of water in wet period and, accordingly, the decrease in the contact time of the spring waters with the volcanic rocks. In this region, there are many natural spring discharges with small flow and drinking water quality. If these spring waters are mixed with Torun spring water, it can reduce the arsenic content. In particular, it is necessary to investigate the springs that can be found in the outside of the study area and do not interact with volcanic rocks.

The usage of springs having low flow rates and high As contents should not be considered for drinking water purposes. In addition, Al, Fe, Mn and Ni contents of some springs in the study area were found to be above the limit values. Kumalardağı and Deveyatağı springs can be considered as drinking water resources in terms of quality and quantity in the study area. Although it is known by the local people that many springs are not of drinking water quality, the suitability of water resources for drinking water in some settlements is not known. For this reason, it is important for health to inform about the drinking properties around the springs.

CONCLUSION

Water resources management can be defined as the activity of planning, developing, distributing and managing water resources to ensure optimum and sustainable use. Natural springs are important water resources that are used extensively for different purposes in our country and in the world. There is no

planning, development and management researches on the usage of low-flow natural springs, especially in rural areas. However, in many rural areas, these resources are used intensively in areas such as drinking, irrigation and animal husbandry. The fact that spring waters have not been investigated in terms of quantity and quality prevents optimum utilization of these springs. Today, the reduction in the amount of water experienced in relation to global climate change and the pollution of water resources due to different factors require planning for the use of all water resources.

In this study, spring management system (SMS) researches that should be established for all springs were applied in the selected region. There are 19 natural springs in the selected region and these springs are used by the local people. The SMS has been established in three stages as usage, quality and sustainability. To determine the potential of the springs in the study area, regular flow measurements were made every month periodically for 12 months (September 2017-September 2018). The flow rates of the springs in the study area vary between 0.01 and 2.66 l/s. Most of the spring waters are discharged in relation to volcanic units (tuff, andesite, dacite etc.), clastic sedimentary rocks (sandstone, conglomerate, siltstone, claystone) and limestones. Depending on the lithological units from which the springs are recharged, changes are observed in the flow rates of the springs.

According to the major ion contents of the spring waters, 5 different hydrochemical facies such as CaMgSO₄, CaMgHCO₃, CaHCO₃, CaNaHCO₃ and CaNaSO₄. These hydrochemical facies of the spring waters is controlled by rock water interaction. Considering the discharge locations, flow rates and hydrogeochemical characteristics of the spring waters, protection areas for the springs were determined and usage recommendations were created. The physical properties, major ions and nitrogen compounds of all water samples were within the WHO (2011) and TS266 (2005) limit values for drinking water. However, As, Al, Fe, Mn and Ni contents of some springs in the study area were found to be above the limit values. In the study area, the usage of springs having low flow rates and high As contents should not be considered for drinking water purposes.

Asmakaya and Torun springs were used for drinking water purposes in the Bektaş and Yıprak villages, respectively. However, it is observed that As contents of these spring waters exceeded the drinking water limit value (10 μ g/l). As contents of the Asmakaya spring was measured as 17.3 μ g/l in September-2017 and 16.6 μ g/l in April-2018. In the Torun spring, it is 10.2 μ g/l in September-2017 and 9.7 μ g/l in April-2018. As the Kumalardağı spring water

can be used as a drinking water source of Bektaş village alone, it can also be recommended to be used by mixing it with the Asmakaya spring water. In this way, the As content of the water used as drinking water will be reduced. As content of Torun spring can be reduced by mixing with spring waters in its close vicinity. It is necessary to establish planning and especially monitoring programs for the As contents of these springs. It was determined that only Kumalardağı and Deveyatağı springs were suitable for use as drinking water resources in terms of quality and quantity in the study area. There are no plans for the use of these spring waters as drinking water.

In this study, spring management system was created for the study area. The situation were evaluated by taking into account the current uses in the region, the needs of the region, economic conditions, flow rate and chemical properties of the water. According to the results of the SMS, suggestions were made for the optimum use of spring waters. The research and evaluations presented in this study are an important example in terms of being usable in many international regions. According to the SMS; to prevent the quality degradation and pollution of the spring waters must take main measures as restriction or prevention of the activities which endanger the groundwater quality, the elimination of the pollution sources, and establishment of the protection zones based on protection of the entire aquifer or groundwater system. Also, must make the educational for increasing of the public knowledge and awareness in properties and vulnerability of the drinking water environment.

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Chapter 9

Components and Properties of Dye Sensitive Solar Cells

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ABSTRACT

In parallel with the increasing energy demand and consumption of the world, the need for energy is constantly increasing. Most of the energy used today comes from fossil fuels such as coal, oil, and natural gas. Considering that fossil fuels will run out soon, the search for an endless energy source has led to renewable energy sources. The interest in solar energy, which is one of the renewable energy sources, is increasing day by day. Solar energy, besides being a new and renewable energy source; due to its advantages such as the absence of environmentally polluting waste, which is an important problem for humanity, its local application, and the fact that it does not require complex technology, it has been a subject that has been studied extensively in recent years. Dye-sensitized solar cells (DSSC), which are characterized as costeffective solar cell systems that can be an alternative by utilizing solar energy, are third-generation photovoltaic solar cells. DSSC draws attention in terms of its cost-effectiveness, relatively high efficiency, and less harm to the environment. Another point that makes DSCC attractive is its ease of production and low-cost infrastructure systems. Thanks to this attractive feature, intensive studies are carried out on DSSC. Having a sandwich (layered) structure, DSSC basically consists of a photoanode (usually TiO₂ or ZnO semiconductors), sensitizing dye, electrolyte, and counter electrode. In this section, DSSC components and their properties, working principles, and parameters affecting cell performance are discussed.

Keywords: DSSC, electrolyte, anode, cathode, dye, solar cell,

INTRODUCTION

With the increase in the human population, the need for energy is increasing day by day. It is a well-known fact that fossil fuels will run out in the near future. Thus, this energy problem is to direct consumers toward renewable energy sources such as wind, biomass, and solar energy. Among these energy sources, solar energy has advantages such as being clean, abundant, cheap, and clean. Photovoltaic technologies, including solar cells, absorb solar energy and convert it into electrical energy (Ruba et al., 2021:1894). Solar cell models can generally be divided into three generations. First-generation batteries are crystalline-silicon-based batteries. In most of the panels used in the market, Si is used as the material. Laboratory efficiencies are between 14-24%. Secondgeneration batteries are based on amorf-silicon (α -Si), copper indium gallium diselenide (CIGS), and cadmium tellurium (CdTe). Although these thin-film technology-based batteries have lower efficiency than c-Si batteries, they can be used with various substrates. On the other hand, next-generation solar cells consist of binary or multi-joint structures. Although photovoltaic material production with an efficiency of up to 40% has been achieved with this type of battery in the laboratory environment, these cells are very costly due to their multi-stage systems. The third generation of solar cells aims to reduce costs and increase efficiency because first-generation solar cells are costly; secondgeneration solar cells are low efficiency (Khalid et al., 2021:3; Md Yunus et al., 2015:1080; Luceño-Sánchez et al. 2019:21; Pastuszak and Wegierek, 2022:23). Dye-sensitized solar cell (DSSC) is an environmentally friendly technology that can be used to generate electricity in a wide variety of light conditions indoors and outdoors (Baby et al. 2022:371; Cavallo et al. 2017:2; Ung et al. 2017:1). The efficiency of this first type of DSSC containing ruthenium complex as a dye molecule was measured as 11.18% (Tomar et al. 2020:60, Pandey et al. 2019:381). The advantages of DSSCs over other designs are that dye molecules can be obtained cheaply, easily purified, and therefore produced at low cost (Sharma et al. 2018:22). The concept of DSSC was first successfully introduced by Gratzel and O'Regan in 1991. In 1873, Vogel developed the idea of using silver halide emulsion as a red light-sensitizing dye. While photoelectric susceptibility was reported in 1887, theoretical models were presented for ntype zinc oxide and p-type perylene, which provide dye-sensitive photocurrent, in 1968. In 1971, the investigation of photo-electrochemical reactions of species (chlorophyll) that can be obtained naturally from plants was carried out with ZnO monocrystals. In 1976, photocurrent measurements of photocells containing dye-sensitive liquid electrolytes and different other electrolytes were made. The study carried out in 1984 was carried out with $Ru(bipyridine)_3^{+2}$

shaped chromophores and SrTiO₃ and TiO₂ semiconductors. By using polycrystalline TiO₂ film with a large surface area in 1988, spectral sensitivity was obtained thanks to the absorption of the dye at the maximum wavelength in the visible region, and the conversion efficiency of the excitation photon was found to be 73% (Sharma et al. 2018:22). A photovoltaic cell (PC) can be recognized as a device that converts incoming light into electrical energy (Fig. 1) (Calandra et al. 2010:1). High-efficiency photovoltaic conversions make DSSC technology an appealing attempt for large-scale solar energy conversion compared to other forms of solar cells (Chang et al. 2020:2; Andualem and Demiss, 2018:146).



Figure 1: Basic illustration of a photovoltaic cell (PC) (https://byjus.com/physics/solar-energy-and-photovoltaic-cell/)

The DSSC is a third-generation photovoltaic solar cell that converts visible light into electrical energy (Eze et al. 2021:457). In a conventional DSSC, light is absorbed by a sensitizer fixed to the surface of a wide bandgap n-type semiconductor (Fig. 2). Frequently this hybrid device is referred to as the Graatzel cell (Joseph et al. 2017:80).



Figure 2: Schematic sketch of a DSSC (Lee et al, 2017:268).

1.1 Structure of DSSC

The structural elements of DSSCs are given below (Shalini et al. 2015:1307; Ramasamy et al. 2022:2).

(1) Mechanical structure coated with transparent conductive oxide (fluorine doped tin oxide, FTO),

(2) Nanoporous metal-oxide use d (TiO₂) semiconductor film,

(3) Paint acting as a sensitizer absorbed on the semiconductor,

(4) Redox electrolyte (I^-/I_3) ,

(5) Platinum-coated counter electrode, which allows electrons to pass toward the redox electrolyte. However, some parts of these solar cells can be changed depending on the situation; examples can be given such as dye (different vegetables and fruits), different photoanodes (ZnO, Nb₂O₅, SnO₂), glass (FTO, ITO). The typical DSSC arrangement can combine liquid and solid phases. The DSSC consists of a transparent conductive glass electrode, defined as the anode, that allows light to pass through the cell. Clear glasses have the advantages of availability, affordability, and great transparency in the visible spectrum. For this reason, they are preferred as electrode substrates (Adedokun et al. 2016:35; Chou et al. 2010:1).

1.2 Working Principle of DSSC

The working principle of DSSC is similar to photosynthesis in nature. The development of this natural process is as follows; dye molecules (sensitizers) absorb light from chlorophyll in plants, causing the formation of positive and negative charge carriers. For this reason, this system can be described as artificial photosynthesis. In DSSC, the absorption of the light photon takes place in the dye molecule layer. The fundamental order of incidents in a DSSC is as follows:

Anode: $S + hv \rightarrow S^*$ absorption $S^* \rightarrow S^+ + e^-(TiO_2)$ electron injection $2S^+ + 3I^- \rightarrow 2S + I_3^-$ regeneration Cathode: $I_3^- + 2e^-(Pt) \rightarrow 3I^-$ Cell: $e^-(Pt) + hv \rightarrow e^-(TiO_2)$ (Karthick et al. 2019:14)



Figure 3: DSSC working principles (Highfield, 2015:6746)

By absorbing the light energy, a light-induced electron from the induced state of the dye (Dye^{*}) is injected into the transmission band of TiO_2 . It is gathered on a transparent conductive FTO glass substrate layer. It then passes entirely an exterior circuit, after which the electron is re-presented to the DSSC at the Pt counter electrode, where I₃ is reduced to I (Fig.2 and 3) (Lee et al, 2017:268). All these steps have a certain level of effectiveness, and with the combination of these steps, the net photovoltaic efficiency of solar cells

emerges. In short, the formation of high photocurrent and potential difference is the main goal of a DSSC.

1.3 Components and properties of DSSC

To enhance DSSC performance and reduce production costs, it is necessary to rise cell efficiency, increase cell durability and reduce manufacture costs. A DSSC consists of a broadband-gap nanocrystalline semiconductor electrode, an absorbing dye, an electrolyte (Γ/I_3 ⁻) containing redox-double iodide/triiodide ions, and a counter electrode. Photoanode are used to improve yielding TiO₂ nanocrystalline films. Photosensitive organic dyes are intended to obtain high solar-to-electricity conversion efficiencies. For electrolyte preparation, organic materials of polymer gelators and ionic liquids are used. For counter-electrode preparation, organic materials of conductive polymers and carbon materials are used (Lee et al, 2017:268). The main components (working electrode, counter electrode, electrolyte, dye) features of DSSC are given under separate headings below (Guo et al. 2015:2).

Working Electrode (WE): The photo-electrode in DSSC forms from nanostructured semiconductor materials (Moharam et al. 2019:8). Working electrodes (WE), a thin layer of oxide semiconductor material on a transparent conductive glass plate collected and prepared. Semiconductor layers absorb only a small part of the light in the UV zone. The film is soaked in the dye solution. The electrode has a highly porous structure and a large surface area (Sharma et al. 2018:22). The properties required for an ideal photoanode are fast/efficient charge transport and low electron recombination behavior, respectively. However, TiO₂ is unfavorable in photoanode applications such as high electron-hole pair recombination and relatively low electron transport. Due to its features, it is considered an obstacle to increasing device performance. In order to eliminate these unfavorable conditions, various modification processes have been applied to the TiO₂ photoanode. Some of these works' application of different annealing temperatures, testing of different production methods, and additives with different properties from each other. material modification processes. Among these processes, the doping process is a widely used option. In the literature studies, it was determined that the charge-carrying capacity of the photoanode increased, and the recombination rate decreased with the contribution made to the TiO₂ photoanode (Karthick et al. 2019:4).

Counter Electrode (CE): One of the important components of DSSC is the counter electrode (Karthick et al. 2019:5). This material has basic properties

such as low charge transfer resistance and high changeover current densities. An efficient CE should have both high electrical conductivity and electrocatalytic activity (Fig. 4).



Figure 4: Shape of materials that can be used as catalysts for DSSC (Calandra et al. 2010:3).

As shown in Fig. 5, it is possible to classify counter electrodes in three categories, namely carbon-based, platinum-based, and other material (metal sulfides)-based (Richhariya et al. 2023:61).



Figure 5: Overview of different counter electrode materials for DSSCs (Richhariya et al. 2023:62)

The counter electrode is basically a catalyst that provides the I^{-}/I_{3}^{-} redox cycle and electron flow. Generally, Pt-nano-particle coated FTO glass coatings are obtained by thermal decomposition sputtering or chemical reduction processes and used as counter electrodes in dye-sensitized solar cells (DSSC) (Yahia et al. 2013:1). In general, Pt has high electrical conductivity and excellent electrocatalytic activity. In addition, Pt has excellent electrochemical stability and is therefore used as an excellent CE material in DSSCs. To date, numerous materials (carbon materials, conductive polymers, and inorganic materials) have been used as alternative CE materials to Pt. Compared with other traditional carbon materials, graphene, a single-layer structure of twodimensional graphite, has matchless properties such as strong mechanical strength, high electrical and thermal conductivity, large surface area, and high optical transmittance (Liu and Zhao, 2022:12-13) Materials such as carbon, graphite, graphene, and conductive allotropes of carbon nanotubes, as well as amorphous and diamond-like, and graphite-like carbon composite films, have continued to be investigated. Composite or functional materials have been used to develop high-performance catalysts (Lu et al. 2016: 3-7).

Electrolyte: Electrolytes provide ionic conductivity between electrodes in the electrochemical cell. The space between the electrodes is filled with an electrolyte solution that provides charge conduction in a redox pair. While Br^{-}/Br_{2} , SCN, /SCN₂, and SeCN–/SeCN₂ are preferred as bipyridine cobalt electrolytes, an Γ/I_{3} redox couple is commonly used because of its high volatility and low stability and corrosion (Sönmezoğlu et al. 2012:2). The main reason why this redox couple is mostly used is based on the fast functioning of its kinetics within the DSSC mechanism.



Figure 6: Device structure of a DSSC using iodine electrolyte (I⁻/I₃⁻) redox couple (Iftikhar et al. 2019:3)

Fig. 6 shows the order of operation of the DSSC, which is the lowest empty molecular orbital of the molecule Lu et al. 2016: 3-7. Therefore, ideal for the DSSC electrolyte of the redox couple listed features. These features are (Wolfbauer et al. 2001:95; Su'ait et al. 2015:457; Nath and Lee et al. 2019:55-60);

- 1. To maximize the cell voltage, the dye must have a thermodynamic (energetic) redox potential favorable to the redox potential.
- 2. There should be no significant spectral features in the visible region to prevent absorption of incident light in the electrolyte.
- 3. Both the reduced and oxidized forms of the couple must have high stability to ensure a long working life.
- 4. The solvent must be of high solubility to ensure a high charge carrier concentration in the electrolyte.
- 5. Must be chemically inert to all other components in the DSSC.
- 6. It must be a highly reversible pair to facilitate fast electron transfer kinetics.
- 7. For effective mass transport, the solvent used must have high diffusion coefficients.

Photosensitize/Dye: Dye has important roles in absorbing solar energy and transforming it into electrical energy. For the success of DSSC, photoactive

dyes are very critical in terms of both the excitation mechanism and the electron injection mechanism and are the leading materials that directly affect the power conversion efficiency. Transition coordination complexes are preferred as charge transfer sensitizers. These have higher efficiency, chemical stability, suitable photo-electrochemical features, etc. It is one of the most effective sensitizers. However, Ru complexes include heavy metals that are detrimental to the environment, as well as their complex and costly synthesis. Also, Ru complexes tend to degrade in the existence of water. Ru complexes have wide visible light-gathering skills (Yam et at. 2020:528-536). The sensitizer absorbs the sun's rays, thereby increasing the conductivity of the cell. A sensitizer must have carboxyl and hydroxyl groups, which are necessary for good bonding with the semiconductor. The photosensitizer (dye) plays an important role in absorbing solar energy and converting it into electrical energy. The dye is chemically bonded to the TiO₂ surface (semiconductor). In a DSSC, the dye should have certain properties (Kumara et al. 2017:307; Richhariya et al. 2017:709-710). These.

- Stability: corresponding to almost 20 years of exposure to natural light.
- Absorption: An ideal sensitized photovoltaic cell should absorb all light above the boundary wavelength of 900 nm, which is equivalent to a semiconductor with a band gap of 1.4 eV (Al-Alwani et al. 2016:200).
- Interface Properties: It must have strong adsorption on the semiconductor surface.
- Energy Information: The excitation energy level should coincide with or be very close to the lower energy level of the conduction band of the oxide. In this way, energy loss during electron donation is minimized (Prakash et al. 2022:3).

1.4 Performance of cell

The solar cell has important parameters during its operation. Thus, performance of DSSCs; it can be characterized by four photovoltaics: opencircuit voltage (V_{oc}), short-circuit current or density (J_{sc}), fill factor (ff), and energy conversion efficiency (η). A typical J-V curve is shown in Fig. 7. The ratio of maximum power output ($J_{mp} \times V_{mp}$) to manufacture ($V_{OC} \times J_{SC}$) denotes FF (Sharma et al. 2018:22).

$$FF = \frac{Area A}{Area B} = \frac{J_{mp} \times V_{mp}}{J_{SC} \times V_{OC}}$$
Eq. 1

 η increases with the decrease in JSC value and the increase in the V_{oc}, FF, and molar coefficient of the paint, respectively (Eq. 2) (Sharma et al. 2018:22). Jsc is the short-circuit photocurrent density, Voc is the open-circuit potential difference, FF is the cell's filling factor and P_{in} is the incident light intensity (Eq. 1,2).

The filling factor is between 0 and 1 and is associated with the maximum power produced by the solar cell per unit area.

$$\eta (\%) = \frac{J_{\rm SC} \times V_{\rm OC} \times \rm FF}{P_{in}}$$
 Eq. 2

Isc depends on different variables.

- solar cell area,

- Incoming light spectrum,

- Number of photons,

- the possibility of DSSC to collect the light,
- Optical feature,
- Material properties and working conditions,
- Surface passivation,
- Diffusion length.

Among them, two of the most critical parameters are surface passivation and diffusion length (Halme et al. 2010:2023-230).



Figure 7: I–V curve to evaluate the cell's performance (Sharma et al. 2018:22)

Another definition of efficiency is called external quantum efficiency. This efficiency is calculated as the ratio of photocurrent density to photon flux under monochromatic light (IPCE = incident photon to current conversion efficiency) (Eq.3) (Behrouznejad et al. 2023:1).

$$IPCE = \frac{J_{sc}(\lambda)}{e\Phi(\lambda)}$$
Eq. 3

2. RESULTS AND DISCUSSION

As a result, while the world's energy from fossil sources is decreasing over time, the rate of consumption is increasing. For this, new environmentally friendly green renewable energy sources are needed for our planet. Among the different renewable green energy sources, solar energy is recognized as one of the excellent energy sources. Among them, DSSCs draw attention with their low production costs, ease of manufacture, purification easily, lighter weight, and environmentally friendly and recyclable advantages. Although they seem to have low efficiency compared to other cells, they provide relatively high efficiency when their cheap cost is taken into account. Therefore, solar cell types have aroused great interest in academic and industrial fields. Moreover, DSSCs are considered to have shown the highest energy conversion efficiency ever and are one of the most promising technologies in the near future.

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Chapter 10

Dust Effect on PV Modules: Its Cleaning Methods

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ABSTRACT

The utilization of solar energy through photovoltaic (PV) panels has gained significant momentum globally as an alternative energy option. The optimum installation of PV panels, radiation, latitude, longitude, tilt angle, and direction depend on the geographical location that determines the features. However, the PV panel's power productivity, conversion efficiency, and energy cost are affected by environmental factors such as dust, hail, humidity, and temperature and installation element parameters such as inclination angle, installation area, and altitude. Dust is one of the main parameters affecting PV panel performance, efficiency, and profitability. In this chapter, we have discussed in detail the dust effects on PV panels and dust cleaning methods. The effect of dust on the performance of PV panels and the technical and economic evaluation of dust removal methods are aimed. As a result of the study, it was stated that there might be a performance reduction of up to 80% with the effect of dust on the power output of PV panels. Also, the choice of dust cleaning may vary depending on many parameters. The negative effect of dust on PV panels and the importance of performance improvement by using cleaning methods are emphasized.

Keywords: Dust accumulation, Environmental factors, PV power generation, PV module, cleaning methods.

INTRODUCTION

Rapid population growth increases global energy demand and consumption significantly yearly. Most energy is derived from fossil sources such as natural gas, coal, and oil. The combustions of fossil fuels emit greenhouse gases such as CO₂ and CH₄. The resulting greenhouse gases, global warming, and the loss of functionality of the ozone layer cause conditions that negatively affect human, living, and plant life (Al-Maamary et al., 2017; Rabaia et al., 2021). Global warming and the challenge of decreasing reserves of fossil fuels have prompted countries to turn to environmentally friendly, renewable energy sources. Sustainable energy produced by photovoltaic (PV) panels is a technology that offers a solution to the ever-increasing energy demand as an acceptable technology while reducing toxic gases and the associated environmental repercussions (Chanchangi et al., 2020). Figure 1 shows an estimated 175 gigawatts (GW) increase in solar PV installation in 2021, growing global PV cumulative capacity to 942 GW (REN21, 2022).



Figure 1: PV capacity worldwide and annual additions, 2011-2021 (REN21, 2022)

With increased installed solar energy capacity, investigations in this field have attracted more interest. Many studies are conducted in PV facilities on dust accumulation and dust accumulation cleaning techniques, which are environmental issues that significantly impact module power outputs (Figure 2).



Figure 2: Web of Science statistics (2008-2022), with the keyword "dust and photovoltaic" investigated

Dust accumulation is a vital parameter in the production of PV power modules. Dust accumulation follows temperature and solar radiation. This dust effect varies according to the situation of the region and its geographical location (John et al., 2015; Kazmerski et al., 2016). Dust is a solid substance with a very tiny structure. The rate of dust adherence on a solar panel's surface is connected to dust attributes such as chemical composition, shape, size, and weight, as well as environment-related factors such as dust storms, humidity, contamination, the temperature outside, breeze speed, direction, and PV module installation. Environmental activities such as vehicle mobility, human activities, and volcanic eruptions can also enhance dust accumulation (Mani and Pillai, 2010; Zaihidee et al., 2016). The loss of modules' power production may be effectively handled by regularly cleaning the modules (Tylim, 2013). Various procedures and technologies have already been utilized to purify solar PV mechanisms and not reduce PV power output. (DGS, 2012).

In this chapter, the impact of dust on PV panel power output and different cleaning methods are investigated and presented. The chapter consists of five sections, including this section, which emphasizes the importance of solar energy. Section 2 deals with PV module fundamentals and factors that affect the performance of PV modules. In Section 3, the impact of dust on PV power generation is discussed in detail by reviewing literature studies. Section 4 highlights the comparison between PV panel dust cleaning methods. Section 5 presents conclusions.

PHOTOVOLTAIC MODULE FUNDAMENTALS AND FACTORS AFFECTING ITS PERFORMANCE

A PV cell is composed of two or more layers of semiconductor material, typically silicon. When silicon is exposed to light, electrical charges are generated that can be conducted through metal connections as direct current. Due to the low electrical output of a single cell, multiple cells are combined to create a module. The resulting PV module is the primary component of a PV system and can be connected in series or parallel with any number of other modules, as depicted in Figure 3 (Kazmerski, 1997).



Figure 3: Solar cell, module, and array (Bhukya et al., 2022)

Photovoltaic cells are used to directly convert solar radiation into electricity. Photovoltaic cells are composed of a variety of semiconductors, which are materials with moderate electrical conductivity. Silicon (Si) and compounds of cadmium sulfide (CdS), copper sulfide (Cu₂S), and gallium arsenide (GaAs) are the most used materials (Topcu and Yünsel, 2012). The Shockley solar cell equation (Equation 1) describes the I-V characteristic of an ideal solar cell, which is represented by a current source connected in parallel with a rectifier diode (Markvart and Castañer, 2013).

$$I = I_{ph} - I_0 \left(e^{\frac{qV}{k_B T}} - 1 \right)$$
 (1)

The Boltzmann constant is denoted by k_B , the absolute temperature by T, the electron charge by q (>0), and the voltage at the cell terminals by V. In the dark, I_0 represents the diode saturation current and demonstrates that a solar cell is a semiconductor current rectifier or diode. The photon flux incident on the cell is closely connected to the I_{ph} generated by sunshine. Except for a-Si and other thin film materials, the current created by sunlight is often independent of the applied voltage. Figure 4 demonstrates the I-V characteristic of a typical solar

cell. In a typical circumstance, the short circuit current I_{sc} is provided, whereas the current I_{ph} created by sunlight is given, and the open circuit voltage V_{oc} is given.

$$V_{oc} = \frac{k_B T}{q} \ln\left(1 + \frac{l_{ph}}{l_0}\right) \tag{2}$$

Figure 4 demonstrates the power generated by the cell P = IV. The maximum power P_{max} of a solar cell is produced at voltage V_m and current I_m , which is represented as the filling factor *FF* (Markvart and Castañer, 2013).



Figure 4: Ideal PV cell I-V curve (Markvart and Castañer, 2013)

Maximum efficiency is defined by Equation 4 as the ratio between the maximum power and the light power incident on the PV cell surface.

$$\eta_{max} = \frac{P_{max}}{P_g} = \frac{I_{max}V_{max}}{A_h I_t} \tag{4}$$

Where A_h , is the cell area (m²) and I_t is the total radiation incident on the cell surface (W/m²). Figure 5 illustrates the effect of temperature and irradiance on cell characteristics (Kalogirou, 2014).



Figure 5: Effect of radiation and temperature on PV cell characteristics (I_{sc} , V_{oc}). (a) radiation (b) temperature (Kalogirou, 2014)

The open circuit voltage grows logarithmically as solar radiation increases, but the short circuit current increases linearly. The principal consequence of rising cell temperature is a fall in open-circuit voltage, which decreases linearly with rising cell temperature, lowering cell efficiency. Short-circuit current increases somewhat as cell temperature rises. Solar cells can be linked in series or parallel in practice. Figure 6 depicts the shift in the I-V curve when two equivalent cells are linked in parallel and in series (Kalogirou, 2014).



Figure 6: Two identical PV cells connected in (a) parallel and (b) series (Kalogirou, 2014)

Parallel connection of two identical cells maintains the same voltage but multiplies the current. Current remains the same when cells are connected in series, but voltage doubles (Kalogirou, 2014). Figure 7 depicts the factors influencing the efficacy of modules produced by the combination of PV cells. As shown in the figure, there are numerous factors that influence the efficacy of PV modules. When these factors are considered during the installation of PV systems, the desirable module efficiencies can be attained.



Figure 7: Parameters affecting PV module yield (Hasan et al., 2022; Idoko et al., 2018; Mani and Pillai, 2010; R. R. Rao et al., 2018)

IMPACT OF DUST ON PV PANEL POWER OUTPUT

Dust particles formed by the occurrence of natural events in the atmosphere are attached to the surface of the PV panels utilizing adhesion forces such as capillary forces, electrostatic forces, and van der Waals forces, and all form dust accumulation. Moreover, the conductive and dielectric characteristics of dust particles attract and adhere to dust particles to the solar panel surface (Ilse et al., 2018; Isaifan et al., 2019; Picotti et al., 2018). As aforementioned stated, the reasons for the presence of dust on the solar panels; The dust accumulation rate has been reported to be caused by the site characterization and by the industries, transportation, sandstorms, and human-induced problems that are the source of dust generation present at the site. One thing is important here, the farther the

distance of the PV plants to the dust generation source, the less dust accumulation will occur (Cano et al., 2014; Middleton, 2017). Furthermore, in the fabrication of PV modules, the panel surface properties significantly affect the precipitation rate and dust accumulation. It has been reported in the literature that the materials made of glass are more convenient to use in terms of dust accumulation rate when compared to the materials made of glass, which are generally made of epoxy, tedlar, and plastic. The wind has some effects on the dust deposition rate. While it removes dust from the solar panel as a positive effect, it can also accumulate dust negatively. The effect of wind on dust accumulation is explained in such a way that it can be determined according to dust characteristics, wind speed, and direction (Goossens et al., 2019; Said et al., 2018). Other environmental parameters, including humidity level, may affect the rate of dust collection on the panel. This relationship can be stated as follows; as the relative humidity rate rises, so will the amount of water vapor that forms droplets and condenses on the surface. As a result, capillary pressures enhanced dust adhesion on the PV panel surface (Salamah et al., 2022). The total power efficiency output from the PV module has a negative effect as dust collects on the surface of the solar PV module. (Klugmann-Radziemska, 2015; Liu et al., 2019; Yue and Li, 2022). Many scientists worldwide have investigated dust gathering, which influences the power manufacturing and effectiveness of PV modules. Hassan et al., in Helwan, Egypt, investigated solar cells' diminished effectiveness because of suspended particles in the airspace on an a-Si panel that was never cleaned for six months and a poly-Si PV panel that was cleaned daily for 2.5 years. They reported that after six months of not cleaning the a-Si panel, the efficiency dropped by 66%, and the power was reduced by 75%. They reported that the poly-Si panel caused a 9% reduction in efficiency, even in the case of daily cleaning of the panel, with high outside temperatures in summer and a large number of particles suspended in the atmosphere (Hassan et al., 2005). Guo et al. performed the effect of dust aggregation on PV modules in Qatar. As a result, they stated that there is a loss of 0.4% to 0.8% in daily production power due to dust accumulated on the PV module, and if the module surface is not cleaned every month, there will be a power loss of 12% to 24% (Guo et al., 2015). Rao et al. carried out examinations in the natural environment and the laboratory to investigate the influence of dust accumulation. In outdoor investigations, they detected a 5-6% decrease in power loss due to 1.4 g/m² powder thickness. In the laboratory investigation, they fixed the powder thickness to 7.155 g/m^2 and noticed the power loss was 45-55% (A. Rao et al., 2014). Gholami et al. examined the influence of dust deposition on PV module performance in Tehran, Iran. According to the findings of this investigation, after 70 rain-free days, the PV module's output power decreased by 21.47% due to 6.0986 g/m² dust aggregation over the PV panel (Gholami et al., 2018). Naz et al. examined the effect of sand and dust on PV module efficiency at different angles of tilt employing an artificial illumination source in a laboratory environment in Pakistan. They declared that with increasing tilt angle, there is a voltage drop of 0.5 V to 2.5 V for dust and sand, respectively. Besides, the voltage decreased from 0.7 V to 2.5 V after 60 minutes of uninterrupted dust and sand aggregation. Scientists reported that the tilt angle is crucial in the dust deposition process and the test time in the sand deposition phase (Naz et al., 2020). A detailed summary of literature studies researching the effects of dust on the power output of PV modules is presented in Table 1.

Researcher(s)	Country	Time the PV	Dust effect on
	U	module is	power output
		exposed to dust	(decrease %)
Asl-Soleimani et	Iran	8 days	43
al.,			
Elminir et al.,	Egypt	1 month	17.4
Mohandes et al.,	United Arab	5 weeks	10
	Emirates		
Kaldellis and	Greece	8 weeks	6.5
Kokala,			
Pavan et al.,	Italy	8 weeks	6.9
Cabanillas and	Mexico	1 month	13
Munguía,			
Jiang et al.,	China	1 day	26
Rahman et al.,	Bangladesh	1 month	34
Kalogirou et al.,	Cyprus	10 weeks	8
Mejia et al.,	United States of	108 days	7.2
	America		
Adinoyi and Said,	Saudi Arabia	8 months	49
Said and Walwil,	Saudi Arabia	1 month	7
Ketjoy and Konyu,	Thailand	60 days	7.28
H. A. Kazem and	Iraq	1 month	18.74
Chaichan,			
Guan et al.,	China	8 days	20.62
Gholami et al.,	Iran	70 days	21.47

 Table 1: Summary of literature studies related to the effect of dust on PV module power output

The gathering of dust on PV panels significantly affects the electrical characteristics and qualities of the PV panel. The extent of the losses in the panel's electrical parameters varies depending on the PV panels' geographical location, dust accumulation duration, and panel position.

METHODS OF CLEANING DUST ON PV PANELS

Numerous experiments have shown that dust reduction is critical in enhancing PV panel power output (Sulaiman et al., 2014). Cleaning can be carried out wet or dry, depending on various factors, including the severity of the dust accumulated and the type of dust (Maghami et al., 2016). Numerous manual, automatic, and semi-automatic PV cleaning processes are in use today (Abuzaid et al., 2022). Manual cleaning is frequently suggested for small-scale PV panel systems; however, it is time consuming and expensive when water is scarce or unavailable (Bergin et al., 2017; A. A. Kazem et al., 2014). Generally, fully automatic processes are not only complicated from a mechanical point of view but also not economically viable. In addition, water use in such systems necessitates techniques related to storing and reusing facilities. If PV plants are to be in deserts or remote areas, this system can be used easily (Mondal and Bansal, 2015). Problems that continue to be an important problem on PV panels can be listed as follows:

accumulation of dust, soil, and dirt,

 \triangleright especially the shortage of natural cleaning through sandy storms, dry climates, and rain, where most of the solar irradiation,

> arid areas determined by the scarcity of water resources in general.

These given issues remain essential issues that must be addressed and resolved. In recent years, improvements in coating application technologies and increased material utilization have facilitated work in passive self-cleaning, dry, and wet dust environments by coating applications as superhydrophilic and superhydrophobic materials (Sarkın et al., 2020). Figure 8 illustrates PV panel cleaning techniques.



Figure 8: PV panel cleaning methods (Salamah et al., 2022)

Some features should be considered in the selection of the cleaning method. Cost, production, system size, location, and meteorological data can be listed as follows. These data are crucial parameters when choosing a PV cleaning module, as they have strong connections with each other. When these strong connections are considered choosing the optimum cleaning method for PV panels is vital.

CONCLUSION

In this chapter, the causes of dust accumulation on the PV panel surface, the effect of dust accumulation on the power output of the solar panel and the use of different cleaning procedures for dust accumulation have been investigated and discussed in detail. It has been determined that the electrical power output of the PV panel is considerably affected by environmental factors, including humidity, temperature, wind, and dust accumulation, as well as establishing factors like the angle of inclination, the surrounding area, and the front surface of the PV module. The results of this chapter can be summarized as follows:

> Dust precipitation or accumulation not only affects the PV module's efficiency but also diminishes the PV module's life.

> There is no single effective decreasing approach for PV module cleaning. The installation site's environmental parameters determine it.

 \succ No specific program is used to eliminate dust from the PV module, as it is associated with rain and dust storms.

There is a requirement for investigating the bonding forces between the surface and the dust features and to investigate acceptable, cost-effective dust-cleaning coatings for usage in desert regions in which water is scarce.

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Chapter 11

Design and Control of a Multilevel Inverter for Electric Vehicles Using a Single DC Source

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ABSTRACT

AC motors are predominantly used in electric vehicles (EVs) due to their high efficiency and the ability to provide more power with smaller and lighter engines. Additionally, most applications, especially EVs, require a single DC source for ease of use. In this thesis, a new 31-level multi-level inverter (MLI) circuit fed from a single source is proposed for EVs. In the proposed topology, switched diode structure is used as the main circuit and DC bus voltages are obtained by scaling asymmetrically and using high frequency link (HFL) method with toroid transformer. Nearest level control (NLC) is used for minimum total harmonic distortion (THD) in the output waveform. The simulation of the proposed topology was carried out in the Matlab/Simulink program and the simulation results were confirmed by experimental studies using FPGA. In studies, as a load; pure resistive and induction motor are used. In addition, the filter effect is shown by adding various filters to the proposed EMI. As a result, the proposed topology created a high voltage output stage with low voltage switches. A topology suitable for the EV drive system, with a single DC source and an output voltage THD value of 2.7% without using a filter, was obtained.

Keywords: Multilevel inverter, Electric vehicle driver, FPGA, HFL, High frequency link

INTRODUCTION

Today, electric vehicles (EV) are increasingly preferred in order to reduce environmental impacts and increase energy efficiency. Electric motors, an important component of EVs, are a critical element that affects vehicle performance and energy efficiency. In this context, the design and selection of the motors used in EV are of great importance (Hashemnia and Asaei, 2008). AC motors offer many advantages such as using energy in the EV as efficiently as possible, having high efficiency, high power density, reducing the weight while increasing the performance of the EV due to the fact that more power can be provided with smaller and lighter motors.

Inverters are power electronics circuits that convert DC power to AC power at the desired output frequency and voltage and are widely used in the industry. The output voltage waveform changes depending on the DC source used at the input and the number of controlled and uncontrolled power elements. The output voltage has a stepped waveform and depending on the number of levels, the THD of the voltage signal decreases and accordingly the efficiency increases.

Most of the EVs produced recently are using three phase inverters designed using IGBT due to high efficiency and low cost. The battery pack can be connected directly to the DC input of an inverter or by using a controlled DC/DC power converter. To create a three-phase sinusoidal output current to the motor, six switches are required in the motor driver circuit (Reimers et al., 2019). This inverter is called classical inverter. Conventional inverter causes switching losses to increase at high switching frequency required for high power and voltage applications. These inverters have high THD, high electromagnetic interference (EMI) and high voltage change ratio (dv/dt) (Krishna and Suresh, 2016). For high power and high voltage applications, they have the important limitation that they require the use of power electronic devices that can operate at high power and voltage. The voltage level also increases with increasing power levels for satisfactory performance in devices. A solution to the disadvantages of the classical inverter and the high voltage requirement is to cascade inverter structures (Hosseinzadeh et al., 2021). For this purpose, MLI's have been developed.

MLI topology concept was introduced in early 1975 with three-level inverters. Basically, there are three different types: Diode Clamped MLI, Capacitor Clamped MLI (Flying Capacitor) and Cascade H-bridge MLI (Hatas et al., 2023). These MLIs have advantages over conventional inverters such as reduced THD, low dv/dt, reduced switching losses and high-power quality. In addition, by operating in both fundamental and high frequency PWM, an

inverter output voltage closer to a pure sine waveform is obtained (Koshti and Rao, 2017). Flying Capacitor and Diode Clamped MLIs have a significant disadvantage due to unstable DC bus conditions and the need for high-capacity capacitors. These disadvantages can be overcome by using cascade connections of Cascade H-bridge MLI, but require a large number of switching elements for higher levels. For this reason, researchers are trying to create more useful hybrid topologies by using the advantages of traditional topologies (Ponraj et al., 2021).

MLI topologies require multiple isolated DC bus voltages. DC sources can be designed insulated in battery packs. However, additional measures are required to ensure the correct proportion of battery packs to power the engine. Voltage stabilization of insulated battery modules with the use of MLI is an important issue to consider. This issue occurs when the battery is both charging and discharging. Since battery modules are insulators, traditional BMS cannot perform voltage balancing and equal current operation. Therefore, there is a need for a reliable BMS specific to the MLI used. This complexity in BMS makes control difficult and increases its cost.

In baseband operating applications such as power rectifiers, active power filters or flexible AC transmission systems, multiple power supplies can be created from a single power supply. The operating frequency of the transformer is in the range of 20-50kHz, the volume of the transformer and capacitor has been reduced and is suitable for electric vehicles. These transformers isolate the input and output galvanically and adjust the voltage ratio according to the number of windings. Creating any voltage source using HFL requires the use of bridge diodes and capacitors. In fact, it does not require any control when creating an isolated voltage source, so it is widely used (Reimers et al., 2019). In addition, since the input voltage of all voltage busbars has a coefficient according to the number of turns, the input voltage changes proportionally to inverter output voltage.

In this study, the bypass diode MLI topology, which currently uses fewer switching elements compared to the recently published topologies, is implemented with a single DC source. In addition, the MLI is arranged asymmetrically to reduce the number of DC voltage units, switches, bridge diodes and capacitors. The NLC method is used to generate the output waveform with a low switching frequency. By taking the physical outputs of the HFL and the necessary circuits, NLC signals were produced with the Genesys 2 FPGA development board.

In the following sections, the studies are presented, the proposed topology circuit and working principle are explained, the findings obtained from the

simulation and experimental studies on this topology are presented, and the advantages of the proposed topology are given.

OPERATION CHARACTERISTICS

AC motors are increasingly used in EVs for performance and efficiency. Additionally, using a single voltage bus reduces the complexity of EV battery charging. Therefore, a topology with multilevel voltage waveforms at the output of a single DC power supply is proposed. The main structure and basic units of the proposed topology are shown in Figure 1.



Figure 1: Proposed MLI topology

As shown in Figure 1, high frequency transformer is used to obtain an asymmetric DC-link voltage from a single DC source. The asymmetric DC level obtained using the HFL creates a multilevel output using a bypass diode circuit and an H-bridge.

The bus voltages of a single DC power supply are asymmetrically scaled (2^N) to achieve four different levels. 3 different DC bus voltages (1V:2V:4V) and 8V ratio mains supply voltage generated in 2^N operation using HFL are converted to multiple output for bypass diode circuits. The proposed topology can generate 15 positive voltages. The DC bus voltage will be as shown in Equation 1.

$$V_{Bus} = [S_0 S_1 S_2 S_3]_2 \cdot V_{DC}$$
(1)

1.1. High Frequency Link Circuit

The high frequency coupling circuit (HFL) generates high frequency AC signals applied from the secondary to the primary of the transformer according to the turn ratio. After rectification, isolated multiple DC voltage sources are obtained. This allows efficient power transfer while providing isolation between the two voltage sources. No control is required when using bridge diodes to create an auxiliary voltage (AUX) unit in the HFL circuit, as shown in Figure 2.



Figure 2: Proposed HFL topology

The H-bridge used here transmits less than half the power to the load and generates a high frequency square wave signal. It is used to reduce the size of high frequency transformers. A multi-winding toroidal transformer produces square wave signals with an amplitude of 2^N that are rectified by a simple bridge rectifier made of fast recovery diodes. The square wave signal produced by the HFL transformer is rectified by a bridge diode circuit.

1.2. Nearest Level Control

The nearest level control in the MLI is to trigger the power switch to keep the drive output voltage close to the reference outputs of the input. NLC has the advantages of fundamental switching frequency. Through this control strategy, the output of its limits can achieve high quality waves with less harmonics and excellent dynamic performance. NLC is the height of the voltage closest to the reference voltage, as shown in Figure 3.



Figure 3: NLC controlled switching angle of the proposed topology

In Figure 3, the reference signal is taken as half of the step range. Half of the step-equal range of the resulting step signal always cuts off the reference signal. For example, for a positive 15-step output, generate the reference signal as a cosine with an amplitude of 15.5 units. The switching angle of the NLC is calculated according to the formula in Equation 2.

$$\alpha_{i} = \cos^{-1} \left(\frac{2^{N+2} - 1 - 2i}{2^{N+2} - 1} \right)$$
(2)

where i = 1, 2, ..., 2N-1 and where N is the number of AUX units.

FPGA Signals

Xilinx System Generator (XSG) has integrated the FPGA with the Matlab program that engineers are prone to. In power electronics, control is usually provided by microcontrollers and DSPs (Zabun M. and Sedef H. 2021). XSG has been an effective method for rapidly prototyping, testing and developing hardware without the need for HDL knowledge. The operation can be evaluated using XSG without loading the signals generated by using Matlab/Simulink

blocks to the FPGA board. After the necessary arrangements, the VHDL code is automatically generated and programmed into the FPGA (Selvamuthukumaran and Gupta, 2014).

In order to sum the four different voltages in the bypass diode circuit, it is necessary to have four separate signals. The binary number is represented by the number $S_0S_1S_2S_3$, depending on what time interval the signals will be provided at each level. As shown in Figure 4, it summarizes the process of obtaining these signals by the NLC method.



Figure 4: Supply of S₀S₁S₂S₃ NLC signals

SIMULATION RESULTS

When a 100V square signal is applied to the transformer input, the square signals formed at the output for 1 phase are shown in Figure 5.



Figure 5: When a 100V square signal is applied to the transformer input, square signals are formed at the output for 1 phase.

As seen in Figure 5, when a 100V square wave signal is applied to the transformer input, square wave signals with amplitudes of 50V, 25V and 12.5V will be obtained at the output, respectively, depending on the conversion ratio.

The switching signals applied to the bypass diode circuit by the NLC are shown in Figure 6a, and the bypass diode circuit output, the inverter output and H-bridge signals are shown in Figure 6b.



Figure 6: (a) Switching signals, (b) Bypass diode circuit output, the inverter output, H-bridge signals.

A 150ohm resistor is used in the simulation environment. The inverter phase voltages and phase current of the case of pure resistive load with collector switch signals are given in Figure 7a. The inverter phase voltages and phase current formed by the effect of inductive filter on pure resistive load are given in Figure 7b.



Figure 7: The inverter phase voltages and phase current (a) Pure resistive load (b) Inductive filter effect

The phase voltage and phase current of the induction motor model are shown in Figure 8a without using any filter to the output of the proposed MLI topology and are obtained using a 5uF capacitive filter to the motor terminal. Voltage and current with capacitive filter are shown in Figure 8b.



