INVESTIGATION OF THE EFFECTS OF SESAME OIL /DIETHYL ETHER (DEE) /DIESEL TERNARY FUEL BLENDS ON DIESEL ENGINE CHARACTERISTICS AND OPTIMIZATION WITH RESPONSE SURFACE METHODOLOGY

2023
MASTER THESIS
MECHANICAL ENGINEERING

Zaid AHMAD

Thesis Advisors
Assoc. Prof. Dr. Samet USLU

INVESTIGATION OF THE EFFECTS OF SESAME OIL /DIETHYL ETHER (DEE) /DIESEL TERNARY FUEL BLENDS ON DIESEL ENGINE CHARACTERISTICS AND OPTIMIZATION WITH RESPONSE SURFACE METHODOLOGY

Zaid AHMAD

Thesis Advisors
Assoc. Prof. Dr. Samet USLU

T.C.
Karabuk University
Institute of Graduate Programs
Department of Mechanical Engineering
Prepared as
Master Thesis

KARABUK
August 2023

I certify that in my opinion the thesis submitted by Zaid AHMAD titled “INVESTIGATION OF THE EFFECTS OF SESAME OIL /DIETHYL ETHER (DEE) /DIESEL TERNARY FUEL BLENDS ON DIESEL ENGINE CHARACTERISTICS AND OPTIMIZATION WITH RESPONSE SURFACE METHODOLOGY” is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Samet USLU ....
Thesis Advisor, Department of Mechanical Engineering

This thesis is accepted by the examining committee with a unanimous vote in the Department of Mechanical Engineering as a Master of Science thesis. August 31, 2023.

Examining Committee Members (Institutions)		Signature
Chairman	: Assoc. Prof. Dr. Mehmet ÇELİK (KBU)	....
Member	: Assoc. Prof. Dr. Samet USLU (KBU)	....
Member	: Assist. Prof. Dr. Süleyman ŞİMŞEK (IAU)	....

The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Institute of Graduate Programs, Karabuk University.

Assoc. Prof. Dr. Zeynep ÖZCAN ....
Director of the Institute of Graduate Programs

“I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well.”

Zaid AHMAD

ABSTRACT

M. Sc. Thesis

INVESTIGATION OF THE EFFECTS OF SESAME OIL /DIETHYL ETHER (DEE) /DIESEL TERNARY FUEL BLENDS ON DIESEL ENGINE CHARACTERISTICS AND OPTIMIZATION WITH RESPONSE SURFACE METHODOLOGY

Zaid AHMAD

Karabük University
Institute of Graduate Programs
The Department of Mechanical Engineering

Thesis Advisors:
Assoc. Prof. Dr. Samet USLU
August 2023, 84 pages

In this thesis, experimental studies were carried out at different engine loads by adding different amounts of diethyl ether (DEE) to improve the response of a single-cylinder diesel engine operating with a mixture of 30% SO + 70% diesel fuel, and it was aimed to determine the optimum operating conditions with response surface methodology (RSM). The SO percentage, DEE percentage, and engine load are chosen as input factors, whereas the output response parameters to be investigated are brake specific fuel consumption (BSFC), carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO_2), and nitrogen oxides (NO_x). Analysis of Variance (ANOVA) supported Pareto charts were generated, and the effectiveness of the specified input components was determined. The optimal engine running factors

revealed a SO percentage of 20.30%, a DEE percentage of 0%, and a load of 1282.83-

W. The ideal responses for BSFC, CO, HC, CO_2, and NO_x were 551.371 g/kWh, 0.0544%, 26.623 ppm, 4.3566%, and 353.650 ppm, respectively, based on optimal input values. According to the validation study, the maximum error between the optimum and experimental findings is 7.18%. The results show that RSM can be effectively used to optimize the impact of SO/diesel/DEE combinations on diesel engine performance and exhaust emissions, saving time and reducing technical effort.

Key Words : Response Surface Methodology, Diethyl ether, Sesame oil, Diesel engine

Science Code : 91413

ÖZET

Yüksek Lisans Tezi

SUSAM YAĞI/DİETİL ETER (DEE)/DİZEL ÜÇLÜ YAKIT KARIŞIMLARININ DİZEL MOTOR ÖZELLİKLERİ ÜZERİNDE ETKİLERİNİN İNCELENMESİ VE TEPKİ YÜZEYİ METODOLOJİSİ İLE OPTİMİZASYONU

Zaid AHMAD

Karabük Üniversitesi
Lisansüstü Eğitim Enstitüsü
Makine Mühendisliği Bölümü

Tez Danışmanı:
Doç. Dr. Samet USLU
Ağustos 2023, 84 sayfa

Bu tezde %30 susam yağı (SO) + %70 dizel yakıt karışımı ile çalışan tek silindirli bir dizel motor yanıtlarının iyileştirilmesi için farklı miktarlarda dietil eter (DEE) ilave edilerek farklı motor yüklerinde deneysel çalışmalar gerçekleştirilmiş ve tepki yüzeyi metodolojisi (RSM) ile optimum çalışma koşullarının belirlenmesi amaçlanmıştır. Susam yağı oranı, DEE yüzdesi ve motor yükü girdi faktörleri olarak seçilirken, araştırılacak çıkış parametreleri fren özgül yakıt tüketimi (BSFC), karbon monoksit (CO), hidrokarbonlar (HC), karbondioksit (CO_2), ve nitrojen oksitler (NO_x) olarak seçilmiştir. Varyans Analizi (ANOVA) destekli Pareto grafikleri oluşturulmuş ve belirlenen girdi bileşenlerinin etkinliği belirlenmiştir. Optimum motor çalıştırma faktörleri, %20,30'luk bir susam yağı yüzdesini, %0'luk bir DEE yüzdesini ve

1282,83-W'lik bir yükü ortaya çıkarmıştır. Optimum girdi değerlerine göre BSFC, CO, HC,

CO_2 ve NO_x için ideal yanıtlar sırasıyla 551,371 g/kWh, %0,0544, 26,623 ppm, %4,3566 ve 353,650 ppm’dir. Doğrulama çalışmasına göre optimum ve deneysel bulgular arasındaki maksimum hata ise %7,18'dir. Sonuçlar, RSM'nin, zamandan tasarruf ederek ve teknik çabayı azaltarak, SO/dizel/DEE kombinasyonlarının dizel motor performansını ve egzoz emisyonları üzerindeki etkisini optimize etmek için etkili bir şekilde kullanılabileceğini göstermektedir.

Anahtar Sözcükler : Tepki Yüzey Metodolojisi, Dietil eter, Susam yağı, Dizel motor

Bilim Kodu : 91413

ACKNOWLEDGEMENT

First of all, I would like to express my deepest thanks to my project advisors, Assoc. Prof. Dr. Samet USLU, for their direction and for providing me with the opportunity to work on this thesis. I would like to express thanks especially to Research Assist. Gürşah GÜRÜF for his assistance during the experiments. I would also want to thank Karabuk University for supplying the essential equipment and tools for the laboratory.

Lastly, I want to express my gratitude to my family for their unflinching support all the way through my master's degree.