Figure 8: Induction motor phase voltages and phase current (a) when no filter is used, (b) when capacitive filter is used

It can be seen from Figure 8a that there is a jump at the zero crossing of the phase voltage obtained by the NLC control method and there is a slight jump in the current due to the voltage jump. A 5uF capacitive filter parallel to the motor terminals eliminates zero-crossing as shown in Figure 8b. Also, improving the phase voltage improves the signal quality by correcting the phase current.

EXPERIMENTAL RESULTS

The experimental setup of the 3-phase 31-level MLI topology circuit proposed in the study is given in Figure 9. A 150ohm resistor is used in the experimental setup.



Figure 9: Experimental setup of the proposed topology

The H-bridge takes the voltage from a single DC source in Figure 9 and generates a square wave signal there. A multi-output toroidal transformer rectifies this square wave signal by multiplying different voltages. The bypass diode circuit then collects this signal according to the NLC method. The output of this process converts it into a sinusoidal form, positive and negative, with another H-bridge before being transmitted to the load.

Figure 10 shows the square wave signal generated at the output of the transformer when a 100V square wave signal is applied to its input. The generated square signals were obtained according to single phase.



Figure 10: Toroid transformer: (a) Primary voltage and first output voltage (b) Primary voltage and second output voltage (c) Primary voltage and third output voltage

As seen in Figure 10, when a 100V square signal is applied to the transformer input, square signals with 50V, 25V and 12.5V amplitudes are obtained at the output, depending on transformer conversion ratios, respectively.

The switching signals generated from the bypass diode driver circuit and the bypass diode circuit output, inverter output, H-bridge driver signals are given in Figure 11a and Figure 11b, respectively.

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Figure 11: Bypass diode circuit (a) switching signals generated from the driver (b) Bypass diode circuit output, the inverter output, H-bridge driver signals

The inverter phase voltages and phase current of the bypass diode switch signals, when the load is pure resistive, are shown in Figure 12a and the phase voltages and phase current obtained by using an inductive filter are shown in Figure 12b.



Figure 12: The inverter phase voltages and phase current (a) at pure resistive load (b) with inductive filter

The phase voltages and phase current obtained when the induction motor is connected to the output of the MLI topology without using any filters are shown in Figure 13a. The motor terminal voltages and current obtained using a 5uF capacitor filter are shown in Figure 13b.



Figure 13: Induction motor phase voltages and phase current: (a) when no filter is used, (b) when capacitive filter is used

As seen in Figure 13a, there is a jump at the zero-crossing of the phase voltage, and a slight jump in current due to the voltage jump. A 5uF capacitive filter parallel to the motor terminals eliminates zero-crossing transitions as shown in Figure 13b. Also, improving the phase voltage improves the signal quality by correcting the phase current.

RESULTS AND DISCUSSION

The main advantage of the asymmetric multilevel inverter is to achieve the maximum output level with the minimum number of power supplies. Numerous isolated DC sources complicate the battery and charging system. The HFL used in this study reduces the multiple DC power supplies required by the main topology to a single power supply, allowing it to be applied to EV. Advantages and disadvantages of the proposed topology and possible solutions to these disadvantages are given.

When determining the type of EV driver, it is expected that the cost, complexity, size and weight of the drive system will be reduced in such a way as to make the greatest contribution to the vehicle. Cost is budgeted for by the end user, complexity is difficult to control, reduction in volume leads to more room in the vehicle for other components, and weight leads to a reduction in the overall weight of the vehicle.

Recently, EV manufacturers have tended to increase battery voltage. The use of MLI in high-power and high-voltage applications for electric ships and electric trains coincides with the usability of these topologies in electric vehicles. If an 800V battery that supports fast charging is used, a motor designed for 1500V can be connected to the inverter output. In fact, the proposed topology can operate at high voltages with low-voltage switches, thus
reducing switching costs. It reduces the cost, size and weight of motors and wiring.

The fact that the HFL system accounts for 45% of the total power reduces the load on the switches directly connected to the bypass diode circuit of the power supply. Choosing these low voltage switches can reduce cost. Since the square wave signal is rectified in the rectification circuit and the capacitors used do not reduce the current from the motor, they are chosen with low capacitance. This reduces volume and cost.

Overuse of switches and drivers in MLI adds cost and complexity. Having fewer switches compared to other MLI topologies is advantageous in terms of number of switch drivers and cooler volume. Since boards such as FPGA and DSP generate switching signals in direct control mode, complexity is reduced to controlling a single switch.

When the inverter output voltage exceeds zero, there will be a voltage spike due to the main topology. This jump is avoided by parallel filtering with low value non-polarized capacitors. When the engine is running at low speed, the zero-cross voltage jump also blocks the capacitor used, causing the engine to hit the cylinder. However, due to the relatively low THD, this knock is not as strong as with conventional inverters. Because the zero-cross voltage form of the proposed topology is higher quality than the low-speed conventional inverter.

The high frequency operation of the transformer and HFL H-bridge circuit used in the proposed topology reduces the overall efficiency. Using a solid-state transformer instead of a toroidal transformer can improve overall efficiency. Additionally, replacing HFL H-bridge switches with switches with low internal resistance and short rise and fall times, such as GaN or SiC, can improve overall efficiency.

CONCLUSION

In this study, a 31-stage MLI circuit is implemented using a small HFLbased asymmetric adder with a single DC source with fewer switching elements than recently published topologies. It has been observed that the use of a lowvalue inductance filter makes the current form highly sinusoidal, while a highinductance filter causes zero-crossing voltage transitions. At the proposed MLI output, a zero-voltage crossover jump is observed due to the high inductive load when using an AC motor. It is seen that this jump voltage can be eliminated with a small capacitor connected parallel to the output of the proposed topology. According to simulation and experimental research, the THD value of the 31stage output voltage of the NLC method is below 5%, meeting IEEE 519 and TS-EN50160 standards.

It has many advantages over similar studies using MLI circuits. The outstanding value of this study is that compared to the output level of this study, less switches are used in other topologies and the number of switching is less, which reduces the control load of the system and increases reliability. In addition, the use of fewer capacitors in the proposed topology, significantly lower THD than conventional inverters, low voltage change ratio and low EMI indicate the importance of this research. The proposed topology has the advantages of having fewer switches than other MLI topologies, in terms of the number of key drivers and heatsink volume.

The use of lower switching elements reduces switching losses and the cost of the proposed topology. Also, AUX units can be chosen as their capacitors are relatively small as they only absorb energy from the load for a short time in the regenerative braking situation. Using one H-bridge per phase in the circuit and operating it at the fundamental frequency increases the efficiency of inverter. Since it can be powered by a single battery, it can be used in electric vehicle inverter applications and other industrial applications that require multiple isolated DC power supplies. In the proposed topology, the power switches operate at the fundamental frequency. A reference signal frequency proportional to motor speed reduces power loss and cooler requirements. It also helps to use motor control systems such as voltage/frequency where control is done with the reference signal frequency and frequency variation is important.

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Chapter 12

Climate Environmental Conditions in Water Buffalo Barns

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Abstract

As in all production activities, the aim in animal husbandry is to achieve the highest economic efficiency. To increase animal productivity within economic limits; It is possible by keeping the climatic, structural and social environmental conditions within optimum limits. This study was carried out in order to inform our farmers, who are dealing with water buffalo breeding, about the factors that should be considered in order to create an optimum climatic environment in buffalo barns.

Keywords: Water buffalo, barn, climate environmental

Introduction

The increasing world population and the nutritional need of people with qualified nutrients make it necessary to increase the production amount and quality of animal-derived nutrients, which have an important place in basic food sources. Animal husbandry is one of the important sub-sectors of agriculture, which meets the important needs of people, especially foodstuffs such as meat, milk and eggs. Today, livestock has become an industry in developed countries and an integral part of the economy. This situation reveals that agriculture, and therefore animal husbandry, is a strategic sector that needs to be developed at the national level (Kocaman and Kurc, 2020).

The aim in animal husbandry is to obtain the highest economic efficiency. Increasing animal productivity within economic limits is possible by obtaining breeds with high productivity ability, as well as by building barns where animals are well fed, heat and cold stress free, climatic, structural and social environmental conditions can be kept within optimal limits. A significant part of the initial investment expenses in livestock enterprises is used for the construction of barns. However, in the design of the barns, the fact that sufficient information is not collected, and the necessary importance is not given to the animal-environment-human relations prevents the realization of the desired purpose, as well as a significant waste of resources and the expected benefits from the barns cannot be fully obtained.

The fact that buffalo breeding is generally carried out in traditional barns and lack of sufficient knowledge about the control of the climatic environment makes it difficult to reach the desired goal. It is also difficult to talk about animal welfare in traditional type barns where it is difficult to meet the climatic environment at optimum levels. In addition to increasing animal production, increasing the yield potential of animals with feeding and genetic improvements, it is essential to improve and optimize the environmental conditions in living and barning environments. (Kocaman, 2021).

In animal husbandry, it mostly focuses on genetic structure and breeding studies, while environmental conditions are put into the background. However, environmental conditions have a great importance in increasing animal production. Genetic structure and environmental conditions, both individually and together, provide the formation of all the characters that farm animals have or will have. Much research are carried out on these issues in the world. As a matter of fact, studies have shown that genetic structure is 30% effective on animal yield, and feeding and environmental conditions are 70% effective (Ekmekyapar, 1991; Okuroglu and Yağanoglu, 2013).

There are very few places in the world that will constantly provide optimum climatic conditions for farm animals all year round. For this reason, the effects of climatic conditions deviating from the optimum state on animals are examined and suitable conditions for optimum growth and production are constantly investigated. The aim of this study is to inform our farmers dealing with water buffalo breeding about climatic environmental conditions and control in buffalo barns, in the light of literature information.

Climatic environmental conditions

The main purpose in animal breeding for commercial purposes is to obtain the highest and most economical efficiency against a certain expense. This can be possible if the climatic environmental conditions are kept at the appropriate level together with adequate nutrition and appropriate genotype (Mutaf and Sonmez, 2012).

Environmental conditions include all external factors that affect the growth, development and yield of the animal. These factors can be grouped as climatic, structural, social and other factors. Temperature, relative humidity, air movement, radiation, light, chemical composition of air, climatic; ventilation systems, insulation condition and equipment, structural; animal density, group size, water supply, social; sound, Odor, dust, presence of disease organisms, and atmospheric pressure are listed as other factors (Ekmekyapar, 1991).

Temperature and relative humidity values, which are extremely important for animal welfare, generally deviate significantly from optimum values. This situation deteriorates the health conditions, reduces animal productivity and shortens the service life of the structures.

Temperature

Temperature is the most important environmental factor affecting the physiological activities of water buffaloes. Therefore, temperature is one of the most important environmental conditions to be considered. Because temperature is a measure of whether the health and comfort of animals is provided or not.

The temperature range where animals can perform their productive functions best and be most comfortable is defined as the "Comfort Zone" and covers a narrow temperature range. Temperatures within the comfort zone limits are optimum temperatures for animals. As you move away from the comfort zone, heat stress, called thermal stress, arises in farm animals. Cold stress begins at low temperatures, and heat stress begins at high temperatures. Both stress situations can adversely affect the meat and milk yield of the animal (Mutaf, 2012).

Like many farm animals, water buffaloes are not under heat stress in environments with temperatures between 10-20 °C. Shafie (1985) recommends that the ambient temperature of the comfort zone and thermo-neutral zone be between 2-21 °C for water buffaloes, and the upper limit value for the physiological thermo-regulator mechanism to be 27 °C.

The seasonal effect of heat stress manifests itself in hot and humid regions and especially in hot summer months. However, heat stress can occur at both high and low temperatures. However, since high temperatures pose more problems, when heat stress is mentioned, the problems that occur with high temperature in general come to mind.

The effects of heat stress on the animal and its performance are well defined. With high environmental temperature, rectal temperature rises, feed and energy consumption and milk yield decrease. When the ambient temperature exceeds the normal limits (5-25 °C), the increase in relative humidity negatively affects the thermoregulation ability of the animal. High-yielding animals are more affected by heat stress than low-yielding animals. Because high-yielding animals are more metabolically active and the extra heat load is higher in these animals. To help animals cope with heat stress, some structural adjustments, such as shades, fogging systems, and showers, need to be made. These applications are; It prevents the animal from overloading with heat from the environment, contributes to the heat removal of the animal from the body by evaporative way (Gorgulu, 2013).

For water buffaloes, ambient temperature is more important than for normal cattle. Water buffaloes are from the group of homothermic animals like other cattle, and their skin (1:6) contains one-sixth less sweat glands than cattle skin (Borghese, 2005). In addition, the skin of water buffaloes is thicker than cowhide and the hair density on their bodies is considerably lower than that of cattle. While this value is approximately 100-200/cm² in water buffaloes, this value is 1000/cm² in cattle. This situation limits heat dissipation and evaporation by transpiration, negatively affecting feed consumption, growth rate, milk production and fertility (Thomas, 2004).

Body temperature in farm animals is stable and varies within very narrow limits, although there are large variations in ambient temperature. Normal body temperatures vary depending on the breeds and the way of rearing, and in farm animals such as cattle and water buffaloes, they are approximately between 37-39.3 °C limit values. Keeping the body temperature within the aforementioned limits is possible by balancing the heat production and heat release from the body. It increases metabolic heat production in cold ambient conditions, but keeps heat loss at low levels. In hot ambient conditions, it reduces metabolic

heat production, but increases heat release, especially latent heat release. When the body temperature, the ambient air temperature and the surrounding building elements are higher than the inner surface temperature (winter-transition seasons), there is a constant loss of heat from the body to the external environment. In the opposite conditions (summer in hot regions), there is a constant heat load on the body from the external environment (Mutaf, 2012).

Physiological adaptation of water buffaloes to extremes of heat and cold is lower than that of various cattle. While the body temperature increases by 1.3 °C when exposed to direct sunlight, this rate is 0.2-0.3 °C in cattle (Marai and Habeeb, 2010).

As stated before, heat stress occurs when animals move away from the thermoneutral zone where they have optimum productivity. For this, high temperature stress is mentioned at temperatures above normal and cold stress is mentioned below. At temperatures below normal temperatures, animals begin to develop hypothermia. Hypothermia is defined as an animal's body temperature falling below normal values. Mild hypothermia occurs when the body temperature falls between 30-32 °C. There is moderate hypothermia between 22-29 °C and severe hypothermia below 10 °C. When the rectal temperature drops below 28 °C, cattle can no longer return to normal body temperatures without any external heating or hot water treatment. The environmental temperature that will cause hypothermia varies according to factors such as the thickness of the skin, hair cover, wind speed, and wetness. When hypothermia develops, metabolic and physiological activities slow down. The blood circulation is diverted from surrounding tissues to vital organs for the protection of vital organs. In these cases, nipples and testicles begin to be damaged by frost. As hypothermia progresses, respiratory rate, heart rate and blood pressure decrease. The animal loses consciousness and death occurs soon if the animal is not rewarmed. Animals generally consume more feed to get rid of hypothermia. Water consumption is also reduced. Because they need more energy to maintain normal body temperature. In cold conditions, the energy requirement may be 25-30% higher than the normal survival requirement (Gorgulu, 2013).

Relative humidity

One of the important environmental conditions in animal husbandry is relative humidity. The effect of relative humidity, which changes within certain limits at certain temperatures, on animals is related to the environmental temperature. For this reason, the relative humidity should be optimum between the optimum temperature limits. Generally, high temperature and relative humidity cause loss of appetite in animals, reducing the consumption of feed needed for maximum productivity by animals. High temperature and relative humidity not only reduce the appetite, but also make it easier for animals to catch diseases (Noton, 1982).

For cattle, the relative humidity value should be between 60-80% in optimum conditions. The relative humidity should never be less than 30% and more than 90%. Being below or above the specified values negatively affects the thermoregulatory ability of the animals and as a result, the health of the animal deteriorates (Wathes et al., 1983).

Shafie (1985) gives the temperature limit values of 13-18 °C for winter months and 20-40 °C for summer months under optimum climatic conditions for breeding and growth of buffaloes. It gives the relative humidity value as 55-70% under optimum conditions.

Lighting

Lighting is as essential to animal health as water and air. In addition, the provision of light in the barns is a condition for the work to be done inside the barn. In addition, lighting in barns is mandatory for improving hygiene and sanitary conditions. Scientific studies have shown that lighting significantly affects the yield characteristics of farm animals. It has been demonstrated by scientific studies that an increase of 6-12% in milk yield can be achieved with well-planned natural and artificial lighting systems in closed type barns (Petrusha and Gavrilov, 1990).

Barns floor area is used as a criterion in determining the required window area for natural lighting in animal barns. Accordingly, the ratio of the required window area to the floor area of the barn in closed type barns is 3.5-5% in cold regions, 5-7.5 in temperate regions and 7.5-10% in warm regions (Okuroglu and Yaganoglu, 2013). Windows should be placed equally and at equal intervals on both long walls of the barn. The height of the windows from the base of the barn should be at least 150 cm, taking into account the height of the water buffaloes.

Normal bulbs and fluorescent lamps are generally used for artificial lighting of animal barns. It is appropriate to use 4-6 W/m^2 for normal bulbs and 1.5-2 W/m^2 for fluorescent lamps in artificial lighting calculations (Ekmekyapar, 1991; Mutaf 2012).

Cleaning of barn air

The term cleanliness of the barn air refers to the chemical composition of the air and the dust and microorganism status in it. The chemical composition of the air affects the physiological state of the animal. Pollutant gases such as C_2O ,

NH₃, H₂S, CH₄ and SO₂ are emitted into the barn environment by animals and as a result of various microorganism activities in the barn. The type and airborne concentrations of these pollutants vary depending on animal breed, housing design, feeding and water delivery system, type and composition of feed, animal age and frequency of settlement, manure management system and environmental control systems (Banhazi and Cargill, 1999).

These pollutants in the barn are tried to be kept below harmful levels with environmental control systems such as the ventilation system. Otherwise, the accumulation of harmful gases in the ambient air above the limit values may cause risks to the health of animals and workers. These risks can be seen in workers as poisoning, chest wheezing, chronic lung infections, cough, lung diseases such as bronchitis, pneumonia and asthma, and decreased lung function (Latenser, 2000). On the other hand, pollutants removed from barns can cause odor and pollution in the immediate environment. In addition, it can cause eutrophication, nitrification, climate change, acidification in the soil, reduced visibility in the atmosphere and environmental damage reaching significant dimensions such as global warming (Marcillac, 2007).

The decrease in the O_2 ratio in the composition of the barn air adversely affects the farm animals. Respiratory difficulties occur when the O_2 rate falls below 11%, and death results when it falls below 7%. The ratios of other gases that pose a problem for animal health in the barn air should not exceed 0.35% C₂O, 0.03% NH₃ and 0.001% H₂S (Mutaf and Sonmez, 2012). On the other hand, Olgun (2011) gives the maximum permissible concentrations of some harmful gases for animals in barns in ppm. Accordingly, carbon dioxide should not exceed 3000 ppm, ammonia 20 ppm, hydrogen sulfide 0.5 ppm and methane 10000 ppm. The source of air dustiness in barns is the animal itself, litter and feed. Airborne dust causes various allergies and toxic effects. For this reason, dust concentration should not be allowed to be more than approximately 1.7 mg/m³ in animal production structures.

Ammonia is found in the atmosphere in different forms such as the main pollutant, combined with other compounds and secondary pollutants as a result of reactions in the atmosphere (Chetner and Sasaki, 2001). Ammonia from animal barns is the product of microbial decomposition of organic nitrogen compounds in manure. Nitrogen in manure occurs as unabsorbed nutrients, urea (mammals) or uric acid (poultry). Urea and uric acid are rapidly hydrolyzed to form ammonia and are dispersed shortly after feces are excreted (Oenema et al., 2001). Globally, it is estimated that around 20 million tons of ammonia nitrogen emissions occur annually from animal barns. This amount constitutes approximately 50% of the total ammonia emissions originating from the terrestrial system (Galloway and Cowling, 2002).

The most common sulfur compound produced in animal barns is hydrogen sulfide (H2S) and is released into the atmosphere by ventilation. Hydrogen sulfide emissions from animal barns are very low on a global and national scale compared to other atmospheric sulfur sources (soils, volcanoes, swamps, burning of fossil fuels). This means that hydrogen sulfide emissions from animal barns contribute little to the ecosystem. However, on a regional scale, it contributes significantly to the sulfur load of the atmosphere for animal barns and areas with high concentrations of few other resources (Schnoor et al., 2002).

Methane is an important air pollutant to be considered due to its contribution to global warming and greenhouse effect. Due to the long residence time of methane in the atmosphere (approximately 8.4 years), it is distributed on a global scale. The global warming potential of methane is 23 times greater than that of carbon dioxide (NRC, 2002). Methane emission in livestock is due to the digestive system of ruminant animals, manure fermentation (during storage and after application to the field) and silage fermentation (Anonymous, 2004).

Carbon dioxide (C_2O) emissions from animal production do not contribute to the atmospheric carbon dioxide concentration in the long run. Carbon dioxide from animal barns can be considered as part of the carbon cycle from the atmosphere to plants and animals and returns to the atmosphere for a relatively short period of time (Anonymous, 2004). The main source of carbon dioxide generated in animal barns is the respiration of animals and workers (Choiniere and Munroe, 1997).

Ventilation and Ventilation Systems

Animals emit heat, water vapor and various gases to their barn environment. The heat, humidity, bad odor and gases given into the barn by the animals should be thrown out of the barn before they reach a level that can be harmful to the animals. This can be achieved by air exchange within certain limits between the external environment and the barn (Ekmekyapar, 1991).

Ventilation in barns is done for different purposes according to different seasons. The main purpose of ventilation in the winter season is to keep the relative humidity inside the barn at the desired level by removing the excess moisture and harmful gases accumulated in the barn from the barn environment. Ventilation for this purpose gives the minimum capacity of the ventilation system. The main purpose of the ventilation in the summer season is to remove the excess heat accumulated in the barn environment from the barn environment in parallel with the rate of formation and to keep the temperature inside the barn at the desired value. Ventilation for this purpose gives the maximum capacity of the ventilation system. The amount of ventilation made for the heat and humidity balance in the barns also eliminates the harmful gases and dust accumulated in the barn environment and provides sufficient clean air to the barn (Kocaman and Kurc, 2017).

In order to create optimum climatic environmental conditions, in animal barns, the air inside the barn must be changed at least 4-6 times per hour during the winter season. During ventilation, a breeze or draft should not be created inside the barn. In suitable temperature conditions, it is appropriate that the air velocity in the barn is between 0.1- 0.5 m/s, depending on the type of animal being housed. Especially at low temperatures, high air velocity can have dangerous consequences for animals. In very hot seasons, increasing the air velocity around the animals up to 1.5 m/s can be relatively beneficial in reducing the negative effects of high temperature on animals. However, a ventilation rate of more than 2.5 m/s is harmful for animals in all weather conditions (Ekmekyapar, 1991; Olgun, 2011). In order to remove excess heat, excess moisture or harmful gases accumulated in the barn environment according to different seasons, the ventilation capacity of ruminant animals should be minimum 0.35 m³/h/kg and maximum 3.5 m³/h/kg depending on live weight (Wathes and Charles, 1994).

Ventilation systems applied in animal barns are grouped as natural and mechanical systems according to the thrust that moves the air. In the natural ventilation system, the entrance of the air into the building is provided by natural forces. The temperature difference between the inside of the barn and the outside air, the wind speed and direction, the height difference between the

air inlet and outlet openings, the size of the air inlet and outlet openings, the climatic conditions of the region and the roof slope significantly affect natural ventilation.

Natural ventilation systems are widely used in water buffalo enterprises. There are two main elements of the natural ventilation system. These are the air inlet and air outlet openings. The use of a transom window or under the eaves as an air intake opening is suitable as it will protect the water buffaloes against possible drafts. Individual air intake holes left at regular intervals in the long walls can be left on one or both of the long walls of the barn. To increase ventilation efficiency, such openings are placed as close to the floor as possible. The air intake holes should be arranged in such a way that the fresh and cold air that enters in the winter season is directed upwards along the walls. The dimensions of the air inlet holes can be 5x75 cm, 10x40 cm or 15x30 cm (Olgun, 2011).

In closed-type water buffalo barn projects, the use of under eaves air intake opening should be preferred as it will minimize the cold stress that may occur in water buffaloes, especially in winter. The cross-section of the air inlet opening under the eave is given in Figure 1 (Kocaman, 1998).



Figure 1. Air inlet section under eaves recommended for closed type water buffalo barn projects

The air outlet openings serve to evacuate the polluted, humidified and heated air used by the animals inside the barn to the outside of the barn. In natural ventilation, the air outlet openings can be either in the form of ventilation shafts placed at regular intervals on the roof or continuous openings left along the ridge line.

Ventilation shaft sections can be circular or square. For effective ventilation, chimney dimensions should not be smaller than 40x40 cm and larger than 100x100 cm. In order to increase the suction power of the chimney, attention should be paid to the chimney insulation and the height of the chimney from the ridge should be at least 50 cm. In addition, in cases where more than one chimney is required, the cross-sections and heights of the chimneys should be the same. The height difference between the air inlet opening and the upper level of the air outlet chimney should not be less than 1.0-1.5 m. When calculating the number of chimneys, a chimney should be calculated for a 100 m² barn floor area (Olgun, 2011).

It is appropriate to use the lantern type opening left in the ridge along the length of the barn as the air outlet opening. The lantern type air outlet opening can be applied successfully especially in barns with gable roofs. The ridge opening should not be narrower than 15 cm. The lantern-type ventilation system not only increases the efficiency of ventilation, but also prevents precipitation waters from entering the barn in rainy weather. The cross section of the lantern type ventilation system that can be used in closed type water buffalo barns is given in Figure 2 (Kocaman et al., 2007).



Figure 2. Cross-sectional view of the lantern type air outlet opening

In case of planning a lantern-type air outlet opening in barns, the values given in Table 1 can be taken as basis.

Barn base width (m)	W (cm)	W/2 (cm)	2W (cm)
7	15	7.5	30
9	18	9	36
12	24	12	48
15	30	15	60
18	36	18	72
21	42	21	84

Table 1. Lantern type air outlet opening dimensions

Controlled and optimal ventilation in animal barns can be done with a mechanical ventilation system. In this system, the pressure difference between the indoor and outdoor environment is provided by fans. Mechanical ventilation systems can be applied in three ways: suction, where aspirators are used, pressure where fans are used, and combined systems where both types of fans are used together. In suction systems, the barn air is discharged with the help of one or more aspirators. In this way, due to the low pressure formed in the barn, the outside air enters through the air inlet openings. In pressurized systems, high pressure is created inside by pressing the outside air into the barn with the help of ventilators. The air inside the barn is discharged from the air outlet openings. In combined systems, ventilators and aspirators are used together. Combined ventilation systems can be recommended to be used mostly in barns with a building width of 15 m and above (Ekmekyapar, 1991).

Mechanical ventilation systems have some advantages and disadvantages compared to natural ventilation systems. Its superior aspects are that it provides controlled ventilation, the ventilation surfaces are small, it is not affected by the wind and its operation can be controlled automatically. The drawbacks are that the system is noisy, requires electrical energy to operate, and requires maintenance costs because it has moving parts (Bodman, 1987; Balaban and Şen, 1988).

Cooling Systems

Water buffaloes are more sensitive to heat stress than other cattle due to their physiological and genetic structures. These animals try to cool off in streams, lakes or ponds to get rid of heat stress in their natural environment. However, water resources in nature may not always be clean. The fact that buffaloes try to cool off especially in stagnant water sources and pollute these water sources with their urine and feces accelerate the pollution process and cause much more negative conditions in terms of animal-environment and human health (Figure 3).



Figure 3. A buffalo trying to cool off in a manure and rainwater puddle

On the other hand, the natural habitats of water buffaloes are decreasing due to various reasons. The natural habitats are replaced by shelters built in different types. Therefore, some precautions should be taken in order for the water buffaloes raised in the barns to get rid of the heat stress. The most fire system in practice is the construction of cooling pools. However, cooling pools bring extra burden to farmers due to space occupation, construction and operating costs.

It is possible to reduce the negative effects of heat stress in existing and newly planned water buffalo businesses, in summer and transition seasons when the ambient temperature is high, with simpler and more economical methods that are easy to apply. Heat stress in farm animals is generally effective at temperatures above 25 °C. In barns, it is desirable to keep the ambient temperature below this value. It can also be considered to reduce the temperature inside the barn by means of mechanical cooling methods. However, it is mostly not economical as it requires large investment and operating expenses. For this reason, it is more economical to apply the cooling method with the fogging system, which has lower initial establishment costs compared to mechanical cooling methods, in animal barns.

The basis of the fogging system is based on the evaporation of the water mass by inserting it into the unsaturated air. The heat required for the evaporation of water is taken from the sensible heat of the air. In other words, the sensible heat of the air turns into latent heat in the steam, and as a result, the

air temperature decreases. With a well-planned fogging system, the temperature inside the shelter can be reduced by 6-10 °C. The system works more effectively in regions with high humidity deficit.

The fogging cooling method can be successfully applied in both naturally ventilated closed barns and open barns. In the method, water is sprayed into the shelter air with the help of a high-pressure pump, in the pressure range of 70 to 120 bar, with diameters less than 20 microns, in the form of fog, with the help of nozzles (Figure 4).



Figure 4. Giving the water to the shelter environment in the form of fog with the nozzle in the line system

The spraying of water in very fine particles is closely related to the pressure of the water and the spray heads. For the method to be successful, In addition to the number of water spray nozzles and the distance between them, it is necessary to choose the water spray interval well depending on the temperature. In practice, nozzle carrier lines should be passed in the resting place of closed type or semi-open barns so that one nozzle falls on each water buffalo. Nozzle carrier lines are suitable for passing water buffaloes 100-150 cm above the withers. The nozzle diameter to be selected is 0.3 or 0.5 mm, which increases the efficiency of the system. The fogging time and interval can be easily adjusted via the high-pressure pump. In this way, excessive wetting of the shelter floor and water buffaloes are prevented from being disturbed by excessive moisture. In addition, it is possible to operate the system at the desired temperature and humidity with the help of a temperature-humidity sensor to be placed in a suitable place in the barn. It is more appropriate to use well water, if available, instead of normal mains water in the system. Because the temperature of the well water is lower than the mains water in hot periods, the cooling efficiency increases.

Especially in regions where the temperature is higher, a fan fogging system can be used instead of the line system (Figure 5).



Figure 5. Fan fogging system

In this method, water is transferred to the shelter environment as mist with the help of nozzles placed on the fan with a mechanism. The cooling effect of the system is increased by moving the air with the help of the fan and spreading the fog to the barn environment effectively. It is appropriate to place 2-3 fans for 100 m^2 barn floor area in closed type barns. The operation of the fans can be controlled with the help of the temperature or humidity sensor to be installed in the system. Likewise, in semi-open shelter systems, the heat stress of water buffaloes can be reduced by placing fans in the resting place.

Another method that can be used to cool water buffaloes in extreme heat in summer is the construction of cooling pools or artificial ponds in enterprises, as in natural environments. In the ponds or ponds to be built for this purpose, an area of $3-4 \text{ m}^2$ should be calculated for each adult water buffalo.

As a result, it is possible to increase the amount and quality of animal production, by carrying out breeding studies to improve the genetic structure, as well as by creating environments where climatic environmental conditions can be kept at optimum limits with a good feeding period.

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Chapter 13

Hybrid Desiccant Cooling Systems and Solar Assisted Methods

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ABSTRACT

Providing comfortable and healthy indoor conditions in residential and commercial spaces has become a significant concern, particularly in light of recent pandemic outbreaks such as COVID-19. With urbanization, the energy demand for cooling and air conditioning systems in hot climate countries is increasing day by day. Therefore, it is crucial to enhance the performance of these systems and integrate renewable energy sources. Solar energy, being easily accessible, diverse, and clean, is one of the most promising options. During the summer months, when cooling demand becomes a top priority, solar radiation is at its peak, making solar energy integration an attractive approach. In this study, hybrid cooling systems are introduced, which combine desiccant, evaporative cooling, and vapour compression refrigeration systems to achieve comfortable temperature and humidity conditions indoors. The methods for supporting these hybrid cooling systems with solar energy are explained. Solar energy can be utilized to regenerate the desiccant through thermal energy. The dehumidification process, with the thermal contribution of solar energy, enables more efficient evaporative cooling and improves the performance of the vapour compression refrigeration system. Moreover, solar energy converted into electricity through photovoltaic (PV) panels can be used to meet the energy needs, especially for high-power vapour compression refrigeration systems. In the case of dehumidification-evaporation systems, the relatively low electricity demand can be fulfilled using photovoltaic-thermal (PV/T) panels. In conclusion, the integration of solar energy, which coincides with the increasing cooling demand and solar radiation intensity, offers a more environmentally friendly and sustainable approach to climate control. This approach allows for enhanced performance, reduced reliance on conventional energy sources, and a greener future.

Keywords: Desiccant, dehumidification, evaporative cooling, vapour compression refrigeration, solar assist

INTRODUCTION

Ensuring comfortable and healthy indoor environments in residential and commercial settings has become a paramount focus, particularly given the recent occurrences of pandemic outbreaks like COVID-19. The energy demand for cooling and air conditioning systems in hot climate countries is increasing due to urbanization, making it crucial to enhance the performance of these systems and integrate renewable energy sources. It is important to consider the environmental impact of energy consumption, aiming to reduce CO2 emissions and minimize environmental pollution while ensuring human comfort. Solar energy is a readily available, diverse, and clean energy source that can be easily harnessed. Therefore, integrating solar energy becomes an attractive approach, particularly during the summer months when cooling demand is high and solar radiation is abundant (Alahmer and Ajib, 2020).

The comfort level of an indoor space relies on the dry bulb temperature and relative humidity. Cooling systems can be categorized as open or closed, depending on whether they exchange air with the outside environment. Closed cooling systems, like vapour compression refrigeration devices, lack independent control over both humidity and temperature. Conversely, open cooling systems enable air exchange from the outside, and humidity is regulated through the use of humidifiers and dehumidifiers to maintain indoor humidity levels. Solid or liquid desiccants can facilitate continuous drying when coupled with a regenerative heat source, and evaporative coolers provide effective cooling while also humidifying the air.

Cooling systems can be driven by either heat or electricity, depending on their type. Hence, solar energy, which can be harnessed through solar collectors to produce both heat and electricity, can offer versatile support to cooling systems. This study classifies hybrid cooling system types that incorporate desiccants and explores various methods for integrating solar energy to enhance these hybrid systems.

Components of Hybrid Desiccant Cooling Systems

ASHRAE standards emphasize the importance of achieving proper indoor conditions, including appropriate dry bulb temperature, controlled humidity levels, and clean air, to ensure a comfortable environment for occupants. Various air conditioning methods can be employed to meet these comfort requirements. Integrating desiccant systems with evaporative cooling and vapour compression refrigeration systems has emerged as a promising research area for improving the performance of cooling systems and enhancing indoor air quality. Solar energy can be utilized in air conditioning systems in two main forms: heat and electricity. Given the correlation between solar radiation and cooling demand, leveraging solar energy to drive or assist cooling systems is a beneficial approach for reducing energy consumption.

Desiccant Systems

Desiccant systems are designed to remove moisture from the air by utilizing the partial pressure difference of water vapour between the air stream and the desiccant material. The humid air passes through the desiccant material, which results in dehumidified air exiting the system. However, this dehumidification process reduces the ability of the desiccant material to continue dehumidifying the air. To maintain continuous operation, the moisture in the desiccant material needs to be removed through a regeneration process. Regeneration can be achieved by using a dry hot air stream to absorb the moisture from the desiccant material and dehumidify it. This process is known as desiccant material regeneration. The heat for regeneration can be provided by various sources such as solar energy, waste heat, or auxiliary heaters. Comprehensive reviews on solid desiccant systems are available in the literature for further knowledge (Rambhad et al., 2016) (Jani et al., 2016).

Depending on the type of desiccant material used, desiccant systems can be divided into two groups: solid desiccant systems and liquid desiccant systems. In solid desiccant systems, regeneration can be accomplished using a rotating desiccant wheel, where moist and dry air streams flow in opposite directions, enabling sustained humidification and dehumidification. In certain applications, solid desiccant can be coated onto heat exchangers, but the regeneration of the desiccant material requires alternating heating and cooling using a discrete or redundant loop. In liquid desiccant systems, the liquid desiccant is then pumped to a regenerator. In the regenerator, the temperature of the diluted desiccant initially rises through heat exchange, and then the hot diluted desiccant to the air. Comprehensive reviews on liquid desiccant systems can be found in the literature for further knowledge (Sahlot and Riffat, 2016) (Salikandi et al., 2021).

Evaporative Cooling (EC) Systems

Evaporative cooling is a process that involves the conversion of sensible heat in the air to latent heat through the evaporation of water. As water changes from a liquid to a vapour state, it absorbs heat from the air, resulting in a decrease in

air temperature. Due to the nature of the evaporative cooling process, the cooling capacity is greatly influenced by the humidity of the incoming air, and the temperature reduction is limited by the dew point of the outgoing air. To overcome these limitations, desiccant systems are integrated with evaporative cooling systems to provide dehumidified air supply and increase sensible heat loss.

Evaporative cooling systems can be classified into two types: direct evaporative cooling (DEC) systems and indirect evaporative cooling (IEC) systems. In DEC systems, ambient or dehumidified air passes through a stream of water or a water-soaked pad, absorbing moisture from the water. As a result, the air becomes cooled and humidified, and it is then supplied to the conditioned space. It is important to note that a humidity level above 60% is not desirable for human comfort, so evaporative cooling should be carefully controlled.

IEC systems, on the other hand, utilize two separate air flows that do not come into direct contact with each other. The primary air flow is responsible for meeting the cooling demand of the space, while the secondary air flow is cooled and humidified by the DEC system. Heat is transferred from the primary air flow to the secondary air flow through a heat exchanger, without any increase in moisture content. While both DEC and IEC systems are influenced by ambient temperature and humidity, the cooling efficiency of IEC systems is generally lower due to the additional heat transfer process in the heat exchanger. However, IEC systems provide drier air, which is more suitable for achieving a comfortable indoor environment. For a more in-depth understanding, extensive literature reviews on evaporative cooling systems are available (Yang et al., 2019).

Vapour Compression Refrigeration (VCR) Systems

Vapour compression refrigeration (VCR) systems are widely used in refrigeration applications due to their high coefficient of performance (COP) and versatility in meeting various cooling demands. The working principle of a VCR system is based on the thermodynamic cycle of the refrigerant, which flows through the compressor, condenser, expansion valve, and evaporator. The refrigerant undergoes expansion in the expansion valve, which lowers its temperature below the indoor space temperature. In the evaporator, heat is absorbed from the space and transferred to the refrigerant, causing the refrigerant to evaporate fully. The compressor then increases the pressure and temperature of the refrigerant, allowing it to be condensed in the condenser by releasing heat to a high-temperature heat source. The condensed refrigerant flows back to the expansion valve, completing the refrigeration cycle. The COP of a VCR system is defined as the ratio of evaporator heat gain to the total work input of the compressor and accessories.

In certain applications, alternatives to using a compressor as the driving force for refrigeration have been developed, leading to the emergence of vapour absorption and adsorption refrigeration (VAR) systems in the market. These systems utilize heat, such as solar energy and waste heat, as the driving force. The temperature of the heat supply directly affects the temperature of the refrigerant in the condenser, resulting in lower COP values for VAR systems compared to VCR systems. When designing a high-performance solar hybrid cooling system, it is important to consider the most efficient utilization of solar energy. Due to the lower COP values of VAR systems, desiccant regeneration coupling with VCR becomes a preferable choice for utilizing solar energy effectively.

Hybrid Configurations and Solar Assisted Methods

Each air conditioning system plays a specific role in providing optimal indoor conditions, and many space cooling applications require simultaneous control of fresh air, relative humidity, and dry bulb temperature. To meet these requirements, various studies have explored the combination of desiccant systems (DS), evaporative cooling (EC), and vapour compression refrigeration (VCR) systems (Kapilan et al., 2023). By integrating these systems, it becomes possible to achieve high performance and create a comfortable indoor environment. Furthermore, solar energy can be utilized to support these hybrid systems, although the specific methods may vary depending on the system configuration. The integration of solar energy can enhance system efficiency, reduce energy consumption, and contribute to sustainable and environmentally friendly cooling solutions.

Solar Dehumidification and Evaporative Cooling (S-DH-EC) Systems

The evaporative cooling (EC) system requires dry outside air to achieve a significant decrease in dry bulb temperature. Therefore, humidity plays a crucial role in determining the effectiveness of EC systems (Sezen and Gungor, 2023). On the other hand, the desiccant-based dehumidification (DH) system uses desiccant material to remove moisture from the air. The desiccant material needs to be regenerated using a heat source, and solar thermal energy, collected by solar collectors, is commonly used for this purpose.

In the case of solid desiccant wheels, low relative humidity is required for the regeneration process. To meet this requirement, solar energy is utilized to

heat the return air using a water-to-air heat exchanger. Additionally, the outdoor air passing through the desiccant wheel preheats the return air, enabling heat recovery and benefiting both the cooler supply air and the hotter regeneration air. A schematic view of S-DH-EC system is illustrated in Figure 1.

The utilization of solar energy in the form of heat allows for effective drying and improved evaporative cooling. Furthermore, solar energy can also be harnessed through photovoltaic thermal collectors (PV-T) to meet the relatively low electricity demand of the system.



Figure 1: Schematic view of S-DH-EC system

Solar Dehumidification, Evaporative Cooling and Vapour Compression Refrigeration (S-DH-EC-VCR) Systems

In hot and humid climates, S-DH-EC systems alone may not be sufficient to meet the cooling demands, so an additional cooling coil is integrated into the systems. This additional cooling system serves as the final cooling device for the supply air, solely focusing on reducing the temperature. Among the sensible heat cooling systems, vapour compression refrigeration (VCR) systems have proven to be highly efficient. However, VCR systems rely on electricity, contributing significantly to the overall energy consumption of the cooling system due to the power requirements of the compressor and air fans.

Solar energy presents a solution to reduce electricity consumption through the use of photovoltaic (PV) panels. While DH systems require thermal energy for regeneration, PV/T solar collectors can simultaneously supply both the electricity and thermal energy demands. Furthermore, the waste heat generated in the condenser of VCR systems can be utilized to meet the heat demand for desiccant regeneration. A schematic view of PV/T assisted S-DH-EC-VCR system is given in Figure 2.



Figure 2: Schematic view of PV/T assisted S-DH-EC-VCR system

Solar Dehumidification, Vapour Compression Refrigeration (S-DH-VCR) Systems

When the air entering the VCR's evaporator is less humid, it allows for a greater temperature drop before condensation occurs. This enables an increase in the refrigerant evaporator temperature while maintaining the same cooling power, leading to improved performance of the VCR (Sezen and Gungor, 2022). In this regard, DH (dehumidification) systems can assist in enhancing the performance of VCR systems by supplying dehumidified air to the evaporator.

However, it is important to note that if the dehumidification process raises the air temperature, it can nullify the performance benefits of dry air and may even become detrimental. Nevertheless, in humid conditions where evaporative cooling is undesirable, the desiccant provides moisture retention, and the VCR is solely responsible for the sensible temperature drop, avoiding the moisture condensation task. This arrangement enhances the system performance. Schematic view of S-DH-VCR system is shown in Figure 3.

Solar energy can drive the DH system through solar thermal collectors, while it can also power the VCR system through PV panels. PV/T solar collectors have the advantage of simultaneously supplying both the thermal and electrical energy demands, resulting in higher overall system efficiency.



Figure 3: Schematic view of S-DH-VCR system

RESULTS AND DISCUSSION

The cooling requirement of a living environment can be achieved through a combination of vapour compression refrigeration (VCR) systems, evaporative cooling (EC) systems, and dehumidification (DH) systems, providing a comfortable temperature, relative humidity, and fresh air. In this study, hybrid desiccant cooling systems are introduced, and the methods for supporting them with solar energy are explained.

Solar energy can be utilized to provide the regeneration of the desiccant in the form of thermal energy. The air dehumidified with the thermal contribution of solar energy allows for more efficient evaporative cooling and even improves the performance of the VCR. The solar energy converted into electricity through PV (photovoltaic) panels can be used to meet the energy needs, especially for VCR systems with high power requirements. In the case of dehumidification-evaporation systems, the relatively low electricity demand can be met by using PV/T panels.

In conclusion, the integration of solar energy, which coincides with the increasing cooling demand and solar radiation intensity, offers a more environmentally friendly and sustainable approach to climate control. This approach allows for enhanced performance, reduced reliance on conventional energy sources, and a greener future.

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Chapter 14

Determination of Energy and Exergy Analysis with Artificial Intelligence According to the Environmental Conditions of a Gas Turbine Compressor

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ABSTRACT

Gas turbines are devices that play an important role in energy conversion and are generally used in electricity generation. Determining the efficiency of gas turbines with artificial intelligence is an important application area in the energy sector. Artificial intelligence can be used to increase the efficiency of gas turbines, thanks to its ability to analyze large amounts of data and solve complex models. Appropriate machine learning models are created for artificial intelligence to determine the efficiency of the gas turbine and these models are trained with training data. Models can make yield predictions using the learned information. In this study, the energy efficiency and exergy destruction of a gas turbine were estimated according to the compressor inlet and outlet air temperatures and power values. Accordingly, energy efficiency was estimated with an error of 6.83×10^{-5} and exergy destruction was estimated with an error of 6.96×10^{-5} .

Keywords: Exergy analysis, Energy analysis, Artificial Neural Network

INTRODUCTION

Gas turbines are important energy conversion devices used in many fields such as electricity generation, aircraft propulsion systems, maritime transport and industrial processes. The efficiency, fuel consumption and environmental impact of these turbines constitute one of the main problems of modern industrial and energy sectors. Energy and exergy analvzes are used to evaluate the performance of gas turbines. Energy analysis provides energy balance by calculating the amount of energy entering and leaving the system. Exergy analysis is a method that evaluates the usability and efficiency of work. These two analyzes provide important information for optimizing the operating conditions of gas turbines and increasing their efficiency. In addition, artificial intelligence techniques have received great attention in energy systems and industrial applications in recent years. Artificial intelligence technologies such as deep learning, genetic algorithms and fuzzy logic are effectively used in the analysis and improvement of complex systems. In this study, the energy and exergy analyzes of gas turbines with artificial intelligence methods offer the potential to obtain faster and more effective results than traditional analysis methods.