CONTENTS

Pages

LIST OF FIGURES

LIST OF TABLES

Pages

SYMBOLS AND ABBREVITIONS INDEX

RSM : Response Surface Methodology
BSFC : Brake specific fuel consumption
CO : Carbon monoxide
HC : Hydrocarbon
CO_2 : Carbon dioxide
NO_x : Nitrogen oxides
DEE : Diethyl ether
SO : Sesame oil
D : Diesel
ICE : Internal combustion engine
EGR : Exhaust gas recirculation
PPM : Parts per million
EGT : Exhaust gas temperature
IP : Injection pressure
CR : Compression ratio
IT : Injection time
DoE : Design of experiments
ANOVA : Analysis of Variance
CI : Compression Ignition
GO : Graphene oxide
bTDC : before top dead center

PART 1

INTRODUCTION

The need for energy increases as the global population continues to expand and as living standards rise. The majority of the world's energy needs are currently fulfilled by fossil fuels, which account for around 80 % of the fundamental energy demand. The huge increase in the usage of fossil fuels has resulted in the production of vast quantities of greenhouse gases, which are regarded as a key contributor to climate change and air pollution. Vehicles, factories, power plants, and transportation fueled by fossil fuels are significant contributors to air pollution, which causes around 3 million fatalities every year. Unfortunately, this figure is projected to reach 4.5 million by the year 2040. Nevertheless, as the supply of these resources decreases and the demand for energy continues to rise, the utilization of renewable energy sources becomes increasingly crucial [1].

In the World Energy Outlook scenario based on existing policy, demand for fossil fuels will for the first time ever peak or plateau. This is due to the increasing use of electric vehicles, which will lead oil consumption to level off in the mid-2030s and then gradually fall until 2050. Since the beginning of the Industrial Revolution, the consumption of fossil fuels has increased, but this trend will now revert. By 2050, the proportion of carbon fuels in the global energy mix will decline from 80% to 60%, and worldwide CO_2 emissions would decline from 37 billion tons to 32 billion tons. However, this is insufficient to prevent severe climate change impacts, and there is still a significant gap between present commitments and the objective of limiting global temperature rise to 1.5°C. Since 1973, the global demand for primary energy has soared by an average of 2.0 % per year. Truth be told, nearly one-third of the global population continues to use non-commercial fuels [2].

In the 1960s, urban centers such as Mexico City, Los Angeles, and Tokyo were besieged by smog. The National Energy Strategy reported in February 1992 that the

United States utilized more than 185 million buses, vehicles, and trucks for mobility. In India, 50 % of oil was used for transit in 1991, but that percentage increased to 61 % by 2010. Every day, more and more oil is consumed, which is extremely detrimental to the environment. The UN conducted the Earth Summit on Environment and Development in June 1992. At this summit, the main objective of delegates from all over the world was to slow global warming [3].

As the need for energy continues to expand and the environmental effect of carbon fuels becomes more evident, it is anticipated that the usage of alternative energy sources will continue to go up. To fulfill the world's long-term energy demands, it will be necessary to continue investing in research and development, establishing laws and regulations that support renewable energy practices, and striving to reduce consumption and improve energy efficiency [4].

The pursuit of new and diverse power sources, such as biofuels, has grown in significance. To fulfill the rising energy demand and solve ecological consequences, the power industry will likely consist of a mix of fossil fuels and renewable energy sources. Although renewable energy sources are believed to be more sustainable and environmentally friendlier than fossil fuels, they are not without their own challenges and drawbacks. The development of biofuels requires land and resources, which might have detrimental effects on food production and ecosystems. Some, such as pyrolysis, can be extremely energy-intensive and need substantial expenditures in equipment and technology. The quest for sustainable and renewable energy sources is a complicated and continuing endeavor that will most likely entail a combination of many tactics and technological processes [5].

1.1. Biodiesel Fuel & Importance of biofuels

Biodiesel is biodegradable, renewable, and no-toxic. It has a greater cetane number and a higher flash point than diesel fuel, and it functions perfectly as a lubricant. It may be produced from both animal and vegetable oils. Diesel engines may utilize a variety of fuels derived from vegetable oil. It has been determined that vegetable oils have the most promise in this field since they can be produced from plants that thrive in rural regions. In many parts of the world, vegetable oils derived from plants such as soybean, peanut, sunflower, rape, coconut, Karanja, neem, cotton, mustard, jatropha, linseed, and sesame seed oil are contrasted to oils that cannot be consumed. And according to the most recent studies, the finest biodiesel created was from vegetable oil [6].