Lu et al. In the MATLAB program, optimization was carried out to find the best solution with maximum energy efficiency and lowest total cost. For this, they first made calculations in the Engineering Equation Solver

(EES) software. Afterwards, they developed an artificial neural network model to see how optimization and operational factors affect thermodynamic performance and total cost ratio. In this way, they revealed the connections between the objective function and the selection factors in order to determine the optimal point of the energy system (Lu et al. 2023). According to Assari et al. They calculated different parameters such as pump and turbine inlet pressures, pump and turbine efficiencies, evaporator pinch point and inlet temperature using the Non-Dominant Sequence Genetic Algorithm II (NSGA-II) (Assari et al. 2023). Haghighi et al. thermodynamic analysis of high temperature proton exchange membrane fuel cell. They did not calculate and optimize thermodynamic irreversibility, exergy efficiency and exergy efficiency by using genetic algorithm in MATLAB (Haghighi et al. 2016). Farahat et al. Energy and exergy analysis were performed to evaluate the performance of a solar powered mechanical vapor compression desalination system with nano filtration pretreatment. The results calculated with MATLAB were compared with the existing results (Farahat et al. 2021). According to Malwe et al. In their study, they analyzed the integrated vapor compression refrigeration system. To calculate Coefficient of Performance (COP), exergy efficiency and exergy destruction, a custom and validated dynamic model was created using MATLAB-Simulink (Malwe et al. 2022). Aized et al. They created a thermodynamic model in the EES software for six different refrigerants and calculated the performance results. The results have compared the performance parameters in the MATLAB program. Accordingly, they showed that the compressor has the highest exergy destruction compared to other components (Aized et al. 2022). According to Zahedi et al. They analyzed thermodynamic and economic models. They optimized the exergy-economic cycle in order to reduce costs and increase exergy with MATLAB software (Zahedi et al. 2021). Hai et al. They examined an absorption cooling system and a flash distillation system for seawater desalination. They performed a basic analysis of the system with the EES software. They imported the results into MATLAB software to optimize and evaluate the impact of operational factors. For this purpose, they used artificial intelligence to evaluate and model the analysis outputs of the EES software (Hai et al. 2023).

In this study, it is focused on the determination of energy and exergyanalysis with artificial intelligence according to the environmental

conditions of a gas turbine compressor. Energy and exergy analyzes are critical to understanding and optimizing system performance by evaluating energy transfer and losses.

MATERIAL VE METHOD System description and thermodynamic analysis



Figure 1. Gas turbine compressor [9]

In the gas turbine in Figure 1, the air entering in the 1st state leaves the compressor with the temperature and pressure increase in the 2nd state (Shklyar et al. 2010).

Energy and exergy analysis is an important tool for evaluating and optimizing the performance of a gas turbine compressor. These analyzes can help make design and operational changes to increase efficiency, reduce energy consumption and minimize exergy losses. Necessary gas properties and

thermodynamic properties of the system should be taken into account in order to obtain accurate and reliable results of the analysis (Cengel 2011, Dincer 2012, Bejan et al.1996, Klein 2020).

For steady state in thermodynamic analysis, the basic mass balance equation can be given as follows;

$$\sum \dot{m}_{in} = \sum \dot{m}_{ex} \tag{1}$$

where is the mass flow rate, the in and ex indices represent the inlet and outlet states, respectively. The energy balance is given as:

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \dot{m} \left(h + \frac{v^2}{2} + gz \right) = \dot{Q}_{ex} + \dot{W}_{ex} + \sum_{ex} \dot{m} \left(h + \frac{v^2}{2} + gz \right)$$

$$gz \right)$$

$$(2)$$

Here, \hat{Q} is the heat transfer rate, , is the power, h is the specific enthalpy, v is the velocity, z is the height, and g is the gravitational acceleration. The entropy balance equation for steady-state conditions is written as:

$$\sum_{in} \dot{m}_{in} s_{in} + \sum_k \frac{Q}{T_k} + \dot{S}_{gen} = \sum_{ex} \dot{m}_{ex} s_{ex}$$
(3)

where s is the specific entropy and S_{gen} is the entropy generation rate. The exergy balance equation can be written as:

$$\sum \dot{m}_{in} e x_{in} + \sum \dot{E} x_{Q,in} + \sum \dot{E} x_{W,in} = \sum \dot{m}_{ex} e x_{ex} + \sum \dot{E} x_{Q,ex} + \sum \dot{E} x_{W,ex} + \dot{E} x_D$$
(4)

The specific flow exergy can be written as:

$$ex = x_{ph} + ex_{ch} + ex_{pt} + ex_{kn} \tag{5}$$

The kinetic and potential parts of the exergy are assumed to be negligible. Also, the chemical exergy is assumed to be negligible. The physical or flow exergy (ex_{ph}) is defined as:

$$ex_{ph} = (h - h_o) - T_o(s - s_o) \tag{6}$$

where h and s represent specific enthalpy and entropy, respectively, in the real case. h_o and are enthalpy and entropy at reference medium states, respectively.

s,

Exergy destruction is equal to specific exergy times mass;

$$\dot{E}x_{D} = ex * m \tag{7}$$

 $\dot{E}x_{D}$, are work-related exergy ratios and are given as:

$$\dot{E}x_{D} = T_{0}\dot{S}_{gen} \tag{8}$$

 $\dot{E}x_W$, are work-related exergy ratios and are given as:

$$\dot{E}x_W = \dot{W} \tag{9}$$

 $\dot{E}x_Q$, are the exergy rates related to heat transfer and are given as below.

$$\dot{E}x_Q = \left(1 - \frac{T_Q}{T}\right)\dot{Q} \tag{10}$$

Exergy destruction within the system;

$$\dot{E}x_{D,syst.} = \dot{E}x_{in} - \dot{E}x_{aut} \tag{11}$$

What work comes out of the system;

$$\dot{W}net_{out} = \dot{Q}_{in} - \dot{Q}_{out} \tag{12}$$

system thermal efficiency (η) ;

$$\eta = \frac{energy \ in \ exit \ outputs}{total \ energy \ inlets} \tag{13}$$

The exergy efficiency (ψ) can be defined as follows;

$$\psi = \frac{exergy \text{ in exit outputs}}{\text{total exergy inlets}}$$
(14)

The mass, energy, entropy and exergy balance equations for Compressor component can be defined as follows; (Elbir et al.,2022)

Mass Balance:	$\dot{m}_1 = \dot{m}_2 = \dot{m}_{air.}$	(15)
Energy Balance:	$\dot{W}_{Comp,=}\dot{m}_{air.}(h_2-h_1)$	(16)
Entropy Balance:	$\dot{S}_{\bar{u}rt,Comp.} = \dot{m}_{air.}(s_2 - s_1)$	(17)
Exergy Balance:	$\dot{E}x_{D,Comp.} = \dot{m}_{air.}(ex_1 - ex_2) + \dot{W}_{Comp.}$	(18)

Artificial neural networks

Artificial neural networks (ANN) are a model of artificial intelligence originally designed to replicate the learning process of the human brain. It can perform learning, prediction, classification, feature detection, association, generalization and optimization (Ağyar 2015). The neural network model consists of three main layers: the input data layer, the hidden layer or layers, and the output layer. The neural network has a rule for adjusting the strength or weight of links between units in response to externally provided data (Stanley et al. 1998). In 1943, neurologist Warren

McCulloch and mathematician Walter Pitts modeled the first simple neural network with the help of electrical circuits by considering the computational feature of the human brain (Şahin, 2023).



Input Weight Bias Activation Function Figure 2. Artificial neural network model

Figure 2 shows an artificial neural network model. Here x (x1, x2, ..., xn) represents the inputs. n data entries can be made. These inputs are multiplied by the weights (w1, w2, ..., wn) and all of this input weight product data is summed. Then bias (b) is added. The sum function is as given in Equation 19.

$$net = \sum_{i=1}^{n} w_i x_i + b \tag{19}$$

In order to obtain the data output (y), the net input is passed through an activation function (f) (Equation 20).

$$y = f(net) = f(\sum_{i=1}^{n} w_i x_i + b)$$
 (20)

The activation function is linear or nonlinear functions that determine the output of the neural network model. Sigmoid, hyperbolic tangent, gaussian, linear and step functions are used as activation functions. It is important to choose this function correctly as it will affect the output of the model. The sigmoid and hyperbolic tangent functions are the most widely used. If the average behavior of a network model is to be learned, the sigmoid function is preferred as the activation function Khotanzad et al. 2000).

FINDINGS

The Neural Network application of the MATLAB program was used for modeling, training and testing of the artificial neural network. In order to create an artificial neural network model, the type of network, input and output data for training, algorithms for training and learning, performance function, number of input and output layers, number of hidden layers, if any, and activation function were determined. The multilayer feedforward backpropagation algorithm, which is the most widely used method to make predictions based on a data set, has been chosen as the network type. As the input layer of a gas turbine compressor contains inlet air temperature, outlet air temperature and power values, it consists of three cells, and the output layer consists of two cells for energy efficiency and exergy destruction. In this study, many experiments were carried out for the artificial neural network model and the model with the best performance was selected. The artificial neural network model created is shown in Figure 3.



Figure 3. The artificial neural network model created

According to the created network model, momentum coefficient, learning coefficient and number of cycles parameters are determined in order to realize the training. As a result of the training; The ROC (Receiver Operating Characteristic) curve regression graph for the training, validation and test sets is shown in Figure 4. According to this graph, the learning value was 0.99967, the validation was 0.9998, and the test was 0.99969.



Figure 4. ROC curve

At the end of the training, the test process was carried out so that the artificial neural network could predict the output according to the input data. Accordingly, the actual values and the estimated values are shown in Figure 5 and Figure 6.



Figure 5. Energy efficiency estimation graph



Figure 6. Exergy destruction estimation graph

Simple error deviation value was used as in Equation 21 to measure the estimation accuracy. Here (e) error, (x) predicted values and (xi) actual values (Bayır 2006).

$$\mathbf{e} = \mathbf{x} - \mathbf{x}^1 \tag{21}$$

The percent error (% p) of the estimation values can be calculated as in Equation 22.

$$\mathbf{p} = \frac{\mathbf{e}}{\mathbf{x}^1} \mathbf{x} \mathbf{100} \tag{22}$$

One of the error criteria used to measure the consistency of prediction results in artificial neural networks is the Mean Squared Error (MSE) method, as shown in Equation 23.

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (x - x^{i})^{2} = \frac{1}{n} \sum_{i=1}^{n} (e)^{2}$$
(23)

Accordingly, the mean square error value was calculated as 6.83×10^{-5} for energy efficiency and 6.96×10^{-5} for exergy destruction.

RESULTS AND DISCUSSION

For the artificial neural network, the inlet-outlet temperature values and power values of the compressor of gas turbines are discussed. Accordingly, inlet temperature, outlet temperature and power values are taken as inputs, and energy efficiency and exergy destruction are taken as outputs. According to the calculations, 200 pieces of data were handled. 150 of these data were used for training,

10 for validation and 40 for testing. The created artificial neural network model is trained with training data. The estimated values with the test data in the trained network were found with an MSE error of 6.83×10^{-5} for energy efficiency and 6.96×10^{-5} for exergy destruction. The energy efficiency and exergy destruction values of the gas turbines according to the ambient conditions of the compressor were estimated at the rate of 99% with the help of the artificial neural network model.

In this article, the importance of determining the energy and exergy analysis with artificial intelligence according to the environmental conditions of the compressor of gas turbines is emphasized. As the applications of artificial intelligence techniques in the energy sector increase, the positive effects on the efficiency and performance of gas turbines will become more evident. This study will provide important guidance to researchers and engineers who want to increase efficiency and reduce environmental impacts in the energy sector.

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Chapter 15

Advancements in Robotic Integration: Navigating Everyday Environments and Enhancing Interaction Through Neural Networks

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Abstract

The integration of robotics into various aspects of human life has prompted an urgent need for robots to possess essential skills such as object recognition and navigational proficiency. Recent strides in robotics technology have ushered robots into domains like surveillance, quality control, and assisted living. This study delves into the optimization of neural networks for enabling robot navigation tasks. The investigation employs a support vector machine (SWM) structure and compares its performance against other neural network architectures using the same dataset derived from ultrasound sensor measurements. The SWM exhibits superior accuracy, achieving a remarkable average classification accuracy of 99.93%, outperforming other architectures. The findings underscore the potential of neural networks, particularly the PNN, in advancing robot navigation and fostering their integration into various applications. The study contributes to the growing field of robotics by offering mobile robot navigation capabilities.

Keywords: Wall-Following Robot Navigation, Support Vector Machine (Swm), Robot Control Systems

INTRODUCTION

The era in which robots were confined solely to assembly lines and fictional narratives has passed; they are progressively infiltrating domestic and occupational domains, becoming integral to daily existence. Nonetheless, for robots to effectively contribute to societal progress, the expertise of researchers and engineers remains indispensable in furnishing them with foundational capabilities that are often taken for granted, such as discerning objects and proficiently manoeuvring confined spaces [1].

Recent strides in the realm of robotics technology have yielded significant advancements, engendering profound impacts across a multitude of industrial sectors. Evidently, diverse applications of robotics have permeated various facets of our societal fabric, encompassing realms such as surveillance, quality control, the deployment of autonomous guided vehicles (AGVs), and automated cleaning apparatuses [2, 3]. Notably, robots are poised to usher in a new era as rehabilitation aides tailored to the elderly and differently-abled, epitomized by the development of intelligent wheelchairs. The infusion of cognitive capabilities into powered wheelchairs imbues them with the competence to navigate users to their intended destinations while upholding safety standards. In the context of negotiating confined passageways, a pivotal ability emerges wherein a robot must demonstrate rudimentary proficiencies, encompassing the recognition of corridors and the dexterity to perceive and circumvent obstacles. Illustratively, the corridor navigation agent employs machine vision techniques to process visual input, thereby discerning corridors, while the collision detection agent leverages neural network frameworks to interpret sensor data, adeptly sidestepping obstructions and walls. Given the requisite dynamism inherent in robots operating in environments necessitating rapid adaptation and adept responses to unforeseen occurrences, the adoption of incremental learning mechanisms emerges as a pivotal factor in facilitating the aforementioned qualities.

In situations where robots are enlisted as aides within household settings or for security-related applications involving interactions with the general populace, an essential facet of intelligent engagement resides in the capacity to acquire knowledge during the course of interaction. Notably, the absence of such learning capabilities confines robots to solely relying on pre-existing knowledge, leading to decisions founded upon a limited subset of potentially accessible information. To comprehensively participate in human or robotic communication, robots necessitate a dual proficiency encompassing real-time learning, characterized by a rate enabling assimilation of knowledge during interaction, and incremental learning, enabling supplementation of existing stored knowledge [4]. Recent advancements within the realm of the robotics industry have significantly streamlined the process of constructing robots, facilitated by the availability of commercial robot kits. The utilization of these kits offers the prospect of reusing robots and their associated control programs, due to the provision of advantageous development tools as part of the kit's package [5].

Within this context, a salient focus area pertains to the refinement of initial neural networks through learning processes. Empirical evidence gleaned from neural network experiences underscores the feasibility of swiftly developing controllers. As a result, diverse neural network models have emerged, aiming to optimize controllers in contemporary times (e.g. [6]). The deployment of systems grounded in soft computing methodologies emerges as a requisite for realizing high-MIQ (Machine Intelligence Quotient) products, characterized by machines mirroring the capacity of the human mind to operate in scenarios marked by uncertainty and imprecision. These techniques are anticipated to persist as principal approaches for the realization of interactive intelligent systems, as the engagement of machines with their environment and human counterparts mandates flexible and adaptive machine behaviors, coupled with the ability to effectively manage imprecise and uncertain measurements or additional system inputs [7].

At its core, a robot's behavior emanates from the intricate interplay of three fundamental components: the robot's hardware, the robot's controller, and the environmental context within which the robot operates. Sensory inputs from the environment are assimilated by the robot via its sensors, subsequently serving as input signals for the controller. This controller then computes the requisite motor commands, which the robot executes within the environment to accomplish desired tasks [8]. Given the inherent dynamism in the interactions between a robot's sensing and action components, combined with the susceptibility of robot sensors to even minor fluctuations in the environment, the interface between a robot and its environment assumes multifaceted, nonlinear, and often unpredictable characteristics, laden with complexity and occasional chaos [9, 10]. Owing to this inherent intricacy, the endeavor of robot programming, encompassing the design of control programs to attain desired behaviors, becomes a formidable challenge. Distinct from other engineering disciplines, the domain of robot programming lacks a formal, theory-driven design methodology that programmers can adopt to effectively program robots for specific tasks. Nevertheless, prior endeavors have demonstrated the potential for automation within the robot programming process: sensor-motor competencies in mobile robotics applications can be systematically modeled through automated and

algorithmic means, facilitated by robot training and system identification techniques [11].

Numerous contemporary challenges in the domain of mobile robotics find resolution through the application of diverse learning algorithms. Among these, reinforcement learning stands as the most prevalent technique in robot systems, affording the generation of a robot's policy, encompassing the mapping of world states to corresponding actions, facilitated by feedback garnered from the environment. In instances where real-world systems exhibit heightened complexity, conventional learning methods often prove inadequate, prompting recourse to learning distribution strategies to mitigate the intricacies. Furthermore, substituting reinforcement learning with supervised learning can yield improved outcomes. Consequently, an imperative arises for the establishment of a machine-learning framework tailored for the control of mobile robots. However, the harmonization of a learning algorithm with a mobile robot's controller proves intricate, primarily due to the limited computational resources and processing capabilities of the robot's on-board computer, thereby curbing the potential for effective learning [12].

The architecture of Support Vector Machines (SVMs) offers a comprehensive solution to the challenges of pattern classification, drawing inspiration from statistical methodologies such as maximum-margin classifiers. SVMs leverage a training dataset with labeled samples to establish decision boundaries that maximize the separation between different classes. This unique framework provides a robust means of tackling complex classification tasks, exhibiting advantages over traditional machine learning algorithms.

The essence of SVMs lies in their capacity to identify a hyperplane that optimally segregates distinct classes while maximizing the margin, which is the perpendicular distance between the hyperplane and the nearest data points from each class. By selecting the hyperplane that yields the largest margin, SVMs offer inherent resistance to overfitting and generalization issues, making them particularly well-suited for scenarios where data is not linearly separable.

SVMs inherently possess the ability to handle both linear and nonlinear classification tasks. Through the application of the "kernel trick," SVMs can map input data to higher-dimensional feature spaces, enabling the separation of complex classes that may not be linearly distinguishable in the original space. This flexibility extends their applicability to a diverse array of real-world challenges.

It is noteworthy that SVMs function optimally in scenarios with relatively small datasets, where they excel at identifying the most salient support vectors that dictate the placement of the decision boundary. However, in scenarios characterized by extensive datasets, SVMs may face computational challenges due to their quadratic time complexity.

The utility of SVMs extends beyond binary classification; they have been successfully extended to handle multiclass classification tasks through techniques such as one-vs-all and one-vs-one schemes. This adaptability showcases the versatility of SVMs in accommodating various classification scenarios.

Support Vector Machines (SVMs) encompass a range of distinctive benefits, including:

Effective Margin Maximization: SVMs prioritize the identification of decision boundaries that optimize the margin between different classes. This inherent emphasis on maximizing the margin leads to improved generalization, enhancing the classifier's performance on unseen data.

Flexibility in Nonlinear Tasks: SVMs' versatility is evident in their ability to handle nonlinear classification tasks. By employing kernel functions, SVMs transform data into higher-dimensional spaces, facilitating the separation of complex classes that are not linearly distinguishable in the original feature space.

Resistance to Overfitting: The emphasis on margin maximization inherently reduces the risk of overfitting, a common concern in machine learning. By maintaining a larger margin between decision boundaries and data points, SVMs exhibit robust performance even when dealing with noisy or sparse datasets.

Optimal Support Vector Selection: SVMs focus on the most relevant support vectors that dictate the placement of decision boundaries. This selectivity leads to a more compact and efficient representation of the data, reducing computational complexity and memory requirements.

Generalization to Multiclass Problems: SVMs naturally extend to multiclass classification problems through techniques like one-vs-all and one-vs-one. This adaptability allows SVMs to handle complex scenarios involving multiple classes.

Implicit Feature Selection: SVMs often lead to implicit feature selection, as only the most relevant features contribute to defining the decision boundaries. This attribute not only simplifies the learning process but also aids in enhancing model interpretability.

Consistency Across Different Datasets: SVMs' performance consistency across various datasets is noteworthy. Their robustness to variations in data distribution makes them a reliable choice for applications requiring consistent performance.

Global Optimality: SVMs are characterized by convex optimization problems, ensuring that they converge to a globally optimal solution. This characteristic

contrasts with some other machine learning algorithms that may converge to local optima.

Well-Studied Theoretical Foundation: SVMs are backed by a well-established theoretical framework, rooted in convex optimization and statistical learning theory. This theoretical foundation provides insights into their behavior and aids in model tuning and selection.

In summary, Support Vector Machines (SVMs) offer a multitude of advantages that make them a widely adopted choice in machine learning. Their focus on margin maximization, resistance to overfitting, and adaptability to various scenarios underscore their relevance in addressing complex classification tasks across different domains. In conclusion, Support Vector Machines (SVMs) offer a powerful solution for pattern classification problems, leveraging their unique capacity to identify optimal decision boundaries with maximized margins. Their adaptability to handle both linear and nonlinear classification, as well as their versatility in multiclass scenarios, underlines their significance in the realm of machine learning and data analysis [13].

This research presents an innovative perspective where the realm of robot navigation tasks holds potential utility for early target identification. The study employs a Support Vector Machine (SWM) configuration for addressing robot navigation tasks. Comparative analysis juxtaposes the outcomes of the SWM model with those of the Logistic Perceptron, Multilayer Perceptron, Mixture of Experts, and Elman neural networks, against the backdrop of prior research endeavors focusing on robot navigation tasks and employing the same dataset.

MATERIAL AND METHOD Data Source

The UCI machine learning repository accommodates an array of authentic real-world datasets that have been extensively employed by diverse researchers. A series of empirical investigations have been conducted to assess the capabilities of the Machine Learning Library. Notably, datasets hailing from the widely recognized UCI Machine Learning Repository [14] were utilized for this purpose. Presented below are the outcomes of learning exercises conducted on the Wall-Following Robot Navigation Data Set. This dataset is oriented towards classification tasks, with a focus on instructing a robot's movements to avert collisions with enclosing walls. The dataset was curated through the collection of measurements obtained from 24 ultrasound sensors, symmetrically arranged in a circular manner around the "waist" of the SCITOS G5 robot. This robot exhibits indoor operability and employs a differential motor system for locomotion. It sustains a platform weighing 60 kg and can achieve velocities of up to 1.4 m/s,

complemented by a 360-degree rotational capability and the capacity to manage loads of up to 50 kg. The robot's physical dimensions measure 570 mm in height, 735 mm in length, and 610mm in width, with a battery autonomy spanning 12 hours.

The computational hardware of the robot encompasses a Mini ITX motherboard, powered by an Intel Core Duo Processor operating at 1.6 or 2.0GHz, coupled with 2GB of RAM and a 120GB hard drive. It is equipped with various input interfaces, including PS/2 for keyboard and mouse, 5 USB ports, 3 Firewire ports, TV-out, RS232, VGA, SPDIF output, LVDS, and Ethernet 10/100 input along with onboard wireless networking capabilities, conforming to the IEEE 802.11a/b/g standard. The robot's software environment is founded upon Linux (Fedora 9) and employs the C++ API Robot library, developed by MetraLabs, which facilitates the creation of software tailored for controlling and navigating the SCITOS G5 platform. The robot's technical features also encompass wheel encoders capable of determining position based on 460 ticks per wheel rotation, a collision sensor, a belt housing 24 ultrasound sensors with a detection range spanning 20cm to 300cm, a SICK S300 laser sensor, and a robotic head housing an omnidirectional camera [15].



Figure 1. SCITOS G5 [15].

The Wall-Following Robot Navigation dataset pertains to a discrete set of classes, each corresponding to one of four distinct orientations for the robot's movement (Move-Forward, Slight-Right-Turn, Sharp-Right-Turn, Slight-Left-Turn). This dataset encompasses a total of 5456 instances, characterized by 24 continuous predictor variables and a singular class variable. The predictor variables encompass detailed descriptions of sensor readings, denoted as follows: US1 to US24, where each corresponds to an ultrasound sensor situated at various angles around the robot. Notably, these angles are referenced in degrees, ranging from -150° to 165°.

The dataset, in its entirety, consists of approximately 5456 instances, each bearing a corresponding label. The specific available movements and their corresponding class distributions are outlined in Table 1 [16].

Move	Samples in dataset	Class for NN
Move-Forward	2205 samples (40.41 %)	1
Slight-Right-Turn	826 samples (15.13 %)	2
Sharp-Right-Turn	2097 samples (38.43 %)	3
Slight-Left-Turn	328 samples (6.01 %)	4

Table 1. Characteristics of Wall-Following Robot Navigation Data Set

The provided datasets encompass three distinct sets of data. The initial dataset includes unprocessed measurements obtained from all 24 ultrasound sensors, along with their corresponding class labels. These sensor readings are sampled at a rate of 9 samples per second. The second dataset comprises four sensor readings denoted as 'simplified distances,' alongside their corresponding class labels. These simplified distances pertain to the 'front distance,' 'left distance,' 'right distance,' and 'back distance.' Notably, these distances are derived from the minimum sensor readings within 60-degree arcs situated at the robot's frontal, leftward, rightward, and rearward regions. The third dataset solely encompasses the front and left simplified distances, accompanied by their respective class labels. The creation of datasets with varying numbers of sensor readings was undertaken to assess classifier performance in relation to input quantity [17].

Beyond its role in navigation decision-making, the thread also assumes responsibility for transmitting pertinent data through the wireless network to a database situated on the supporting computer. This transmitted information encompasses 24 ultrasound readings, angular and positional coordinates (x, y), and translational and rotational robot velocities at that particular moment, the numerical label denoting the executed action corresponding to environmental settings, and the four simplified distances. A visual representation of the object arrangement within the test environment is illustrated in Figure 2 [15].



Figure 2. Sketch of the robot's navigation environment [15].

Navigation

Navigation stands as a paramount challenge within the ambit of designing and advancing intelligent mobile robotic systems. The foremost imperative is maintaining operational integrity, which encompasses averting perilous situations like collisions and adhering to secure operational parameters encompassing variables such as temperature, radiation, and weather exposure. However, should tasks necessitating interaction with specific locations within the robot's surroundings be contemplated, navigation becomes an essential prerequisite.

Robot navigation is delineated by the mobile robot's capacity to ascertain its positional coordinates within its established reference framework and subsequently formulate a trajectory toward a designated target location. When the environment remains unfamiliar to the robot, the phase of path planning loses its relevance. Under such circumstances, the navigation approach is inherently reactive. The inputs to the mobile robot's navigation system encompass the target's spatial coordinates and the data procured from the sensor array. Should no obstacles obstruct the trajectory between the robot and its objective, the navigation course is linear, a direct line interconnecting the two points. In the event an obstacle is detected, the deployment of an avoidance strategy becomes requisite.

Diverse methodologies come into play for circumventing obstacles, encompassing potential function-based techniques, neural networks, and controllers grounded in fuzzy logic. These controllers are trained via a heuristic repository of rules. Figure 6 furnishes an illustration of the positioning of motion control, focusing on obstacle avoidance, and the realm of exploration, which pertains to navigation, in relation to other domains within mobile robot research [18].



Figure 3: Relationships between mobile robot research areas [19].

Wall-Following

As previously indicated, the execution of movements around sizable objects or the traversal between distinct rooms necessitates the application of a wallfollowing technique. Instances arise where the mobile robot must navigate in a manner contrary to its intended target, as in scenarios involving U-shaped obstacles or when transitioning to another room is required to reach the ultimate objective. Such a deviation from the target-oriented movement is facilitated by excluding the target's direction from the purview of the wall-following strategy. Thus, within this module, the orientation of the target does not exert any influence on the determinations rendered by the neural networks.

Upon encountering a wall or a substantial obstacle, a directional choice is established, either left or right, for circumnavigating the obstruction. This chosen direction for wall-following remains constant until the event of object avoidance reoccurs. To illustrate, if the robot follows the right side of the wall (with walls consistently positioned on its right side), the wall-following direction remains unaltered unless necessitated by the initiation of object-avoidance actions. In essence, the decision pertaining to the wall-following direction is solely established during the transition from object avoidance to wall-following phases [18].

Sensors

The mobile robot navigation conundrum encompasses three fundamental facets: map construction, localization, and path planning. This challenge pertains to the formulation of a trajectory directed towards a designated target, the execution of this plan guided by sensor-derived inputs, and stands as a pivotal factor enabling the robot's engagement in specific tasks. Artificial Neural Networks (ANNs) are increasingly finding applications across diverse domains of machine learning, spanning pattern recognition, speech production and recognition, signal processing, medicine, and commerce. In recent times, ANNs, encompassing architectures like feedforward neural networks, self-organizing neural networks, principal component analysis (PCA), dynamic neural networks, support vector machines (SVM), and neuro-fuzzy paradigms, have gained significant traction within the realm of mobile robot navigation. This upsurge in adoption can be attributed to their inherent attributes, including nonlinear mapping capabilities, capacity to acquire knowledge from exemplars, adeptness at generalization, highly parallel processing, and the capability to approximate arbitrary functions given a sufficient neuronal complement.

For a mobile robot to ascertain its positional status and the trajectory it has traversed, or to engage in rational discourse regarding its navigational history, reliance on sensors is imperative. These sensors serve the purpose of gauging wheel distance travel on terrain as well as capturing inertial changes and extraneous environmental characteristics. The categorization of these sensors primarily unfolds into two divisions: internal state sensors, such as accelerometers and gyroscopes, and external state sensors, encompassing laser, infrared, sonar, and visual sensors. Internal state sensors like accelerometers and gyroscopes furnish insight into the robot's internal movement dynamics, while external state sensors, comprising laser, infrared, sonar, and visual sensors, furnish information about the external environment [18].

Support Vector Machine (SVM)

The pionering support vector machine (SVM) framework devised by Cortes and Vapnik in 1995 offers a comprehensive methodology for binary classification. Through intricate mechanisms like margin maximization, handling overlapping classes, and addressing nonlinearity using kernel methods, SVMs provide a versatile toolset for various classification tasks. The approach extends to scenarios including one-class classification, multi-class classification, regression, and v-regression, encapsulating a wide spectrum of machine learning challenges. The SVM framework's efficacy lies in its capacity to formulate these intricate tasks as optimization problems, rendering them amenable to rigorous computational solutions.

The fundamental objective is to ascertain the optimal hyperplane that effectively separates the two classes. This is achieved by maximizing the margin between the nearest points from each class, often referred to as support vectors.

The SVM classification method is a process which has two steps. In first step, the input of the classifier which is high dimensional is matched nonlinearly to

another attribute space. In second step, a new linear hyperplane is formed from this attribute space with the maximum portion to decorate the parts of the samples [20]. According to the mathematical model given in Equation 1, "h" represents the hypothesis function, and the X and y parameters represent the classification dimensions. The point on or above the hyperplane is classified as +1, and the point below the hyperplane is classified as -1 [21].

$$h(x_i) = \begin{cases} -1, \text{ if } w. x + b < 0\\ +1, \text{ if } w. x + bx \ge 0 \end{cases}$$
(1)

In Equation 2, n is the number of features, and w is a point in the hyperplane. Choosing a sufficiently small value for lambda is used in the soft-margin classifier since it gives the precise boundary classifier for input data that can be classified linearly [21].

$$\left[\frac{1}{n}\sum_{i=1}^{n}\max\left(0,1-y_{i}(\mathbf{w}.x_{i}-\mathbf{b})\right)\right]+\gamma\|\mathbf{w}\|^{2}$$
(2)

The optimal separating hyperplane resides at the midpoint of this margin, as depicted in Figure 4.



Figure 4. Architecture of SWM [22]

Handling Overlapping Classes: In instances where classes overlap, data points located on the "incorrect" side of the discriminant margin are assigned reduced weights, introducing a concept of a "soft margin." This weighting mechanism reduces their influence on the classification process.

Addressing Nonlinearity: When a linear separator cannot be found in the original feature space, data points undergo a projection into a higher-dimensional space, where linear separability is achievable. This transformation is facilitated through kernel techniques, allowing for nonlinear classification.

Quadratic Optimization Problem: The overall task can be cast as a quadratic optimization problem, amenable to solution through established techniques. A computational entity capable of performing these tasks is referred to as a Support Vector Machine.

One-Class Classification: This model is designed to identify the support of a distribution, enabling the detection of outliers or novel instances that deviate from the established distribution.

Multi-Class Classification: While SVMs inherently address binary classification problems, the extension to multi-class scenarios is facilitated through techniques like one-against-one. This involves training multiple binary classifiers and determining the final class through a voting mechanism.

Regression: In regression tasks, data points are situated between the two margins of the hyperplane, optimizing the margin while considering appropriate conditions to mitigate the inclusion of outliers.

v-Regression: Analogous adaptations to the regression model, as seen in the classification context, are applied to v-regression tasks.

PREVIOUS STUDY

The employed datasets originate from the publicly accessible sensor readings provided by the University of California Irvine (UCI) machine learning repository, commonly utilized by researchers for validation purposes. In practical terms, the primary factors influencing the precision of robot behavior in obstacle avoidance encompass the model learning process, the count of considered sensors, and the velocity of reasoning based on sensor configurations. The initial dataset incorporated into the UCI repository was generated by researchers from the Federal University of Ceará in Portugal, who embarked on an investigation involving diverse learning systems to facilitate their robot's navigation within a room while avoiding collisions with walls or objects [15]. Among the methodologies they evaluated were logistic perceptrons and multilayer perceptron networks. It became evident that, unless augmented with short-term memory mechanisms, the logistic perceptron struggled to guide the robot around the room effectively, which led to the deduction that this classification task lacks linear separability.

In reference [1], the performance of various tools was juxtaposed not only in terms of classification rates but also with regards to usability and computational speed. The study commenced by exploring the multilayer perceptron, yielding an average classification rate of 80.2% across all runs and datasets. Subsequently, the investigation extended to the k-nearest neighbor classifier, achieving a classification rate hovering around 32% upon each run. The analysis then

encompassed the maximum likelihood classifier, attaining an average classification rate of 89.3%, showcasing an almost 10% superiority over the MLP's rate.

In the context of reference [12], the dataset was partitioned with 60% of samples from each category allocated to a training set, while the remaining 40% constituted a test set. The C4.5 algorithm (combining Naïve Bayes and the Apriori Data Mining algorithm) was employed within a supervised learning framework. The classifier achieved a commendable performance by correctly categorizing 97.5% of samples from the test set. Notably, the overall execution time was substantial due to the adoption of Erlang for all computations.

Reference [17] undertook a comparative analysis of different classifier methods, including Bagging, Dagging, Decorate, MultiClassClassifier, and MultiboostAB. Among these, Bagging emerged as the most effective algorithm for achieving accuracy. The assessments employed the same robot navigation datasets, with Classification Accuracy and Time computed through a 10-fold validation technique.

In reference [23], the identical dataset was investigated concerning the MaxDistance strategy, which excelled primarily in the initial iterations. The authors proposed a novel framework for classification incorporating labels.

In reference [16], a selection of five applicable normalization techniques was made, following which the chosen datasets were subjected to normalization. Subsequently, the accuracy of the classification algorithm was calculated both before and after normalization. In this study, the classification employed the SVM algorithm. Eventually, the application of Data Envelopment Analysis (DEA) was pursued for ranking the normalization methods. The utilization of four datasets enabled the ranking of normalization methods based on accuracy improvement, and subsequently, through the application of DEA and the AP-model, these methods were ranked. The vector normalization method exhibited a maximum success rate of 77.52% for the wall-following robot navigation dataset.

Reference [24] delved into an examination of the proposed method's performance using multiple UCI datasets [14], and conducted a comparative analysis with other established feature extraction methods such as PCA (Principal Component Analysis), LDA (Linear Discrimination Analysis), SDA (Subclass Discriminant Analysis), and the MI-based (Mutual Information) feature extraction method introduced in [25], also known as MRMI-SIG. Within this study, a novel feature extraction technique termed MIDA was introduced, which leverages the concept of Mutual Information (MI). MIDA aims to create new features by transforming original features, with the transformation being designed to simultaneously maximize the Mutual Information between the transformed

features and the class labels, while minimizing redundancy. Unlike other Discriminant Analysis (DA) algorithms grounded in second-order statistics, the proposed MIDA method is rooted in information theory, enabling the assessment of nonlinear relationships between random variables, such as between feature vectors and class labels. The evaluation of the proposed method encompassed six datasets from UCI repositories. Among these, the third dataset pertained to wallfollowing robot navigation, characterized by 24 features. The objective was to examine the hypothesis that a seemingly straightforward navigation task entails a classification challenge that is, in fact, nonlinearly separable. Empirical results indicated that the performance of the MIDA method was on par with existing methodologies, frequently exhibiting superior performance compared to alternative methods.

Reference [26] undertook a series of three primary experiments to contrast and assess the performance achieved by various models operating within the framework of a four-ultrasound sensor configuration. These experiments encompassed: (a) evaluating the efficiency of collision avoidance in static environments, (b) assessing the efficiency of collision avoidance in dynamic environments, and (c) conducting a comparative analysis of average performance across the models. Employing a three-fold cross-validation technique, the entire dataset was randomly partitioned into three subsets. One of these subsets was designated for testing, while the others were utilized for training. Generally, the training dataset accounted for approximately 95% of the entire dataset, leaving the remaining 5% for testing purposes. Given the utilization of the crossvalidation method, this procedure was reiterated thrice. The three-fold crossvalidation approach involved isolating the test set from the training instances, subsequently introducing these test instances as new obstacle readings to the models. Across all folds, the efficacy of autonomous collision avoidance was quantified through the Employment Ratio of Bypass (ERB) and the outcomes of the Probability of Robot Bypass (PRB), both of which endorsed the viability of Bayesian Network (BN) and k-Nearest Neighbors (k-NN) approaches in dynamic environments. Remarkably, the BN model exhibited a remarkable average accuracy of 93.3%, which was considerably superior in predicting the robot's behavior compared to the 73.3% achieved by the k-NN model.

CONCLUSIONS

These investigations have employed diverse methodologies to address the wall-following mobile robot navigation issue, utilizing an identical dataset. The findings underscore that the most suitable configuration of a neural network for the task of classifying wall-following mobile robot data is the SWM structure.

In this study, the SWM structure yielded the most favorable outcome, achieving an average classification accuracy of 99.93%, as outlined in Table 2.

Name	Method	Accuracy (%)
Ref [1]	Maximum Likelihood Classifier	89.30
Ref [12]	Naïve Bayes and a Data Mining algorithm: Apriori	97.50
Ref [16]	Data Envelopment Analysis (DEA)	77.52
Ref [17]	Bagging	99.28
Ref [24]	Mutual Information Discriminant Analysis (MIDA)	92.10
Ref [26]	Bayesian Network	93.30
This Study	Support Vector Machines	99.93

Table 2. Comparison of the results for studies.

The research indicates that neural network architectures consistently demonstrate commendable performance in the context of wall-following mobile robot navigation challenges. This high classification accuracy is robustly dependable for such problem scenarios, as the system's misclassification of samples remains minimal. Ultimately, artificial neural network (ANN) structures can serve as valuable learning-based decision support systems, contributing to engineers in their project endeavours.

In the future, the potential exists for replicating these experiments with distinct datasets in lieu of employing multiple datasets. Furthermore, an exploration of multiclass classification and the amalgamation of various ensembles with diverse foundational classifiers could provide insights into how ensemble methods, in conjunction with base classifiers, amplify performance accuracy.

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Chapter 16

Boxed Medicine Robot Shelving Design Based on Dynamic Storage Allocation In AS/RS Systems

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ABSTRACT

Automated Storage and Retrieval Systems (AS/RS) have revolutionized warehouse operations, offering efficient and accurate solutions for inventory management and order fulfillment. This study focuses on the design and application of dynamic storage allocation techniques in AS/RS systems, specifically in the context of a boxed medicine robot.

The objective of this study is to optimize the storage allocation process within the AS/RS system to enhance its efficiency, adaptability, and responsiveness. Traditional AS/RS systems often employ static storage allocation, where items are assigned fixed storage locations based on predetermined criteria. However, this approach may lead to suboptimal space utilization and inefficient retrieval times. To address these limitations, dynamic storage allocation techniques are proposed. These techniques utilize real-time data and advanced algorithms to determine the optimal storage locations for boxed medicines based on factors such as demand patterns, product characteristics, and retrieval frequency. By dynamically allocating storage positions, the system can adapt to changing inventory profiles and maximize space utilization, leading to improved efficiency and cost-effectiveness. The study also investigates the integration of dynamic storage allocation techniques with a boxed medicine robot. This involves developing intelligent algorithms and control mechanisms that enable the robot to retrieve medicines from the AS/RS system based on the dynamically allocated storage positions.

The goal is to optimize the robot's picking routes and minimize retrieval time, ultimately enhancing the overall performance of the system. Simulation experiments and case studies are conducted to evaluate the effectiveness of the proposed dynamic storage allocation techniques and their impact on the boxed medicine robot's performance. The results demonstrate significant improvements in space utilization, retrieval efficiency, and overall system productivity compared to traditional static allocation methods. The findings of this study contribute to the advancement of AS/RS system design and optimization, particularly in the pharmaceutical industry, where boxed medicine handling plays a crucial role. The dynamic storage allocation techniques presented in this study have the potential to be applied to other industries as well, enabling adaptive and efficient storage solutions in various automated warehousing contexts.

Keywords: Boxed Medicine Robot Design, Automated Storage and Retrieval Systems (AS/RS), Dynamic Storage Allocation, Warehouse Optimization, Inventory Management, Retrieval Efficiency.

Introduction

The relationship between Automated Storage and Retrieval Systems (AS/RS), warehouse management, Industry 4.0, and e-commerce is highly interconnected and has significant implications for modern supply chain operations(Guven, 2020). AS/RS refers to a system that uses automated machinery and computer-controlled processes to store and retrieve goods in a warehouse. These systems typically involve racks, shelves, robotic cranes, conveyors, and other automated equipment. AS/RS provides a highly efficient and accurate solution for inventory management and order fulfillment. Warehouse management encompasses the strategies, processes, and systems implemented to efficiently manage the operations within a warehouse. It involves tasks such as inventory control, order processing, picking and packing, storage optimization, and logistics coordination. Industry 4.0 refers to the integration of digital technologies into industrial processes. It encompasses various technologies such as the Internet of Things (IoT), automation, data analytics, artificial intelligence (AI), and cloud computing (Song et al., 2021). Industry 4.0 aims to create "smart factories" that are highly connected, datadriven, and capable of making autonomous decisions. E-commerce, which refers to the buying and selling of goods and services online, has experienced rapid growth and transformation in recent years (Yu et al., 2016). It has reshaped the retail landscape and introduced new challenges and opportunities for businesses.

With all of the aforementioned interconnected parts of the supply chain give the opportunity of enhanced efficiency, being able to perform real-time data analysis, seamless integration, scalability and flexibility, and enhanced customer experience. AS/RS systems integrated with advanced warehouse management systems (WMS) can greatly enhance the efficiency of warehouse operations. The automation and optimization capabilities of AS/RS enable faster and more accurate inventory management, order processing, and order fulfillment. This increased efficiency is crucial for meeting the demands of ecommerce, where speed and accuracy are vital (Yetkin Ekren, 2021). Industry 4.0 technologies play a pivotal role in enabling real-time data collection, analysis, and decision-making. AS/RS systems equipped with IoT sensors and connected devices can gather data on inventory levels, movement, and other relevant metrics. This data can be utilized by analytics and AI algorithms to provide insights for better inventory planning, demand forecasting, and operational optimization (Suleykin et al., 2022). AS/RS systems can be seamlessly integrated into the overall supply chain ecosystem, including ecommerce platforms, WMS, transportation management systems (TMS), and other components. The integration allows for smoother coordination, real-time visibility, and improved synchronization between different stages of the supply chain, resulting in enhanced responsiveness and customer satisfaction (Minashkina & Happonen, 2020). AS/RS systems, when combined with Industry 4.0 technologies, offer scalability and flexibility to adapt to changing business needs. The modular design of AS/RS allows for easy expansion or reconfiguration of storage capacity as demand fluctuates. Additionally, data-driven insights from Industry 4.0 technologies enable agile decision-making and proactive adjustments to optimize warehouse operations in response to market dynamics.

The relationship between AS/RS, warehouse management, Industry 4.0, and e-commerce ultimately aims to enhance the overall customer experience. The efficient and accurate order fulfillment enabled by AS/RS systems, coupled with real-time tracking and timely delivery, contributes to improved customer satisfaction. Industry 4.0 technologies further enable personalization, customization, and real-time interaction with customers, adding value to the ecommerce experience (Minashkina & Happonen, 2020). Relationship between AS/RS, warehouse management, Industry 4.0, and e-commerce revolves around leveraging advanced automation, data analytics, and integration to achieve efficient, agile, and customer-centric supply chain operations. This integration allows businesses to meet the challenges of e-commerce, optimize warehouse processes, and enhance overall competitiveness in the digital marketplace.

With all these important facts about AS/RS systems, it will be beneficial to mention the types and how these systems work. Automated Storage and Retrieval Systems (AS/RS) encompass a range of technologies and designs used to automate the storage and retrieval of goods in a warehouse or distribution center. There are several types of AS/RS systems, each tailored to specific operational requirements and storage needs. Some of them are Unit Load AS/RS, Mini Load AS/RS, Vertical Lift Modules (VLMs), Horizontal Carousels, Vertical Carousels, and Autostore Systems. Unit Load AS/RS is designed for handling large, unitized loads such as pallets or containers. It typically employs high-rise storage racks and automated cranes or conveyors to store and retrieve the entire unit loads. Unit Load AS/RS systems are efficient for high-density storage and can handle heavy loads (Singbal & Adil, 2023). Mini Load AS/RS systems are used for storing and retrieving smaller loads, such as totes or cartons. They employ smaller robotic cranes or shuttles that navigate within compact storage modules or shelves to access individual items. Mini Load AS/RS systems are well-suited for applications that require highspeed order fulfillment and flexibility in item access (M. et al., 2019). VLMs

are compact AS/RS systems consisting of vertically arranged columns with trays or shelves that automatically move up and down. Items are stored in the trays, and retrieval is facilitated by bringing the appropriate tray to the operator at an ergonomic height. VLMs are often used for storing small parts or components and are efficient in saving space and increasing picking accuracy (Jaghbeer et al., 2020).

Horizontal Carousels consist of a series of horizontally rotating shelves or bins that bring the desired items to the operator. The operator manually picks items from the rotating shelves as they come into position. Horizontal Carousels are suitable for applications with high-speed picking requirements and a wide range of SKUs (Journal & Sep, 2003). Vertical Carousels are similar to Horizontal Carousels but operate vertically, with shelves that rotate up and down. They provide automated storage and retrieval of items and are often used in applications where space is limited and high-density storage is required (Journal & Sep, 2003). Autostore Systems are innovative AS/RS solutions that utilize a grid-like structure with bins stacked on top of each other. Small robots travel on top of the grid and retrieve or store bins as needed. Autostore Systems offer high-density storage, flexibility, and scalability, making them suitable for e-commerce and order fulfillment operations (Trost et al., 2022). The choice of AS/RS system depends on factors such as the size and weight of items, throughput requirements, space availability, order picking speed, and other logistical considerations. Implementing the right type of AS/RS system can significantly improve warehouse efficiency, accuracy, and overall productivity.

Each type of Automated Storage and Retrieval System (AS/RS) operates in a slightly different manner, but they generally follow similar principles of automation and mechanization. AS/RS systems consist of a storage configuration, such as racks, shelves, bins, or trays, where items are stored. The configuration can be designed to accommodate different sizes and types of items, depending on the specific AS/RS system (Schenone et al., 2020). AS/RS systems utilize inventory tracking technologies, such as barcode or RFID, to identify and locate items within the storage configuration. Each item is assigned a unique identifier that is linked to its storage location. When a retrieval request is initiated, typically by a warehouse management system (WMS) or an operator, the AS/RS system receives the request and determines the storage location of the item to be retrieved (Yu et al., 2023). The AS/RS system's automation components come into play to retrieve the requested item. In the Unit Load AS/RS, automated cranes or conveyors maneuver through the storage configuration, picking up entire unit loads (e.g., pallets) and transporting them to a designated retrieval area. In Mini Load AS/RS, robotic cranes or shuttles

navigate within the storage configuration, identifying and picking individual items or containers (e.g., totes or cartons) and delivering them to a retrieval point. In the Vertical Lift Modules (VLMs), the storage trays or shelves move vertically within the VLM, bringing the desired item to the operator at an ergonomic height for retrieval. In Horizontal/Vertical Carousels, the rotating shelves or bins bring the requested items to the operator's position, who manually picks the items as they come into reach. In Autostore Systems small robots travel on top of the grid-like structure, locating and retrieving bins containing the requested items and transporting them to a designated retrieval area.

After retrieval, AS/RS systems may also handle the storage and restocking of items. If an item needs to be stored, the AS/RS system identifies an available storage location and places the item accordingly. This process ensures efficient space utilization and optimization of the storage configuration (Accorsi et al., 2012). Throughout the entire process, AS/RS systems rely on advanced control systems, sensors, and software algorithms to manage and coordinate the movement of automated components, track inventory, and ensure accurate and timely retrieval. AS/RS systems can be integrated with other warehouse technologies, such as Warehouse Management Systems (WMS) or Order Management Systems (OMS), to enable seamless communication, order fulfillment, and inventory management within the larger supply chain operations.

AS/RS systems have to place and retrieve goods in their storage spaces like bins, shelves, or aisles. The method of storage is effectively altering the performance of the system. One of the effective methods of placing the goods is based on dynamically allocated storage positions. This study is about the very effective and simple decision tree algorithm applied to the dynamically allocated storage positions on single medicine boxes, which is a fundamental reconfigurability element for AS/RS to gain the capability to dynamically allocate storage space based on real-time inventory needs.

Reconfigurable AS/RS Systems

Reconfigurable AS/RS (Automated Storage and Retrieval Systems) refers to a type of storage and retrieval system that is designed to be flexible and adaptable to changing operational requirements. Unlike traditional fixed-layout, AS/RS systems, reconfigurable AS/RS systems can be modified and reconfigured easily to accommodate different storage needs, item sizes, throughput requirements, or changes in the facility layout. They have properties like Modular Design, Flexibility in Storage Unit Sizes, Adjustable Storage

Innovative Research in Engineering

Density, Scalability and Expansion, Dynamic Reconfiguration, Integration with Warehouse Management Systems, and Adaptability to Facility Layout Changes. Reconfigurable AS/RS systems are built with a modular design approach. The system consists of modular components such as racks, shelves, conveyors, lifts, and robots. These components can be easily assembled, disassembled, or rearranged to create different configurations based on the specific needs of the application. Reconfigurable AS/RS systems allow for variable storage unit sizes. The system can accommodate different sizes of bins, shelves, or compartments to store a wide range of products. This flexibility is particularly useful when handling items of varying dimensions or when the product mix changes over time. The storage density in a reconfigurable AS/RS system can be adjusted based on the requirements. The system can be configured to have higher storage density by reducing the aisle width or increasing the vertical height between shelves. Alternatively, if easy access to items is prioritized, the system can be reconfigured to have wider aisles and lower shelving heights.

Reconfigurable AS/RS systems are designed to support scalability and expansion. As business needs grow or change, additional modules or storage units can be added to the system easily. This allows the system to accommodate increased storage capacity or higher throughput requirements without requiring a complete overhaul of the existing infrastructure. Reconfigurable AS/RS systems excel at dynamic reconfiguration, enabling rapid changes to the system layout. For example, if there is a need to reorganize storage space to optimize picking routes, the system can be quickly reconfigured by rearranging the modular components or by adjusting the routing algorithms. Reconfigurable AS/RS systems often integrate with Warehouse Management Systems (WMS) or other control software. This integration allows for efficient management of inventory, order processing, and system control. The WMS can provide realtime information about inventory levels, item locations, and order priorities, enabling intelligent reconfiguration decisions. Reconfigurable AS/RS systems are designed to adapt to changes in the facility layout. If there are changes to the building structure or storage area, the system can be easily reconfigured to fit the new layout. This adaptability reduces the need for major structural modifications and provides cost savings and flexibility. Reconfigurable AS/RS systems offer significant advantages in terms of adaptability, scalability, and operational efficiency. They provide the flexibility to handle changing storage requirements and optimize space utilization. By enabling dynamic reconfiguration, these systems can adapt to evolving business needs, improve productivity, and maximize the return on investment for warehouse operations.

Dynamic Storage Allocation

In the context of AS/RS (Automated Storage and Retrieval Systems), dynamic storage allocation refers to the process of allocating and managing storage space for items within the system. AS/RS systems are commonly used in warehouses and distribution centers to automate the storage and retrieval of goods (Accorsi et al., 2012). In an AS/RS system, the available storage space is divided into storage units such as bins, shelves, racks, or compartments. Dynamic storage allocation involves assigning these storage units to specific items based on various factors such as size, weight, fragility, and accessibility requirements (Revillot-Narváez et al., 2020). Dynamic storage allocation in AS/RS systems requires effective inventory control mechanisms. Each item to be stored is assigned a unique identifier, and its information (e.g., SKU, dimensions, weight, quantity) is recorded in a database or warehouse management system. This information is used to determine the most appropriate storage unit for the item (Ferrari et al., 2022). The goal of dynamic storage allocation is to optimize the utilization of storage space within the AS/RS system. This optimization includes maximizing storage capacity, minimizing empty space, and ensuring efficient use of available resources. The system must analyze the characteristics of the items to be stored and determine the most suitable storage unit to minimize wasted space (Lei et al., 2020)(Wu & Chen, 2022)(Tabatabaei et al., 2021). AS/RS systems often require flexibility to accommodate changing storage needs. Dynamic storage allocation allows for the reconfiguration of storage space as per changing requirements. For example, if a particular item's demand increases, the system can dynamically allocate more storage units or rearrange existing ones to accommodate the additional inventory (Kumar et al., 2019).

Dynamic storage allocation not only affects the storage of items but also influences the retrieval process. Efficient retrieval is crucial in AS/RS systems to minimize the time required to retrieve items. The system must consider the accessibility of storage units, the frequency of item retrieval, and the orderpicking process when allocating storage units to items. Frequently accessed items may be allocated to easily reachable locations to reduce retrieval time (Yu et al., 2023). Dynamic storage allocation requires real-time tracking and monitoring of the inventory and storage units. AS/RS systems employ various technologies such as barcode scanning, RFID (Radio Frequency Identification), or computer vision to track the movement of items and maintain accurate inventory records. This tracking information is used to make informed decisions regarding storage unit allocation and optimize the overall system performance (Song et al., 2021). Dynamic storage allocation in AS/RS systems plays a vital role in maximizing storage capacity, optimizing retrieval efficiency, and accommodating changing storage needs. By intelligently assigning storage units to items and utilizing real-time tracking, these systems can streamline operations, reduce errors, and improve overall warehouse productivity.

The main objective of dynamic storage allocation is to utilize the storage space efficiently while ensuring easy accessibility and minimizing operational costs. By dynamically allocating storage slots or locations, the AS/RS system can adapt to changing inventory levels, product mix, and order profiles. In reconfigurable AS/RS systems, works by Real-Time Inventory Tracking, Demand Analysis and Slot Assignment, Intelligent Algorithms, Dynamic Reorganization, Optimization Objectives, and Adaptation to Workload Changes. The AS/RS system continuously monitors the inventory levels and tracks the availability of storage slots or locations. This can be achieved through the use of sensors, barcode scanners, or RFID technology. Based on the realtime inventory data, the system analyzes the incoming demand and determines the optimal storage slots for each incoming or outgoing item. The analysis considers various factors such as item characteristics, storage constraints, order priorities, and accessibility requirements. The AS/RS system utilizes intelligent algorithms to determine the most suitable storage slots or locations for each item. These algorithms consider factors such as proximity, item size, weight, and storage policies (e.g., first-in-first-out or last-in-first-out). When the inventory profile changes or new products arrive, the AS/RS system dynamically reorganizes the storage layout. It may involve rearranging existing items, consolidating storage space, or creating new storage slots to accommodate the new inventory. Dynamic storage allocation algorithms often aim to optimize several objectives simultaneously. These can include maximizing space utilization, minimizing travel distances for retrieval operations, balancing inventory across storage units, or ensuring efficient picking sequences.

Dynamic storage allocation allows the AS/RS system to adapt to workload changes, such as peak periods or seasonal fluctuations. It enables the system to allocate storage space more effectively during high-demand periods and adjust storage configurations as the demand subsides (Rimélé et al., 2021).

Benefits of dynamic storage allocation in reconfigurable AS/RS systems include Efficient Space Utilization, Improved Accessibility, Adaptability to Inventory Changes, and Cost Optimization. Dynamic allocation optimizes the use of available storage space, reducing wasted or unused areas within the system. By strategically assigning storage slots based on demand patterns, dynamic storage allocation enhances the accessibility of frequently requested

items, reducing retrieval times and improving overall system productivity. The ability to dynamically allocate storage space allows the AS/RS system to accommodate changes in inventory size, shape, or quantity, ensuring efficient storage and retrieval operations. Through intelligent slot assignment and optimization, dynamic storage allocation can minimize operational costs by reducing travel distances, consolidating storage space, and eliminating the need for excessive storage units. Dynamic storage allocation is a crucial aspect of reconfigurable AS/RS systems, enabling efficient and adaptable storage management that aligns with changing inventory needs (Rimélé et al., 2021)(Bertolini et al., 2023)(Kim & Hong, 2022).

Intelligent algorithms, also known as smart algorithms or machine learning algorithms, are computational techniques designed to process data and make decisions or predictions based on patterns, trends, and statistical analysis. These algorithms are characterized by their ability to learn from data and improve their performance over time without being explicitly programmed.

Intelligent Algorithms

Intelligent algorithms are often employed in various domains, including reconfigurable automated storage and retrieval systems (AS/RS), to optimize system operations, enhance efficiency, and enable adaptive behavior. They employ Data Collection, Pattern Recognition and Analysis, Learning and Training, Decision-Making and Optimization, Adaptability and Flexibility, and Continuous Improvement. Intelligent algorithms require data as input for analysis and decision-making. In the context of reconfigurable AS/RS systems, data can include real-time inventory levels, historical demand patterns, system performance metrics, or other relevant information. The algorithms collect and process this data to gain insights and make informed decisions. Intelligent algorithms are designed to recognize and analyze patterns within the collected data. They utilize statistical and computational techniques to identify correlations, trends, and anomalies. By identifying patterns, the algorithms can understand the relationships between variables and make predictions or classifications based on these patterns. One key characteristic of intelligent algorithms is their ability to learn from data. Through a training process, the algorithms adjust their internal parameters or models to optimize their performance. They learn from past data and experiences to improve their accuracy, reliability, and generalization capabilities. This learning process can involve techniques such as supervised learning, unsupervised learning, or reinforcement learning. Based on the learned patterns and analysis, intelligent algorithms can make decisions or recommendations to optimize system

Innovative Research in Engineering

operations. In reconfigurable AS/RS systems, these decisions can include storage slot assignments, picking strategies, inventory reorganization, or resource allocation. The algorithms leverage their understanding of the data and past experiences to make informed choices that improve system efficiency and performance. Intelligent algorithms exhibit adaptability and flexibility in their decision-making processes. They can adapt to changes in data patterns, shifts in demand, or modifications in system configurations. These algorithms can adjust their models or parameters to continuously optimize performance and adapt to evolving conditions in real time. Intelligent algorithms can continuously improve their performance over time. As they receive new data and gain additional insights, they refine their models, adjust their decision-making criteria, and enhance their accuracy. The algorithms can adapt to changing conditions and optimize their behavior based on new information. Intelligent algorithms play a vital role in reconfigurable AS/RS systems by leveraging data-driven insights to optimize storage allocation, enhance picking strategies, improve resource utilization, and adapt to changing inventory needs. By employing intelligent algorithms, these systems can achieve higher efficiency, adaptability, and responsiveness in managing and organizing storage operations (Song et al., 2021)(Fottner et al., 2021)(Jiang et al., 2019)(Wu & Chen, 2022).

Automated Storage Slot Assignment

Automated storage slot assignment refers to the process of automatically assigning storage slots or locations to items within an automated storage and retrieval system (AS/RS). This process aims to optimize storage space utilization, minimize retrieval times, and ensure efficient organization of items in the storage system. Automated storage slot assignment typically works through Data Input, Storage Space Analysis, Optimization Algorithms, Slot Assignment Criteria, Real-Time Adjustments, and Feedback and Performance Evaluation. The automated storage slot assignment process requires input data, including information about the items to be stored, their characteristics, and any relevant constraints or requirements. This data may include item dimensions, weight, fragility, expiration dates, or other specific attributes. The AS/RS system analyzes the available storage space, taking into account the dimensions, layout, and capacity of the storage units or racks. It considers factors such as the number of available slots, their sizes, and any limitations or constraints related to accessibility, load-bearing capacities, or item categorization. Automated storage slot assignment relies on optimization algorithms to determine the most efficient allocation of storage slots for the items. These algorithms consider various factors, including item characteristics, storage constraints, accessibility requirements, and operational objectives. The optimization algorithms use predefined criteria or rules to assign slots to items. These criteria can include proximity-based assignment (placing similar items in adjacent slots), load balancing (distributing items evenly across storage units), retrieval frequency (placing frequently requested items in easily accessible slots), or other specific guidelines based on operational requirements.

The automated storage slot assignment process is dynamic and can adapt to changes in inventory or operational needs. As new items arrive or inventory levels change, the system may dynamically reassign storage slots to accommodate the evolving inventory profile. This dynamic adjustment ensures efficient storage organization and retrieval. The AS/RS system continuously monitors and evaluates the performance of the storage slot assignment process. It collects feedback on retrieval times, travel distances, and other relevant metrics to assess the effectiveness of slot assignment decisions. This feedback helps refine the optimization algorithms and improve future slot assignments. The automated storage slot assignment process enhances the efficiency and organization of items within an AS/RS system. By utilizing optimization algorithms, it optimizes storage space utilization, reduces retrieval times, and improves overall system productivity. The automated nature of the process eliminates manual effort and reduces the likelihood of human error, ensuring consistent and reliable slot assignments (Lei et al., 2020)(Tabatabaei et al., 2021)(Jaghbeer et al., 2020).

Automated Storage Slot Assignment

Dynamic reorganization of storage units refers to the process of adapting and rearranging the configuration of storage units within an automated storage and retrieval system (AS/RS) in response to changing inventory needs or operational requirements. It involves modifying the layout, arrangement, or allocation of storage units to optimize storage space utilization, improve accessibility, and enhance overall system performance. Dynamic reorganization of storage units typically works via Assessment of Inventory Changes, Evaluation of Operational Objectives, Reconfiguration Planning, Layout Adjustments, Optimization Considerations, and Real-Time Adaptation. The AS/RS system continuously monitors inventory levels and tracks changes in the inventory profile. This can be achieved through real-time data collection using sensors, barcode scanners, or RFID technology. The system analyzes the inventory data to identify any shifts in demand, changes in item characteristics, or fluctuations in storage requirements. Based on the assessment of inventory changes, the AS/RS system evaluates operational objectives and constraints.

These objectives may include optimizing storage space utilization, improving accessibility to frequently requested items, minimizing retrieval times, or maintaining balanced load distribution across storage units. The system considers these objectives in the dynamic reorganization process.

The AS/RS system employs algorithms and planning techniques to determine the most effective reconfiguration strategy. This planning phase considers various factors, such as the dimensions and characteristics of items, storage unit capacities and configurations, accessibility requirements, and operational constraints. The system aims to achieve an optimal layout that aligns with the defined operational objectives. Once the reconfiguration plan is developed, the AS/RS system executes the necessary adjustments to the layout of storage units. This may involve moving or relocating storage units, changing the allocation of storage slots, adjusting shelving heights or configurations, or even adding or removing storage units from the system. The adjustments are made in a coordinated and efficient manner to minimize disruption to ongoing operations. During the dynamic reorganization process, the AS/RS system employs optimization algorithms to ensure the best possible arrangement of storage units. These algorithms may consider factors such as proximity, retrieval frequency, load balancing, or other predefined criteria to optimize the storage configuration. The goal is to create a layout that maximizes storage utilization, enhances accessibility, and aligns with the operational objectives. The dynamic reorganization of storage units is an ongoing and continuous process. As inventory levels change or new items are introduced, the system dynamically adapts the storage layout to accommodate the evolving storage requirements. This real-time adaptation ensures that the AS/RS system remains responsive, efficient, and aligned with the changing operational needs. Dynamic reorganization of storage units in an AS/RS system allows for efficient utilization of storage space, improved accessibility to items, and optimized retrieval operations. By dynamically adapting the storage layout, the system can respond to changes in inventory and operational demands, ensuring optimal performance and maximizing the benefits of automation in storage management (Bertolini et al., 2023)(Kipnis, 1990)(VodiČka et al., 2014).

Optimized Space Utilization

Optimized space utilization refers to the efficient and effective use of available storage space in a system or facility. It involves maximizing the utilization of the storage area while ensuring that items are stored in an organized and accessible manner. Optimized space utilization aims to minimize wasted space, reduce storage costs, and improve overall operational efficiency. Optimized space utilization can be achieved by applying Storage Layout Planning, Inventory Analysis, Storage Slot Optimization, Vertical Space Utilization, Compact Storage Techniques, and Continuous Evaluation and Optimization. To optimize space utilization, careful planning of the storage layout is essential. This includes determining the optimal placement of storage units, racks, shelves, or other storage infrastructure within the available space. Factors such as the dimensions of the storage units, the layout of the facility, and accessibility requirements are considered during the planning phase. An analysis of the inventory or items to be stored is conducted to understand their characteristics, sizes, weights, and storage requirements. This analysis helps determine the most suitable storage configurations, such as shelving heights, aisle widths, or stackability options, to maximize space utilization. It also helps identify any specific storage constraints or considerations. Optimizing the allocation of storage slots or locations is crucial for efficient space utilization. Algorithms or optimization techniques are used to assign items to appropriate storage slots based on factors such as item dimensions, retrieval frequency, storage policies (e.g., FIFO - First In First Out or LIFO - Last In First Out), or other relevant criteria. By strategically assigning items to slots, the available storage space can be utilized optimally. Maximizing vertical space is a key aspect of optimized space utilization. This involves utilizing the full height of the storage area by employing tall storage units, mezzanines, or multi-level racking systems.

Vertical space utilization can significantly increase storage capacity without expanding the physical footprint of the facility. Various techniques and systems are employed to achieve compact storage and maximize space utilization. These techniques include high-density storage systems like mobile racking, vertical carousels, or automated storage and retrieval systems (AS/RS). Such systems allow for dense storage by eliminating wasted aisle space and maximizing the number of items stored within a given area. Optimized space utilization is an ongoing process that requires continuous evaluation and optimization. Regular reviews of the storage layout, item characteristics, and operational requirements are conducted to identify areas for improvement. Adjustments, reconfigurations, or system upgrades may be implemented to further enhance space utilization and address changing needs. The benefits of optimized space utilization include reduced storage costs, improved accessibility, increased storage capacity, and streamlined operations. By efficiently utilizing available space, organizations can minimize storage-related expenses, enhance inventory management, and create a more productive and organized storage environment (Lei et al., 2020)(Su et al., 2022)(Kong, 1862).

Dynamic storage allocation in boxed medicine robots

Dynamic storage allocation in boxed medicine robots refers to the process of intelligently assigning storage locations within the robot system for efficient and optimized storage of boxed medications. It involves dynamically allocating storage slots based on real-time inventory needs, optimizing space utilization, and facilitating easy retrieval of medications when needed (Zhang et al., 2023). Dynamic storage allocation works in boxed medicine robots through Real-Time Inventory Monitoring, Storage Slot Optimization, Adaptive Slot Assignment, Space Utilization, Intelligent Slotting Decisions, Real-Time Adaptation, and Enhanced Medication Retrieval. The boxed medicine robot continuously monitors the inventory of medications in real time (Barrett et al., 2012). This is typically achieved through barcode scanning or RFID technology. The system collects data on the available medications, their quantities, and expiration dates. Based on the real-time inventory data, the robot system utilizes optimization algorithms to determine the most efficient allocation of storage slots for boxed medications. These algorithms take into account factors such as medication attributes, such as size, type, stability requirements, and storage constraints. The optimization algorithms dynamically assign storage slots to boxed medications, considering various factors such as medication demand, frequency of access, and expiration dates. Popular or frequently accessed medications can be assigned to easily accessible slots to minimize retrieval times and improve operational efficiency. Dynamic storage allocation optimizes space utilization within the boxed medicine robot system. The system aims to minimize wasted or unused space by efficiently arranging boxed medications in available storage slots. This maximizes the storage capacity of the robot system, reducing the need for additional storage units and saving space-related costs.

The algorithms used in dynamic storage allocation make intelligent slotting decisions based on the specific requirements of boxed medications. For example, medications with shorter shelf lives or those requiring temperature-controlled storage may be allocated to appropriate slots to ensure proper storage conditions. As the inventory of boxed medications changes due to medication dispensing, restocking, or expiration, the dynamic storage allocation process adapts to accommodate the evolving inventory needs (Franco et al., 2018).

The system can dynamically reassign slots, optimize storage configurations, and adjust allocation strategies in real-time to maintain optimal storage organization and accessibility. Dynamic storage allocation ensures that medications are stored in a way that facilitates easy and efficient retrieval when required. By assigning storage slots based on demand patterns and optimizing the location of frequently accessed medications, the system minimizes retrieval times, reduces human errors, and enhances the speed and accuracy of medication dispensing. Dynamic storage allocation in boxed medicine robots optimizes storage space, improves inventory management, and enhances medication retrieval efficiency. It ensures that medications are stored in the most appropriate slots based on real-time inventory needs, facilitating smooth operations and reducing operational costs associated with storage inefficiencies or medication retrieval delays (Mourral & Lesaffre, 2020)(Lei et al., 2020)(Jiang et al., 2019)(Song et al., 2021)(Khader et al., 2016).

Application of Dynamic Storage Allocation in Boxed Medicine Robot

Commercialized boxed medicine robot named EBOT have been designed with the application of a simple but effective dynamic storage allocation methodology is shown in Fig.1. This robot help pharmacists to store and order pick their boxes in desired fashion.

In this context, a pharmacy automation system refers to a comprehensive platform designed to streamline and optimize pharmacy operations by leveraging various automated, semi-automated, and manual processes. Its primary objectives are to reduce workload, minimize errors in service, and optimize space utilization for drug storage, leading to increased efficiency and an improved Over The Counter (OTC) valuable area.

The automation system incorporates cutting-edge technology and innovative methodologies for the sorting, transferring, and storage of medications. It utilizes automated mechanisms for sorting prescriptions efficiently. The semiautomated component facilitates seamless and secure medication transfers and storage, ensuring accuracy and safety in handling pharmaceuticals.

Moreover, the system includes a manual aspect, where pharmacy personnel are guided by the automation system to carry out specific tasks, ensuring a seamless integration of human expertise with technology. This collaborative approach ensures precise handling of medications, maintaining quality standards while leveraging the advantages of automation.

Key to the automation system is the utilization of a Cartesian robotic system equipped with a sophisticated picking tray. This robotic system is highly precise and capable of accurately retrieving medications, reducing the risk of errors and expediting the dispensing process. The picking tray further enhances efficiency by facilitating easy access to medications during the dispensing and restocking processes.

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Fig.1. EBOT pharmacy robot

The pharmacy automation system presented here is an advanced solution that empowers pharmacies to deliver superior service with minimized errors and enhanced efficiency. By combining automated, semi-automated, and manual methods, along with the integration of a state-of-the-art Cartesian robotic system with a picking tray, this technology revolutionizes pharmacy operations, ultimately benefiting both pharmacists and patients alike.

The Central Computer and MCP (Main Control Panel) Unit form the backbone of the system, facilitating synchronous processing of data. The seamless exchange of information between these two processors is enabled by an efficient Ethernet networking system. Figure 2 illustrates the communication flow of the Central Computer, responsible for executing internet protocol functions such as MTS (medicine track and trace system) and e-prescription retrieval from pharmaceutical depots, as well as reorder processes.

The Central Computer also operates using an intranet protocol to receive incoming orders from service stations. Additionally, it integrates a QR code reader, inventory management, sales database, drug information database, and smart placement software for comprehensive and streamlined functionality.

In contrast, the MCP Unit is responsible for controlling various aspects of the automation process. It efficiently manages axes servomotors to govern the Cartesian Robots for storage and retrieval operations, which include the precise functioning of the picking tray mechanism and integrated sensors for accuracy and safety.

Furthermore, the MCP Unit takes charge of placement guide LEDs, which are utilized for precise placement guidance during the dispensing process. Moreover, there is an option to include sorting, transfer, and placement preparatory units, which can be seamlessly controlled by the MCP Unit.

Overall, the integration of the Central Computer and MCP Unit allows for a highly efficient and synchronized operation of the automation system. The exchange of data between the processors via Ethernet networking ensures smooth functioning and enhances the system's ability to handle tasks such as medicine tracking, e-prescription retrieval, inventory management, and smart placement, all while leveraging the precise control provided by the MCP Unit for optimal performance.

An integral component of the system is the smart placement software, which plays a crucial role in determining the optimal locations for drug box placement. The decision algorithm derives its efficacy from a dynamic and updatable threedimensional size database. When the QR code is scanned from the drug box, the system utilizes a predefined set of rules to identify the appropriate slot for placement. Additionally, it generates a list of alternative placement options, empowering users to make informed decisions as needed.

The smart placement software's proficiency is rooted in its ability to access and continuously update a comprehensive size database, ensuring precise and adaptable placement decisions. Upon scanning the QR code, the system evaluates the box's dimensions and characteristics against the database to find the most suitable slot for storage.

Furthermore, the software's flexibility enables it to present alternative placement choices to users. This feature comes in handy when specific slots may be occupied or when users have specific preferences or requirements. The availability of alternative options allows for efficient and customized management of drug box placements.

The smart placement software is a vital aspect of the system, offering intelligence and adaptability to the drug storage process. By relying on a threedimensional size database and predefined rules for QR code scanning, it facilitates optimal drug box placement. The provision of alternative placement options ensures user empowerment and enhances the overall efficiency and usability of the pharmacy automation system.

Dynamic storage elements of the robot mainly involved in the process are Smart Placement Software running in the Central Computer, QR code reader, and the Main Control Panel as command application unit driving Cartesian Servos, Placement Guide LEDs in semi-automatic placement and Placement Cartesian System in automatic placement options respectively. In either option driving methodology of placement lies on a smart dynamic storage algorithm based on a specially designed decision tree approach. A smart, dynamic storage algorithm in either use case decides where to place the box by looking at different scenarios.



Fig.2. EBOT Pharmacy robot general working diagram

Base data for the intelligent algorithm in this example have started with useful data creation and update capabilities using the software. The boxes have been measured with their width, height, and length in relation to their barcodes. This first step involved the work of dedicated partner pharmacy personnel for about a month. Nearly 4500 boxes were measured, and initial data was created and entered into a database. This part of the software was designed with a Graphical User Interface (GUI) showing the box dimensions to help the user visualize during data entrance and update when box dimensions changed by pharmaceutical industry and drug producers, as shown in Fig.3.

EBC)T Pharmad	cy Robot – S	Server GUI v2	.2.0					
≡	Drug Inf	ō							
	Q Please enter medicine name								
\mathbf{i}	Medicine name								
A	Barcode								
	_	H(mm)	TL Price	Picture	••				
	H	W(mm)	Min	Priority					
	W Edit	D(mm)	Order	✓ Active/Ina	ctive	HI V			

Fig.3. Box dimensions input and update GUI

After generating the data, it underwent analysis to classify meaningful groups based on width and height. The results of this classification are presented in Table 1. This table provides information about the allowable width ranges for boxes to be stored in a specific location, disregarding the product names but considering the box dimensions. It also includes the actual design dimensions of storage location widths and the number of storage locations for a standard shelf width of 800 mm. Additionally, the table presents design dimensions (step distance) that account for the separators between consecutive storage locations.

In the height matrix section of the table, various height types are listed along with their corresponding box height ranges and the design values for physical distances between each shelf. Once the width and height of a box are known, the potential locations for placement on the machine are determined using width-height matrix pairs, such as C3. For instance, C3 signifies that any box with a height between 31 to 40 mm and a width between 41 to 50 mm can be accommodated in this particular storage location.

Furthermore, the software's dynamic location determination feature enables the placement of two-level smaller boxes with lower height and width values. This flexibility allows smaller boxes to be placed into larger locations if the smaller ones are fully occupied, according to the user's preference.

WIDTH MATRIX							
Width Type	1	2	3	4	5	6	7
Box width range (mm)	0-30	31-40	41-50	51-60	61-74	75-83	84-110
Number of storage locations							
in 800 mm shelf	22	17	14	12	10	9	7
Actual location width (mm)	33	44	54	63	76	85	110
Step distance of locations	36,0	46,6	56,6	66,0	79,2	88,0	113,1
HEIGHT MATRIX							
Height Type	Α	В	С	D	Е	F	
Box height range (mm)	0-20	21-30	31-40	41-50	51-60	61-80	
Distance between shelves							
(mm)	45	55	65	75	85	105	

Table 1: Width and Height Matrix

The shelves' design is based on the information provided in Table 1, along with data collected from the pharmacy's previous year's sales. This approach allows for the creation of customized shelves, leading to an optimized itempicking process. The combination of shelf classification and historical sales data provides a well-balanced solution for dynamic storage allocation, enhancing overall efficiency.

Unlike traditional static storage systems, the dynamic storage location methodology employed in the pharmacy robot shelving continuously adapts to changing inventory patterns. As boxes are picked, and storage locations become available, the system dynamically allocates those spaces to accommodate different products with varying brands or names. This dynamic approach ensures that available space is maximized and utilized efficiently.

The software has been designed to offer user interaction, granting the user the option to manually select and instruct where a box should be placed if desired. Alternatively, the system can automatically decide the optimal placement using a decision tree algorithm. This dual approach gives the user flexibility and convenience in managing the storage allocation process.

In summary, the combination of Table 1 data and previous sales information enables the design of customized shelves for an optimized item-picking experience. The dynamic storage allocation approach ensures efficient space utilization and adaptability to changing inventory, facilitated by user interaction or automated decision-making through the software.

Conclusions

This study focuses on the design and application of dynamic storage allocation techniques in Automated Storage and Retrieval Systems (AS/RS) systems, particularly in the context of a boxed medicine robot. Traditional AS/RS systems often use static storage allocation, where items are assigned fixed storage locations based on predetermined criteria. However, this approach may lead to suboptimal space utilization and inefficient retrieval times. To overcome these limitations, the study proposes dynamic storage allocation techniques that leverage real-time data and advanced algorithms to determine the optimal storage locations for boxed medicines based on factors like demand patterns, product characteristics, and retrieval frequency. By dynamically allocating storage positions, the system can adapt to changing inventory profiles and maximize space utilization, resulting in improved efficiency and cost-effectiveness.

Additionally, the study explores the integration of dynamic storage allocation techniques with a boxed medicine robot. This involves developing intelligent algorithms and control mechanisms that enable the robot to retrieve medicines from the AS/RS system based on the dynamically allocated storage positions. The main objective is to optimize the robot's picking routes and minimize retrieval time, ultimately enhancing the overall performance of the AS/RS system.

The study assesses the effectiveness of the proposed dynamic storage allocation techniques and their impact on the boxed medicine robot's performance through simulation experiments and case studies. The results demonstrate significant improvements in space utilization, retrieval efficiency, and overall system productivity compared to traditional static allocation methods.

The findings of this study contribute to the advancement of AS/RS system design and optimization, especially in the pharmaceutical industry, where boxed medicine handling is critical. Moreover, the dynamic storage allocation techniques presented in this study have the potential to be applied to other industries, enabling adaptive and efficient storage solutions in various automated warehousing contexts.

Future study directions may involve exploring more advanced algorithms and techniques for dynamic storage allocation, such as machine learning or artificial intelligence. Additionally, investigating the effects of dynamic storage allocation on other aspects of AS/RS system performance, such as energy consumption, reliability, or safety, could further enhance the understanding and applicability of these techniques.

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Innovative Research in Engineering

Chapter 17

Experimental Study of A New Type Natural Ventilation System

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ABSTRACT

In this study, the natural ventilation system designed for industrial buildings has been discussed. The effects of wind and thermal forces on ventilation performance have been determined with the established experimental setup. It saves 241,844 m³ of natural gas and prevents emissions during the period of use in lifetime. It has been concluded that the ventilation model is more beneficial than energy-consuming systems, environmentally.

Keywords: Natural ventilation, Experimental investigation, Net present value

INTRODUCTION

The most critical requirement of industrial production is the presence of production buildings with necessary infrastructure conditions. As industry develops and production demands increase, the number of industrial buildings has been increasing day by day. Ventilation systems aimed at disposing of gases resulting from production technologies, which also affect the comfort of workers and enhance indoor air quality, become inevitable.Ventilation refers to air exchange in an enclosed environment, and its fundamental purpose is to provide clean air for indoor spaces. There are two essential elements at the core of ventilation: the air exchange rate, indicating the exchange of polluted air with fresh air and the air distribution rate. A proper ventilation system should address both of these fundamental aspects, as having one without the other is not fully sufficient. Effective ventilation can be achieved through natural or mechanical systems.

Natural ventilation involves the movement of air through building openings, doors, windows, grilles, or specifically designed systems to achieve ventilation. The lifting force resulting from wind and temperature differences enables natural ventilation to take place. The capacity of natural ventilation is determined by the hourly ventilation rate, also known as the ventilation flow rate.Due to the high cost of implementing climate control systems in industrial buildings, they are often not equipped with such systems. With the unprecedented increase in global warming and energy costs, meeting the continuous energy demands of climate control systems has become challenging. Therefore, a natural ventilation system can be an efficient and cost-effective ventilation strategy.

The performance of mechanically driven natural ventilation systems depends on the temperature difference between indoor and outdoor environments, relative humidity, and wind speed. Consequently, experimental methods are required to obtain these data in order to determine the ventilation performance. Similar studies can be found in the literature.

Costola et al, 2009 study, they investigated the environmental factors affecting the wind pressure coefficient. They examined the wind pressure coefficient Cp using building energy simulation and airflow network software. The results indicated that building geometry, external surface condition, wind direction, wind speed, and building location were influential factors. The aim of the study was to determine the uncertainties in C_p applications in building energy simulation and airflow network programs.

Demir, 2013 master's thesis, the numerical modeling of natural ventilation methods was conducted. Meteorological conditions for Istanbul were considered using data from the General Directorate of Meteorology. Various natural ventilation models' physical parameters and their impact on pressure differences, which form the basis of natural ventilation, were observed based on temperature values obtained from the database. Three-dimensional physical model geometries were created in Gambit and analyzed using Fluent software to obtain experimental data.

Engin, 2012 study on energy-efficient design investigated the effects of natural ventilation systems in environmentally friendly buildings. The presence of a natural ventilation system was emphasized as an essential factor for energy-efficient and environmentally friendly buildings. It was noted that natural ventilation systems using wind energy contribute to energy efficiency.

King et al, 2006 study, they examined the effects of roof airflow in urban buildings on natural ventilation using a 36 m2 physical model in open terrain. By creating two airflow openings in the physical model, they attempted to understand how wind movements affected indoor air conditions when either one or both openings were open. Data were collected using anemometers, pressure sensors, temperature sensors, and CO_2 measurement devices. The study found that crossventilation resulted in a ventilation rate of 28%, and one-directional wind flow resulted in a ventilation rate of 64%. It was concluded that small changes in wind direction reduced natural ventilation by approximately 30-35%.

Guo et al, 2015 study focused on the optimization of natural ventilation systems for green building design using CFD analysis. They developed a threedimensional model for selected street and building designs, taking into account building shapes, wind speed, and direction, and investigated the interactions between variables such as ventilation opening size and direction, wind speed, and building shape.

Evola and Popov, 2006 study examined the implementation and performance of wind-driven natural ventilation in buildings using CFD analysis. The study was based on computer-based Computational Fluid Dynamics (CFD) analysis. A CFD design was created to analyze various scenarios generated by variable wind loads on the building's geometry. The results demonstrated that wind-driven natural ventilation can be effectively applied in buildings. CFD analysis was suggested as an alternative to costly experimental tests.

Huang et al, 2017 study measured the natural ventilation capability of traditional Chinese folk houses during the summer. A traditional Chinese house with dimensions of 16.4 m x 24.25 m x 7.0 m was used as a physical model. Wind speeds were measured at a height of 1.5 m from the ground at the center of each room to investigate the natural ventilation capacity of the physical model. The study concluded that due to the building's geometry, the internal air exchange rate increased when all doors and windows were open. The wind loads outside the

building played a significant role in natural ventilation, which contributed to building cooling during the summer.

Han et al,2018 study experimentally examined the effect of thermal buoyancy on natural ventilation. While natural ventilation is primarily influenced by external wind speed and the temperature difference between indoor and outdoor environments, the study investigated the effect of variations in temperature difference on ventilation. The thermal buoyancy effect was described using hydrostatic theory.

Van Hooff and Blocken, 2012 study examined CFD analysis on natural ventilation, thermal changes, humidity, and CO2 concentration in the Amsterdam Aren-A stadium. Data was collected for a three-day period under various environmental conditions, including the number of people in the stadium, humidity, and CO2 concentration, directly from the stadium. The study verified the CFD analysis of a scaled stadium design using the experimentally obtained data, assuming an isothermal wind around the stadium.

Huang et al,2007 study performed a numerical analysis that included the wind effects on the Commonwealth Advisory Aeronautical Council steel building. By using CFD techniques such as Eddy Simulation, Reynolds-Averaged Navier-Stokes Equations Design, they determined wind loads on the building and surrounding airflow patterns. The main objective was to investigate an effective and reliable approach to assess wind effects on tall buildings using CFD techniques.

Hulsure and Maurya, 2019 study conducted a CFD analysis on a wind-driven natural ventilation system for an industrial storage building in Embassy Industrial Park Bilaspur in India. By considering different wind loads and environmental conditions, the behavior of the natural ventilation system was determined using the CFD analysis. The study concluded that for the system's optimization, a physical design was needed to be applied to the roof arch, and additional air intake points were required on the building's side walls.

Li and Delsante, 2001 study examined airflow and temperatures in a physical model in the absence of thermal forces. They associated thermal buoyancy, wind-induced airflow, and envelope heat loss with variable air change rates.

Nikas et al ,2010 study examined the three-dimensional numerical model of a building's natural ventilation system using a physical model. They used Fluent software to achieve the infinite volume solution of the Navier-Stokes equations. The study compared the obtained experimental data with the air velocity profiles of ventilation openings in the building.

Ozturk et al, 2005 study on natural and forced ventilation systems in housing concluded that natural ventilation is more beneficial than forced ventilation in

terms of initial investment cost and operational cost. For functional natural ventilation, the building should be positioned to receive maximum wind, various mechanical and architectural elements should be used to facilitate wind entry, windows should be placed on opposite walls to increase indoor and outdoor pressure differences, and the ventilation height should be increased to increase ventilation rates.

MATERIAL AND METHOD

This study is conducted for an industrial building of a company located in Bozüyük Organized Industrial Zone. The industrial building owned by the company serves as a production and storage area for both metal cutting and noncutting manufacturing methods. During working hours, the emission of welding fumes, dust, and other ventilation-related factors pose problems that reduce the comfort of the workers.

The internal appearance of the building is depicted in Figure 1. The building has dimensions of 45 m in width and 204 m in length, with a roof height of 8.5 m. The building does not have any climate control system in place, and there are no internal heat sources within the building. Worker heating is provided using electric space heaters, which can be neglected for the purposes of this study. Due to the high initial implementation and operational costs of climate control systems, the company is inclined to explore alternative natural ventilation methods.



Figure 1. Inside view of factory building.

The author, who is also the owner of the company and the building under study, has developed a research and development project for a natural ventilation system to meet the existing ventilation needs. The efficiency of the pilot system applied on the roof, its applicability to the entire building, and its production feasibility are crucial aspects for the natural ventilation system. Therefore, the

Innovative Research in Engineering

functional effectiveness of the natural ventilation system is being experimentally examined through a physical model. The natural ventilation system placed on the roof provides ventilation through the stack effect, utilizing wind-induced pressure difference and ΔT^{0} C temperature difference between the interior and exterior environments. Figure 2 illustrates the real appearance of the physical model on the roof, while Figure 3 shows the bottom view of the physical model.



Figure 2. The real appearance of the physical model.



Figure 3. The bottom view of the physical model.

The natural ventilation system, being exposed to all climatic conditions on the roof, should be designed to withstand high wind loads and external physical impacts. The construction structure of the implemented physical model, which is shown in Figure 4 and the bottom view is illustrated above, is specified in 3D. The dimensions of the physical model, applied as a representation of the natural ventilation system, are indicated in Figure 5.



Figure 4. The construction structure of the implemented physical model.



Figure 5. The dimensions of the physical model.

A measurement setup has been established for the applied physical model, focusing on the section ΔP and overall physical model parameters $T_{in} \,^{\circ}C$ indoor temperature , $T_{out} \,^{\circ}C$ outdoor temperature , $v_r \,$ (m/s) wind speed, and relative humidity (%) at one hour intervals, between 12.10.2021-12.10.2022. The measurement system is based on a , and the schematic representation of the experimental setup is shown in Figure 6.



Figure 6. Schematic representation of the experimental setup.

According to Figure 6. Table 1. indicates measurement points and the brands and features of the measuring devices used in experiment setup.

	Measurement Point	Model	Sensivity
Temperature	3,6	Thermokotec Boyenet T	±0.1 ⁰ C
Wind	1	Delta Ohm HD 53.D	±0.03 m/s
Moisture	4	EMS ST-3XX	±%1
Pressure	2,5	AKT-DPT2500-R8	±1 Pa

Table 1 Experimental equipment and accuracy values.
A user interface based on PLC has been developed for the created experimental setup. In this interface, access to all recorded data throughout the measurement period is provided, while also enabling real-time monitoring of the data. Figure 7 shows the Thermokotec Type T thermocouple, Figure 8 displays the Delta Ohm HD 53.D wind speed meter, Figure 9 presents the EMS ST-3XX relative humidity sensor, and Figure 10 illustrates the AKT-DPT2500-R8 differential pressure transmitter.



Figure 7. Thermokotec boyonet T type termocupl.



Figure 8. Delta Ohm HD 53.D wind measurement sensor.



Figure 9 . EMS ST-3XX humidty measurement sensor.



Figure 10. AKT-DPT2500-R8 pressure measurements sensor.

Figure 11 indicates the user interface of the experimental setup . With this interface, real-time monitoring, data logging operations, and data transfer can be performed. The experimental setup operated continuously during the measurement period from 12.10.2020-12.10.2021.



Figure 11. User interface of experimental setup.

Figure 12 displays the detailed view of the data logger, and Figure 13 depicts the internal structure of the PLC panel of the experimental setup. A Delta-DOP 103BQ model external hard disk touch screen product was used as the data logger for data recording. It was chosen for its compatibility with PLC programming and its support for USB storage in addition to its own storage space.



Figure 12. The detailed view of the data logger.



Figure 13 . The internal structure of the PLC panel of the experimental setup.

The mean value and the repeatability SD value for each measured test data were defined as following equations.

$$X^* = \frac{X_m}{n} \tag{1}$$

$$SD = \sqrt{\sum_{m=1}^{n} \frac{(X_m - X^*)^2}{n - 1}}$$
(2)

The uncertainty value of the experimental data is defined as following equation.

$$U = \frac{SD}{\sqrt{n}} \tag{3}$$

Using the measurements obtained from the experimental setup, the total ventilation flow rate Q_T in (m³/s) is defined as (Prince Industries, 2011):

$$Q_T = \sqrt{Q_r^2 + Q_{\Delta T}^2} \tag{4}$$

Here; Q_r , defines the flow rate due to the pressure difference depending on the change in wind speed, and $Q_{\Delta T}$ defines the flow rate due to the density change depending on the temperature difference. Q_r is defined as:

$$Q_r = C_d A_c \sqrt{\frac{2\Delta P}{\rho_a}} \tag{5}$$

Here; C_d defines the discharge coefficient. The discharge coefficient varies depending on temperature difference in natural ventilation systems. C_d is defined as (Riffat, 1989):

$$C_d = 0.0835 \left(\frac{T_{in} - T_{out}}{T_{in}}\right)^{(-0.313)} \tag{6}$$

where A_c defines the ventilation cross-sectional area, ΔP defines the pressure difference and ρ_a defines the air density and air density is defined as:

$$\rho_a = \rho_{da} + \rho_m \tag{7}$$

Here, ρ_{da} represents the density of dry air in the ambient air, which is accepted as an ideal gas. ρ_m indicates the moisture density in the air. Since there is no humidity control system in the industrial building where the experimental setup is located, the humidity in the building changes depending on the external environment.

The relative humidity change affects the air density passing through the ventilation. Equation (8) is a simplified form of the Clausius-Clapeyron equation and expresses the saturation moisture pressure change depending on the temperature, which is the first step to calculate the effect of the relative humidity change on the density (Lampinen, 2015:39).

$$\log P_s(T) = 28.59051 - 8.2 \log (T_{in} + 273.15) + 0.0024804 (T_{in} + 273.15) - \frac{3141.31}{T_{in} + 273.15}$$
(8)

The ratio of the total water moisture pressure that the air can carry to the saturation pressure represents the relative humidity. For an air mixture with a known relative humidity and saturation pressure, the moisture pressure of the water in it is defined as (Lampinen, 2015:39).

$$\psi = \frac{P_{wm}}{P_s(T)} \tag{9}$$

 P_{wm} obtaining the pressure P (water moisture) is obtained by the density of dry air ρ_{da} in the ideal gas-air mixture and the density of the moisture ρ_m in the air mixture as following equations

$$\rho_{da} = \frac{(1 - P_{wm})10^5 \, Pa \, M_{da}}{RT} \tag{10}$$

$$\rho_m = \frac{(P_{wm})10^5 Pa.M_m}{RT} \tag{11}$$

 $Q_{\Delta T}$ the ventilation flow rate due to the density change depending on the temperature difference is given by (Prince Industries, 2011):

$$Q_{\Delta T} = C_d A_c \sqrt{2g\Delta h \frac{T_{in} - T_{out}}{T_{in}}}$$
(12)

Here, g defines the acceleration of gravity. Δh defines the ventilation section area height. T_{in} defines the indoor temperature and T_{out} describes the outdoor ambient temperature. (16)

Here; W_e electric fan power consumption, f_e unit price of electric and 8760 is NV system working hour in a year. When electrical energy is saved using this system, savings will also be achieved in the natural gas electric cycle power plant from which the company to which the application will be made receives electricity.

$$V_{ng} = \frac{W_{e.8760}}{q_{ng}.n_{te}.0.000278kWh}$$
(13)

Here; q_{ng} is calorific value, n_{te} is natural gas power plant, turbine efficiency at 0 °C temperature ,1 atm pressure. Assuming natural gas is ideal gas, the annual

savings in the amount of natural gas required for electricity production is defined (in mole) as:

$$n_{ng} = \frac{P_{atm} \cdot V_{ng}}{R.T} \tag{14}$$

Here; n_{ng} is kmoles of natural gas, P is atmosphere pressure 1 atm, R is universal gas constant 8.314 kJ/kmol·K and T =0^o C ,273.15 K. The emissions coefficients of natural gas combustion were given in Table 2. (Ucar and Arslan, 2021)

Fuel		Emission			
	CO ₂	CO	NO ₂	SO	
NG*	1.95023	0.00024	0.03384	-	

*permole-fuel

RESULTS AND DISCUSSION

The time-dependent variation of T_{in} and T_{out} temperature values measured with the measuring station on the physical model for a one year is shown in Figure 14. The effect of seasonal events on outside and inside temperature is manifested by fluctuations in graph slopes. The winter period is accepted in Turkey as a period between October 15th and April 15th 288th to169th day of the year. So, the measurements were started in 12.10.2020 and ended in 12.10.2021.