1.1.1. Importance Of Biofuels

Biofuels are deemed significant for the following reasons [6,7]:

- Biofuels are sustainable energy sources that may be created from a variety of bio resources, hence decreasing reliance on fossil fuel-based petroleum resources.
- Biofuels emit less CO_2 than petroleum-based fuels, therefore mitigating the consequences of climate change.
- Utilizing biofuels can minimize reliance on foreign oil and enhance energy security.
- Biofuel production may encourage rural development and generate new job possibilities.
- The rising demand for biofuels has led to the development of cutting-edge production and usage methods.

The usage of biofuels has the potential to solve a number of challenges, including the reduction of air pollution, the enhancement of engine performance and affordable fuel alternative, and the reduction of total fuel prices. Further enhancing their sustainability and environmental effect, biofuels may also be mixed with fossil fuels to minimize their CO_2 emissions. The transportation industry is one of the greatest contributors to global carbon emissions, and the usage of biofuels can help reduce these emission levels. This is essential if we are to address the worldwide crisis of climate change and ensure the sustainability of our energy future [7].

The significance of biofuels rests in its ability to offer a sustainable and renewable energy source, reduce reliance on finite petroleum resources, and mitigate the consequences of climate change. As a researcher, it is essential to continue investigating and enhancing the usage of biofuels to assist solve these vital concerns and promote the creation of a future with sustainable energy [8].

Vegetable oils are an alternative fuel, and a lot of studies and experiments are being conducted to enhance their performance, it is claimed that the original diesel engine created by Rudolf Diesel ran on vegetable oil. Nowadays, vegetable oils are a viable alternative to petroleum-based fuels. They can be substituted by conventional diesel fuel in diesel engines. Vegetable oils are a renewable source of energy because the vegetables used to produce them are also renewable, they release heat at a rate comparable to diesel, their emissions (CO, HC, and PM) are low, they do not contain much sulfur, and they can be used in engines with very little or no modification. Due to these significant advantages, a great deal of research and development has been conducted on vegetable oils [9].

Their high viscosity is the greatest obstacle to utilizing fresh vegetable oils as fuel in diesel engines. High viscosity causes the following complications in diesel engines [9,10]:

- Choking of fuel lines and filters,
- Poor atomization of the fuel,
- Inefficient combustion,
- Severe engine deposits,
- Injector coking with trumpet development and piston ring sticking,
- Gum formation and thickening of the lubricating oil.

1.1.2. Benefits and Challenges to Using SO-DEE-Diesel Ternary Fuel Blends in a Diesel Engine.

Combining SO with other fuels provides a viable alternative to conventional fossil fuels. There are several pros of using SO, but it also comes with some challenges [10].

There are several benefits to using SO-DEE-diesel ternary fuel blends in a diesel engine. These benefits may include [10,11,12]:

- **Potential for reduced emissions:** The use of SO-based fuels can potentially lead to reduced emissions of certain pollutants, such as CO and particulate matter, compared to diesel. This can be beneficial for the environment and public health.
- **Improved fuel efficiency:** SO has a higher energy content than DEE, which can potentially improve the fuel efficiency of the blend.
- **Improved ignition and combustion characteristics:** The addition of DEE to the fuel blend can potentially improve the ignition and combustion characteristics of the fuel, leading to better engine performance.
- **Potential for reduced dependence on fossil fuels:** The use of SO-based fuels can potentially reduce dependence on fossil fuels, which may be beneficial from a sustainability perspective.