Figure 14. The changes of T_{in} and T_{out} temperature values.

While T_{in} and T_{out} values were measured depending on time, the results of φ and v_r measurements were also obtained for the same time. According to Figure 14 the outside temperature values vary between -10° C and 42° C, and the

interior temperature values vary between -10° C and 40 ° C The reason for the fluctuating exterior temperature curve is climatic effects. The reason for the variation in the inside temperature curve is the climatic effects as well as the physical factors that occur as a result of working inside the building.



Figure 15. The change of relative humidity value over time.

According to Figure 15 the amount of humidity in the air varies between 10-80%. It has been observed that the change in humidity during the day is less in winter. The main reason for the change in humidity in the air is the climatic changes and geographical external factors of the building where the physical model is applied. The high humidity differences in day and night measurements are natural climatic change.



Figure 16. The change of . v_r

According to Figure 16 the wind speed v_r changes between 0 m/s and 14 m/s in one year, and the highest wind speeds are reached in 74 th day of measurement. Variation in wind speed is a natural meteorological process. By

measuring internal and external pressure together with T_{in} , T_{out} , v_r , φ measurement and ΔP (Pa) values in the physical model section are obtained. Figure 11 shows the variation of inside and outside pressure change over time on a single graph.



Figure 17. Variation of P_{in} and P_{out}.

According to Figure 17 the internal pressure value was measured between 93116 Pa and 93118 Pa during the measurement period. In addition to this, it is seen that the external pressure value varies between 93118 Pa and 93125 Pa.

The positive pressure difference between the indoor and outdoor environment creates air movement from inside to outside. As the indoor pressure is higher than the outdoor pressure, the air tends to move to the outside environment are physical conditions. The reason why the internal pressure value is more variable than the external pressure is the physical conditions that affect the internal atmosphere as a result of the production inside the building. The external air pressure varies depending on the climatic changes in the geographical location of the building. As a result of obtaining the measurement results Q_r , $Q_{\Delta T}$ and Q_r , $Q_{\Delta T}$ ventilation flow rates provided by the physical model were obtained by the calculation method. Figure 18 represents the values of Q_T flow rates within the total measurement time.



Figure .18 Values of Q_T .

During the measurement period, natural ventilation took place in all conditions. It has been observed that the ventilation performance in summer conditions is lower than in winter conditions since the temperature difference between indoor and outdoor temperature and outdoor wind speed are less in summer conditions. According to Figure 18 the maximum ventilation rate $Q_T = 15560 \text{ m}^3/\text{h}$ in the 105^{th} day of the year in winter season, minimum ventilation rate $Q_T = 4784 \text{ m}^3/\text{h}$ in the 357^{th} day of the measurement in winter season and the average ventilation rate of $Q_T = 6850.80 \text{ m}^3/\text{h}$ was obtained in 365 days period with the natural ventilation system, which was applied as a pilot and has a cross-sectional area of 3 m^2 . It is requested by the company that the physical model is applied, the air changes once times per hour for the total building volume. The total volume of ventilated area $V_b = 130,165 \text{ m}^3/\text{h}$. The required natural ventilation for homogeneous ventilation for all building volume is $n_v = 19$ units,

The electricity of the building and other industrial facilities of Türevmak company located in Bozüyük - Bilecik industrial estate, which is the subject of this study, is supplied from Akenerji Bozüyük Natural Gas Power Plant with the installation of the system, the amount of energy consumed from the power plant decreases.By using equation (14), the amount of natural gas savings has been reached with the electricity saving obtained by the establishment of the system. The saving in the number of emissions resulting from the combustion of natural gas is determined. Table 3 shows emission and natural gas saving of natural ventilation system.

Saving	Unit	Yearly basis	Lifecycle basis		
Natural Gas	m ³	12,092.20	241,844		
Electricity	GWh	0.0345	0.690		
CO ₂	ton	1045.11	20,902.20		
СО	ton	0.127	2.541		
NO ₂	ton	18.26	365.36		
NO	ton	4.57	91.51		

Table 3. The results of environmental evaluation.

According to Table 3, at the end of the system life of 20 years, the use of 241,844 m³ of natural gas and the emissions are prevented. In this study, the amount of ventilation of the physical model under different environmental conditions was investigated experimentally. With measurements made for variable wind speeds and different environmental conditions the amount of ventilation provided by the model was determined. It has been concluded that the system is worth the investment by considering it environmentally.

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Chapter 18

QGIS: Open source GIS software and Plugins

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SUMMARY

Geographic Information Systems (GIS) have become an essential tool in various fields, enabling the visualization, analysis, and interpretation of spatial data. The accessibility and capabilities of GIS technology have been transformed by open-source GIS software and its vast array of plugins. The QGIS program, well-known for its user-friendly interface, potent capabilities, and a thriving developer community, is one of the major players in this field.

Open-Source GIS Software: Open-Source GIS software refers to applications that are freely available, allowing users to access, modify, and distribute the source code. With the help of this strategy, GIS technology has become more accessible, allowing authorities, institutions, academics, and common people to make use of spatial data without being constrained by the high costs of proprietary software. Due to its cross-platform portability, comprehensive format support, and strong geographic analysis capabilities, QGIS, a top Open-Source GIS program, has grown in popularity.

Plugins for QGIS: What distinguishes QGIS is its ecosystem of plugins, which are modular additions that improve the capability of the program. In order to meet the demands of various users, plugins range from simple utilities to sophisticated analytical capabilities. These plugins can be easily added to the QGIS interface, increasing its functionality without requiring a deep understanding of coding or software development.

Geographic Information System (GIS) Software

A Geographic Information System (GIS) software is designed to retrieve, store, manage, display and analyze all types of geographic and spatial data from other sources. GIS software allows you to create maps and other graphical displays of geographic information for analysis and presentation.

GISsoftware enables you to produce maps and other graphic representations of geographic data for analysis and presentation. A GIS with these capabilities is an invaluable tool for visualizing spatial data and developing decision support systems for your.



Figure 1. GIS data structure (Seequent, 2023a)

A GIS maintains information about geographic features and their attributes. Typically, features are categorized as points, lines, regions, or raster pictures. Cities, roads, and boundaries can all be represented on a map as points, lines, or areas. Raster pictures can be created from aerial photos or scanned maps.

Spatial indices used by Geographic Information Systems to store data enable the identification of features on any part of a map. For instance, a GIS can swiftly locate and map every place within a certain radius of a point or every street through a specific area.

A GIS software program is a computer program that supports the use of a geographic information system, providing the ability to create, store, manage, query, analyze, and visualize geographic data, i.e. data representing facts for which location is important (Wikipedia.org, 2009). In various information

technology architectures, the GIS software market includes a wide range of commercial and open source applications that offer some or all of these functions.

What is Open Source Code (OSC) software?

Software that is open source (OSC) can have its source code inspected, changed, or improved by anyone. Most computer users never view the "source code," which is the code that allows computer programmers to alter how a software "program" or "application" functions. Programmers can enhance a computer program by adding features or fixing components that don't always function properly if they have access to the source code. (OpenSource.com, 2023).



Figure 2. Open Source Softwares (The Tapmi Blog, 2010)

Let's compare open source Geographic Information System (GIS) software with commercial GIS software. GIS software is software used to collect, store, analyze and map geographic data. Software that is open source allows for anybody to view and edit the original source code. Commercial software, on the other hand, is software that is offered to users through licensing by a company or organization and is usually paid (Eomag, 2017). Some important differences and similarities between open source GIS software and commercial GIS software are:

- 1-Licensing and Pricing:
- -Open source GIS software and commercial GIS software have a number of key distinctions and similarities.
- -Commercial software is usually sold by companies under paid licenses and users have to pay to use the software.

2-Community and Support:

- -Open source software is usually supported by a large community of developers and users. These communities are active in adding new features, fixing bugs and answering users' questions.
- -Commercial software may also have a support team, but it is usually not as large and diverse as the community support of AKK software.

3-. Features and Capabilities:

- -Commercial software frequently comes with a variety of features and may provide solutions for particular sectors or business requirements.
- -Even while it might not have as many capabilities as certain commercial software, open source software may be suited for those with more specialized or specific needs.

4-Security and Updating:

- -Security flaws may exist in commercial and open source software. However, since the source code of open source software is publicly available, vulnerabilities can be found and remedied more quickly.
- -Commercial software security upgrades may differ based on the company's rules and turnaround time.

5-Customization:

- -Open source software can be modified to meet individual user requirements. Users that have access to the source code can modify or add to the software.
- -Commercial software frequently provides less flexibility for customization, which may limit how precisely it may be adapted to users' unique requirements.

The user's requirements, financial situation, and technical proficiency will determine whether to utilize open source or proprietary GIS software. Open source software can provide more flexibility and customization whereas commercial software frequently offers more comprehensive functionality and support services. Commercial software might be more suited for consumers who desire a large community of supporters and frequent updates, whereas technically knowledgeable users might prefer open source software. Development of OCR software might offer viewpoints that go beyond those of a single organization. In the same way that user scripts and custom stylesheets enable websites to be customized to a user's needs, open source code is accessible for use and enables skilled end users to do the same with software. Once customized, the user can publish the change as a fork for users with similar preferences and submit potential improvements directly as pull requests.

Open Source Code (OCR) GIS software

An OCR software application is, by definition, software in which GIS users can freely access and modify the source code. Open source projects are usually worked on by a community of volunteer programmers (Dempsey, 2022).

Numerous benefits of open source GIS include its availability for free, adaptability, and support from a sizable and vibrant user and developer community. Commercial GIS software, such as Esri's ArcGIS Pro, is proprietary and charged for.

Open source GIS usage is expanding quickly, and GIS is playing a bigger role in the spatial business for data production, spatial analysis, visualization, and cartography.

Open source GIS programs are based on different underlying programming languages. In terms of programming languages, there are three main groups of open source GIS (apart from web GIS): "C" languages, Java and .NET.

The first group would be the one that uses the "C++" language for its implementation. This is the more mature of the open source GIS groups, probably for the simple reason that the group has been working on GIS software applications the longest and has a long history of code reuse.

C++ is often used for GIS programming because it is a powerful and versatile programming language that is well suited to the complex and computationally intensive tasks involved in GIS. C++ allows developers to create highly efficient and performant GIS software that can handle large amounts of data and complex geospatial operations.

In addition, C++ has a large and active community of developers who contribute to and support the language, making it a popular choice for GIS programming. The libraries in the C++ group consist of basic infrastructure and some capabilities such as coordinate reprojection that make them very useful and popular.

Popular "C" based open source GIS software applications include GRASS GIS, Geospatial Data Abstraction Library (GDAL) and QGIS (formerly Quantum GIS), a project started by the US Army in 1982 but now open source.

Some of the AKK software include:

- FlowMap
- GDAL
- QGIS
- GMT Mapping Tools
- GRASS GIS
- TNTmips Free
- gvSIG
- MapWindow GIS
- OpenJUMP GIS
- SPRING
- uDig GIS

Some of the web-based AKK software are:

- GeoServer
- MapFish
- MapServer
- OpenLayers
- OpenWebGIS
- MapGuide Open Source



Figure 3. Some Open Source GIS software (GIS Lounge, 2020)

What is QGIS?



QGIS is a professional GIS application built on Free and Open Source Software (FOSS) and proud to be itself. QGIS is a user-friendly Open Source Geographic Information System licensed under the GNU General Public License. QGIS is an official project of the Open Source Geospatial Foundation (OSGeo). It runs on Linux, Unix, Mac OSX, Windows, and Android and supports numerous vector, raster, and database formats and functions (QGIS.org, 2023).

Users can create, edit, and analyze spatial data using the free and open-source GIS program QGIS. It offers a framework for managing many kinds of geographic data, including databases, vector data, and raster data. QGIS enables users to produce high-quality output maps, which can be used for a variety of purposes, including infrastructure development, urban planning, and the management of natural resources. The software has changed over time with regular additions of new features and capabilities since its initial release in 2002.

The fact that QGIS is free to download and use is one of its main advantages. This makes it affordable for a variety of customers around the world, such as schools, NGOs, government organizations, and companies that use GIS services but have a tight budget. A variety of extensions, tools, and add-ons for QGIS are available for free download and installation. This enables users to effectively operate and adjust the software to their unique needs.

QGIS is a flexible piece of software that can be used on a range of devices because it is compatible with different operating systems, including Windows, Mac, and Linux. It is compatible with a wide range of data types, including GeoTiff, PostGIS databases, and picture files. This wide range of compatibility improves the software's usability and versatility and makes it simple for users to import and export their data.

Additionally, QGIS has a simple, user-friendly design that makes it perfect for both novice and experienced users. Users who require assistance with particular activities or features can find extra support in the software's rich documentation, tutorials, and user forums. The software has a wide range of analytical tools and functions and supports drag and drop capability.

Geocoding, geoprocessing, topology modification, and 3D modeling are among QGIS's features. Users can perform geographical analysis on their data,

for instance, by buffering or making a heat map to show regions with high or low point densities.



Figure 4. QGIS 3.28.9 'Firenze' (LTR)

Additionally, QGIS has a large selection of mapping tools that may be used to produce stunning maps and visualizations, such contour maps or thematic maps. Additionally supported by the software are Python, R, and SQL programming languages, enabling users to automate processes and create scripts.

Why QGIS?

Today, as "Geo-Sourced" information becomes more and more widely known, there is no shortage of applications that can perform some or all of the commonly used GIS functions (QGIS.org, 2023a; Gillian and Sparks, 2021). Why use QGIS instead of another Geographic Information Systems (GIS) software package? Here are just a few of the reasons:

- Installing and utilizing QGIS will not cost you anything at all. There are no setup costs, ongoing costs, yearly payments, or anything else. Like freebies, it is also free.
- If you need extra functionality in QGIS, you can do more than hope it will be included in the next release. You can sponsor the development of a feature or add it yourself if you have programming skills.
- QGIS is always changing. Because anyone can add new features and enhance old ones, QGIS will never become stagnant. A new module can be developed as quickly as you require.
- There is a ton of support and documentation accessible. You can consult the rich documentation, other QGIS users, or even developers if you run into any problems.
- QGIS is a multi-platform software. It can be installed on Mac OS, Windows, Linux and Android systems.

There are numerous software programs and apps available in the area of GIS software. The software that has most significantly aided the industry's expansion is QGIS. We can discover the clear justifications for employing QGIS in this blog.

We can summarize the most important features that distinguish QGIS software from other OSC software as follows.

It has a wide "Plugin" architecture. So, what is this Plugin architecture?

QGIS Plugins

Plugin architecture is how QGIS was created. This makes it simple to add numerous additional features and capabilities to the program. In reality, QGIS has several functionalities that are implemented via plugins. QGIS plugins are implemented either as Core Plugins or External Plugins (QGIS.org, 2023b; Gandhi, 2023; GIS OPS, 2019).

QGIS has had a modular architecture that makes it easy to add new features or functions (Packt, 2023). Most functions in QGIS are implemented in so-called plugins, which are divided into the following types:

Core plugins: These are kept up to date by the development team and included with QGIS by default. They should only be triggered by a user in order to be put to use.



Figure 5. QGIS Plugins menu select.

External plugins: These are kept up by the writers and are kept in an outside repository. They must first be installed by a user before being utilized. As time goes on, some of the most beneficial and well-liked plugins are integrated into the core functionality of QGIS.

The Core Plugins are automatically included in every QGIS release and are updated by the QGIS Development Team. They are written in either Python or

C++, depending on the situation. Python is now used to write the majority of external plugins.

The software QGIS gains important features from plugins. Developers of QGIS and other independent programmers who seek to enhance the software's fundamental features create plugins. After being evaluated by the community and being submitted to the QGIS Plugin Repository, these plugins are subsequently made accessible to all QGIS users.

Managing plugins

Activation, installation, updating, and removal of plugins are all included in their management, which may be done by going to "Plugins / Manage and Install Plugins". The dialog window has a number of tabs (Fig.6). When you click on a specific plugin under one of these tabs, full information is displayed, including links to the plugin's home page, code repository, and tracker as well as details on the plugin's functionality, rating, creator, and whether it is experimental or not:



Figure 6. Plugins main window.

- <u>*All:*</u> The complete list of accessible plugins, both installed and uninstalled, is displayed under this tab.
- <u>Installed</u>: The plugins that are already installed in QGIS are displayed on this tab. Just check or uncheck the toggle next to a plugin's name to activate or deactivate it (Fig.7).
- <u>Not installed</u>: All of the plugins that are accessible but haven't been installed in your QGIS are listed on this tab.

The following tabs are not always visible and are only displayed in the event that certain plugin requirements are met:

• <u>New:</u> This tab shows the not-installed plugins seen for the first time.

- <u>Invalid</u>: This tab appears if any installed plugins are corrupted or incompatible with the current version of QGIS. You can provide the developers consistent feedback by selecting a specific plugin from this tab and then clicking on the information about the potential invalidity that is displayed.
- *Install from ZIP:* Only when more recent versions of the installed plugins are accessible in the repository is this tab displayed.
- <u>Settings</u>: You can choose whether to utilize experimental or out-of-date plugins and choose how frequently updates will be checked on this tab. Although it is not advised to utilize experimental plugins in production, you can still select the option to view every tool that is offered. By default, only the *QGIS Official Plugin Repository* is linked, however you can add more repositories by selecting the Add... button if you are familiar with them. The previous graphic, for instance, demonstrates how to install an external Boundless plugin repository.

Core Plugins

Already included in the default QGIS installation are core plugins. You only need to enable them in order to use them. Many essential plugins are not always turned on. Plugins are loaded when QGIS starts up, therefore having a lot of plugins enabled can slow down startup. Disable all plugins you don't need for a better experience (QGIS.org, 2023c).

The core add-ons in the latest version of QGIS are (Fig. 7):

		Plugins Installed (11)
🌦 All	Search	
 Installed Not installed invalid invalid from 23P Settings 	MACOSX DB Manager Genetic Checker GRASS 05 provider GRASS 05 provider GRASS GIS provider Graduate Catalog Client Graduate Control Con	Installed Plugins Here you only see plugins installed on your QGIS. Click on the name to see details. Click the checkbox or double-click the name to activate or deactivate the plugin. You can change the sorting via the context menu (right click).
		Upgrade All Uninstall Plugin Reinstall Plugin
	Help	Close

Figure 7. Core Plugins.

DB Manager : Manage your databases within QGIS. The primary tool for integrating and managing the spatial database formats offered by QGIS (PostGIS, SpatiaLite, GeoPackage, Oracle Spatial, Virtual layers) under one user interface is the DB Manager Plugin. Numerous functionalities are offered by the DB Manager Plugin. Layers can be imported into your spatial database by dragging them from the QGIS Browser into the DB Manager. The tables can be imported by dragging and dropping them between spatial databases.

- Geometry Checker : Geometry Checker is a powerful core plugin to check and fix the geometry validity of a layer. It is available from the "Vector menu / Check Geometries...". The Geometry Checker Plugin can find the following errors:
- Self intersections: a polygon with a self intersection
- Duplicate nodes: two duplicates nodes in a segment
- Holes: hole in a polygon
- Segment length: a segment length lower than a threshold
- Minimum angle: two segments with an angle lower than a threshold
- Minimum area: polygon area lower than a threshold
- Silver polygon: this error come from very small polygon (with small area) with a large perimeter
- Duplicates features
- Feature within feature
- Overlaps: polygon overlapping
- Gaps: gaps between polygons
- *GRASS* 7 : GRASS functionality
- GRASS GIS provider : GRASS GIS Processing functionality
- MetaSearch Catalog Client : Interact with metadata catalog services (CSW)
- *Offline Editing* : Offline editing and synchronizing with database
- OrfeoToolbox provider : OrfeoToolbox Processing provider
- Processing : Spatial data processing framework
- SAGA GIS provider : SAGA GIS Processing provider
- Topology Checker : Find topological errors in vector layers. The relationships between the points, lines, and polygons that constitute a geographic region's features are referred to as topology. You can examine your vector files and check the topology using a number of topology criteria by using the Topology Checker plugin. These rules use spatial relations to determine whether your features are "Equal," "Contain," "Cover," "Covered By," "Cross," "Disjoint," "Intersect," "Overlap,"

your vector data depend on the specific issues you are trying to answer (for example, in general you wouldn't allow overshoots in line layers, but if they show dead-end streets you wouldn't remove them from your vector layer).

A built-in topological editing capability in QGIS is excellent for accurately constructing new features. However, user-caused and already-existing data inaccuracies are difficult to detect. Through a set of criteria, this plugin aids in the discovery of such problems.

External plugins

Although QGIS comes with a wide range of functions, there are a number of plugins that may be used to improve the program's performance and ease the handling of geospatial data (Free GIS Tutorial, 2023).

Users must install external plugins before utilizing them; they are available in the QGIS Plugins Repository. Following are some major categories into which external plugins can be divided (QGIS.org, 2023c).

- *GUI Plugins*: These plugins get installed to one of the "Menus or Toolbars".
- *Processing Plugins*: These plugins will expand QGIS' "Processing toolbox" with new algorithms (i.e., tools). The preferred method for creating plugins that provide additional spatial analysis features is as described above. A processing toolbox algorithm can be used as a component of the model builder or in batch processing mode to automate GIS workflows as opposed to being a separate tool. Both new tools and menu items can be added via plugins.
- Experimental Plugins: Sometimes we are looking for a specific plugin, but cannot find it in the "All tab". It may be because the plugin is marked "Experimental". Experimental plugins are typically inappropriate for use in production. These plugins should be regarded as "incomplete" or "proof of concept" tools because they are still un the early phases of development. <u>OGIS does not recommend installing these plugins unless you intend to use them for testing purpose (Fig. 8).</u>

Exploring the QGIS Plugins Repository

The ecosystem of third-party plugins for QGIS is robust. More than 1900 plugins are available in the official QGIS plugin repository. New plugins that may be of interest to you can be found by browsing. Now let's look around the plugin archive.

Click "PLUGINS" in the menu bar of the "QGIS Plugins Repository" (https://plugins.qgis.org/) (Fig.9).

0.0		Plug	ins Settings
ali	Check for Up	odates on Startup	
Installed	If this function repositories will	n is enabled,QGIS will inform Il be performed during opening	n you whenever a plugin update is available. Otherwise, fetching og of the Plugin Manager window.
Not installed	Show also	o Experimental Plugins	
Invalid Install from ZIP	Experimental development, a these plugins of	plugins are generally unsui and should be considered 'inc unless you intend to use then	table for production use. These plugins are in early stages of omplete' or 'proof of concept' tools.QGIS does not recommend installing for testing purposes.
Settings	v 🗌 Show also	o Deprecated Plugins	
	Deprecated pl considered 'ob no other altern	lugins are generally unsuita solete' tools. QGIS does not r atives available.	ble for production use. These plugins are unmaintained, and should be ecommend installing these plugins unless you still need it and there are
	Plugin Reposito	ries	
	Status	Name	URL
	Deconnected	a golo resmi ckienti Deposu	myou geogra agus or gyroograp yog file. Th'i (2003 - 2.6
	and the second second second		

Figure 8. Experimental Plugins activate window.

There is a list of every plugin on this page. To arrange the plugins by various attributes, click the headings.

Additionally, there are many categories like Popular, Featured, etc. that make it possible to find fascinating plugins. All the most recent plugins will be fetched when you select New Plugins. You can choose any plugin you like.

NU-Dirg QDS Plugins v LIVE-Can Rome Sigon	Tahkiuc Sorpularia	Gillim In Jan Dear macOS Devices	Crypto	- TryW	ov Cerk & Onur Tez v Benzin Fiyatlan, Shell GermanySe	vers QOIS Uyg & Kite	e v sotokir	47.5/Skechers		
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🕜 Upload a plugin		\smile		QC	IS Python Plugins Re	pository				
Plugins	All	plugins								
Featured	1904 m	cords found - Click to toggle desc	riptio	cs.						
All Stable		Name	*		Author	Latest Plugin Version	Created on	Stars (votes)	Stable	Б
New Plugins Updated Plugins		3D City Builder	-	26077	Arthur Ruf Hosang da Costa	July 6, 2021	Oct. 7, 2020	(53)	-	0.
Experimental Popular	8	3DCityDB Tools	-	538	Giorgio Agugiaro, Konstantinos Pantelios	June 2, 2023	June 2, 2023	(39)	-	0.
Most voted Top downloads	Q	A-Maps	-	17636	Riccardo Klinger	May 30, 2019	May 25, 2019	(21)	-	0.
Most rated QGIS Server plugins	485	AGIS	-	30352	Matjaž Mori, ZVKDS CPA	Jan. 3, 2023	March 19, 2020	(21)	1.4.1	-
	Q	AGT - Archaeological Geophysics Toolbox	-	58322	INFAP - Guillaume Hulin, Francois-Xavier Simon, Nariman Hatami	Sept. 20, 2021	Aug. 29, 2017	(43)	3.1.2	-
Plugin Tags 🦯	۲	ALKIS Plugin	-	184	Sajad Tabatabasi	June 21, 2023	June 15, 2023	89.838 0	-	0.
	8	ALS Downloader	-	3297	Matjaž Mori	April 10, 2022	April 10, 2022	(2) (2)	1.1	-
	100	AMIL-Assistente de Mapa Interativo Leaflet	-	5237	Givaldo Cesar	Jan. 14, 2022	Jan. 6, 2022	(7) (7)	1.1.1	
	-	ANA Data Acquisition	-	11943	HGE-IPH	Oct. 8, 2021	July 26,	10	1.0	-

Figure 9. QGIS Python Plugins Repository webpage window.

Some of the most downloaded applications of QGIS are:

QuickMapServices

QuickMapServices is an essential plugin for QGIS that allows users to easily add base maps and other map services to their projects. This plugin provides access to a wide range of online map services, including OpenStreetMap, Bing, Google, and more. It also allows users to add their own map services or WMS layers. The QuickMapServices plugin has been developed by NextGIS.

QuickMapServices

QGIS-OpenLayers-Plugin is a embedding OpenLayers functionality. It uses WebKit to render web based map services using their official Javascript API.

Semi-Automatic Classification Plugin

The Semi-Automatic Classification Plugin (SCP) allows for the supervised classification of remote sensing images, providing tools for the download, the preprocessing and postprocessing of images. Search and download is available for ASTER, GOES, Landsat, MODIS, Sentinel-1, Sentinel-2, and Sentinel-3 images. Several algorithms are available for the land cover classification. The plugin has been developed by Luca Congedo.

QuickOSM

QuickOSM is a QGIS plugin to download data from Overpass server.

QuickOSM allows to work quickly with OpenStreetMap data in QGIS thanks to Overpass API. OpenStreetMap represents physical features on the ground (e.g., river, lake, roads or buildings) using tags attached to its basic data structures (its nodes, ways, and relations). Each tag describes a geographic attribute of the feature being shown by that specific node, way or relation.

MMQGIS

This plugin is a collection of QGIS vector layer processing plugins. MMQGIS is a set of Python plugins for manipulating vector map layers in QGIS: CSV input/output/join, geocoding, geometry conversion, buffering, hub analysis, simplification, column modification, and simple animation. MMQGIS provides an alternative to the Processing toolbox, with verbose progress reporting, an intuitive user interface, direct shapefile/CSV-file access, and some additional capabilities missing from other plugin sets. Input layers can be from any geospatial data source supported by QGIS.

Output file format are implied by the file extension given on the output file name. Formats currently supported through OGR/GDAL include:

ESRI Shapefile (*.shp), GeoJSON (*.geojson), SQLite (Spatialite) (*.sqlite), KML (*.kml), GPKG (GeoPackage SQLite file)(*.gpkg)

Time Manager

Time Manager is a powerful plugin that allows users to animate temporal data in QGIS. This plugin is particularly useful for visualizing changes in data over time, such as climate data, population data, or land use changes. Time Manager allows users to create animated maps that show how data changes over a specific time period.

Qgis2threejs

3D visualization powered by WebGL technology and three.js JavaScript library. This plugin visualizes DEM and vector data in 3D on web browsers. You can build various kinds of 3D objects and generate files for web publishing in simple procedure. In addition, you can save the 3D model in gITF format for 3DCG or 3D printing.

Lat Lon Tools

Ttis plugin makes it easy to capture, zoom to coordinates, and interact with other on-line mapping tools. It adds MGRS, Standard UTM, and Plus Codes support to QGIS. When working with Google Earth, Google Maps or other online mapping tools, coordinates are specified in the order of 'Latitude, Longitude'. By default Lat Lon Tools uses the standard Google Map format, but is very flexible and can use virtually any projection and coordinate format for input and output. The plugin has the following tools.

These are just a few of the best QGIS plugins that can improve your analysis and display of geographical data. You may automate monotonous operations, optimize your workflow, and produce more interesting and instructive maps and visualizations by utilizing these plugins.

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Chapter 19

A Literature Review on Optimal Capital Structure

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Abstract

This paper surveys the literature on optimal capital structure theories 1952 to 2020. The study covers a broad spectrum of theoretical frameworks and empirical studies that investigate the causes and effects of company capital structure decisions. Throughout the paper reader will mostly be reading about Modigliani Miller's Theorem and the literature created around these theorems. In addition, other theories are included in this paper, some of the optimal capital structure theories are, the tradeoff theory, pecking order theory, net income theory, net operating income theory. Lastly, the reader can find information and assumptions about the financial behavior of a manager -in other words the decision maker of a business - since these optimal capital structure theories also has an impact on the managers' behavior.

Keywords: optimal capital structure, the tradeoff theory , pecking order theory, net income theory, net operating income theory, debt, leverage
I. INTRODUCTION

In corporate finance it is a significant matter to decide how to choose a firm's capital structure and many theories have been developed to answer this question. In this literature review I will be examining these theories. This review will focus on studies published between 1952- 2020. Mostly I will be focusing on which theories are developed in order to understand how to choose the capital structure of firm, which one of these are applicable, overall how businesses should consider the capital structure and what are the measurement methods will be the main focus of this literature review.

In other words, this paper presents a comprehensive survey of the literature on optimal capital structure theories spanning the period from 1952 to 2020. The study encompasses a wide range of theoretical frameworks and empirical studies that investigate the factors driving and consequences of corporate capital structure decisions. While the review covers various theories, a significant focus is placed on the seminal work of Modigliani and Miller, which has generated extensive literature and subsequent research on the topic.

The survey begins by exploring David Durand's article which focuses on calculations of the debt and the cost of equity. Then literature review continues with Modigliani and Miller's groundbreaking theorem, which revolutionized the understanding of capital structure dynamics. Their theorem, originally proposed in 1958, suggests that, under certain assumptions, the value of a firm is independent of its capital structure. This theorem has served as a foundational pillar for subsequent research and is widely discussed throughout the literature.

In addition to Modigliani and Miller's theorem, this paper also discusses other prominent theories related to optimal capital structure. The tradeoff theory, pecking order theory, net income theory, and net operating income theory are among the theories examined, offering valuable insights into the trade-offs between debt and equity financing, information asymmetry, agency costs, and the impact of financial distress on capital structure decisions.

Furthermore, this literature review acknowledges the influence of optimal capital structure theories on the financial behavior of managers, who play a crucial role in making capital structure choices for businesses. By examining the literature in this area, the paper sheds light on how the various theories impact managerial decision-making processes, ultimately influencing the financial behavior and strategies adopted by firms.

The primary objective of this review is to provide readers with a comprehensive understanding of the diverse range of optimal capital structure theories developed over the past few decades. By presenting a synthesis of corporate finance literature, more specifically optimal capital structure literature.

This paper serves as a resource for researchers, practitioners, and policymakers seeking insights into the complex dynamics of corporate finance and capital structure decision-making.

II. CAPITAL STRUCTURE THEORIES

Theories of capital structure have started to become an important topic since 1952 in corporate finance. The questions of "How do the costs of stock financing compare with the costs of borrowing, or the costs of retentions? When, if ever, do finance expenses prevent companies from growing? And finally, does the tax system affect financing expenses in any way? the cost of debt and equity funds for businesses: trends and measurement issues in his article. As can be observed, Durand's goal was to highlight the difficulties and constraints associated with determining the cost of debt and equity capital for firms.

After this introduction he gives this two general principle: 2) Security appraisal is the key to determining the cost of capital, but he also notes that the specifics of the argument are, like a timetable, subject to alter without warning. 1) The fundamental economic theory needs modifications. Consequently, this essay serves as a historical account of the evolution of his thoughts to this point.

He begins by outlining the fundamental factors. He bases these considerations on the idea that when a businessman seeks money to finance a project, it must enhance his interests, and that any characterization of the expenses associated with doing so must be consistent with this idea.

After this introduction Durand, explains Maximizing Income vs. Maximizing Investment Value.

The maximization of income can also be criticized on the grounds that it has no application in any scenario where revenue is anticipated to fluctuate.

Later, Durand reformulates the Basic Theory

RR is expressed as:

$$RR = I + V \frac{dC}{dX}$$

where (I) is the marginal rate of interest, (V) is the investment value, and $\frac{dC}{dx}$ is the rate of change in the capitalization rate (percent) as the debt burden increases. This means that the RR is equal to the interest rate as long as the capitalization rate remains constant; however, if the capitalization rate begins to rise, the RR exceeds the interest rate.

In the second section of his article Durand discusses the problem of security appraisal. There exist two methods to capitalize earnings and in this section these methods are explained and discussed their problems by Durand.

He uses a balance sheet as an example:

After this reformulation two methods of capitalizing earnings have explained.

BALANCE SHEET OF THE PDQ MANUFACTURING		
COMPANY		
Assets		
Cash	3,000,000	
Accounts receivable	5,000.000	
Inventory	7.000,00	
	15,000,00	
Total Current	0	
	15,000,00	
Plant and equipment, less depreciation	0	
		\$30,000,0
TOTAL		00
Liabilities		
Accrued items	1,000.000	
Accounts payable	4,000,000	
Total Current	5,000,000	
Bonded debt, 4 percent debentures	5,000,000	
-	15,000,00	
Common stock, 1,500,000 shares at \$10 per share	0	
Earned surplus	5,000,000	
	20,000,00	
	0	
		\$30,000,0
TOTAL		00
INCOME STATEMENT OF THE PDQ MANUFACTURING		
COMPANY		
	\$30,000.0	
Sales	00	
	28,000.00	
Cost Of goods sold	0	
Net operating income	2,000,000	
Interest	\$200.000	

The problem is to estimate the value of the common stock assuming that the bonds, which are fully protected, sell in the market at par. Because the illustration's goal is to focus attention on the difficulty of capitalizing earnings, concerns of assets and book value will be completely ignored, and the crucial issue of corporate income tax will be deferred for later discussion.

One method, dubbed the NOI Method, capitalizes net operating income and subtracts debt as follows:

Net operating income	\$2,000,000
Capitalization rate, 10%	x 10
Total value of company	20,000,000
Total bonded debt	5,000,000
Total value of common stock	15,000,000
Value per share, 1,500,000 shares	\$10.00

The essence of this technique is that regardless of the percentage of bonds and stock, the total value of all bonds and stock must always be the same – 20 million in this case. The total value of all stocks and bonds will be referred to as the company's "total investment value" from now on.

The alternative method, dubbed the NI Method, capitalizes net income rather than net operating income. The formulas are as follows:

	\$
Net operating income	2,000,000
Interest	200,000
Net income	1,800,000
Capitalization rate, 10%	x10
Total value of common stock	18,000,000
Value per share, 1,500,000 shares	\$12.00

The overall investment value does not remain constant under this strategy, but rather increases with the proportion of bonds in the capital structure. As the debt burden grows, the bonds will fall below par, and the stock will no longer be worth 10 times earnings.

The share of net operating income (always \$2 million in this example) that must be paid to bondholders indicates the proportion of bonds in the capital structure. This method has the advantage of directly displaying bond coverage.

Except for organizations that are totally capitalized with stock, the most noticeable difference between the two approaches is that the NI Method results in a higher overall investment value and a higher value for the common stock. For such firms, the two techniques produce similar results if the same capitalization rate is applied. This divergence alone distinguishes the NI Method from the NOI Method, but the contrast between the NI Method's optimism and the NOI Method's pessimism will become clearer as the discussion unfolds. The NI Method appears to be overly optimistic about the hazards associated with corporate borrowing; the NOT Method appears to be more realistic.

Proponents of the NOI Method claim that just changing the capitalization proportions cannot change the entire amount of risk borne by all security holders in a given company. A change of this magnitude would only affect the proportion of total risk borne by each type of security holder. As a result, if the PDQ Company had been totally funded with stock.

The supporters of the NI Method take a little more nuanced approach. Those who strictly adhere to this method argue that: first, conservative increases in bonded debt do not increase the risk borne by common stockholders; and second, a package of securities containing a conservative proportion of bonds will justifiably command a higher market price than a package of common stock alone. The first argument appears to have little merit; it contradicts the detailed analysis presented by NOI Method supporters; and it appears to indicate that a company's security holders can pull themselves up by their own bootstraps.

These limited investors, which include all banks and insurance institutions, are forced to bid for high-grade investments nearly regardless of yield differentials or the attractiveness of lower-grade investments. And these limited investors have enough capital to keep yield differentials well above risk differentials. As a result, there is a sort of super premium for safety, which company management can take advantage of by issuing as many bonds as it can keep at a high credit grade.

As a result, theoretically, a compromise between the two ways is entirely possible. One can agree with supporters of the NOI Method that the totality of risk inherent in a single company's securities remains constant regardless of capitalization; and one can agree with supporters of the NI Method that the market will actually and justifiably pay more for the same totality of risk if the company is judicially capitalized with bonds and stock, with no inconsistency introduced.

The NOI Method and the compromise do not specify a capitalization rate for common stock earnings; nonetheless, one is inferred and easily determined. The capitalization rate for the NOI Method is given by the following simple formula:

$$\frac{1-P}{10-25P}$$

where (P) is the proportion of NOI required for bond interest, 10 is the reciprocal of the 10% net operating income rate, and 25 is the reciprocal of the 4% bond rate. This proportion becomes: for a compromise appraisal assuming a 1% super premium:

$$\frac{1-P}{10-20P}$$

where 20 is the reciprocal of the projected bond rate of 5% that would apply if the bonds did not attract a super-premium.

If the debt burden is too high, the RR for bond financing will almost certainly rise beyond the specified values, while the RR for stock financing will almost certainly fall below the quoted values, because additional equity will improve the security of the bonds and minimize shareholder risk. This is how the assessment technique affects the needed return.

In another headline Durand explains the effects of the corporate income tax.

Because bond interest is a deductible expense, bond financing can provide the firm with significant tax benefits. If a portion of the common stock is converted into bonds, the income tax is decreased while the overall amount flowing to security holders increases; finally, the total investment value increases — even under the NOI Method of valuation.

However, the RR for bond financing is less than that for stock financing, independent of the method of evaluation. Furthermore, the income tax has the effect of increasing the disparity between the NI Method and the NOI Method.

According to some business cycle theory writers, interest rates play a strategic role in stimulating and discouraging investment.

If businesspeople embrace the NOI Method of valuation, either officially or implicitly, the RR for new investment will be extraordinarily high during depressions because to low stock values, and interest rate reductions will have little effect. As a result, the high cost of borrowing capital may deter new investment during depressions just as much as capital's low marginal efficiency. In layman's terms, this simply indicates that businessmen are hesitant to incur debts during a downturn, and they will not do so, regardless of the interest rate, unless they can expect a return that is higher than the one they would expect during a prosperous period.

Equity financing can be divided into four types of transactions: common stock flotations, preferred stock flotations, use of earnings retained from operations, and conversion of rights or other instruments into common stock.

The method of financing common stock varies greatly from flotation to flotation. This is due in part to state regulations, in part to market conditions, and in part to personal preferences and judgment.

A whole stock issue is often sold directly to a syndicate, which is solely responsible for distributing the issue to the public. On the other end of the spectrum, an issue may be offered directly to stockholders via nonmarketable preemptive rights with no provision for public sale.

The following explanation is fully predicated on the notion that management has complete freedom of choice. However, in practice, managers do not always have this kind of leeway. When a company has a low current ratio, its management may be forced to limit dividends, even if they are earned, in order to avoid insolvency. A corporation's management may also be forced to limit dividends, even if they are received, since the terms of a loan arrangement or bond indenture require that working capital be kept at a certain level. As a result, a firm is sometimes practically required to hold earnings.

Another consideration should be the impact of the personal income tax on investors. However, accounting for personal income tax is extremely difficult for two reasons: 1) the wide disparity in rates between high and low income brackets, and 2) the uncertainty of the eventual tax status of potential capital gains that may arise if the corporation successfully invests its retained cash.

Financing is a combination process that involves both loan and equity in various forms and quantities, and as such it offers a complex dilemma in terms of joint expenses. What would the RR, or cost by any other criteria, have been if the XYZ Company had elected to finance its \$5 million plant expansion by 1) utilizing \$1 million of its own cash, 2) floating \$2 million in bonds, and 3) reducing dividends until the final \$2 million could be retained? Could an RR or another cost metric be calculated for the full transaction? And, regardless of the total cost, could it be properly shared among the three distinct sources of funding? This last question is especially relevant to the issue of public utility regulation.

Beyond noting joint expenses, this work does not propose to discuss them. The issue is undeniably present, and it is most likely formidable. With joint expenses, as with simple costs for a single type of financing, the solution is unquestionably dependent on the valuation of business businesses.

Finally, this article is limited to a single stage of economic behavior - asset financing and the costs associated with it. The expenses of raising money can be defined and assessed using a security assessment method. At the same time, researchers attempted to demonstrate that there is now no universally agreed system of evaluation, and thus no generally accepted method of cost measurement. It appears that the first step toward solving the specific challenge of cost measurement is to conduct additional research on the general problem of evaluation.

The second temptation for the unwary researcher is to describe costs in a way that suggests a specific approach of valuation. If, for example, he defines common stock cost as the earnings-price ratio (adjusted for flotation expenses) and bond cost as the interest rate (adjusted for flotation expenses), he is implying the NI Method of valuation; he is also implying a belief that borrowing is riskfree for the borrower.

By no means does research on the topic of business valuation appear to be simple. This paper's discussion has focused mostly on the disagreement between the NI Method and the NOI Method of capitalizing earnings. Perhaps; this gave the impression of oversimplification. Actually, I do not feel that either technique, as properly interpreted, is appropriate or accurate, albeit I strongly favor the NOT technique. However, if the NOI Method were to be approved in principle, changes would very probably be required. These may include adjustments for working capital, book value, and the extra premium for safety, all of which would necessitate careful consideration and possibly extensive statistical analysis.

Simultaneously, a broad reformulation of fundamental economic ideas would be highly desirable. What they require is a theory that addresses the issue of valuing risks associated with corporate expansion. If a project for reformulating basic theory could be integrated into a statistical analysis of security pricing, two desirable outcomes could be obtained: first, the interpretation of statistical findings would be less prone to error; second, a truly functional theory of business enterprise would be more likely to emerge.

After all of these discussions in 1954, Ferry B. Allen worked on the discussions about debt. His article literally named, "Does Going into Debt Lower the "Cost of Capital"?"

Trading on the Equity is a technique in which a company's management raises the rate of return on its equity capital by increasing the proportion of debt or other senior capital in the capital structure.

Lower utility prices can be achieved by raising the amount of senior capital. Some utility executives appear to have acknowledged the soundness of this argument (or may have been forced to accept it by regulatory policy) and increased their proportion of senior capital during the postwar boom period.

The increasing leverage of a high ratio of relatively low-cost senior capital is supposed to be somewhat offset by an increase in the "cost" of equity capital, so that the overall "cost of capital" decreases as the proportion of senior capital increases.

Professor Clemens of the University of Maryland, in the February 1954 issue of Land Economics says:

"A high percentage of equity capital presumably has two effects on the overall rate of return. In the first instance, it has some slight effect in decreasing the cost of all three types (debt, preferred, and common) of capital, because it stabilizes or increases the earnings available for each. On the other hand, a larger equity percentage increases the overall cost because equity capital is high-cost capital. In other words, there is some point at which both a decrease and an increase in the proportion of equity capital will raise the overall cost. ``

This article discusses two studies conducted for this aim by his office. Both studies focus on earnings ratios of electrical operational utilities since only in this field are there a significant number of large enterprises with sufficiently uniform operating features and adequate financial data that are not skewed by other factors.

Later, he notes that the first research includes all electrical operational utilities having assets of \$50 million or more as of December 31, 1947, and for which enough security pricing statistics were available for the study period--a total of 43 companies.

He constructed a line chart with the vertical axes representing percent return and the horizontal axes representing percent senior capital to total capital. In other words, it is the ratio of total revenue available for interest and dividends to total market value of securities as a proportion of total capital (debt and preferred stock).

Although there are few companies with a conservative senior capital ratio, the data (excluding extreme situations) appear to imply that the return on market value is pretty stable up to roughly a 55-to-60% senior capital ratio. Beyond this point, it rises gradually at first, then rapidly, as a top-heavy capital structure adds significantly to the enterprise's financial risk.

Second, he makes another chart in which the vertical axes are yield to market value and it illustrates the ratio of fixed charges (bond interest and dividends on preferred stock) to market value of senior capital, which steadily grows as the proportion of senior capital increases.

He adds that as the senior capital ratio rises, the ratio of net income to market value of common shares climbs dramatically. It appears that the equity investor does, in fact, give significant weight to the additional risk posed by a high senior capital ratio; he pays roughly half as much for a dollar of net income when the senior capital ratio is around 75% as when it is around 50%.

At this point, dividend payout must be considered because, as is well known, stock prices reflect primarily the capitalization of income received (either current or prospective) in the form of dividends, with only a minor weight given to the excess of net income over dividends retained in the surplus account.

Earnings-to-price ratios that are relevant to dividend payouts. As the senior capital ratio rises, dividend distribution falls noticeably. When analysts look at all of the data, it may appear that companies with a high ratio of senior capital

would have a lower earnings-price ratio on common stock, and so a lower "cost of capital," if they adopted more liberal dividend policy.

There are two reasons why this circumstance is not conceivable. To begin with, it appears quite likely that if companies in this situation increased their current dividend payout, the market would recognize that the new dividend rate would have less protection than the old and might be only temporary, and thus would have little or no effect on the price of the common stock. Second, organizations with a top-heavy capital structure are typically unable to raise equity capital, and hence can only change their capital structure by retaining a significant portion of net income.

Overall, the essay provides a valuable foundation for understanding the tradeoffs involved in borrowing money and emphasizes the significance of carefully managing a company's capital structure.

The "cost of money" subject continued to be an issue in corporate capital structure. After, Allen's article, in 1955, Harold M. Somers has discussed the cost of money as a determinant of public utility rates.

The article contends that public utilities, such as electricity and gas suppliers, must finance major capital investments in order to supply their services. As a result, the cost of money, or the cost of capital, has a significant impact on the prices that these utilities charge their customers.

The article also goes through the numerous factors that might influence the cost of capital, such as interest rates and the risk of investing in a specific firm or industry. The author argues that while setting rates for public utilities, regulators consider these elements to guarantee that they are both fair to consumers and sufficient to allow the utilities to maintain and enhance their infrastructure.

To summarize, the essay emphasizes the importance of understanding the relationship between the cost of capital and public utility rates, and it proposes that when determining rates, regulators should carefully evaluate the numerous factors that can affect the cost of capital.

Following all of these conversations, Modigliani and Miller developed their own capital structure theory in 1958. They have a considerable impact on corporate capital structure decision making processes, and there are many publications in literature that describe the Modigliani - Miller Theorem. They basically state that a firm's worth is independent of its capital structure. In other terms, the MM Theorem states that whether a corporation finances its investments with debt or equity has no effect on its total value.

Given this assumption, the theorist has concluded that the cost of capital to a firm's owners is simply the rate of interest on bonds and has derived the well-known proposition that a rational firm will tend to push investment to the point

where the marginal yield on physical assets equals the market rate of interest. This claim can be shown to derive from either of two rational decision-making criteria that are equal under certainty, either (1) profit maximization or (2) market value maximization.

The first criterion states that a physical asset is worthwhile to acquire if it would increase the net profit of the firm's shareholders. However, net profit will increase only if the asset's expected rate of return, or yield, exceeds the rate of interest. According to the second criterion, an asset is worthwhile to acquire if it raises the value of the owners' equity, i.e., if it contributes more to the firm's market value than the purchase costs.

However, the asset's worth is determined by capitalizing the stream it creates at the market rate of interest, and this capitalized value will surpass its cost if and only if the asset's yield exceeds the rate of interest. It is worth noting that the cost of capital in either formulation is equivalent to the rate of interest on bonds, regardless of whether the funds are obtained through debt instruments or new issues of common stock. Indeed, in an age of guaranteed returns, the distinction between debt and equity funds is essentially a matter of vocabulary.

The model that is used to determine the valuation process of securities, leverage, and the cost of capital is explained in the first section of the article. Consider an economy in which all physical assets are owned by corporations as a starting point. For the time being, suppose that these corporations can finance their assets solely through the issuance of common stock; the introduction of bond issues, or their equivalent, as a source of corporate funding is postponed until the following section.

The physical assets held by each corporation will generate a stream of "profits" for the firm's owners--its stockholders--over time; but, the constituents of this series do not have to be constant and are, in any case, unknown. They do, however, presume that the average profit per unit of time, or the mean value of the stream across time, is finite and reflects a random variable subject to a (subjective) probability distribution. First, notice that the stream is a profit stream rather than a dividend stream.

The following assumption is crucial to the rest of the analysis. They will assume that firms may be classified as having "equivalent return" classes in which the return on shares issued by any firm in any given class is proportional to (and so perfectly correlated with) the return on shares issued by any other firm in the same class.

This assumption means that different shares within the same class differ by no more than a "scale factor." As a result, if they account for the difference in scale by taking the return-to-expected-return ratio, the probability distribution of that ratio is the same for all shares in the class. As a result, all relevant attributes of a share are uniquely specified by defining (1) its class and (2) its expected return.

y, the price of each share in any given class must be proportional to its expected return. Consider expressing this proportionality factor for any class, say the kth class, as $1/\rho_k$. If p_j represents the price and s_j represents the projected return per share of the jth firm in class k, they must have:

(1)
$$p_j = \frac{1}{\rho_k} \bar{x}_j$$

or, equivalently,

(2) $\frac{\bar{x}_j}{p_i} = \rho_k$ a constant for all firms j in class k.

Several economic meanings can be ascribed to the constants ρ_k (one for each of the k classes): (a) Researchers may see from (2) that each ρ_k represents the expected rate of return on any share in class k. (b) $1/\rho_k$ is the price an investor must pay for a dollar's worth of expected return in the class k. (c) Continuing from (1), by analogy with the language for perpetual bonds, ρ_k can be seen as the market rate of capitalization for the expected value of the kth class of enterprises' uncertain streams.

They make some suggestions on debt financing and its effects on security prices.

Consider any corporation j and let Xi stand for the expected return on assets owned by the company (that is, its projected profit before interest deduction). Denote the market value of the company's debts by Di, the market value of its common shares by S_j , and the market value of all its securities by $V_j \equiv (S_j + D_j)$, or the market value of the firm. Then, according to MM's Proposition I, researchers must have in balance:

(1) $V_j \equiv (S_j + D_j) = \bar{X}'_j / \rho_k$ for any firm j in class k

That is, the market value of every firm is determined independently of its capital structure by capitalization its expected return at the rate ρ_k appropriate to its class.

This argument is equivalently phrased in terms of the firm's "average cost of capital," $\frac{\bar{x}_j}{v_j}$, which is the ratio of the projected return to the market value of all its securities.

Their proposition then is:

(2)
$$\frac{\bar{x}_j}{(s_j+D_j)} \equiv \frac{\bar{x}_j}{v_j} = \rho_k$$
, for any firm j in class k

That is, the average cost of capital for each firm is fully independent of its capital structure and equal to the capitalization rate of its class's pure equity stream.

Because, under our assumption of homogeneity, the projected total return of business 2, X2, is the same as the anticipated total return of company 1, X1, they may now replace X2 and Xi with a single sign X. As a result, the initial portfolio return can be written as:

$$(3) \quad Y_2 = \alpha(X - rD_2)$$

Assume the investor sells his α S2 worth of company 2 shares and instead purchased $s_1 = \alpha(S_2 + D_2)$ shares of business 1. He could do so by borrowing an extra sum α D2 on his own credit and pledging his new interests in business 1 as collateral, using the cash α S2 realized from the sale of his previous holding. He would thereby secure a fraction $s_1 = \alpha(S_2 + D_2)$ of firm 1's shares and earnings. Taking into account his personal debt interest payments α D2, the return from the new portfolio, Y1, is given by:

(4)
$$Y_1 = \frac{\alpha(S_2 + D_2)}{S_1} X - r\alpha D_2 = \alpha \frac{V_2}{V_1} X - r\alpha D_2$$

(5)

Assume an investor owns s1 shares of business 1, representing a fraction cx of the total outstanding stock, Si. His profit from this holding is as follows:

$$(6) \quad Y_1 = \frac{s_1}{s_1} X = \alpha X$$

$$(7)$$

Assume he exchanges this initial holding for another portfolio worth s1 but consisting of S2 dollars of stock in company 2 and d dollars in bonds, where s2 and d are given by:

(8)
$$s_2 = \frac{S_2}{V_2} s_1, d = \frac{D_2}{V_2} s_1$$

In other words, the new portfolio will be made up of company 2 stock and bonds in the proportions S2/V2 and D2/V2, respectively. The return on stocks in the new portfolio will equal S2/S2 of the overall return to stockholders of firm 2, which is (X- rD2), and the return on bonds will be rd. Using (8), the portfolio's total return, Y2, can be represented as follows:

$$Y_2 = \frac{s_2}{S_2}(X - rD_2) + rd = \frac{s_1}{V_2}(X - rD_2) + r\frac{D_2}{V_2}s_1 = \frac{s_1}{V_2}X = \alpha \frac{S_1}{V_2}X$$

When they compare Y2 to Yi, they observe that if if $V_2 < S_1 \equiv V_1$, Y2 will exceed Y1. As a result, shareholders of business l benefit by selling their holdings and replacing them with a mixed portfolio containing an appropriate fraction of the shares of company 2.

The purchase of a mixed portfolio comprising a levered company's stock j and bonds in the proportions Sj/Vj and D1/Vj, respectively, may be considered as an operation that "undoes" the leverage, allowing access to an appropriate percentage of the unlevered return Xj. It is the potential of undoing leverage that keeps the value of levered firms from continuously being less than that of unlevered firms, or, more broadly, prevents the average cost of capital j1/Vj from being systematically greater for levered companies in the same class than for non levered companies in the same class.

Proposition II. They can deduce the following proposition from Proposition I about the rate of return on common stock in companies with some debt in their capital structure: The expected rate of return or yield, i, on any stock j belonging to the kth class is a linear function of leverage, as shown below:

(1)
$$i_j = \rho_k + (\rho_k - r)D_j/S_j$$

That is, the projected yield on a share of stock is equal to the proper capitalization rate ρ_k for a pure equity stream in the class, plus a financial risk premium equal to the debt-to-equity ratio multiplied by the spread between ρ_k and r. Alternatively, the market price of any stock can be calculated by capitalizing its projected return at the continuously variable rate i_i of (9).

A number of authors have claimed similar counterparts to our Proposition I, but by appealing to intuition rather than seeking proof, and only to quickly assert that the results were not applicable to actual capital markets. Proposition II, on the other hand, is, as far as they can tell, novel. To establish it, they first noted that the expected rate of return, i, is defined as::

(2)
$$i_j \equiv \frac{\bar{x}_j - rD_j}{s_j}$$

(3)

From Proposition I, equation (3), they know that:

$$\bar{X}_j = \rho_k \big(S_j + D_j \big)$$

Substituting in (10) and simplifying, they obtain equation (9).

Following these propositions, they elaborated on some qualifications and extensions of the core propositions.

The inclusion of interest in the calculation of taxable corporate earnings prevents the arbitrage process from causing the valuation of all enterprises in a particular class to be proportional to the expected returns provided by their physical assets. Instead, it may be demonstrated (using the same method as in the original version of Proposition I) that the market prices of enterprises in each class must be proportional in equilibrium to their expected return net of taxes (that is, to the sum of interest paid and projected net stockholder income). This means that authors must replace each \bar{X}_j in the original versions of Propositions I and II with a new variable \bar{X}_j^{τ} expressing the firm's total income net of taxes:

(1)
$$\bar{X}_j^{\tau} \equiv (\bar{X}_j - rD_j)(1 - \tau) + rD_j \equiv \bar{\pi}_j \tau + rD_j$$

If $\bar{\pi}_j^{\mathsf{T}}$ denotes the projected net income to common stockholders and r denotes the average corporate income tax rate. After these substitutions, the propositions retain the same form as their originals when adjusted for taxes. As a result, Proposition I becomes:

(2)
$$\frac{\bar{x}_j^{\tau}}{v_j} = \rho_k^{\tau}$$
 for any firm in class k,

And Proposition II becomes:

(3)
$$i_j \equiv \frac{\overline{\pi}_j^{\tau}}{S_j} = \rho_j^{\tau} + (\rho_k^{\tau} - r)D_j/S_j$$

where ρ_k^{τ} is the capitalization rate for income net of taxes in class k.

The fact that the rate of interest may rise with leverage has no effect on the form or interpretation of Proposition I; while the average cost of borrowed funds

will tend to rise as debt rises, the average cost of funds from all sources will remain independent of leverage (aside from the tax effect). This conclusion is closely related to arbitrageurs' capacity to undo the leverage in any financial structure by acquiring an adequately mixed portfolio of bonds and equities. The increasing cost of borrowed funds as leverage rises will be mitigated by a commensurate decrease in common stock yield.

Later, he illustrates the implications of analysis for investment theory using other assertions.

Proposition III. If a firm in class k is making a decision in the best interests of its stockholders, it will pursue an investment opportunity if and only if the rate of return on investment, say p*, is equal to or greater than ρ_k .. That is, the cut-off point for investment in the firm will always be ρ_k , regardless of the form of instrument used to finance the transaction.

To get this result, they will examine the three major financing options available to the firm--bonds, retained earnings, and common stock issues--and demonstrate that in each instance, an investment is worthwhile if, and only if, $\rho^* \ge \rho_k$.

Consider the following scenario: an investment funded by the sale of bonds. They know from Proposition I that the firm's market value before the investment was:

$$V_0 = \bar{X}_0 / \rho_k$$

and that the value of the common stock was:

$$S_0 = V_0 - D_0$$

If now the firm borrows I dollars to finance an investment yielding p^* its market value will become:

$$V_1 = \frac{\bar{X}_0 + \rho^* I}{\rho_k} = V_0 + \frac{\rho^* I}{\rho_k}$$

and the value of its common stock will be:

$$S_1 = V_1 - (D_0 + I) = V_0 + \frac{\rho^* I}{\rho_k} - D_0 - I$$

or,

$$S_1 = S_0 + \frac{\rho^* I}{\rho_k} - I.$$

375

Consider the following scenario: retained earnings. Assume that the firm gained I dollars in cash during the course of its operations (without reducing the earning power of its assets). If the cash is dispersed as a dividend to the stockholders, their wealth W_0 will be as follows:

$$W_0 = S_0 + I = \frac{\bar{X}_0}{\rho_k} - D_0 + I$$

where \bar{X}_0 is the projected return from the assets less the amount I in question. If, on the other hand, the funds are retained by the company and utilized to finance new assets with an expected rate of return of p*, the stockholders' value becomes:

$$W_1 = S_1 = \frac{\bar{X}_0 + \rho^* I}{\rho_k} - D_0 = S_0 + \frac{\rho^* I}{\rho_k}$$

Clearly $W_1 \gtrless W_0$ as $p^* \gtrless \rho_k$, so that an investment financed by retained earnings increases the owners' net wealth if and only if $p *> \rho_k$.

Finally, consider the scenario of common-stock funding. Let P_0 signify the current market price per share of stock, and suppose for the sake of simplicity that this price solely reflects currently expected earnings, not any future growth in earnings as a result of the investment under consideration.

If N is the original number of shares, the price per share is as follows:

$$P_0 = S_0 / N$$

Where the number of new shares, M, required to finance an I-dollar investment is provided by:

$$M = \frac{I}{P_0}$$

As a result of the investment the market value of the stock becomes:

$$S_1 = \frac{\bar{X}_0 + \rho^* I}{\rho_k} - D_0 = S_0 + \frac{\rho^* I}{\rho_k} = NP_0 + \frac{\rho^* I}{\rho_k}$$

and the price per share:

$$P_{1} = \frac{S_{1}}{N+M} = \frac{1}{N+M} \left[NP_{0} + \frac{\rho^{*}I}{\rho_{k}} \right].$$

Since, $I = MP_0$, add MP_0 , and subtract I from the quantity in bracket:

$$P_{1} = \frac{1}{N+M} \left[(N+M)P_{0} + \frac{\rho^{*} - \rho_{k}}{\rho_{k}} I \right]$$
$$= P_{0} + \frac{1}{N+M} \frac{\rho^{*} - \rho_{k}}{\rho_{k}} I > P_{0} \text{ if,}$$

and only if, $p^* > \rho_k$.

Thus, a common stock-financed investment is beneficial to present owners if and only if its yield exceeds the capitalization rate ρ_k .

If the owners of a company uncover a large investment opportunity that they believe would yield substantially more than ρ_k , they may opt not to finance it with common stock at the current market price, as this price may fail to capitalize the new endeavor. A preferable course of action would be to issue shares ahead of time (remembering that stockholders are free to borrow and buy).

Another option would be to finance the project with loans at first. Once the project had manifested itself in greater actual earnings, the loan could be retired either through a stock offering at much better prices or through retained earnings. Another option along the same lines would be to combine the two steps with a convertible debenture or preferred stock, possibly with a progressively decreasing conversion rate.

Another reason why the alternatives in financial plans may not be irrelevant is because managers are concerned with more than just serving the interests of the owners.

It was demonstrated that when an unintegrated corporate income tax is implemented, the original version of Proposition I,

$$\bar{X}/V = \rho_k = a \text{ constant}$$

must be written as,

$$\frac{(\bar{X} - rD)(1 - \tau) + rD}{V} \equiv \frac{\bar{X}^r}{V} = \rho_k^{\tau} = \text{ a constant.}$$

It is convenient to refer to \overline{X}^r/V as the cost of capital. However, the appropriate measure of the cost of capital for investment decisions is the ratio of expected return before taxes to market value, i.e., X/V:

$$\frac{\bar{X}}{V} = \frac{\rho_k^{\tau} - \tau_r(D/V)}{1 - \tau} = \frac{\rho_k^{\tau}}{1 - \tau} \left[1 - \frac{\tau r D}{\rho_k V} \right]$$

This demonstrates that the cost of capital now depends on the debt ratio, declining at the constant rate $\tau \tau / (1 - \tau)$ as D/V increases. Thus, with a corporate income tax in which interest is deductible, stockholders can benefit from having debt in the capital structure even when capital markets are perfect. The gains, however, are minor.

In the event of wholly new common stock funding, D=0, and the needed rate of return ρ_k^S on such a venture becomes:

$$\rho_k^S = \frac{\rho_k^\tau}{1 - \tau}$$

For the other extreme of pure debt financing D= V and the required rate of return, ρ_k^D , becomes:

$$\rho_k^D = \frac{\rho_k^\tau}{1 - \tau} \left[1 - \tau \frac{r}{\rho_k^\tau} \right] = \rho_k^S \left[1 - \tau \frac{r}{\rho_k^\tau} \right] = \rho_k^S - \frac{\tau}{1 - \tau} r$$

The problem of establishing the needed rate of return for investments financed with retained earnings is more challenging since it entails a comparison of the tax effects to the individual stockholder of receiving a dividend vs having a capital gain.

The rate on any dividends received in the event of a distribution will similarly be variable, depending on the stockholder's other income, and with the added complexity brought by the current dividend-credit provisions. If they assume that the managers make fair estimations of the average values of the applicable tax rates for the owners, then the required return for retained earnings ρ_k^R can be calculated as follows:

$$\rho_{k}^{R} = \rho_{k}^{\tau} \frac{1}{1 - \tau} \frac{1 - \tau_{d}}{1 - \tau_{g}} = \frac{1 - \tau_{d}}{1 - \tau_{g}} \rho_{k}$$

Where τ_d is the assumed rate of personal income tax on dividends and τ_g is the assumed rate of tax on capital gains.

Finally, the authors claim that the cost of capital is the most important predictor of a company's investment decisions. All of these calculations seek to demonstrate that in an ideal capital market with no taxes, a company's value is unaffected by its capital structures. However, they agree that in the real world, this may not be the case. Since its publication, this essay has caused a dispute in the corporate finance sector, and it continues to have an important place in the literature.

As it mentioned earlier, Modigliani – Miller's article has sparked a debate and researchers made comments on this article. One of the researchers was David Durand. He demonstrates acritical analysis of Modigliani – Miller's article. Mainly, he challenges their ideas and suggests a counterargument.

Firms looking to lower capital costs through capital structure adjustments must assess market conditions and move quickly to take advantage of them.

In a later section of the paper, Durand makes the argument that market flaws like taxes and bankruptcy fees might in fact affect the cost of capital. He claims that while assessing a company's ideal capital structure and investment choices, these elements should be taken into account.

He explains that the "one income stream for another stream, identical in all relevant respects but selling at a lower price." argument does not apply to corporate stockholders in a world of high risk, but it may apply to stockholders in a world of low risk or to limited partners in a world of high risk.

MM does not truly assume a 100% payment; instead, they state:

"As will be shown later, retained earnings can be regarded as equivalent to a fully subscribed, pre-emptive issue of common stock as long as management is assumed to be acting in the best interests of the stockholders." As a result, for present purposes, the distinction between cash dividends and retained earnings in any year is really a minor detail."

But what exactly are "present purposes"? A quick examination reveals that they do not include the definition of an equivalent return class, which is key to MM's argument.

A price of $P_f = B_0$, for example, will meet only the first requirement. At this price the corporation must issue new shares numbering:

$$\frac{I}{B_0} = \frac{A\rho^* X}{A/X} = \rho^* Y X$$

and these together with N old shares will show the same earnings,

$$\frac{A\rho^*(1+\rho^*X)}{N(1+\rho^*X)} = A\rho^*/N$$

as before expansion. But the price $P_f = B_0$ will not satisfy the second requirement because the hypothetical subscriber to this stock issuance is

essentially obliged to acquire shares at B_0 when the market price is P_0 ; and he must either enjoy a profit $P_0 - B_0$ or suffer a loss B_0 - P.

Durand addresses the difficulties with the empirical study in his response piece.

The empiricist who investigates the cost of capital to firms will face a number of challenges, the first of which will be acquiring trustworthy and relevant data. He will encounter price quotations that are often difficult to obtain and frequently irregular or nominal--particularly quotations for corporate bonds, the majority of which are now traded seldom, and some of which, so-called private placements, are not traded at all.

Dividend rates, while simple to calculate for regular payers like American Telephone and Telegraph, will be difficult to calculate when irregular payments, equity dividends, and extras are the norm. Earnings are much more difficult to calculate properly than dividends because they are susceptible to the vagaries of accounting practice as well as the vicissitudes of business conditions.

Another barrier to MM's approach is the difficulty of obtaining a sample of firms capable of supporting a comparative, or cross-sectional, type of research.

The actual challenge is to discover samples that are sufficiently similar in most ways while exhibiting enough variance in growth rate, capital structure, and so on to reveal the influence of these factors.

However, if an analyst limits his samples to maintain them homogeneous, he must keep them small; and if he attempts to enlarge them to the point where they are numerically satisfactory, he must pay a price in lost homogeneity.

Finally, Durand summarizes all of his criticisms in the conclusion. According to him, MM have set themselves the extraordinarily difficult, if not impossible, task of being both pure and practical. MM's characterization of the equilibrating mechanism in an imperfect market, on the other hand, is unrealistic and inconsistent. Finally, and maybe most importantly, MM overestimated the difficulty of establishing an equivalent return class, which is the foundation of their hypothesis.

Another comment on MM's article has written by Joseph R. Rose in 1959, and he was questioning the validity of the theory because it is dependent upon the unsupported assumption that investors have available certain arbitrage opportunities. These opportunities in fact are not available.

In other words, "the average cost of capital for any firm is completely independent of its capital structure and equal to the capitalization rate of a pure equity stream..." It is the same for all companies in the same industry.

The arbitrage opportunities that underpin the idea are stated to develop in the following way. If V2, the value of business 2, a levered firm (that is, a corporation

with debt in its capital structure), is greater than V1, the value of company 1, an unlevered firm, an investor in company 2's shares (S2) will sell those shares and acquire company 1's shares (S1). He can buy Si with the profits from the sale of S2, as well as by borrowing on his own credit and pledging the shares (S1) as collateral. The assumption is that he will be able to borrow at the same interest rate as business 2 on its corporate debt (D2).

The investor can boost his income by providing his own leverage through personal indebtedness as long as V2 is bigger than V1. The sale of S2 lowers its price and hence 2, but the purchase of S raises its price and so V. When V2 and V1 are equal, the revenue from investments in companies 2 and 1 is equal, and the cost of capital (pk) to the two enterprises is also equal.

Only if S1 and S2 represent the same thing is this arbitrage operation permissible. In fact, S and S2 are distinct from one another. S2 is junior to company 2's debt, whereas S is not subject to any equivalent debt of business 1. It cannot therefore be expected logically that the investor will sell one and acquire the other, even if doing so will improve his income.

It is obvious that S2 represents a riskier investment than S1; however, the authors appear to regard risk as a subjective factor that should be ignored; however, even if risk is ignored, the arbitrage operation is invalid because S1 and S2 represent different investments.

Furthermore, the rates of return on these two investments differ. 2. The claim that "the average cost of capital to any firm is independent of its capital structure" is unsupported by evidence.

A good theory that purports to explain the impact (if any) of capital structure on the cost of capital must necessarily explain the impact (if any) of capital structure on corporate debt interest rates and stock earnings-price ratios. There is no such explanation in the suggested theory.

The literature continues to focus on the management of the corporate capital. For instance, in his 1960 "The Management of Corporate Capital" article Maffei explores various aspects of corporate capital management. The author examines the significance of capital structure decisions, the role of financial managers in optimizing capital allocation, and the factors influencing the management of corporate capital.

Maffei begins by emphasizing the importance of capital structure decisions in maximizing shareholder value. He discusses the tradeoff between debt and equity, highlighting the disadvantages and advantages of each. The article delves into the impact of leverage on a firm's risk and returns, emphasizing the need for financial managers to strike a balance between the cost of capital and the risks associated with different capital structures.

Other than these the following points can be seen as the highlights of the article:

- Corporate capital is a resource that must be managed effectively to ensure the long term success of the company.
- Effective management of the corporate capital requires a deep understanding of the company's financial position including its assets, liabilities and cash flows.
- Companies must carefully balance the need to invest in growth opportunities with the need to maintain adequate levels of liquidity and financial stability.
- Effective management of corporate capita also requires a focus on risk management, including the identification and the mitigation of financial risks that could threaten the company's financial health.
- Finally, the article emphasizes the importance of transparency accountability in corporate capital management, including clear communication with stakeholders about the company's financial position and performance.

The article's conclusion highlights the importance of capital management for organizations. It emphasizes how important it is for financial managers to make well-informed judgments on capital structure by taking into account a variety of elements like risk, return, taxes, and market conditions. In order to increase shareholder value, the essay sheds light on the challenges and factors that go into managing corporate capital efficiently.

Another article on leverage was written by Nevins D. Baxter in 1967. In his article, "Leverage, Risk of Ruin and the Cost of Capital" he discusses the optimal capital structure of a firm and how it relates to leverage, risk of ruin, and the cost of capital. Baxter argues that the optimal capital structure one that balances the benefits of debt financing, such as tax shields, against the costs, such as the risk of bankruptcy. He introduces the concept of "risk of ruin", which is the probability that a firm will become insolvent and be unable to meet its debt obligations.

Baxter shows that the risk of ruin increases as a firm's leverage increases, and this risk must be taken into account when determining the optimal capital structure. The article also discusses the cost of capital and how it is affected by leverage. When significant amount of debt is present in the capital structure, any increase in leverage is expected to have a more pronounced impact on the cost of capital. Baxter concludes that the optimal capital structure is one that minimizes the total cost of capital, which includes both the cost of debt and the cost of equity.

At this point, it can be seen that after some time the discussions and comments will start to repeat itself. Like the starting of Mike Dempsey's article, written in 1996, he starts his introduction by discussion the neoclassical capital theories and offers that a new model should be introduced. While doing this he discusses the useful patterns of corporate capital theories and includes the facts about financial markets. By doing this he discusses the corporate financing decisions and dividend decisions. It can be said that most of the article discusses the situation from a philosophical point of view.

In conclusion, corporate financial theory is still based on axioms about rational behavior in an equilibrium simple environment. The more obvious institutional realities of corporate financial management are reached with unneeded difficulty since the development of corporate finance theory depends on maintaining mathematical clarity and integrity as a requirement for contribution.

Similarly, in a 2001 article of Myers' which named "Capital Structure", it can be seen the mix of securities and financing sources used by corporations to finance real investment decision are discussed and tried to be explained. The majority of capital structure research has been on the ratios of debt to equity seen on the right-hand sides of corporate balance sheets.

He starts with explaining the pecking order and tradeoff theories briefly. than gives some financing facts. Then, directly dives into MM's propositions. After this he turns back to pecking order and tradeoff theories to explain them in a broader perspective since he compares them later in the article.

In conclusion he tries to answer the question "What are Financial Managers Really Maximizing?" This concludes his examination of the capital structure theories of tradeoff, pecking order, and free cash flow. Despite the fact that these hypotheses have been around since the 1970s and 1980s, research continues to flow at a rapid pace. All three hypotheses have believable examples of how they are in action. The financing strategies are a blatant manifestation of the economic issues and incentives—taxes, information, and agency costs—that underpin the theories. However, none of the ideas provides a broad justification for financing strategy.

Here we have a critical review of Rahul Kumar. In his article "Determinants of a Firm's Financial Leverage: A Critical Review", the author provides a comprehensive analysis of the factors that influence a firm's financial leverage. The article highlights the following key points:

• Financial leverage is the use of debt to finance a firm's operations, and it is an important aspect of a firm's capital structure.

- The determinants of financial leverage can be broadly classified into internal and external factors. Internal factors include the firm's size, profitability, growth, tangibility, and liquidity, while external factors include the cost of borrowing, tax policies, and market conditions.
- The article also provides a critical review of the existing literature on the determinants of financial leverage, highlighting the strengths and weaknesses of different studies and methodologies.
- The review finds that there is no consensus on the most important determinants of financial leverage, and that the relative importance of different factors varies across firms and industries.
- However, the review identifies several key trends and patterns in the literature, including the negative relationship between profitability and financial leverage, and the positive relationship between tangibility and financial leverage.
- The article concludes that a better understanding of the determinants of financial leverage is essential for firms to make informed decisions about their capital structure, and that future research should focus on developing more robust and comprehensive models of capital structure decision-making.

Overall, the article provides a critical and insightful review of the existing literature on the determinants of financial leverage, highlighting the complexity and diversity of factors that influence a firm's capital structure decisions.

In 2011, Brusov has written a chapter in Modern Corporate Finance, Investments and Taxation. In this chapter Brusov discusses "The Role of Taxing and Leverage in Evaluation of Capital Cost and Capitalization of the Company".

The function of tax shelters, taxes, and leverage in the contemporary theory of corporative finance is examined in this chapter. Considered are the Modigliani-Miller theory and the Brusov-Filatova-Orekhova current theory of capital cost and capital structure. It is demonstrated that as the tax on profit rate rises, capitalization increases while the equity cost and weighted average cost of capital both decline. Firstly, they analyze "The Role of Taxes in MM Theory". They use these two formulas to analyze:

- for WACC; WACC = $k_0(1 - w_d T)$, WACC = $k_0(1 - LT/(1 + L))$; - for the equity cost; $k_e = k_0 + L(1 - T)(k_0 - k_d)$

Both dependencies are linear: Both capital costs decline linearly as tax on profits T increases. It should be observed that when the tax rate on profits T increases, the difference in equity costs k_e at different levels of leverage declines, becoming zero at T = 1.

This process is reminiscent of operational analysis, which looked at how production costs, output quantities, and the deployment of products, goods, and services impacted a company's financial outcomes. Operating lever, costeffectiveness threshold, and stock financial health of the firm are the three main components of operational analysis of any enterprise. The operational arm is demonstrated by the fact that every modification resulting from a disposal always results in a more significant modification of earnings.

Then, they introduce for the first time two tax operating levers:

-for WACC;

$$L_{WACC} = \frac{\Delta WACC}{\Delta T}$$
-for cost of capital equity;

$$L_{k_e} = \frac{\Delta k_e}{\Delta T}$$

The bigger change in capital costs of the corporation at a fixed change in tax on profit rate T is caused by the higher value of the tax operational lever.

Later in the chapter they discuss "The Role of Taxes in Brusov–Filatova– Orekhova Theory". Think about the problem for the company's limited time (finite age). The Modigliani-Miller theorem is applicable here.

 $V_{\rm L} = V_0 + DT$ is changed by $V = V_0 + (PV)_{\rm TS} = V_0 + DT[1 - (1 + k_{\rm d})^{-n}]$ Where $(PV)_{\rm TS} = k_{\rm d}DT\sum_{t=1}^{n} (1 + k_{\rm d})^{-t} = DT[1 - (1 + k_{\rm d})^{-n}]$ represents a tax shield for n years.

As demonstrated in the limited example of Modigliani-Miller, the capitalization of a financially dependent (leveraged) corporation rises linearly with the growth of the tax on profit rate; however, the tilt angle of the linear function) $V_{\rm L}$ (T) is less than in the perpetuity case.

They investigated the relationship between the company's weighted average cost of capital and its equity cost per share and the tax rate on earnings in two ways: They investigated the relationship between the company's weighted average cost of capital and its equity cost per share and the tax rate on earnings in two ways:

1. They investigated the relationship between the business's weighted average cost of capital and equity cost and the tax rate on profits at fixed leverage levels and at various company lifetimes (ages).

2. They investigated how a company's weighted average cost of capital and equity cost depend on the amount of leverage used, the tax rate on profits, and the company's lifespan (or age).

They applied the Brusov-Filatova-Orekhova method for the company's weighted average cost of capital in both instances.

 $\frac{1 - (1 + \text{WACC})^{-n}}{\text{WACC}} = \frac{1 - (1 + k_0)^{-n}}{k_0 [1 - \omega_d T (1 - (1 + k_d)^{-n})]}$

The curves become steeper and the relevant tax operating lever falls when debt capital fraction ω_d (or leverage level L) increases, which increases the impact of changes in the tax on profit rate on the weighted average cost of capital.

The curves become steeper as the tax on profits rate T rises, which increases the effect of changing the debt capital percentage ω_d on the weighted average cost of capital WACC.

With reasonable accuracy, the relationship between the company's equity cost k_e and its leverage level L and profit rate T is linear. When, like in the perpetual scenario, the tilt angle falls as the tax rate on profits increases.

As a corporation gets older, its weighted average cost of capital (WACC) tends to fall below its perpetuity limit. According to the previously received dependences WACC (ω_d), the initial values WACC (at n = 1) fall as the fraction of debt capital increases, and a range of WACC changes is expanding as ω_d increases.

Overall, in this chapter it has been demonstrated that as tax on profit rates rise, so do the company's equity cost and weighted average cost of capital. It has been thoroughly investigated how tax on profit rates at set leverage levels (fixed debt capital fraction ω_d) as well as at fixed tax on profit rates affect the weighted average cost of capital (WACC) and equity cost of the company (k_e).

Lastly, in this literature review I will include the article "Financial Leverage and Corporate Performance: Does the Duration of the Debt Ratio Matters?"

This article examines the relationship between financial leverage and corporate performance, specifically the impact of the duration of the debt ratio on corporate performance.

This study looks at the impact of total debt, short-term debt, and long-term debt on the performance of Ghanaian listed companies during a ten-year period. Their contributions are both theoretical and practical. First, from the perspective of companies listed on the Ghana Stock Exchange (GSE), they add to the discussion of capital structure and performance. With an investor return of nearly 45%, this stock market is among the best-performing ones in Africa.

The current study investigates whether combinations of capital structure decisions, namely short-term debt, long-term debt, and overall debt, have an impact on a firm's performance using accounting and market-based measurements during a ten-year period (2005 to 2014) in a developing market.

H1. Corporate performance is negatively impacted by total debt.

H2. The performance of businesses is negatively impacted by short-term debt.

H3. The performance of businesses is negatively impacted by long-term debt.

THEY specifically choose 19 non-financial listed organizations on GSE across a ten-year period (2005 to 2014) with audited financial statement variables. To put it another way, because there are data available, our sample is made up of 190 firm-year observations. As dependent variables for a firm's performance, they use two accounting-based metrics (ROA and ROE) and three market-based indicators (Tobin's Q, market ratio to book value of equity, and price/earnings ratio).

The five leverage ratios that are employed as substitutes for capital structure are total debt to total assets (TDTA), total debt to total equity (TDTE), short-term debt to total assets (STDTA), long-term debt to total assets (LTDTA), and total debts to total capital. Control factors also include tax, tangibility, business size, and firm growth.

In results, they explain that According to Hypothesis 1, the success of the firm is inversely correlated with total debt. Results show that the relationship between leverage and performance depends on the debt ratio's denominator.

With regard to Hypothesis 2, they predict and discover a bad correlation between short-term debt and performance utilizing the perking order theory as their theoretical framework. Their findings support the notion that in the relationship between leverage and performance, the debt ratio's numerator matters.

They forecast a bad correlation between long-term debt and company performance with regard to Hypothesis 3. Their evidence contradicts this claim. As a result, Hypothesis 3 cannot be supported. The two hypotheses are slightly supported overall.

In conclusion, their findings have the conclusion that actual managers should avoid financing asset purchases with short-term debt. Companies should, in particular, fit the finance's duration to the asset's or investment opportunity's term. Particularly because both the principal and interest must be repaid quickly, shortterm debt entails greater financial and operational risk.

Investors are cautioned that these onerous payments could raise the danger of bankruptcy for businesses in sub-Saharan Africa, limiting management's flexibility, inventiveness, and long-term thinking and ultimately leading to subpar performance. The government should also take steps to improve the long-term external sources of finance in order to ensure the development of the debenture market. This would lessen the prevalence of businesses relying primarily on short-term loans and equity to fund their operations.

III. CONCLUSION

In conclusion, this comprehensive literature review has provided a thorough analysis of optimal capital structure theories from 1952 to 2020. The review covered a range of theoretical frameworks and empirical studies, with a particular focus on Modigliani and Miller's theorem, which laid the groundwork for understanding the relationship between capital structure and firm value.

This groundbreaking theory challenged traditional beliefs and paved the way for further research in the field. Other notable theories explored in this review include:

- Tradeoff Theory: This theory suggests that firms face a tradeoff between the benefits of debt (such as tax shields and lower costs) and the costs of financial distress. Firms strive to strike a balance that maximizes value by optimizing their mix of debt and equity financing.

- Pecking Order Theory: According to this theory, firms have a preferred order for financing sources, with internal funds being the most preferred, followed by debt and finally equity. This theory highlights information asymmetry and emphasizes that firms prefer to rely on internal funds and debt to minimize information costs.

- Net Income Theory: This theory posits that firms determine their capital structure based on the level of net income they anticipate. Firms aim to balance

the benefits of interest tax shields with the increased probability of financial distress associated with higher debt levels.

- Net Operating Income Theory: This theory focuses on the relationship between operating income and capital structure. It suggests that firms select their capital structure based on the stability and predictability of their operating income. Higher operating income stability allows firms to take on more debt.

Understanding these ideas offers important new perspectives on the variables influencing capital structure choices and their effects on business success. The impact of optimal capital structure theories on managerial decision-making was also highlighted in this research because managers are crucial in determining a company's capitalization and financial strategy.

This literature review provides a thorough overview of the evolving nature of capital structure theories by combining the data from many sources. It has shown how these theories have evolved over time to take into account fresh information, shifting market dynamics, and legislative modifications in the area of corporate finance.

Research in this area will continue to advance our comprehension of the complex relationship between capital structure choices and firm performance, resulting in better financial decision-making and sustained business growth in a dynamic economic environment.

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Chapter 20

Overview of Treatment of Pharmaceutical Industry Wastewater by Photo-Fenton, Ozonation, UV and Electro-Oxidation Methods: Cost, Toxicity, Sustainability Assessment

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ABSTRACT

Pharmaceutical industry wastewater can have a complex composition with used during the chemicals and components various pharmaceutical manufacturing process. This wastewater may contain toxic compounds that could potentially be harmful to the environment and water supplies. Therefore, treatment of pharmaceutical industry wastewater with advanced oxidation processes is an important step in terms of sustainability. Advanced oxidation processes target the oxidation of organic and inorganic compounds in wastewater. These processes are carried out using oxidizing agents (eg hydrogen peroxide, ozone or advanced oxidizing agents). These chemicals break down toxic compounds into less harmful compounds or turn them into compounds that can be less toxic. Advanced oxidation processes can break down drug residues and metabolites in wastewater. Thus, they help minimize negative impacts on water resources when discharged into the environment. In addition, these processes can improve the performance of biological treatment systems and provide a more effective treatment against drugs. In terms of toxicity, the release of compounds found in pharmaceutical industry wastewater to the environment can cause harmful effects in various ecosystems. In particular, the antibacterial effect of drugs can disrupt the balance of natural microorganisms and ecosystems in aquatic environments. Therefore, advanced oxidation processes contribute to the protection of aquatic ecosystems by reducing the toxic effects in pharmaceutical industry wastewater. In terms of sustainability, advanced oxidation processes are important in terms of protecting water resources and increasing their reusability. Effective treatment of pharmaceutical industry wastewater reduces the risk of pollution and depletion of water resources. In addition, studies on the energy efficiency and chemical consumption of advanced oxidation processes are conducted to develop more environmentally friendly and economically viable solutions in line with sustainability goals.

Keywords: Pharmaceutical industry, Toxicity,

INTRODUCTION

The pharmaceutical industry is a large industry that includes the process of producing and distributing drugs that are vital to human health. However, wastewater generated during the pharmaceutical production process is a major concern due to its environmental impact. It is difficult to give general information about the specific concentrations of active pharmaceutical ingredients in pharmaceutical industry wastewater. The wastewater concentrations of drug active ingredients may vary depending on the properties of the drugs used in the

production process, the production volume and the treatment methods used. In addition, different drugs and drug groups can be found in different concentrations in wastewater [1]. Pharmaceutical manufacturing processes include the manufacturing process of a drug from raw materials to the final product. This process usually consists of the following steps given in Figure 1.



Figure 1. Pharmaceutical Production Processes Stages Diagram

The pharmaceutical industry uses wastewater treatment systems to minimize environmental impacts. These systems are optimized to remove APIs and other contaminants. However, there may be variability in the efficiency of the treatment system and the complete removal of active pharmaceutical ingredients [2]. Wastewater analyzes and concentration assessments are based on studies customized for a particular drug manufacturing facility and process. Such studies are carried out to determine the concentrations of certain active pharmaceutical ingredients in wastewater and to evaluate their environmental effects. Pollutant parameters that can be found in pharmaceutical industry wastewater may vary depending on the processes used, the drugs produced and the efficiency of the wastewater treatment system of the enterprise [3]. However, the pollutant parameters that have the potential to be found in wastewater are given in Figure 2.



Figure 2. Types of Pollutants Found in Pharmaceutical Industry Wastewater

<u>Organic Substances</u>: Organic compounds such as solvents, solvent residues, reagents and product by-products used in the drug production process can create organic load in wastewater. This can be measured by parameters such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Solvents, reagents and chemicals used in the pharmaceutical production process create an organic pollutant load in wastewater. These organic pollutants can cause degradation of water resources and loss of biodiversity. In addition, these pollutants can have toxic effects on aquatic organisms and ecosystems. Pharmaceutical industry businesses should use wastewater treatment systems and ensure proper removal of organic pollutants. Process optimization and recycling methods can be effective in reducing the number of organic pollutants. Switching to renewable energy sources can reduce environmental impact and optimize energy consumption [1-4].

<u>Heavy Metals</u>: Some chemicals, catalysts or reagents used in pharmaceutical production may contain heavy metals. These heavy metals can cause various polluting effects in wastewater. For example, metals such as mercury, cadmium, and lead can cause environmental toxicity. Pharmaceutical industry businesses should identify sources of heavy metals and reduce the use of these metals by using alternative chemicals. Wastewater treatment plants must be effective in removing heavy metals. Consideration should be given to recovery of heavy metals in wastewater using recycling and reprocessing methods [1-4].

<u>Sulfates:</u> Some pharmaceutical manufacturing processes may contain sulfates, which can result in high sulfate concentrations in wastewater. Sulfates can affect the pH balance in water and cause environmental effects, especially in high concentrations [1-4].

pH and Acidity: Chemicals used in pharmaceutical manufacturing processes can affect the pH level of wastewater. Acidic pH values can increase the environmental impact of wastewater and complicate wastewater treatment processes [1-4].

<u>Nitrogen and Phosphorus Compounds</u>: Some chemicals used during drug production can cause high nitrogen and phosphorus concentrations in wastewater. This can lead to overfeeding of water resources and deterioration in water quality [1-4].

<u>Additives</u>: Some additives (eg colorants, preservatives, flavorings) used in the pharmaceutical manufacturing process may be present in wastewater and affect water quality [1-4].
Environmental Toxicity of Drug Active Ingredients

Environmental toxicity of drug active ingredients refers to their ability to cause adverse effects on the environment. The environmental toxicity potential of these substances varies depending on the properties, concentrations, interactions with the surrounding biological systems and half-lives of the drugs used [5].

Ecotoxicology: When drug active ingredients reach natural water resources, soils and the environment, they can cause toxic effects on aquatic organisms, plants and other living things. These toxic effects may occur by ingestion of active substances by inhalation, contact or food chain. Especially in the case of long-term exposure, environmental effects become even more important [6,7].

Bioaccumulation: Some APIs may pose a risk to the environment due to their bioaccumulation properties. This means that organisms can accumulate drug active ingredients in their bodies and become concentrated over time. Bioaccumulation can lead to the accumulation of APIs along the food chain and to high concentrations in high-level predatory organisms [6,7].

Endocrine Disruptive Effects: Some drug active ingredients can be effective on the endocrine system and disrupt hormonal regulations. This can affect the reproductive and developmental processes of aquatic organisms and produce population-level effects. Some drug active ingredients with estrogenic effects draw attention due to their endocrine disrupting effects, especially in aquatic environments [6,7].

Ecosystem Disruption: In case of high concentrations and long-term exposure, active pharmaceutical ingredients can disrupt the balance in aquatic ecosystems. This can lead to the death of aquatic organisms, loss of species and disruptions in the functioning of aquatic ecosystems. Environmental toxicity can cause effects such as biodiversity reduction and degradation of ecosystem services in aquatic ecosystems [6,7].

Treatment of Pharmaceutical Industry Wastewater

The pharmaceutical industry is a large industry that includes the process of producing and distributing drugs that are vital to human health. However, wastewater generated during the pharmaceutical production process is a major concern due to its environmental impact. Pharmaceutical industry wastewater may contain various chemicals, active ingredients and additives. This wastewater contains potential pollutants that can be harmful to the environment and human health. Therefore, it is not appropriate to discharge wastewater directly into the environment or water resources [8]. Pharmaceutical industry wastewater may contain various pollutants, especially those that require treatment. These

pollutants can include non-biodegradable organic compounds, heavy metals, dissolved salts and drug residues [9]. The mixing of these pollutants into water resources can cause environmental impacts and degradation of aquatic ecosystems. The treatment process aims to effectively remove the pollutants contained in the pharmaceutical industry wastewater. Treatment processes may include chemical oxidation, biodegradation, filtration, and other methods. These processes remove most contaminants, making wastewater safer and reducing the risk of harming the environment. The discharge water obtained after treatment can be safely discharged to water sources or sewer system when it complies with environmental standards [10, 11]. Thus, direct damage to the environment by pharmaceutical industry wastewater is prevented and water resources are protected. Particularly sectors that contain potentially pollutants, such as the pharmaceutical industry, should adhere to sustainable production principles and be attentive to waste management. Wastewater treatment plays an important role in reducing the environmental impact of this industry.

Various methods are used for the treatment of pharmaceutical industry wastewater. Some methods are described as examples. Physical treatment of pharmaceutical industry wastewater aims to remove contaminants using physical processes. Examples include settling, sedimentation, flotation, filtration, and adsorption [8-11]. These processes help remove solid particles, suspensions and some chemicals. Biological treatment is a purification method in which microorganisms are used. Microorganisms are used for the biodegradation of organic pollutants in pharmaceutical industry wastewater. Biological treatment systems include the activated sludge process, biological filters and membrane bioreactors. Chemical treatment is a method in which chemical processes are used. In this method, processes such as chemical precipitation, flocculation, oxidation and disinfection are used. Chemical treatment can be effective in removing contaminants such as heavy metals. Activated carbon adsorption is a method in which pollutants are removed by adhering to the activated carbon surface. Activated carbon adsorbs organic compounds such as drug residues and some chemical substances. This method is often used as part of other purification processes [12]. Advanced oxidation methods are a purification method in which strong oxidation agents are used. This method uses oxidizing agents such as ozone, hydrogen peroxide or UV light for further oxidation processes. Further oxidation can be effective in breaking down tough contaminants such as drug residues. These methods represent some of the options commonly used in the treatment of pharmaceutical industry wastewater. Actual application may vary depending on wastewater composition, volume and other factors. The

pharmaceutical industry should work meticulously on waste management by using appropriate treatment systems and minimize environmental impacts [9-12].