Using SO, DEE and diesel ternary fuel mixes in a diesel engine may potentially provide a number of obstacles and constraints. These challenges may include [10,11,12]:

- **High viscosity:** SO has a higher viscosity than diesel, which can potentially lead to issues with fuel flow and atomization in the engine. This can affect the ignition, combustion, and emission characteristics of the fuel blend.
- **Lower energy content:** SO has a lower energy content than diesel, which can potentially reduce the power output of the engine when using the fuel blend.
- **Compatibility with the engine:** The use of SO-based fuels may require some modifications to the engine, such as the fuel system, to ensure compatibility.
- **Cost:** SO may be more expensive than diesel, which can potentially increase the cost of using the fuel blend.
- **Limited availability:** SO may not be widely available, which can make it difficult to use on a large scale.

1.2. Scope Of The Study

Due to its high energy density and affordable price, diesel fuel is commonly utilized in ICE. Meanwhile, the rising need for eco-friendly and more efficient fuels has prompted the investigation of alternate fuel solutions. Blends of diesel fuel with other components, such as vegetable oils and ethers, is one such option [13].

Vegetable oils, such as SO, have been investigated as viable alternative diesel fuels due to their renewability and low cost. The high cetane number of SO makes it an ideal contender for diesel engine applications.DEE is another viable alternative fuel due to its high-octane number and lower emissions. Using diesel fuel blended with SO and DEE has the potential to enhance engine performance and reduce emissions [14].

The research on the properties and optimization of these blends for diesel engine applications is limited. This research intends to address this deficiency by exploring the impact of SO, DEE and diesel ternary fuel mixes on diesel engine parameters and optimization using RSM. The objective of this research is to investigate the effects of different blends on engine performance, combustion, and emissions, as well as to determine the best blend composition that improves engine efficiency while reducing emission levels [15].

These diesel ternary fuel mixes have higher lubricity, reduced particulate matter, and decreased NO_x emissions, the usage of alternative fuel mixes such as SO and DEE may offer significant advantages. The use of SO as a feedstock for the creation of biofuels might result in the creation of sustainable and local fuel sources. However, the use of biofuels in diesel engines might also create some obstacles. For instance, the viscosity of vegetable oils such as SO is often substantially higher than that of diesel fuel, which might interfere with the fuel injection process and increase engine component wear. In addition, the usage of DEE in diesel engines might result in increased combust sound and temperature. When optimizing the usage of SO, DEE and diesel ternary fuel mixes in diesel engines, these problems must be thoroughly evaluated and resolved [13,15].

1.2.1. Research Objectives And Scope

This study's main purpose is to evaluate the effects of sesame oil/DEE/diesel ternary fuel blends on diesel engine characteristics and to optimize the blend composition using response surface methodology. Specifically, the research aims to**:**

- Study the effects of SO, DEE and diesel ternary fuel blends on engine performance, such as BSFC.
- Investigate the effects of these blends on combustion parameters, such as SO ratio, DEE ratio and engine load.
- Evaluate the emissions of these blends, such as CO, HC, NO_x, and CO_2 emissions.
- Use the RSM to optimize the blend composition and to model the relationship between the input variables and the output responses of an engine performance and emissions.
- Identify the optimal blend composition that maximizes engine efficiency while minimizing emissions.

The research will be restricted to a certain spectrum of blend compositions. The compositions will be chosen based on practical concerns such as the availability of alternative fuels, the viability of blending them with diesel fuel, and the desire to study a wide variety of blend ratios SO30%, DEE (15, 20, 25%). The proposed blend ratios will also be informed by prior research to ensure that they span the projected range of engine performance and emissions improvement. The purpose of this research is to offer a broad knowledge of the impacts of SO, DEE, diesel ternary fuel mixes on diesel engine characteristics and response surface optimization. The use of the RSM will give a systematic strategy for optimizing the blend composition, which may be extended to different alternative fuel blends or engine configurations [14,15].