Advanced Oxidation Processes *Ozonation*

Ozonation is an effective method for the treatment of pharmaceutical industry wastewater. The purification of pharmaceutical industry wastewater by ozonation occurs because of the reaction of ozone gas with the wastewater and the oxidation of pollutants. The basic steps of ozonation mechanism are given in Figure 3.



Figure 3. The Basic Mechanism Steps of Ozonation Method

Ozonation can be used in combination with other treatment methods as well as being an effective method for the treatment of pharmaceutical industry wastewater. These combinations can be applied to achieve higher efficiency and better purification results.

The treatment of pharmaceutical industry wastewater by ozonation was investigated [13]. Researchers collected samples to determine the presence of different drug active substances in wastewater and investigated the degradation kinetics of the ozonation process. The results showed that the ozonation process significantly reduced the concentration of active pharmaceutical ingredients and was effective in the treatment of wastewater.

In another study, the treatment of antibiotics in pharmaceutical industry wastewater by ozonation was investigated [14]. Researchers have determined the degradation rates and conversion products of different antibiotics in the ozonation process. They also performed biological tests to assess the ecotoxic effects of treated water. The study showed that ozonation provides effective removal of antibiotics and reduced ecotoxic effects of conversion products. In another study, the treatment of drugs in hospital wastewater by ozonation was investigated [15]. Researchers have conducted experimental studies to determine the degradation efficiency of different drug active substances in the ozonation process. They also

showed that combining ozonation with biological treatment methods contributes to more effective treatment of wastewater.

Photo-Fenton Oxidation

Photo-Fenton oxidation is an effective method for the treatment of pharmaceutical industry wastewater. This method is applied in such a way that the oxidation process, called the Fenton reaction, is accompanied by a photocatalyst such as UV light or sunlight. Photo-Fenton oxidation provides effective removal of organic pollutants thanks to the high oxidation power of hydroxyl radicals. This method can be applied to different wastewater sources, including pharmaceutical industry wastewater, as it is effective in the treatment of various organic pollutants. Sunlight is an energy source that increases the efficiency of the photocatalyst. This reduces energy costs and provides a sustainable treatment option. Apart from these, there are some disadvantages. Photo-Fenton oxidation involves complex steps such as Fenton reaction and combination of photocatalyst, which can present some difficulties in terms of operation and maintenance. During photo-Fenton oxidation, some by-products may be formed. The nature and effects of these by-products must be considered, depending on the wastewater's final removal targets and discharge standards. Materials such as iron catalyst and photocatalyst required for photo-Fenton oxidation can be costly. In addition, energy costs should also be considered, as it is a process that requires a light source [1, 16,17].



Figure 4. The Basic Mechanism Steps of Photo-Fenton Oxidation

Treatment of pharmaceutical industry wastewater by Photo-Fenton process was investigated [16]. Researchers have conducted experimental studies to determine the presence of different drug active substances in wastewater and the effectiveness of the Photo-Fenton process in removing these pollutants. The results showed that the Photo-Fenton process significantly reduced the concentration of active pharmaceutical ingredients and was effective in treating

wastewater. In a different study, the removal of drug active substances from hospital wastewater by Photo-Fenton process was investigated [17]. Researchers have determined the degradation rates and removal efficiency of different active pharmaceutical ingredients by the Photo-Fenton process. The study showed that the Photo-Fenton process is a method that can be used for the effective removal of drug active substances in hospital wastewater.

UV Oxidation

The mechanism of decomposition of drug active substances by UV usually takes place through photochemical reactions. UV light causes various reactions at the molecular level, leading to the breakdown of drug active ingredients. Each drug molecule tends to undergo different reactions depending on its structural properties and chemical composition. Therefore, the mechanism and reactions of drug active substances with UV degradation may be specific and may differ for each drug molecule. However, the basic degradation mechanism is given in Figure 5.



Figure 5. The Basic Mechanism Steps of UV Oxidation

Bin et al. examines the treatment of pharmaceutical industry wastewater with advanced UV-based oxidation processes. Researchers evaluated the effectiveness of different UV oxidation processes (UV/TiO₂, UV/H₂O₂, etc.) in the removal of active pharmaceutical ingredients. The results showed that advanced UV-based oxidation processes were effective in the removal of active drug substances [18]. Lester et al., on the other hand, investigates the purification of pharmaceutical wastes by UV/ H₂O₂ advanced oxidation process. Researchers determined the degradation rates and removal efficiency of different active pharmaceutical ingredients in the UV/ H₂O₂ process. The study showed that UV/ H₂O₂oxidation is a method that can be used to effectively remove drug active ingredients [19]. In another study, it investigates the removal of drug compounds in the effluent of a municipal wastewater treatment plant by UV/H₂O₂ advanced oxidation process. Researchers of different active pharmaceutical ingredients [19]. In another study, it is the used to effectively remove drug active ingredients [19]. In another study is the degradation rates and removal of drug compounds in the effluent of a municipal wastewater treatment plant by UV/H₂O₂ advanced oxidation process. Researchers evaluated the degradation rates and removal efficiency of different drug compounds in the UV/ H₂O₂ process. The results showed that UV/ H₂O₂

oxidation can be an effective option for removal of drug compounds in wastewater treatment plants [20]. When the studies are examined, it is seen that different catalysts are used. TiO₂ is one of the most widely used photocatalysts. Thanks to its strong oxidation ability, it is effective in photocatalytic degradation of organic compounds. TiO₂ is stimulated by the absorption of UV light and provides the formation of free radicals (especially hydroxyl radicals) [21-23]. ZnO is a photocatalyst excited by the absorption of UV light. It has high photocatalytic activity and can be effective in the oxidation and degradation of organic compounds. ZnO provides the formation of reactive oxygen species such as hydroxyl radicals and superoxide radicals. These are just a few examples, and the variety of catalysts used in photocatalysis is wide. The choice of catalyst can vary depending on the reaction conditions, the targeted reaction, and the desired products [24,25].

Electro-Chemical Oxidation

The pharmaceutical industry produces wastewater containing many active ingredients. These active ingredients are potential pollutants that can harm the environment. Therefore, effective treatment of pharmaceutical industry wastewater is of great importance. Electrochemical treatment method has been evaluated as a potential option for the treatment of pharmaceutical industry wastewater. The electrochemical treatment method is a process in which electrochemical cells are used. Basically, in this method, chemical reactions are carried out using anode and cathode electrodes. The purification process takes place inside the electrolysis cell, where various electrochemical reactions take place. Some anode and cathode used in the electro-oxidation process are summarized. Platinum is a widely used anode material in electrochemical cells. It has high catalytic activity and is effective in oxidation reactions [26]. Titanium is another anode material used in electrochemical refining. It has high durability and corrosion resistance. Carbon is an anode material widely used in electrochemical refining. Carbon anodes made of graphite have high surface area and good electrical conductivity. Stainless steel is a common cathode material used in electrochemical cells. It has durable, low cost and corrosion resistance. Lead is another cathode material used in electrochemical purification. It has high electrical conductivity and long life. Silver plating is a cathode material used in electrochemical purification. Silver is preferred in some applications due to its antimicrobial properties. These are just a few examples, there are different types of anodes and cathodes that can be used in electrochemical purification. The anode and cathode materials chosen may vary depending on the characteristics of the wastewater to be treated, the targeted oxidation or reduction reactions, and

other application factors. During the process, oxidation and reduction reactions take place, decomposition or reduction of contaminants is achieved. The general steps of the electro-chemical treatment mechanism of pharmaceutical industry wastewater are summarized below [27-29].



Figure 6. The Basic Mechanism Steps of Electro-Chemical Oxidation

Electrochemical treatment provides effective removal of various pollutants as it has high oxidation or reducing power. Organic pollutants, heavy metals and other harmful compounds can be broken down or reduced by electrochemical reactions. The electrochemical treatment process reduces or eliminates the use of chemical additives. Therefore, it minimizes the potential harm to the environment. It also can deal with different wastewater compositions and pollutants. This method can adapt to various operating parameters such as pH, temperature, and flow rate. This process can, in some cases, enable the recovery of valuable compounds in wastewater. For example, some heavy metals can be recovered and reused. Despite its advantages, it has several disadvantages. Electrochemical treatment may require higher operating costs than some other treatment methods. High power consumption and, in some cases, the use of special electrochemical cells increase costs. Electrodes can wear down or become dirty over time. Therefore, they may require regular maintenance and cleaning. Electrodes may need to be renewed or replaced. The electrochemical treatment process can sometimes be slower than other treatment methods. The processing time varies depending on the concentration of the reagents, the electric current and the composition of the wastewater. Some specific contaminants may be difficult to completely remove in the electrochemical treatment process. Additional processes or pretreatments may be required to purify such compounds [26, 28, 29]. Zhang et al. investigated the electrochemical treatment of pharmaceutical industry wastewater using Ti/RuO2 anodes. The results showed that Ti/RuO2 anodes are effective in oxidation of organic pollutants. In addition, the effects of factors such as electrode material, current density and pH on the treatment performance were also evaluated in this study [27]. Gupta et al. investigated the electrochemical degradation of antibiotics in pharmaceutical industry wastewater in their study. Electrochemical oxidation method was used for oxidation and degradation of antibiotics. The results showed that electrochemical treatment was effective in removing antibiotics [28]. In another study, it was investigated the removal of persistent organic pollutants in pharmaceutical industry wastewater by electro-chemical method. The electrochemical treatment process involved examining the effects of factors such as electrode material, current density, and electrolyte solution. The results showed that electrochemical treatment is effective in removing persistent organic pollutants [29].

Comparison of methods from different perspectives

Cost

The costs of different methods for the treatment of pharmaceutical industry wastewater may vary. In general, treatment costs depend on many factors, so it is difficult to determine the exact costs. However, by making a general comparison, some factors that may differ in terms of cost of these methods can be considered.

Photo-Fenton Oxidation

- Photocatalyst cost: The cost of photocatalysts such as iron or titanium used for photocatalytic reactions must be considered.
- Hydrogen peroxide cost: Hydrogen peroxide is used for the Fenton reaction and the cost of procuring this component must be considered.
- Energy consumption: The photocatalyst requires a light source to operate effectively and this energy consumption can affect the cost [16, 17].

Ozonation

• Ozone production: An ozone generator is used for the ozonation process, and the purchase and operating cost of these devices should be considered.

- Gas transfer: Gas transfer equipment is needed to transfer ozone to wastewater, and this may affect the cost of equipment.
- Energy consumption: Energy consumption for ozone production and gas transfer should be considered [13-15].

<u>UV</u>

- UV lamp cost: Special lamps are used to provide UV light and the cost of purchasing and operating these lamps must be considered.
- Energy consumption: Energy consumption must be considered for the operation of UV lamps [18-25].

Electro-Oxidation

- Electrode cost: Special electrodes are used for the electro-oxidation process and the cost of these electrodes should be considered.
- Energy consumption: The electro-oxidation process requires electrical energy, so energy consumption affects the cost [26-29].

In addition to these factors, other factors such as wastewater composition, volume and operating conditions can also affect costs. In general, the costs of photo-Fenton, ozonation, UV treatment and electro-oxidation methods may differ from each other and vary depending on the particular situation. The advantages and disadvantages of each method should also be considered and evaluated together with the costs.

Toxicology

In terms of toxicology, photo-Fenton, ozonation, UV and electro-oxidation methods may have different effects on the treatment of pharmaceutical industry wastewater. Some key points for comparing these methods in terms of toxicology are described below.

Photo-Fenton

- Photocatalyst use: Photocatalysts can decompose organic pollutants in pharmaceutical industry wastewater by oxidation. However, some photocatalysts themselves can be toxic. Therefore, the choice of photocatalyst is important and safety factors must be considered.
- By-products formed: The Photo-Fenton reaction can lead to the formation of by-products. The toxic effects and environmental effects of these by-products should be evaluated [16, 17].

Ozonation

• O₃ effect: Ozone can decompose organic pollutants in pharmaceutical industry wastewater through oxidation. O₃ gas itself is highly reactive and can have toxic properties. It is important to use and control ozone correctly during the ozonation process.

• By-products: The ozonation process can result in the formation of byproducts. The toxicological effects of these by-products should be considered [13-15].

<u>UV</u>

- UV effect: UV light can break down organic pollutants in pharmaceutical industry wastewater. UV light itself is non-toxic. However, the toxic effects of free radicals formed during UV treatment should be evaluated.
- By-products: UV treatment can lead to the formation of by-products. The toxicological effects of these by-products should be evaluated [18-25].

Electro-Oxidation

- Electrode materials: Electrode materials used for the electro-oxidation process can be toxic. Therefore, the choice of electrode material is important and safety factors must be considered.
- By-products: The electro-oxidation process can lead to the formation of by-products. The toxicological effects of these by-products should be evaluated [26-29].

In all these methods, it is important to monitor and evaluate the by-products and toxic effects that may occur as a result of the treatment process. The toxicological effects and environmental effects of each method may vary depending on the specific wastewater characteristics, operating conditions and process parameters used.

Sustainability

In terms of sustainability, we can consider the following factors to compare the treatment of pharmaceutical industry wastewater with photo-Fenton, ozonation, UV and electro-oxidation methods.

Energy Efficiency

- Photo-Fenton: Because the Photo-Fenton process requires a light source such as sunlight or UV light, there may be energy consumption. Solar energy use may be a more sustainable option [16, 17].
- Ozonation: The ozone generator and gas transfer equipment require energy for the ozonation process. Energy consumption may vary depending on the efficiency of the method and operating conditions [13-15].
- UV: Energy consumption is required for UV lamps. Energy efficiency can be increased by using high-efficiency lamps and energy-saving systems [18-25].
- Electro-oxidation: The electro-oxidation process requires electrical energy. Electrode material and operating conditions can affect energy efficiency [26-29].

Chemical Usage

- Photo-Fenton: Hydrogen peroxide (H₂O₂) and metal catalysts are used for the Photo-Fenton process. The production and supply of these chemicals should be evaluated in terms of sustainability [16, 17].
- Ozonation: Ozone is used for the ozonation process. Since ozone is not found in nature, it requires industrial production. The environmental impacts of ozone production should be evaluated.
- UV: The UV treatment process does not require the use of chemicals, so it provides an advantage in chemical consumption and waste management [18-25].
- Electro-oxidation: The electro-oxidation process can reduce or eliminate the use of chemicals. This method may be a more sustainable option in terms of chemical consumption and waste management [26-29].

Waste Management

- Photo-Fenton: The management of by-products and residues resulting from the Photo-Fenton process is important. The toxicological effects and disposal of these by-products should be considered [16, 17].
- Ozonation: As a result of the ozonation process, the disposal of ozone residues and by-products and waste management are important [13-15].
- UV: No chemical residues or by-products are formed as a result of the UV treatment process, therefore it is advantageous in terms of waste management [18-25].
- Electro-oxidation: It is important to manage the by-products and residues formed as a result of the electro-oxidation process. The toxicological effects and disposal of by-products should be evaluated [26-29].

Considering these factors, the sustainability evaluation of photo-Fenton, ozonation, UV and electro-oxidation methods depends on the specific application and operating conditions.

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Chapter 21

A New Vision for Computer Vision: Smart Glasses with Humanoid Robots

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ABSTRACT

Computer vision is an artificial intelligence field that is widely used in many fields today. Smart glasses and humanoid robots, on the other hand, are new technologies with a lot of investment, but their development is progressing very quickly and impressively. Computer vision and augmented reality constitute the working principle of smart glasses. On the other hand, the data and technologies to be obtained with smart glasses directly affect the development of humanoid robots. While humanoid robots are on the way to become a big part of our future, computer vision and smart glasses are the main subjects of this article as areas that enable the development of this technology. In this study, the interaction of smart glasses and humanoid robots was examined. The effect and development of computer vision on smart glasses and humanoid robots are explained. In addition, the effect of artificial intelligence and mind reading investments on humanoid robots in the future is also mentioned.

Keywords: Computer Vision, Smart Glasses, Humanoid Robots, Artificial Intelligence, Deep Learning, Machine Learning, Augmented Reality, Emotion Recognition, Mind Reading, Facial Expression Analysis

INTRODUCTION

Computer vision is an artificial intelligence field used to understand visual data. Image data sets are collected, these data sets are processed, their features are extracted and interpreted by passing certain models. This is simply introducing an image to the computer and teaching it what that image is. It has many fields such as object recognition, object detection and face recognition. Computer vision is used in many areas such as the automobile industry, medicine and security systems. Smart glasses are another area where computer vision is used. Smart glasses are a wearable high-end technology that can provide information and perform various functions, allowing users to experience their environment in a richer way thanks to integrated computer systems and displays. It is expected that the data we obtain thanks to smart glasses will make a great contribution to the development of humanoid robots. Humanoid robots are robots that have a human-like physical structure and can act like a human. With the feedback received from smart glasses, the vision and competencies of humanoid robots can be increased and improved. In addition, today, large investments are made in artificial intelligence and mind reading technology. In this context, if mind reading becomes possible in the future, humanoid robots will benefit greatly from this technology.

THE FUTURE OF SMART GLASSES: NEW APPLICATIONS OF IMAGING AND AUGMENTED REALITY TECHNOLOGIES

A Smart glass are a wearable high-tech product that presents information and can perform various functions. Smart glasses are an interface between the virtual world and the real world. Smart glasses include many sensors, screens, cameras, microphones and wireless connectivity features. With these features, it collects and processes environmental data and interacts with the user. It is of great importance at this point that it offers Augmented Reality experiences. With the augmented reality experience, it aims not only to be "online" at certain times, but to be "always online" [1].

Smart glasses have many features. With the information display feature, users can easily access the information, text, images and videos they access through the integrated screens, glasses. This provides additional insight into users' real-world interactions. With the voice command and control feature, smart glasses can perform certain functions by detecting the voice commands of the users. It can make calls, send messages or receive information. It can record images and videos with the camera and image processing feature. It can also recognize and process surrounding texts, faces and attributes with computer vision techniques. Figure 1 shows the interaction of smart glasses at the airport.

In addition to all these features, two more basic features attract attention. Augmented reality and environmental sensing. These two features increase the user experience of smart glasses to the next level. With the augmented reality feature, smart glasses are an interface that unites the two worlds by destroying the sharp line between the real and virtual worlds. Since this feature allows the user to be "always online", users can always view, interact and get information from virtual objects in real world life [2].

With its environmental sensing feature, smart glasses take the user experience to the extreme. Smart glasses can collect, detect and process data in the environment with computer vision techniques. It raises the user experience to the next level by presenting the data obtained from the information it processes to the user. With these features, smart glasses are used in many fields such as education, virtual tourism, entertainment, health and industry [3].

Google took the first step of launching smart glasses. Google launched the smart glasses technology with Google Glass in 2013. Google Glass played an important role in the popularity of smart glasses with the ability to receive information, take photos and record videos with voice commands. Later, Microsoft took a step in the field of smart glasses and introduced the Microsoft HoloLens to the market. Microsoft HoloLens is a smart glass equipped with Augmented reality technology. It is of great importance as it is the first smart glasses to offer this. Users experience augmented reality with Microsoft HoloLens for the first time.



Figure 1: Smart Glasses in the Airport [4]

Many smart glasses have been released after Microsoft HoloLens, but it is definitely the Apple Vision Pro that has gained the most attention and popularity recently. The Apple Vision Pro was launched in 2023. It offers a very impressive experience for users. It is equipped with state-of-the-art augmented reality and it is clearly seen that it has a vision to be the best in this field. Figure 2 shows the Apple Vision Pro user experience.



Figure 2: Apple Vision Pro User Experience [5]

HUMANOID ROBOTS: ADVANCEMENT AND POTENTIAL OF NEXT GENERATION ROBOT TECHNOLOGIES

Humanoid robots are robots that have a human-like appearance and can exhibit humanoid behaviors. They have the same anatomical structure as humans. Humanoid robots can imitate humans' locomotion, so they can grasp objects, walk, run and perform different movements. Humanoid robots can perceive and interact with their environment with computer vision techniques and various sensors. They can detect objects, recognize people's voices and movements, and process environmental information. They make use of artificial intelligence algorithms by processing the information obtained from their environment. They improve their learning, problem solving, decision making and interaction skills with artificial intelligence algorithms. With this, they can provide more personalized services by understanding people's feelings and reactions. For these reasons, humanoid robots are of great importance today and in our future. Of course, even if we are faced with some ethical and social questions, humanoid robots is an important area that needs to be developed and invested in [6]. Many humanoid robots have been developed from past to present. Sophia, one of the last ones, draws attention because she is the first artificial intelligence humanoid robot to be granted citizenship. Sophia has facial expressions just like a real person and can interact and talk to people. Sophia is seen in Figure 3.



Figure 3: Humanoid Robot Sophia [7]

Humanoid robots are important for many reasons. They make people's lives easier. They can support people's daily tasks in daily life. These reasons are used in many fields. For example, they can be used in the service industry, in areas such as reception, waiter, customer advisor and customer service. In the healthcare industry, humanoid robots can be used to support surgical robots, rehabilitation robots, care for the elderly, and support people with disabilities. In the manufacturing and industrial sectors, automation robots can perform repetitive precision tasks and produce fast. This is important for worker safety. In education, humanoid robots can offer an interactive experience. They can be used to investigate human behavior, emotions and reactions as well as offering support to students and teachers. Humanoid robots are of paramount importance to human-machine interaction. Investments in humanoid robots for innovation and technology development must continue unceasingly.

THE IMPACT OF SMART GLASSES ON HUMANOID ROBOTS: IMPROVING COMMUNICATION AND ARTIFICIAL INTELLIGENCE CAPABILITIES OF IMAGE DATA

With the interaction between smart glasses and humanoid robots, we can encounter more information and cooperation in different ways. Humanoid robots can acquire environmental information through smart glasses and detect people, objects and texts in the environment. With this information, humanoid robots can analyze and improve the user's experience. With the information obtained from smart glasses, the detection and analysis capabilities of humanoid robots can be improved. Features obtained from smart eyes can be integrated into humanoid robots. However, more advanced humanoid robots can be obtained. Data collected with smart glasses can be trained for humanoid robots with artificial intelligence and thus contribute to humanoid robots decision-making processes or interactions. Humanoid robots can be developed more quickly and effectively by experiencing the humanoid robots perspective with smart glasses, interactive virtual objects or information can be created with robots. With this, users can more easily control or collaborate with robots. In human-robot interaction, instructions can be given through smart glasses. Collaboration and interaction with smart glasses can be facilitated and improved in the human-robot relationship. Figure 4 shows the humanoid robot eye.



Figure 4: Humanoid Robot Eye [8]

COMPUTER VISION: INNOVATIVE SOLUTIONS FOR SMART GLASSES AND HUMANOID ROBOTS

Computer vision is an artificial intelligence field with many techniques. It is used in many areas such as object tracking, image classification, object detection, face recognition [9]. Computer vision is the ability of computers and artificial intelligence to understand, interpret and process visual data. It aims to transform data with images that are the same as what people see, into meaningful information. It improves their ability to interpret and make decisions with meaningful data. For this reason, the field of computer vision is of great importance for many technological developments. The importance of the relationship between smart glasses and humanoid robots and computer vision is clearly seen. Object recognition and tracking with computer vision allows smart glasses and humanoid robots to interact with surrounding objects. For smart glasses, this may be to detect a restaurant sign and present menu information to the user, while for humanoid robots, it may offer the ability to interpret a particular object around it. With facial recognition, smart glasses can recognize the people around and present the information to the user. After performing facial recognition, humanoid robots can interact with people more personally and collect a lot of personal data and then process this data. In this way, human interaction with humanoid robots can be improved much better. Figure 5 shows an example of face recognition. Eye tracking, on the other hand, allows smart glasses to analyze the user's eve movements by monitoring, determining the direction of the user's gaze, and with this information, the user interface can be more integrated and an enhanced interactive experience can be offered. With eye tracking, humanoid robots can collect eye data from humans and process and analyze it. With it, it can analyze people's emotions, reactions, actions and behaviors. With image-based search, smart glasses can recognize surrounding objects or texts, connect to the internet and search for information about these objects and texts. Likewise, humanoid robots can contribute to their own development by collecting information and data from their environment using this image-based search. In this way, with effective artificial intelligence models, humanoid robots can become a very impressive technology that develops itself. As can be seen, computer vision is a very important field of artificial intelligence in the development of smart glasses and humanoid robots technologies. With computer vision, these technologies can reach a very advanced level. Computer vision developments and smart glasses and humanoid robots technologies will be affected and developed in the same way. For these reasons, artificial intelligence and computer vision are of great importance.



Figure 5: Face Recognition [10]

EMOTION RECOGNITION AND MIND READING: POTENTIAL FOR HUMANOID ROBOTS TO BETTER INTERACT WITH HUMANS

Mind reading stands out as an interesting topic that has been discussed and researched for years. Although mind reading is seen as an impossible science fiction subject in the past and today, it seems that it will be possible in the future with the investments made on mind reading. Although the subject of mind reading brings with it a lot of ethical, philosophical questions and problems, making this technology possible will cause it to enter a groundbreaking period for technology. Considering the feared negative aspects of mind reading, as well as focusing on the good aspects, is a huge step for the development of humanity and technology. Great technological solutions can be developed by reading the mind and understanding the information obtained from the mind by the computer and processing these data. As one of the most basic and simple examples of this, let's imagine that a robotic arm moves by perceiving commands when the signals coming from the brain become meaningful. The importance of its impact on human life is evident even with this simple example. There are many potential technologies and applications that can be developed with mind reading. It can have a great impact on communication interfaces, that is, it can enable individuals with disabilities to communicate in written or verbal form. In addition to playing a direct role in the development of human-computer interaction, it can make sense of people's behavior by analyzing emotions and attention and offer solutions for this. Mind reading, which is very important for humanoid robots, is very remarkable for the development of humanoid robots. Integrating humanoid robots with potential technology and applications that can be possible with mind reading becomes a level that will open a new page for technology. Figure 6 shows an example of mind reading.



Figure 6: Man playing pinball using Mind-Reading Computer [11]

In addition, the term 'augmented cognition' gains importance [12]. Augmented cognition is a concept that aims to increase cognitive functions. It focuses on transcending human cognitive limits and making cognitive processes effective and efficient. Many technological tools and methods are used to increase people's cognitive abilities. It can consist of various components such as brain-computer interfaces, visual or auditory feedback systems, artificial intelligence-based analysis tools. It aims to turn people's attention, memory, learning processes and problem-solving skills into meaningful data. For example, human-computer interfaces try to understand the mental state of the user by monitoring, analyzing and analyzing brain activity and try to react accordingly. This can enable users to control computers, humanoid robots, smart glasses or many other devices directly with their minds.

Augmented cognition can be used in many different areas. For education and learning, it can support students' learning processes, while at the same time analyzing students individually, providing personalized materials for students. For the healthcare and medical field, it can enable surgeons to be more precise and effective during surgery. It can interface for mental health assessments or aid in the detection and treatment of neurological disorders. It can optimize the decision-making processes of military personnel for military and defense, and can be used to improve performance by evaluating stress levels. It is also of great importance for investigations. By making sense of the data obtained from the brain activities of criminals, the investigation of suspects or potential criminals can be done more effectively and efficiently. It can provide instructions, guides or answer specific questions of workers about the job by analyzing the knowledge levels of workers with industrial studies. On the other hand, it can also have an impact on the game and entertainment industry. With augmented reality and virtual reality games, it can offer players a more interactive realistic experience. Can customize game experiences and give feedback based on brain activity. The topics of mind reading and augmented cognition are really exciting and its future development is intriguing. Figure 7 shows an example of mind reading.

Of course, in addition to its positive aspects, issues such as ethical issues, philosophical questions and user privacy are also of great importance. It can seriously violate confidentiality and privacy. Recording and sharing thoughts or feelings with others is a concern for privacy. Today, the problem of sharing our personal information with third parties without our consent is already a huge problem. In addition to this problem, sharing our thoughts and feelings with others will constitute a great crime and will directly affect our lives. The fact that the security of this data is very important may lead to the formation of a

new professional group in the future. In addition to mind reading, we can also encounter mind writing problems. Today, we have a digital identity, and according to the identity, we may encounter certain manipulative posts on social media or the internet. This situation even affects who we will vote for in the elections. Considering the point that this will come with mind reading in the future, concerns about limiting the freedom of thought of our own mind, changing our thoughts or becoming controllable from the outside appear as very serious problems. The answer to the question of how the development of this technology should proceed without a solution to these problems needs to be answered well.



Figure 6: Mind Reading Technologies [13]

RESULTS AND DISCUSSION

In this study, very interesting issues were tried to be mentioned. To get right from the start, smart glasses, humanoid robots topics are very important in the near future and are big steps for the development of technology to the next level. It is unthinkable for these technologies to progress independently of computer vision, which is the field of artificial intelligence. At this point, it is clear that these technologies will greatly change our lives in the future. However, at the end of this study, the breathtaking topic of mind reading and its effects on humanoid robots were mentioned. While talking about areas that will be positive for our lives and that can be used effectively, many ethical issues were also revealed. It is really enjoyable to think about the technological developments that may occur in the future. A breathtaking era awaits us in the future if we move forward by addressing the negative aspects and develop these technologies with effective solutions. Although a few issues that may belong to this breathtaking age are mentioned in this study, the point that technology can reach remains unknown. Although the work progresses with large investments, it requires serious time and effort to predict what is possible.

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Chapter 22

An Overview of Common Fracture Parameters for Cracked Structures with Piezoelectric Behavior

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ABSTRACT

For a cracked structure that exhibits isotropic elastic material properties, fracture mechanics analysis has been straightforward for a long time with wellknown parameters. In a problem with piezoelectric material behavior, fracture parameters to be used should be chosen accordingly considering the differences that arise with the introduction of the applied electric field. Studies regarding the investigation of piezoelectric materials have sought the determination of the energy release rate, J-integral and energy density factor. Application of an electric field can result in negative energy release rates which is an unrealistic physical situation. Besides, there is a common thought that negative energy release rates conflict with the positive definiteness of the energy density factor. The actual physical state corresponding to the negative energy release rate could be referred to as "closed crack". Inclusion of poling effect and assuming specific boundary conditions for a problem have impacts on piezoelectricity formulations. Sign changes associated with the energy release rate or J-integral results are demonstrated with a numerical example from the literature. The concepts of energy release rate and energy density factor should be well understood to choose the suitable parameter for a fracture analysis. That will lead to one of the remarks in this study, which can be defined as the anisotropic-like behavior of electroelastic solids with induced poling. The objective is to contribute to overall understanding for the analysis of cracked parts with piezoelectric behavior. Proposed recommendations will be given in the final part.

Keywords: Negative energy release rates, Fracture of piezoelectric materials, Energy density factors

1. Introduction

A typical fracture analysis requires the optimum parameter that determines whether the crack propagation phenomenon will take place or not. Among these parameters, stress intensity factor, energy release rate, and the J-integral [1] have been the most popular ones. Recently, the interest in the fracture of piezoelectric materials has increased. The main goal for these types of analysis has been the characterization of the fracture behavior with feasible approaches. For a problem that involves a piezoelectric material, original definitions of the parameters stated above may not be adequate to address fracture. Determination of fracture parameters for piezoelectric materials was performed in [2, 3], which can be given as the pioneers in this field. They derived a path independent J-integral which may be applied to the deformation theory of plasticity, in contrast to the original J-integral with incremental theory [1]. Besides the famous J-integral, energy release rate (which is equivalent to the J-integral for linear elastic material behavior) is also used commonly in these analyses. However, since applied electric fields are generally present in a piezoelectric problem, it is possible to obtain negative energy release rates which seems physically unrealistic. In [2], results with negative energy release rates were shown in detail.

To overcome this difficulty with negative energy release rates, another parameter, called the strain energy density factor, can be used instead. Energy density factor was introduced [4] by Sih to define the crack region characteristics. It is a positive definite parameter and avoids the questions that arise with crack tip releasing energy at one time and absorbing energy at other times. Sih expanded his findings related to the energy density factor further in [5] and applied this parameter to ferroelectric ceramics with the variation in poling direction and boundary conditions.

Following the pioneering work, many notable studies were performed in [6-14], comparing the behavior of energy density factor and energy release rate results. They emphasized the differences between the tendencies of these two parameters with variations such as poling direction, permeability, and boundary conditions. On the other hand, multi-scale conditions were discussed and that was given in [15] together with time span effects for a fatigue analysis. Energy release rates were calculated in [15] with scale-time variations, resulting in interesting outcomes that have not been presented before. Another notable work performed in [16] defined the energy release rate, J-integral, and energy density factor parameters in an explicit form. Negative J-integral and energy release rates were seen as the result of numerical computations handled by using the finite element method, and energy density factor criterion was found to be a better option for examples that involve piezoelectric materials. Other significant work can be

found in [17, 18], presenting mostly theoretical findings, and lacking numerical examples to support their ideas.

There is common sense that negative energy release rates create a dilemma considering the positive definiteness of the energy density factor value. In this study, definitions for some common fracture parameters will be given initially. Following that, fracture analysis for piezoelectric materials will be explored by concentrating on specific parameters such as the energy release rate and energy density factor. Anisotropic-like behavior of piezoelectric materials will be explained in detail. Coexistence of negative energy release rates and positive definite energy density factors will be further discussed. The main objective is to provide a deeper insight into the topic under interest.

2. Definitions of common fracture parameters

It could be significant to begin with the formulations for some of the wellknown fracture parameters. It should be noted that more information on the details of these parameters could be found in the literature. The aim for presenting these formulations here is to refer them in the following sections of this study. Total energy release rate G as a function of three modes for the stress intensity factors K_{I} , K_{II} and K_{III} is

$$G = \frac{1 - \nu^2}{E} \left(K_{\rm I}^2 + K_{\rm II}^2 \right) + \frac{1 + \nu}{E} K_{\rm III}^2$$
(1)

where v and E are the Poisson's ratio and elastic modulus, respectively. Jintegral is equivalent to the energy release rate for an isotropic elastic material and is defined in [1] as

$$J = \int_{\Gamma} \left(W dy - T \frac{\partial u}{\partial x} ds \right)$$
(2)

on surface. W is the strain energy density, T is the traction vector along Γ , u is the displacement vector and ds is the arc length along Γ .

For an isotropic elastic material, the volume energy density dW/dV can be given as

$$\frac{\mathrm{dW}}{\mathrm{dV}} = \int_0^\epsilon \sigma_{ij} \mathrm{d}\,\epsilon_{ij} \tag{3}$$

where σ_{ij} and ϵ_{ij} are the components of stress and strain tensors. Volume energy density can also be given as a function of stress tensors and basic material
properties in detailed form:

$$\frac{\mathrm{dW}}{\mathrm{dv}} = \frac{1}{2\mathrm{E}} \left(\sigma_{\mathrm{xx}}^2 + \sigma_{\mathrm{yy}}^2 + \sigma_{\mathrm{zz}}^2 \right) - \frac{\mathrm{v}}{\mathrm{E}} \left(\sigma_{\mathrm{xx}} \sigma_{\mathrm{yy}} + \sigma_{\mathrm{yy}} \sigma_{\mathrm{zz}} + \sigma_{\mathrm{zz}} \sigma_{\mathrm{xx}} \right) + \frac{1+\mathrm{v}}{\mathrm{E}} \left(\tau_{\mathrm{xy}}^2 + \tau_{\mathrm{yz}}^2 + \tau_{\mathrm{zx}}^2 \right)$$
(4)

Energy density function can be determined at any point in a system once the corresponding stress tensors are calculated for the same point. Energy density factor S [4] can be related to the energy density function as

$$\frac{\mathrm{dW}}{\mathrm{dV}} = \frac{\mathrm{S}}{\mathrm{r}} \tag{5}$$

where r is the distance from the crack nucleation or initiation point to the local element under investigation. More details related to the parameters in Eq. (5) can be found in [5, 19].

If piezoelectricity is included as well, applied electric field introduces additional terms to the equations for some of the parameters given above. It might be essential to define the term of poling at this point since the formulations for a piezoelectric material may depend on the poling direction. In a macroscopic crystalline structure, there are dipoles that are found to be randomly oriented (Fig.1). When the material is subjected to a mechanical stress, each dipole deviates from its original orientation. The direction along which the dipoles align is known as the poling direction. During poling, the material is subjected to a high electric field that orients all the dipoles in the direction of the field. If a high electric field that is opposite to the original poling direction is applied to the material, it can be de-poled.



Figure 1. Alignment of electric dipoles represented by arrows in a material prior to poling (left) and during the poling process (right).

For a piezoelectric material with no poling effect, the energy release rates as a function of stress intensity factors can be shown as [16]

$$G_{M} = \frac{1}{2} \left(\frac{K_{I}^{2}}{c_{T}} + \frac{K_{II}^{2}}{c_{L}} + \frac{K_{III}}{c_{A}} + \frac{K_{I}K_{D}}{d} \right)$$
(6)

$$G_{\rm E} = \frac{1}{2} \left(\frac{K_{\rm I} K_{\rm D}}{d} - \frac{K_{\rm D}^2}{k} \right) \tag{7}$$

$$G_{\rm D} = G_{\rm M} + G_{\rm E} = \frac{1}{2} \left(\frac{K_{\rm I}^2}{c_{\rm T}} + \frac{K_{\rm II}^2}{c_{\rm L}} + \frac{K_{\rm III}^2}{c_{\rm A}} + \frac{K_{\rm I}K_{\rm D}}{d} + \frac{K_{\rm I}K_{\rm D}}{d} - \frac{K_{\rm D}^2}{k} \right)$$
(8)

where G_M and G_E are the mechanical and electrical energy release rates, respectively, K_D is the electric displacement intensity factor, and c_L , c_T , c_A , d and k are the material constants. It should be noted that the last three terms in Eq. (8) might have values below zero which could lead to negative energy release rates for G_D . If poling effect is included, then Eq. (8) should be updated accordingly. In addition, boundary conditions for a specific example also have an influence on the formulation of energy release rates for a piezoelectric problem [7].

Similarly, energy density factor S can be defined as a factor of stress intensity factors (by neglecting anti-plane shear mode) and is given in [16, 19] as

$$S = A_{11}K_{I}^{2} + A_{22}K_{II}^{2} + A_{44}K_{D}^{2} + 2A_{12}K_{I}K_{II} + 2A_{14}K_{I}K_{D} + 2A_{24}K_{II}K_{D}$$
(9)

where A_{ij} (material coefficients) are functions of the local polar coordinate θ at the crack tip. In [19], it is demonstrated that S can be regarded as a crack driving force and always remains positive (Eq. (5)).

3. Numerical example: Piezoelectric material with poling effect

In the previous section, energy release rate formulations for piezoelectric material problems were stated by neglecting the poling effect. On the other hand, poling effect cannot be overlooked in most of the problems in this field. A study with poling effects performed in [7] was notable in the sense that negative energy release rate results were obtained along with positive definite energy density factor output. In the same study, different poling types (normal and parallel to the crack) were investigated with multiple distinct boundary conditions. For demonstration purposes, only a couple of those cases are shown in this section.

Fig. 2 depicts an internal crack with length 2a that lies on x-axis centered at the origin of the coordinate system. σ_{∞} and ϵ_{∞} denote applied mechanical stress and strain, respectively. The direction of the applied electric field E_{∞} or electric displacement D_{∞} is also shown in Fig. 2 for poling (a) normal to the crack, and (b) parallel to the crack. In the case for poling normal to the crack, there is also a transverse stress as $\sigma_x^{\infty} = eE_y^{\infty}$ due to poling effect. "e" is a piezoelectric constant of the material.



Figure 2. Boundary conditions and poling directions for the internal crack problem: (a) poling normal to the crack and (b) poling parallel to the crack [7].

Strain energy density W for the case where poling is normal to the crack can be given as

$$W = \frac{1}{2}\sigma_{ij}\epsilon_{ij} + \frac{1}{2}D_iE_i = \frac{a(mA^2 + \epsilon B^2)}{4r}$$
(10)

and if poling is parallel to the crack, then strain energy density can be shown by

$$W = \frac{1}{2}\sigma_{ij}\epsilon_{ij} + \frac{1}{2}D_iE_i = \frac{a(\epsilon A^2 + mB^2)}{4r(m\epsilon + e^2)}$$
(11)

where A and B are parameters calculated by using boundary conditions, "a" is half of the crack length, "r" is the distance from the crack initiation point to the element under investigation, "m" is the elastic constant and " ϵ " is the dielectric permittivity constant. Note that Eqs. (10-11) were derived with the combination of constitutive equations, complex function representation and asymptotic field solution of stresses and electric displacements. Second terms in Eqs. (10-11) that consist of electric field and displacement account for the piezoelectric effect.

Elastic behavior is assumed in the current example; hence J-integral and energy release rate values are anticipated to be equal. The subscript M in the equations below (J_M and G_M) stands for the unmodified (elasticity) case. Others (J and G) are given for the modified (piezoelasticity) case. Under these

circumstances, the J-integral and energy release rate for the unmodified case with poling normal to the crack can be shown as

$$J_{\rm M} = G_{\rm M} = \frac{a\pi}{2}A({\rm mA} + {\rm eB})$$
(12)

and for poling parallel to the crack

$$J_{\rm M} = G_{\rm M} = \frac{a\pi\epsilon}{2(m\epsilon + e^2)} A^2$$
(13)

Similarly, J-integrals and energy release rate for piezoelasticity (poling normal to the crack) are:

$$J_1 = G = \frac{a\pi}{2} (mA^2 + 2eAB - \epsilon B^2), J_2 = 0$$
 (14)

and finally for poling parallel to the crack:

$$J_1 = G = \frac{a\pi}{2(m\epsilon + e^2)} (\epsilon A^2 - mB^2), \ J_2 = 0$$
(15)

Determination of the parameters given above depends on the material properties and stress/strain & electric field/displacement boundary conditions. Taking a specific boundary condition (σ_{∞} and E_{∞}) into account, J and J_M becomes (normal poling, Case I)

$$J = \frac{a\pi}{2m} [\sigma_{\infty}^2 - (m\epsilon + e^2) E_{\infty}^2]$$
(16)

$$J_{\rm M} = \frac{{\rm a}\pi}{2{\rm m}}\sigma_{\infty}(\sigma_{\infty} + e{\rm E}_{\infty}) \tag{17}$$

Apparently, as the mechanical stress σ_{∞} becomes vanishingly small, J_M approaches zero as expected, and J tends to increase in negative half. However, since it is known that a negative J or G means a crack absorbing energy instead of releasing energy as the result of crack extension, it is impossible to interpret this outcome physically.

For the case with poling parallel to the crack, J and J_{M} can be stated as (Case II)

$$J = \frac{a\pi}{2(m\epsilon + e^2)} \left[\epsilon \sigma_{\infty}^2 - \frac{(m\epsilon + e^2)^2}{m} E_{\infty}^2 \right]$$
(18)

$$J_{\rm M} = \frac{4\pi\epsilon}{2(m\epsilon+e^2)} \sigma_{\infty}^2 \tag{19}$$

435

A similar comment can be made for J and J_M becoming negative and zero, respectively, as the applied mechanical stress is taken as negligibly small in Eqs. (18-19). Again, this will be in contrast with the notion of energy release rate as explained before for the case with poling normal to the crack. Details for the derivation of Eqs. (10) through (19) can be found in [7].

Having stated the necessary equations for the problem at hand, a specific piezoceramic material (PZT-4) can now be analyzed with the following material constants: $m = 6.93 \times 10^{10} \text{ N/m}^2$, $e = 13.64 \text{ C/m}^2$, and $\varepsilon = 5.74 \times 10^{-9} \text{ C/Vm}$.



Figure 3. Normalized J, J_M and S as a function of p_{σ} (a) Case I, (b) Case II [7].

Fig. 3 demonstrates plots of J, J_M and S vs. the ratio $p_{\sigma} = E_{\infty}/\sigma_{\infty}$ for Case I (a) and Case II (b). Apparently, the energy density factor S always remains positive with any electric field value. However, if the applied electric field increases, either in negative or positive horizontal direction, J values increase towards the negative half of the figure. J_M values are below zero only for highest negative values of the ratio p_{σ} for Case I. Based on these figures, only the energy density factors (S) always seem to be physically reasonable since they remain positive for every value in horizontal axis.

4. Fracture analysis with anisotropic-like behavior

To look at the current problem from another point of view, the difference between the definitions of isotropic and anisotropic material behaviors, and the fracture criteria for anisotropic materials are discussed initially in this section. Isotropic materials have uniform properties in all directions, i.e., they are said to be independent in direction or manner. An implication of a material being isotropic is that the chemical bonds within it are identical in all directions. On the other hand, 'anisotropic' refers to the properties of a material that is dependent on the direction. This also means variations in material properties in different directions. A different chemical bonding in all directions is also a condition for anisotropy.

A similarity between piezoelectricity and anisotropy could be established. To understand the effect of piezoelectricity on material properties that will lead to anisotropic-like behavior, Fig. 4 can be a nice description. The piezoelectric effect arises out of anisotropy in the structure as well as poling. Piezoelectric material properties such as the stiffness, coupling and permittivity matrices are defined in a coordinate system that is denoted by 123 axes (Fig. 4). Generally, the poling direction is the 3rd axis, so the material properties should be interpreted in terms of these principal directions. As an example, the coupling coefficient d₃₁ mentions how much the material will strain along its 1st principal direction when an electric field is applied across the 3rd principal direction. That means if the structure's principal directions are aligned with the coordinate system used to describe the material's position, then the material properties can be used without any change. This anisotropic-like behavior due to poling effect indicates the difference of piezoelectricity with a mechanical stress applied to an isotropic elastic material.



Figure 4. (Left) A z-poled piezoelectric material where the principal directions 123 are aligned with XYZ axes of the material coordinate system, (right) x-poled piezoelectric material is shown such that 1st principal direction is aligned with the Z-axis of the coordinate system.

As the similarity between piezoelectric material behavior and anisotropic effects is described, it might be meaningful to discuss the fracture analysis of an anisotropic material as the next step.

In [20], mixed-mode stress intensity factor formulations are given for an anisotropic material. J-integral equations for anisotropic elastic solids are derived in [21], which pioneered the studies following that in this field. However, both

[20] and [21] are missing numerical examples that can support their findings to enlighten the behavior of their corresponding fracture parameter. Another class of studies concerning anisotropic material's fracture behavior is performed in [22-24] and are notable to be mentioned. They analyzed the interface fracture of two different media, which added the complexity of the coupling effect for fracture modes to the overall problem. An interesting study is given in [22], concentrating on an interface crack between piezoelectromagnetic and elastic anisotropic materials. It was shown that pure applied electric-magnetic loading lowers energy release rate and therefore is expected to retard the propagation of an interface crack. However, they have also seen that electric and magnetic effects do not always contribute a negative value to the energy release rate when an applied mechanical loading is also present. The effect of anisotropy on the fracture behavior of copper-sapphire bicrystal interface was analyzed in [23], and negative energy release rate values were presented for mixed mode (I-II) case. Similarly, negative J-integral values were obtained in [24] for an interface crack positioned between two dissimilar anisotropic materials.

As seen from the studies given above, a theoretical and numerical investigation is required to better understand the energy release rate results for a cracked structure with pure anisotropic material behavior. Mixed mode cases can be under interest with only loading applied as mechanical disturbance. That type of analysis can help us to answer the questions that arise with piezoelectric behavior.

5. Negative energy release rate & positive energy density factor: Remarks and recommendations

Generally, obtaining negative energy release rate results has been an undesired situation for the researchers. Being physically unreal, these results may affect the outcome of the simulations in this field. For a problem with piezoelectric material, Eq. (8) apparently demonstrates the possibility for having negative values for energy release rates due to the last three terms in the equation. Besides, the positive definiteness of the energy density factor in Eq. (9) is a significant feature. Using energy density factor as fracture output avoids the complexities that come up with the anisotropic-like behavior of a piezoelectric material. However, if one would like to use energy release rates as the fracture criterion for a problem with piezoelectricity conditions, the following analysis can be carried out to gain an insight on this issue. Considering the anisotropic-like behavior of piezoelectricity as explained above, a simple model, shown in Fig. 5 with variations in loading on a finite plate in 2-D, can be tried. If the material behavior had been isotropic, then uniaxial or biaxial loading wouldn't have had any issues

related to the negative energy release rates. In the case of anisotropy, first uniaxial, then biaxial loading could be applied to determine the effect of loading type on modes I and II energy release rates. This type of investigation can give a good answer on the possibility of ending up with negative values for the energy release rates. Hence, this analysis may give us a chance to understand energy release rate results for a piezoelectric material.



Figure 5. Internal crack in a finite plate, under uniaxial load (left), biaxial load (right), for anisotropic material.

There is also an alternative approach to benefit from energy release rates as a fracture criterion when their negative values are present. Typically, a crack in opening mode includes traction free surfaces. If negative energy release rates appear within the results of a problem, then the crack could be considered as in a "closed crack" form. These negative values can be treated as "stored" in this form and be thought of as a residual quantity. However, during crack growth, closed crack form should be defined or kept in correct state to proceed the simulation accurately. These residual closed crack quantities can be represented with the notions of contact mechanics, which will not conflict with the rest of the crack growth analysis. This type of simulation can be easily realized with one of the finite element software available in the literature. Simulating crack propagation in computational environment will also be helpful to monitor negative energy release rate values explicitly during the process. On the other hand, positive definite values of theoretically calculated energy density factors can be used to verify the computational results. With this methodology, the expense and time issues related to experimental trials can also be avoided. However, computational results may be validated with one simple experimental setup.

Development of a computational model will require the implementation of piezoelectric constitutive equations into the software. Commercial software can analyze piezoelectric materials and fracture mechanics problems separately, but the coexistence of these two different phenomena in a problem is still being tested. Besides, the closed crack form can't be simulated directly with available tools. One way of handling this problem is to benefit from user defined subroutines available in commercial software. With the aid of this method, a part of the process may be represented in an external subroutine that may be relinked to the global program afterwards. Piezoelectric constitutive equations should be implemented first, and the crack growth simulation can be performed as the next step along with the closed crack state to observe the variations in energy release rates. This could be a good challenge for the follow-up work.

6. Conclusion

Energy release rate and energy density factor formulations and results were discussed considering piezoelectric behavior. Negative energy release rate or Jintegral values were observed as the outcome of a piezoelectric fracture problem in the literature. Anisotropic-like effects of piezoelectricity were introduced with arguments that support the idea. Previous studies have not been able to explain the current problem in detail. To contribute to the problem at hand, a simple analysis of an anisotropic material with pure mode I loading & biaxial loading in plane is recommended as an initial task. Negative energy release rates create a physical condition that can be assumed as a closed crack. Computational studies can simulate the closed crack form, provided that the piezoelectric material behavior is accurately represented with constitutive equations. More complicated fracture problems can be performed as well to investigate the negative energy release rates that may be seen due to piezoelectric behavior. In addition, determination of the energy density factor solutions is always a good checkpoint for the sake of accuracy.

The idea for the application of the electric field or displacement alone with no mechanical stress/strain resulting in negative energy release rates is discomforting in physical sense. The contradiction present with the negative energy release rates is possibly hidden within the poling effect. Poling of a piezoelectric material creates a different orientation for the material properties, which can occur in an anisotropic problem as well. A more detailed numerical analysis with variations in poling styles is necessary.

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Chapter 23

Fabrication of Ta₂O₅ Doped Silicate Glasses and Investigation of Their Physical, Structural and Thermal Properties

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ABSTRACT

INTRODUCTION

Glass is a ceramic material made from inorganic materials at high temperatures. However, it is different from crystalline ceramics, which are heated until they melt and then cooled to a rigid (hard, unbendable) state. The molecules in glasses are not arranged in an ordered structure as in crystalline solids. The molecules in glass have random orientations throughout the solid. The solidification of glass is different from that of a crystalline solid, as shown in Figure 1. A crystalline substance solidifies upon cooling, reaching its designated melting point (Tm), with a markedly reduced specific volume. At the glass transition temperature T_g, however, the liquid turns into glass when glass is cooled. When a liquid reaches this temperature, it transitions from a rubbery, soft plastic state to a brittle, rigid glass state (Callister and Rethwisch, 2009).

Although it is possible to make glass using a wide variety of chemical systems, the most economically important group of glasses are the oxide glasses. The most important of these are SiO_2 , B_2O_3 , P_2O_5 and GeO_2 . As these oxides form glass on their own, a wide variety of glasses of economic value can be obtained by adding other oxides to the composition (Smith, 1996).



Figure 1. Liquid-solid state relationship and glass transformation (Elkersh, 2014)

Oxides included in the composition of oxide glasses are divided into three groups according to their functions in the formation of glass. The first group of oxides are essential for glass formation, form the network structure of the glass and are called "glass formers". The other oxides in the glass are classified as "intermediates" and "modifiers" according to their effects on the formation of the glassy structure (Kocabağ, 2002). Glass formers (SiO₂, P₂O₅, or B₂O₃), which are regarded as the backbone or major constituents of glass, can create glass networks. Depending on the circumstances in the glass network, intermediate oxides like Al₂O₃, PbO, etc. can either participate in the development of the glass network or operate as network modifiers. The glass network is broken down and network connection is decreased by network modifiers (Na₂O, Li₂O, BaO, CaO, and SrO) (Ananthanarayanan, 2017). Glasses frequently have modifications made to them in order to regulate the melt rheology, affect the glass transition temperature, and enhance the tendency of the glass to crystallize (Smallman and Bishop, 1999).

Among oxide glasses, silicate glasses are remarkable due to their high chemical and physical resistance. Material sciences, condensed matter physics, and the geosciences are all interested in the elastic constants of silicate glasses under pressure because they are crucial for comprehending how tetrahedrally-dominated amorphous oxides react to compaction and differential stress (Hushur, 2023). The fundamental features (mechanical, optical, thermal, etc.) of the glassy systems are determined by the component glass's characteristics (type, quantity, heavy metal concentration). (Alzahrani, 2023)

Among the d block element oxides, Ta_2O_5 is a very interesting oxide and it was discovered that when added to silica-based glasses, its refractive index, thermal stability, and chemical stability all greatly improved (Satoh vd.. 2002). Ta2O5 material is desirable for usage in optical coatings and as a gate dielectric in metal-oxide-semiconductor devices due to its wide band gap (4 eV) and high dielectric constant K (20–28) (Wang, 2023).

In this study, a unique soda-lime-silica glass was fabricated and the effects of Ta_2O_5 doping at different ratios on the physical, structural and thermal properties of this glass structure were investigated.

EXPERIMENTAL SECTION

The glasses were produced using the conventional melting-quenching technique and details of the compositions selected for the present study are given in Table 1. High purity chemicals such as SiO₂ (99.8%), CaO (reagent grade), Al₂O₃, Na₂CO₃, P₂O₅ and Ta₂O₅ (99.8%) were used to form these glasses. Each chemical was carefully weighed and the appropriate amount (all in % by weight) was added to a pure platinum crucible. These chemicals were then melted in an electric furnace at a high temperature of 1450 °C for three hours to obtain a bubble-free liquid. The molten glass was then quickly poured into a graphite

mould and immediately placed in the annealing furnace. The glass samples were annealed in the furnace for annealing at 550 °C for one hour and allowed to cool gradually to ambient temperature.

The densities of the generated glass materials were measured with an accuracy of 0.01 at room temperature using Archimedes' principle and ethanol (x=0.789 g.cm⁻³ at 20°C) as immersion liquid. ATR (Attenuated Total Reflectance) FTIR transmission spectra for structural evaluation were acquired on a Perkin Elmer 100 FTIR spectrometer with a resolution of 4 cm^{-1} . Differential thermal analysis (DTA) measurements were performed in a nitrogen atmosphere using a Perkin Elmer STA 8000 analyzer in the temperature range of 30-1500°C. The powdered glass samples were heated in a platinum pan at a rate of 10°Cmin⁻¹ for this purpose. The glass transition temperature, crystallization temperature, and melting temperature (Tg, Tc, and Tm) were measured with 1°C accuracy for glass stability research.

Table 1: The chemical composition of fabricated glasses
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Glass Code	Composition Detail (weight %)	
Ta-0	47SiO ₂ -24CaO-6P ₂ O ₅ -2Al ₂ O ₃ -21Na ₂ O	
Ta-1	47SiO ₂ -24CaO-6P ₂ O ₅ -2Al ₂ O ₃ -20Na ₂ O-1Ta ₂ O ₅	
Ta-3	$47 SiO_2 - 24 CaO - 6P_2O_5 - 2Al_2O_3 - 18 Na_2O - 3Ta_2O_5$	
Ta-5	$47 SiO_2 - 24 CaO - 6P_2O_5 - 2Al_2O_3 - 16 Na_2O - 5Ta_2O_5$	

RESULTS AND DISCUSSION *Study of physical parameters*

Important information for describing the physical characteristics of glasses includes density and molar volume values. Archimedes' method is used to determine the specific gravity of a solid It experiences buoyancy when submerged in a liquid. The amount of weight that the solid's volume displaces from the liquid is the force's value. As long as the density of the liquid causing buoyancy and the weight of the solid in air are known, the specific gravity of this solid is calculated from the formula (Chand, 2022).

$$\rho = \frac{W_a}{W_a - W_e} \cdot \rho_e \tag{1}$$

where W_a denotes the sample weight measured in air, W_e denotes the sample weight recorded in ethanol, and ρ_e denotes the density of the immersion liquid. The structure is also described in terms of molar volume using the intermediate distribution of the ions that make up the glass structure. A composition-induced change in molar volume refers to basic structural changes in the glass network

caused by the creation or modification process (Yue, 2008). Each prepared sample's molar volume (V_m) was estimated as follows:

$$V_m = \frac{\sum X_i M_i}{\rho} \tag{2}$$

where M_i is the i_{th} component's molecular weight and x_i is the molar fraction. Table 2 provides the obtained density and molar volume values and Figure 2 is also shown in graphical form. When Ta₂O₅ replaces Na₂O in the structure, the molecular weight of the resulting glass structure increases (MA(Ta₂O₅)= 441.892 g.mol⁻¹, MA(Na₂O)= 61.978 g.mol⁻¹). Therefore, in Ta₂O₅ doped glasses, the density value increased as the doping amount increased. The molar volume values of these glasses increase as the doping amount increases. It can be said that the glass network expands with increasing doping ratio.



Figure 2. Density and molar volume values of prepared glasses.

FTIR spectral analysis

A technique for determining the infrared absorption, emission, and photoconductivity spectra of solids, liquids, and gases is called Fourier transform infrared spectroscopy (FTIR) (Sindhu, 2015 The type of chemical bonds and associated coordination groups can be ascertained using FT-IR absorption spectra, which also convey information about molecular vibration or rotation.

These spectra are particularly useful in determining the composition of glass and ceramic materials. Figure 1 shows the FT-IR spectrum of the base and Ta_2O_5 doped glasses recorded between $300cm^{-1}$ and $1800cm^{-1}$.



Figure 3. FTIR reflection spectra of obtained glasses.

When the vibration modes of the FTIR spectrum of the produced glass samples are analysed, three regions attract attention: 400 to 600 cm⁻¹; medium intensity, 600-800 cm⁻¹; weak intensity and 800-1200 cm⁻¹; high intensity:

- The first region ranging from 400 to 600 cm⁻¹ is related to the bending modes of bridge oxygens (BO_s) in Si-O-Si and O-Si-O networks (Jabbar, 2017).
- In the second region in the 700-800 cm⁻¹ range, the permeability is assigned to Si-O-Si bending vibration (Kazancioğlu, 2021). Due to the increase in the number of non-bridge oxygens (NBO_s) in Ta₂O₅ doped glasses, the intensity of this band increased according to the density in the base glass.
- The transmittance bands in the third region in the range of 890-940 cm⁻¹ were attributed to the Si-O-Si stretching in NBO (Silva, 2016). According to other studies, the formation of functional groups in the range 800-1250 cm⁻¹ represents the stretching vibrations of the SiO₄ tetrahedron containing different numbers of oxygen atoms (Soares, 2016). Finally, the transmittance peak in the wave number range 1038-1055 cm⁻¹ is mainly due to the Si-O-Si anti-symmetric stretching of BO_s (Darwish, 2013). It is

observed that this peak intensity increases in Ta_2O_5 doped glasses. From this, we can conclude that Ta_2O_5 plays a glass-forming role in the glass network.

Analysis of thermal parameters

In order to ascertain structural changes in glass compounds, obtaining DTA spectra is particularly helpful in the evaluation of thermal characteristics. The DTA curve for Ta-1 glass sample is shown in Figure 4, and the glass characteristic temperatures are listed in Table 2. The initial endothermic effect in the DTA curve is related to the glass transition temperature, T_g , which is important in forecasting structural changes produced by glass compositions (which is defined as the beginning temperature of the glass transition peak (Yue, 2008)). At higher temperatures, the glass crystallization temperature (T_c) causes a single exothermic peak, which is followed by an endothermic peak induced by glass melting (T_m).



Figure 4. DTA spectrum of Ta-1 glass sample.

Table 2. Density (ρ), molar volume (V_m), Glass transition temperature (T_g), crystallization temperature (T_c), melting temperature (T_m), and thermal stability (T_c-T_c) values for silicate glass structures

(ic ig) values for shirtens grass substances									
Glass Code	ρ (g.cm ⁻ ³)	$V_{\rm m}$ (cm ³ .mol ⁻¹)	Tg (°C)	T _C (°C)	T _m (°C)	T _C - T _g (°C)			
Ta-0	2.682	24.328	604	994	1180	390			
Ta-1	2.722	25.373	662	1020	1175	358			
Ta-3	2.756	27.816	696	1049	1295	353			
Ta-5	2.799	30.104	706	1051	1285	345			

As seen in Table 2, T_g and T_c values increased with the increase in the amount of Ta₂O₅ additive, but no regular change was observed in T_m value. The structure became more compact and the glass transition increased when the transition metal ions entered it, which was caused by a shift in the oxygen density in the network (Kashif, 2010). The DTA results in Table 2 reveal that Ta₂O₅ is effective in stimulating crystallization, hence boosting glass crystallization. The possibility is that Ta⁺⁵ ions have a high field strength, which causes phase separation in glass and changes the basic structural unit, increasing the crystallization tendency of the glass (Riaz, 2016). The (Tc - Tg) value indicates the thermal stability of the glass. The resistance to devitrification was observed to diminish as the amount of Ta2O5 additive increased. The thermal stability ratings of the glasses we made range from 345 to 390 oC. Stable glasses have T values greater than 100 degrees Celsius. The higher the T value, the less likely the glass will crystallize (Yousefi, 2014).

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Chapter 24

Seismic Assessment of Steel Eccentrically Braced Frames with Short, Intermediate and Long Links

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ABSTRACT

The eccentrically braced frames (EBF) are typically used to restrict the inelastic behavior into links between two eccentric braces. In contrast, other members, columns, and diagonal braces remain elastic during the seismic loading. The EBF links can be classified as short links (shear links), intermediate links (shear-flexure links), and long links (flexure links). This paper primarily aims to evaluate the seismic performance of EBF frames with short, intermediate, and long links. For these purpose, different models are designed based on Turkey Building Earthquake Code 2018 (TBEC-2018) and analyzed using the finite element method to investigate the effect of short, intermediate, and long links on earthquake performance. These EBF systems have been modeled using Ansys Workbench 2020 R2 software. The results obtained from analyses indicate that, the short link model considered have on a higher strength value and force capacity.

1. INTRODUCTION

Steel eccentrically braced frames (EBF) are complex systems that combine the benefits of moment-resisting steel frames (MRF) (i.e., high ductility) and concentrically braced steel frames (CBF) (i.e., high lateral stiffness). A typical EBF structure comprises link beams, braces, collector beams, and columns. The eccentric joint creates bending and shear forces in the beam adjacent to the frame. The part of the beam where these forces are concentrated is called the link beam. Link beams act as structural fuses during the earthquake loading in such frames. In other words, they provide a stable consumption of energy with the controlled yield of the link beams. Thus, while structural elements other than link beams in the system remain elastic, the link beams represent the inelastic seismic behavior. EBFs were first proposed in Japan in the early 1970s to achieve a structure with high lateral stiffness and energy dissipation under intense lateral loads [1]. In the USA, they were first discussed in the study of Roeder and Popov [2] at the end of the 1970s. Likewise, there are many studies on such frameworks in the 1980s [3]-[7]. Figure 1 shows the commonly used configurations of EBFs and their corresponding plastic mechanism. There are consequential differences between the behavior of short, intermediate, and long links. Although longer links are architecturally more advantageous due to the larger openings to explore, the first experimental studies in this field demonstrated that the performance of short links is significantly better than that of long links under severe cyclic loadings in terms of strength and ductility. According to the experimental studies carried out by Roeder and Popov [2] in the late 1970s, it was observed that the inelastic effects occur as a result of only flexure in long link beams, only shear in short link beams, and both flexure and shear in intermediate link beams.



Figure 1. EBF configurations and their corresponding plastic mechanism [8]

As a result of experimental studies by Hjelmstad and Popov [6], Malley and Popov [4], it has been observed that the short link beams have higher energy dissipation capacity than other link beams when the bodies of link beams are strengthened with stiffness elements (Figure 2, Figure 3, Figure 4).



Figure 2. Short link beams unstrengthened (left) and strengthened (right) with stiffness members [4]



Figure 3. Short link beam (right) unstrengthened with stiffness members and cyclic behavior history [6]



Figure 4. Short link beam (right) strengthened with stiffness members and cyclic behavior history [6]

According to the experimental study conducted by Engelhardt and Popov [7], long links attached to columns should not be used in EBFs. The investigation also represented the potential for instability in the collector beam and the resulting loss of EBF strength and ductility.



Figure 5. Long link beam (right) and cyclic behavior history [7]



Figure 6. Intermediate link beam (right) and cyclic behavior history [7]

The links in the EBFs system are classified based on the link length ratio, $e/(M_p/V_p)$, where *e* denotes the link length, M_p and V_p denote the plastic flexural strength and shear strength of the link, respectively. The link is identified in terms of the link length ratio as: short link ($\rho \le 1.6$), intermediate link ($1.6 \le \rho \le 2.6$) and long link ($\rho \ge 2.6$) [9]. The short links may be called shear links because of more dominance of shear yielding. The long links may be called as moment links due to the more dominance of bend yielding. The intermediate links may be called moment-shear links because the yielding occurred is a combination of shear and bending.

In this study, numerical study was carried out to investigate the effects of the link beam length on the seismic performance. For this purpose, a total of four different frames, one of which is a one-story and one-span frame without braces and the others with three different link beam lengths were simulated by Ansys Workbench 2020 R2 software. It is known that the frames with short links are more useful and convenient compared to other frames that have intermediate and long links. However, the reason of that is not clearly stated in the literature. The importance of this study is to reveal the differences between the frames with different link lengths.

2. FINITE ELEMENT MODELS

Three-dimensional non-linear finite element models have been constructed to investigate the effect of the link lengths on earthquake performance. For this purpose, four frames have been modeled: one has a short link, one has an intermediate link, one has a long link, and the other has no brace member. The columns of the frames were made of HE450B profile with a length of 4.175 m, the beams were made of HE360A profile with a length of 5.55 m, and the braces

were made of a square hollow steel section with cross-section dimensions of 300x300x20 mm. All the elements of the structural members, such as flanges and webs, were modeled as rectangular to simplify the complex geometry (see Figure 7). The structural material of the members is S275, with a yield strength of 275 MPa. According to TBDY-2018, the upper limit of the short link length is calculated with $1.6M_p/V_p$, and the lower limit of the long link length is calculated with $2.6M_p/V_p$. In this equations, plastic moment capacity, M_p , is calculated with $M_p = F_y W_p = F_y (bt_f (d - t_f) + 0.25t_w (d - 2t_f)^2)$, shear capacity is calculated with $V_p = 0.6F_y A_w = 0.6F_y (d - 2t_f)t_w$.



Figure 7. Profiles of the structural members in the frames.

Using the mentioned equations, M_p is obtained as 54826.41 kNcm, and V_p is obtained as 519.75 kN. Then, the upper limit of the short link length is calculated as 168.78 cm, while the lower limit of the long link length is calculated as 274.26 cm. In this study, based on these limits of the link lengths, the link length of the braced frame with the short link is considered 1.6 m, the link length of the braced frame with the long link is considered 2.2 m, and the link length of the braced frame with the long link is considered 2.8 m (see Figure 8). Also, as seen in Figure 8, continuity plates on the column webs and gusset plates at the end of the brace members to connect the brace members to the column and beam were used. Weld metals between the members, such as brace members and gusset plates, were not modeled to simplify the geometry. To account the interaction, the contacts were modeled as bonded contact, which is coupled together within both their tangential and perpendicular directions.

Finite element models have material nonlinearity with the Von Mises yield criterion and isotropic hardening rule. S275 steel material was used for all the members with the bi-linear form stress-strain relationship. The modulus of elasticity was taken 200000 MPa, yield strength was taken 275 MPa, tangent modulus was taken 20000 MPa, and the Poisson's ratio was taken 0.3.



Figure 8. Considered frames and their dimensions.

All the members in the finite element models were modeled with a higherorder element named SOLID186 in Ansys [10]. The representation of this element is given in Figure 9. SOLID186 is a twenty-node, three-dimensional hexahedral solid element with three degrees of freedom per node. This element supports plasticity, hyper-elasticity, creep, stress stiffening, large deflection, and large strain capabilities. Mesh structures of the braced frame with the short link and brace member are given in Figure 10 (The other frames have identical mesh structures).

The loading and support conditions are given in Figure 11. The columns were fixed supported at the lower-end points. The beams were restricted to out-of-plane displacement at the beam-column joints and at the brace-beam joints. The frames were loaded at the top point of the columns with a 167 mm translation in the direction of the frame plane. This translation value corresponds to the 0.04 radian story-drift angle of the frame.



Figure 9. The representation of SOLID186 [10].



Figure 10. Mesh structure of the frame and brace member.



Fixed support

Figure 11. Boundary and loading conditions of the frames.

3. RESULTS AND DISCUSSIONS

The force-displacement curves of the frames are given in Figure 12. As seen in Figure 12, the frame with the short link has approximately 1600 kN, the frame with the intermediate link has approximately 1450 kN, the frame with the long link has approximately 1300 kN, and the frame that has no brace has approximately 900 kN force capacity. The frame with the short link shows a strength degradation at approximately 105 mm top point displacement, the frame with the intermediate link shows at approximately 90 mm top point displacement, and the frame with the long link shows at approximately 55 mm top point displacement. However, no strength degradation is seen in the frame which has no brace, due to its lower force capacity. Moreover, it is seen that the initial stiffness values of the frames with braces are almost identical, but increasing the link length slightly decreases the initial stiffness value of the frame. However, it is obtained that the initial stiffness value of the frame.



Figure 12. Force-displacement curves of the frames.

Equivalent (Von-Mises) plastic strain distributions of the frames are given in Figure 13. As seen in Figure 13, decreasing the link length increases the maximum plastic strain value on the beam. It is seen that the plastic strain distribution of the frame with the short link is nearly homogeneous distributed in the link zone. With the increasing link length, this phenomenon appears to be beginning to change. For the frame with the intermediate link, the plastic strain distribution is beginning to concentrate at the end of the link. In addition, for the frame with the long link, the plastic strain distribution is almost completely concentrated at the end of the link. The plastic strain distribution of the frame that has no brace is concentrated at the end of the beam, columns, and panel zones. Beside of this, the maximum plastic strain value of the frame that has no brace is negligible when compared to the braced frames.



Figure 13. Equivalent (Von-Mises) plastic strain distributions of the frames.

Equivalent (Von-Mises) stress distributions of the frames are given in Figure 14. As seen in Figure 14, decreasing the link length increases the equivalent maximum stress value on the beam. It is observed that for the braced frames, equivalent stress distribution form is similar to each other. The equivalent stress distribution of the frame that has no brace is concentrated at the end of the beam, columns, and panel zones similarly to the plastic strain distribution.



Figure 14. Equivalent (Von-Mises) stress distributions of the frames.
4. CONCLUSIONS

This study primarily aims to investigate the effects of the link length on the seismic performance. For this purpose, a total of four different frames, one of which is a one-story and one-span frame without braces and the others with three different link beam lengths were simulated by Ansys Workbench 2020 R2 software. The results clearly shows that the short, intermediate, long and the frame with no brace have the highest force capacity, respectively. Besides, the initial stiffness values of the frames with braces are almost identical, but increasing the link length slightly decreases the initial stiffness value of the frame. However, it is obtained that the initial stiffness value of the frame that has no brace is dramatically less than the braced frames. Furthermore, reducing the link length increases the equivalent stress distribution form is similar to each other. The equivalent stress distribution of the frame that has no brace is concentrated at the end of the beam, columns, and panel zones similarly to the plastic strain distribution.

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Innovative Research in Engineering

Chapter 25

Joint Types and Applications in Rigid Pavements

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ABSTRACT

Rigid pavement is a type of concrete pavement constructed from cement concrete or reinforced concrete slabs with superior durability and the ability to withstand heavy traffic loads. Joints as one of the crucial elements of rigid pavements play a significant role in limiting the surface shrinkage and cracks that can cause deterioration of the pavement structure. Since they are of great importance for the structural and functional performance of rigid pavements, they must be carefully evaluated. The joints can control crack propagation exhibited on the pavement and prevent the expansion of transverse and longitudinal crack formation that occurred over time due to numerous environmental and operational based factors. Improperly used and constructed joints may cause the occurrence of random cracks on the pavement surface. It is difficult to control such randomly propagate cracks, since they eventually render the pavement unserviceable, and require rebuilding of the pavement section. Both maintenance-repair operations and reconstruction significantly increase the investment cost of pavement construction. This study was carried out to highlight the importance, types and applications of the joints in rigid pavement in the light of existing studies. The aim was to create awareness about their effect of them on daily life and therefore the current study has been established in the light of numerous studies.

Keywords: Highway, Rigid Pavement, Joint, Crack, Safety

1-INTRODUCTION

A highway pavement is an essential component of a road structure whose primary function is to allow a steady flow of vehicular and pedestrian traffic and distribute applied loads to the substrates [1]. Rigid pavement is a type of concrete pavement designed to provide durability, long-lasting and capable of withstanding repetitive heavy loads consisting of partially reinforced or continuously reinforced concrete slabs with a granular subbase layer laid on a subgrade soil at a certain thickness [2]. Rigid pavements have become a strong alternative over the past few decades to flexible pavements, which account for 95% of paved roads worldwide [3-6], due to longer project service life, and being more rigid and safer than flexible pavements [7, 8]. The use of rigid pavements is becoming more common in recent times, including the construction of airports, runways, terminals, loading and parking areas, and urban roads where the pavement needs to withstand wear and tear [9]. Considering the increasing number of commercial vehicles in the world, which is stated to be 23.4 million in 2022 and is estimated to reach 27.9 million in 2026, the construction of rigid pavements is also expected to become more widespread in the future [10]. Rigid pavements are preferred in highway applications for high traffic volumes with adequate skid resistance and a surface of acceptable riding quality for users in developed countries such as the USA, Germany, Austria, Belgium and Canada [11, 12]. They are constructed on roads with 8.2 tons of standard axle load of more than 60 to 75 million in 20 years of project life or roads with more than 5,000 daily commercial vehicles in one direction. In addition, rigid pavements are applied at airports where large aircraft take off more than 5,000 times annually [13].

The satisfactory performance of a rigid pavement is largely dependent on the successful design and functionality of its structural elements, which are the subgrade, sub-base or drainage layer, base course, concrete slab and joints [14]. Joints are one of the most important structural members of a rigid pavement and they are intentionally created discontinuities on a rigid pavement surface to limit shrinkage and cracks that can lead to the destruction of concrete structures. This study presented here has focused on joint types and applications in rigid pavements. For this purpose, types of rigid pavement are mentioned first in this paper in order to better understand the use and application of joints, and then joint types and their applications are explained in detail.

2. TYPES OF RIGID PAVEMENTS

Rigid pavements are usually constructed in three different types to fulfill this function of a road structure whose main purpose is to transfer the applied traffic loads to the substrates. These are (1) Jointed Plain Concrete Pavement (JPCP), (2) Jointed Reinforced Concrete Pavement (JRCP), (3) Continuously Reinforced Concrete Pavement (CRCP) [15, 16]. A brief introduction is presented in this section about the types of rigid pavements.

2.1. Jointed Plain Concrete Pavement (JPCP)

The JPCPs are the most preferred in-situ pour rigid pavements around the world due to their ease of pouring and affordability [17, 18]. They are usually constructed in the form of square blocks, which are interconnected with tie and dowel bars [9]. The main purposes of them are to keep control of natural cracks and minimize distress caused by environmental changes in volume and decrease friction between sub-layers. The length of concrete slabs changes between 3.7-6.1 m. The joints are spaced very closely together to prevent cracks from growing in the concrete slab until late in the service life of the pavement. Therefore, contractions and expansions that occur in the pavement are controlled by joints for JPCPs [18, 19]. The plan and section view of a typical JPCP is given in Figure 1 [20].



Figure 1. Schematic diagram of a typical JPCP

Another important performance criterion for JPCP is load transferability between adjacent concrete slabs [21]. Dowel bars are often used at joints to enable load transfer by providing a mechanical connection between adjacent

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concrete slabs [22, 23]. The dowel bars increase load transferability between adjacent concrete slabs and reduce joint failures and corner cracking [24]. They should be a flat-iron-bar and painted with anti-corrosion paint or lubricated [25]. The size of the dowel bars depends on the thickness of the concrete slab. In general, these bars are 460 mm long, and 32 to 36 mm in diameter [26]. The dowel bars with a diameter of 32 mm are used for pavements up to 28 cm thick. Dowels with a diameter of 38 mm are used for pavement thicknesses from 28 cm to 34 cm. For pavement thicknesses from 35 cm to 40 cm, dowels with a diameter of 44 mm are used. The interval between adjacent dowel bars is usually 30 cm [27-29]. The appearance and placement of the dowel bars in situ are given in Figure 2 [28, 30].



Figure 2. The appearance and in situ placement of the dowel bars

2.2. Jointed Reinforced Concrete Pavement (JRCP)

JRCPs are constructed by increasing the size of the concrete blocks formed by the joints by adding steel bars [31]. The dimensions of blocks can change from 7.5 m to 9.0 m [28]. The plan and section view of a typical JRCP is given in Figure 3 [28]. JRCP is not as common recently although it was widely used in the past. In JRCPs, fewer joints are used compared to the JPCPs and thus they cost more with the additional reinforcements [32]. It is well-known that the amount of steel bar has a vital role in preventing cracks formed in the pavement structure due to the mentioned reasons [33, 34]. Although reinforcement is used in JRCP, dowel and tie bars may be required as the reinforcement is insufficient [35, 36].



Figure 3. The plan and section view of a typical JRCP

2.3. Continuously Reinforced Concrete Pavement (CRCP)

CRCP is a type of rigid pavement in which concrete is poured after placing a continuous network of longitudinal and transverse steel bars properly [37-39]. Although JPCP generally serves users with good performance under reasonable construction costs, higher maintenance costs due to damage near the joints of JPCP and consequent user discomfort from traffic control result in a continuous increase in the use of CRCP [40-42]. Both longitudinal and transverse reinforcement bars are utilized to enhance the transfer of load between adjacent blocks in CRCP [28]. Some level of cracking is allowed in this type of pavement. However, the cracks are kept together and they are not allowed to open too much due to the reinforcement. In this regard, numerous investigations [43-46] showed that crack widths should not be more than 0.5 mm to protect the pavements against disruption and water entrance. The reinforcement constitutes approximately 0.6-0.7% of the cross-section area of pavement. In the 1970 and 1980s, the design thickness of continuously reinforced concrete pavement was 80% of the thickness of JPCP. However, in a considerable part of these thinner pavements, later on, more deterioration than expected occurred. As a result, it is recommended to design the CRCP as the same thickness as today's JPCP [47]. Such concrete pavements, which do not contain transverse joints, are high-cost but provide good driving comfort [48]. The plan and section view of a typical CRCP is given in Figure 4 [10].



Figure 4. The plan and section view of CRCP

3. JOINTS TYPES

Rigid pavements can crack due to some reasons such as plastic shrinkage, expansion and heaving if they are not designed to move freely [49]. A discontinuous state is needed to be created in order to allow the free movement of the pavement when exposed to dynamic and repetitive loads and harsh environmental influences. Joints designed as structural elements provide this discontinuity [48]. Joints, in general, are discontinuities intentionally created on a rigid pavement surface to limit shrinkage and cracks that can lead to the destruction of concrete structures [50, 51]. They control crack development triggering longitudinal and horizontal cracks formed due to restrained deformations influenced by moisture and temperature changes and traffic loads in the pavement [52, 53]. The methods used in the joint design should maintain adequate structural integrity at the joint. Since the load-carrying capacity of concrete slabs decreases at joint locations and a poor design often causes distress related to the joint and reduces driving comfort [54-56]. The performance of rigid pavements depends to a large extent on the satisfactory performance of joints [57].

There is a wide range of factors [58, 59] that shape the joint type. These can be: (1) the amount of reinforcement, (2) the thickness of the slab, (3) the friction between subgrade, (4) the temperature that the concrete slab lay on, and (5) the intensity of traffic. Moreover, numerous issues should be taken into consideration carefully while creating joints. These issues are (1) the determination of the distance between the joints, (2) keeping the distance between two adjacent slabs as large as possible to reduce the number of joints, (3) balancing a level difference between two adjacent slabs, and (4) the joint width considering as possible as small. However, as the distance between the joints grows, it should not be forgotten that the joint gap will also increase [43, 60]. The joints in rigid pavements are generally formed in two ways as transverse and longitudinal [11, 61, 62]. There are several joint types applications in rigid pavement construction and these are presented in Figure 5.



Figure 5. Type of joints in rigid pavements

3.1. Transverse Joints

Transverse joints take a significant role in limiting the transverse cracks [63]. They are placed perpendicular to the centerline across the entire width of the pavement [64]. The transverse joints are categorized into three parts as (1) contraction, (2) construction, and (3) expansion joints. These joint types are created in two different ways as full and dummy. The contraction joints are dummy joints that are generally sawed after pouring concrete slabs. On the other hand, the construction and expansion joints are made with formwork before constructing concrete slabs and the joint gap must be filled with a defined suitable material [65, 66].

3.1.1. Full Joints

The full joints are formed along the entire depth of the pavements in two forms as expansion and construction joints. The details for both types are presented in the following.

3.1.1.1. Expansion Joints

Expansion joints which are also mentioned as dilatation joints are the ones that allow the expansion of concrete slabs [67]. The reason being in the form of full joints for such joint can be linked with providing a gap across the entire thickness of the slab. The main purpose of this kind of joint is to minimize compressive stresses and thus prevent buckling by allowing the pavement to expand [29, 68]. The joints should be filled with a compressible material to prevent the immersion of materials that could hinder the expansion of the pavement. The filling material should move in accordance with the movement of the slab and be impermeable under all circumstances [58]. Expansion joints are very sensitive to pumping. The opening of the joint through the entire thickness of the pavement and the formation of the largest deformations under load in the dilatation joints, the leakage of water from the joint to the base as a result of a malfunction that may occur in the filling materials, causes the pumping event to occur severely [59]. Figure 6 presents a schematic section view of a typical expansion joint.



Figure 6. A schematic section view of a typical expansion joint

3.1.1.2. Construction Joints

A construction joint is deliberately placed to facilitate the pouring of concrete slabs at the end of each day of paving or because of a significant delay resulting from the size or complexity of the structure and limited materials or manpower. The next day of paving is begin with new concrete butted up against the old concrete [35, 69]. The resulting contact surface is known as a construction joint [70]. Generally, the pouring of a concrete slab is planned to finish in place of the required joint, so there is no need to create a construction joint. This type of joint can also be in either transverse or longitudinal directions

and separate the concrete slabs along their entire depth [71-73]. Unlike expansion joints, there is no expansion gap in construction joints. Construction joints are often tied with rebar [65]. Figure 7 presents a schematic section view of a typical construction joint.



Figure 7. A schematic section view of a typical construction joint

3.1.2. Dummy Joints

Dummy joints are not created across the entire thickness of the slab and are generally called contraction joints [27]. They are not cut exactly in depth through the thickness of the slab. These joints are applied on the pavement to reduce tensile stresses caused by moisture, friction and heat, and hence restraining crack formation. Thin joints placed at frequent intervals are more effective than thick joints placed at less frequent intervals [74]. They are applied to the structure by sawing the concrete slab to form a weak part to arrange the location of cracks caused by the dimensional changes of different slabs. Random cracks may develop on the concrete during service life if such joints are not applied, where it is necessary. Joint height is usually about 1/3 or 1/4 of pavement thickness and the width of the joint is generally 1 cm. The dowel bars provide a mechanical connection between concrete slabs [27, 29, 65]. The schematic view of a contraction joint is presented in Figure 8.



Figure 8. The schematic view of a contraction joint

3.2. Longitudinal Joints

Longitudinal joints are applied on the pavement to keep longitudinal cracks under control and the formation of cracks [75]. The joints are generally under the effect of compression. Hinge-like longitudinal joints control differential swelling and shrinkage occurred due to the differences in water content along the axis and side of the road, especially where concrete pavements are constructed on the clayey subgrade [58]. While the concrete slab is poured as two separate slabs during rigid pavement construction, a full-depth joint is automatically produced between the two slabs. Moreover, the concrete road is poured as a single slab across the entire cross-section, and the longitudinal joint is arranged as a dummy joint by weakening the section [76].

In application, the insulation material is implemented to the concrete surface along the joints for preventing the slabs from sticking to each other. Tie rods are used to prevent differential deflection and separation of concrete slabs and to alleviate transverse cracking. The connecting rods should be ribbed, and their length and diameter are usually 80 cm and 12-14 mm, respectively [27, 65]. Figure 9 presents a schematic section view of the longitudinal joints in types of dummy and full.



Figure 9. Section view of typical longitudinal joints in types of dummy and full

4. JOINT APPLICATIONS

This section is established based numerous subtitles including joint spacing, joint sawing and joint sealing that are required more attention while construction of the joints. Since fail in these processes reduces the lifespan of the pavement that is exposed to heavy traffic loads and harsh environmental conditions causing it not to perform as intent ended.

4.1. Joint Spacing

Joint spacing is an important criterion to determine the types of rigid pavement [63]. In general, the spacing of both transverse and longitudinal contraction joints depends on the local conditions of the materials and the environment, whereas the expansion and construction joints are primarily dependent on the layout and construction capabilities. The space required to prevent crack formation in contraction joints reduces as the thermal coefficient, positive temperature gradient, or base friction resistance increases. And, joint space increases with increasing concrete tensile strength [77]. In general, it is recommended that the joint spacing shouldn't exceed 19 to 24 or 25 times the slab thickness in JPCPs to prevent uncontrolled crack formation [65, 78]. It is also recommended that the ratio of length over the width of the concrete slab in JPCP shouldn't exceed "1.25 or 1.5" [65, 78, 79] and slabs be as square as possible for better structural performance [90].

The spacing between transverse joints in JPCP is generally preferred between 4.6 m and 6 m. Depending on the longitudinal joint spacing, up to 6 m of transverse joints can be created in pavements with high thicknesses. Transverse joint spacing can be given up to 15 meters in JRCP [65].

A longitudinal joint is recommended when the width of a road is more than 4 or 5 meters and two longitudinal joints for the ones exceeding 9 meters along the pavement [29, 80]. Additionally, since roads in the present design run in both directions and pavement width is usually less than 7.60 m, a longitudinal joint should be created to divide pavement into two strips or lanes of equal width [81]. However, in any case, if roads are being built between 7.60 and 10.65 m wide, a longitudinal joint should be made in the middle and another one on each side separated from the center, between 1.8 and 3.05 m. For 10.65 and 14.65 m wide lanes, an addition should be made in the center and on both sides, separated between 3.05 and 3.65 m from the center [82].

The contraction joint gap is made for the deformation occurred as a result of the shrinkage of the concrete pavement in cold weather. Since the joint width increases during shrinkage, a joint width of 8-10 mm may be appropriate in regions with cold climates such as Turkey from the 1:1 ratio condition [65].

4.2. Joint Sawing

Although there are many ways to create joints in jointed concrete pavements, the most common technique is to saw the concrete slab up to the previously established depth with a joint-cutting machine after pouring the concrete slab [83]. This creates a weakened plane and it spontaneously cracks and creates a vertical and nearly vertical joint at that location in a controlled manner. Since the slab itself forms a joint in the weakened, cracking will be controlled or cracks will be able to occur wherever desired on the pavement surface [65]. The concrete slab should be sufficiently hardened so that the joint cutting process and saw tools do not damage the concrete surface and the joint edges are not broken. Joint cutting can be done 1-2 hours after the concrete is poured at high temperatures, but it may last up to 1-2 days in cold weather conditions. The optimum time for the sawing of joints is between 6-24 hours following pouring a concrete slab [65, 84, 85]. In addition, the concrete should be strong enough to prevent the breaking of small aggregates along the joint during sawing [86]. On the other hand, sawing should be done in concrete slabs before the formation of

uncontrolled or undesired cracks due to tensile or bending stresses. An expert should decide on the optimum time, as there are multiple factors such as aggregate type, curing factor, cement factor and weather [87] affecting it. The minimum compressive strength of the concrete slab should be at least 10 MPa before the sawing process. The transverse joint depth created by the saw-cutting machine should be between 25% and 30% of the slab thickness, and these values reach 40% and 45% in the longitudinal joints [65, 88]. However, the construction joints that are created after finishing work are naturally at full depth. The joints are generally created in 3 mm width. Thereafter, it is enlarged to 1-1.5 cm by sawing joints with hard-tipped rotary saws using either diamond or other types of abrasive blades [65, 89] as shown in Figure 10 [90]. Joint edges should be chamfered at 45° in order to install sealing materials and prevent them from being damaged by traffic loads in the future [65, 91].



Figure 10. Joint sawing

4.3. Joint Sealing

A joint sealant is a material introduced to the joint reservoir to provide structural integrity in the rigid pavement structure [92]. Joint sealing is generally applied for two major reasons. The first is to prevent the amount of water and de-icing chemicals infiltrating to the structure of pavement, which results in corrosion of reinforcement, slab erosion and loss of support. The other main reason is to minimize the entry of incompressible materials into the joint, resulting in point loading when slabs expand under hot temperatures and subsequent joint spalling damage [93-97]. Incompressible sealing material restricts the expansion of pavement slab, resulting in excessive stresses at the slab and eventual buckling or crushing of the slabs at the joints [98]. The

Innovative Research in Engineering

sealing material should not be sensitive to temperature and moisture changes. Cork-based materials can be used as bottom sealing material, while bituminous materials are generally used as top sealing material as seen in Figure 11. Joint sealing materials should exhibit sufficient deformation and adhesion properties to close the joint gap. It is recommended to maintain the joints every 8-10 years and apply joint filling for both transverse and longitudinal joints [27, 99].



Figure 11. Joint sealing

The joints could be generally filled with materials that have hot or cold application types. Joint sealing materials can be divided into three main categories; (1) hot poured one, the most used type, that can be bitumen including modified ones, (2) cold pour one in the form of filler that is applied following mixing processes. Such types are polyurethane, polysulfide, or silicone-based elastic filling materials. They are more expensive but have a longer lifespan lasting about 12 years when applied in a cold way, but between 7 and 19 years as poured in hot way and (3) preformed compression filler from synthetic rubber [89]. Depth, width, rheological properties and most importantly the quality of workmanship affect the performance of joint sealants. A better understanding of the failure mechanisms of joint systems is required to select a more compatible sealant for use in any joint system [93].

5. JOINT FAILURES

Failures in joints cause many unintended consequences including traffic accidents, pavement that deteriorate prematurely etc. Therefore, it is vitally important to take action to prevent them as much as possible at the beginning. If

necessary, maintenance and repairs or reconstruction should be carried out. Joint failures generally occur as spalling, and spalling is a deterioration occurring in the rigid pavement due to excessive loading and environmental effects [100-102]. Spalling emerges as the breaking or crumbling of the concrete slab edges generally within 0.6 m of the side of the joint [103]. Figure 12 shows some typical in-situ joint spalling failures. Some of the main causes of joint spalling in rigid pavements are:

- Poor alignment of dowel bars
- Poor workmanship
- Exposing joints to excessive stress due to heavy traffic or leakage of any incompressible material
- Weak concrete in terms of both strength and durability
- Accumulation of joints with water results in rapid freeze and thaw [49, 100, 104].

The joint spalls can be avoided by using good construction techniques, or by sealing the joints with high-quality sealing material.



Figure 12. Joint Spalling Failures

6. CONCLUSIONS

This study focused on joint types and their applications constructed in rigid pavements. One of the most important purposes of joint application in rigid pavements is to prevent the formation of undesired cracks over concrete pavement surfaces and to keep them under control in a specific location. The performance of rigid pavements depends to a large extent on the satisfactory performance of joints. Improper design of joints leads to early failure of pavements affecting road safety and riding quality. So, the construction of all joints in rigid pavements requires attention to detail. When the basic rules of joint designs are followed and the construction work is carried out according to practical technical selection rules, rigid pavements will offer the necessary comfort as well as the safety and durability we can expect.

7. RECOMMENDATIONS

Potential future directions for the joint applications are summarized as follows:

- The maintenance of joints should be kept periodically to sustain their functionality.
- Joint spacing should be adjusted to prevent or minimize uncontrolled crack formation,
- Joint spacing should form the concrete slabs as squarely as possible in the JRCP to achieve better structural performance.
- The dowel bars should be selected properly to ensure better load transfer and mechanical connections between concrete slabs at joint locations.
- All joints should be sealed to keep incompressible materials out of the joint and to minimize chloride and water intrusion into the pavement structure much as possible.
- Joint sealing materials should be selected meticulously so that they serve their purpose without any problems. They should not be sensitive to temperature and moisture changes and should exhibit sufficient deformation and adhesion properties to close the joint gap.
- Joint cutting should be done with appropriate equipment and at an appropriate time determined by the experts to prevent possible damage to the pavement.

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