1.3. Research Methodology

Several approaches exist for optimizing the performance of diesel ternary fuel mixes; however we will just focus on the RSM method. We will use this method to minimize the experiments. RSM is a statistical approach that may be used to optimize the mix of SO, DEE, and diesel by examining the correlations between various parameters (such as the proportions of SO ratio and DEE ratio) and the response (e.g., engine performance of CO, HC, CO_2 and NO_x emissions). RSM entails running a series of trials with various combinations of SO, DEE, and diesel and monitoring the results. The results of these trials are then examined using statistical methods to determine which factors have the most impact on the response and to construct a mathematical model that represents the link between these factors and the response. Due to the high cost and time consumption associated with traditional methods, researchers have shifted their attention towards computer-based methods which offer faster and more cost-effective solutions. As computer technology advances, there are less research on the RSM-based optimization of diesel engine characteristics [14].

1.4. Significance Of The Study

SO is a type of vegetable oil extracted from sesame seeds. It has a high flash point and low volatility, making it a viable fossil fuel substitute [12]. DEE, commonly known as is a clear, colorless liquid with a low flash point that is extremely combustible. It is often employed as a solvent and as a material for the synthesis of a broad variety of compounds. When blending SO and DEE with diesel, the resultant fuel may have enhanced ignition and combustion properties compared to diesel alone. However, the mixture may also have a higher viscosity and lower energy content, which might impact the engine's performance.

RSM may be used to optimize the mix of SO, DEE, and diesel by analyzing the correlations between different parameters (e.g., the quantities of SO (30%) and DEE (15%, 20%, 25%) in the blend) and the response (e.g., engine performance). RSM can determine the ideal SO, DEE, and diesel combination to enhance or decrease a reaction and anticipate its response. Blending SO, DEE, and diesel on diesel engine characteristics depends on the engine and operating circumstances. SO-based fuels may potentially harm the environment and health.

Multiple variables can affect the performance of SO-DEE-diesel ternary fuel blends in diesel engines. The proportions of SO, DEE, and diesel in the blend, the attributes of the individual fuels (such as their viscosity, density, and flash point), and the operating conditions of the engine are all variables (such as the load). Using RSM, it is able to investigate the correlations between these components and the response (e.g., engine performance, emissions) and to determine the ideal mixture that optimizes or minimizes the response. RSM normally entails completing a number of trials with various combinations of SO, DEE, and diesel and monitoring the results. The results of these trials are then examined using statistical methods to determine which factors have the most impact on the response and to construct a mathematical model that represents the link between these factors and the response. Once the mathematical model has been created, it may be used to forecast the reaction to a given blend of SO, DEE, and diesel. This can be important for adjusting the blend and enhancing the engine's performance [13-15].

PART 2

LITERATURE REVIEW

Samet Uslu et al, attempted to increase the performance and emissions of a single-cylinder diesel engine by adding varying quantities of GO to a mixture of 30% SO and 70% diesel fuel. RSM was utilized to optimize the quantity of GO with the minimum testing procedure. The results indicated that GO is an effective additive for diesel biodiesel blends and that the ideal level of GO for performance was between 75 and 100 ppm. The study also indicated that GO had a favorable impact on emissions, with 100 ppm being the optimal concentration for reducing CO and HC and 75 ppm for reducing NO_x. According to the study, increasing engine load had a favorable effect on power, BSFC, and CO, but a negative effect on EGT, HC, and NO_x. The study found that 100 ppm of GO with a load of 1950 W was optimal for all outcomes [1].

According to Ehmus Altuna et al., SO may be used as an alternative fuel in diesel engines. The study indicated that a blend of 50% SO and 50% diesel fuel may be effectively utilized in a diesel engine without modification and produces fewer exhaust emissions than diesel fuel alone. The study also discovered that the power provided by the blend is equivalent to that of diesel fuel, although BSFC is greater due to the blend's lower heating value. In addition to being more expensive than diesel fuel, SO is presently not a feasible option. However, the study recommends that future research might examine the use of alternative blends and the enhancement of SO's blended fuels. There are issues associated with the high viscosity and high prices of vegetable oils. The study offers fuel mixing as a method to enhance the performance and emissions of diesel engines in order to overcome these obstacles. The engine power and torque were found to be similar to diesel fuel, but the exhaust pollutants were lower than those of diesel fuel. Therefore, the study reveals that SO-diesel fuel blends may be utilized effectively as an alternative fuel in a diesel engine, and it is a fuel that is ecologically beneficial in terms of emission metrics [16].

Shailaja et al, discovered throughout experiments that biodiesel produced from SO had the potential to be used as a diesel engine fuel and had superior performance and emissions compared to the traditional diesel. Biodiesel might be used directly in any diesel engine without requiring any alterations to the engine. The study demonstrates that biodiesel derived from SO is a viable alternative fuel for diesel engines and has the potential to be employed in a variety of applications [17].

Sateesh Reddy oversaw the investigation of biodiesel alternatives such as SO to replace conventional diesel fuel. Experimentally analyzing the performance of two blends of SO biodiesel to traditional diesel. The findings revealed that the blend B10 possessed the best brake thermal efficiency and indicated thermal efficiency at a weight of 12 kg, whereas the blend D100 possessed the maximum mechanical efficiency at the same load. At 0kg, the D100 blend had the highest specific fuel consumption and CO emissions. At a load of 12 kg, B20 had the maximum CO_2 emissions. Overall, the B10 blend shown promising performance, and the further blends may be evaluated in the future to determine the most effective alternative to diesel fuel. SO has the potential to be utilized as a biofuel in diesel engines due to the fact that it is renewable, non-toxic, and readily available locally. With transesterification, SO is converted into biodiesel. The study indicated that while both blends of SO biodiesel were less efficient than conventional diesel, the B10 blend had the maximum thermal efficiency, indicating that it might be a future viable alternative [18].

In a research done by Nilamkumar et al. revealed that the employed a blend of SO in various proportions with diesel fuel as an alternative fuel in a direct injection diesel engine. It was determined that a combination of 30% SO and 70% diesel fuel had the greatest engine performance, with fuel consumption and thermal efficiency closest to that of traditional diesel fuel. the study indicated that adding ethanol to this blend in concentrations of 5%, 10%, and 15% did not significantly influence engine performance. It was decided that SO might be utilized as an alternate fuel in diesel engines in the future, and that the SO30 D70 blend can be used without modification to the engine [19].

According to Nilesh Kumar Sharma's Review research, the high viscosity of vegetable oils, such as SO, might pose issues in a CI engine. Fuel blending, where SO is mingled with diesel fuel in a diesel engine, is one solution to this problem. This blend's impacts on engine performance and emissions were investigated and determined to be superior to diesel operation alone. SO is appropriate for blending with diesel fuel because of its heating value, viscosity, density, cetane number, and flash point. The primary objective of this study was to identify an affordable mix that enhances engine performance and reduces emissions. The study may have also assessed the impact of different ratios of SO to diesel fuel on engine performance and emissions [20].

M. D. Trivedi, et al. The purpose of this study is to evaluate the potential of SO as biodiesel. Its high viscosity, which creates issues with atomization and self-ignition, is the fundamental factor inhibiting its usage as a fuel. However, SO's viscosity may be lowered by transesterification, and diesel can also be added to aid. Varying the amounts of SO to diesel can reduce the viscosity of diesel. This blended SO has been tested in a diesel engine with a single cylinder, and its performance and emission characteristics are promising [21].

According to Sehmus Altun et al, the use of vegetable oils as a fuel in diesel engines offers significant difficulties due to their higher viscosity than standard diesel fuel. However, there are other methods available to alleviate these problems, including fuel mixing. In order to do this, a combination of 50% SO and 50% diesel fuel was tested as an alternative fuel in a diesel engine with direct injection, and the engine's performance and exhaust emissions were compared to those of conventional diesel fuel. Experiment findings reveal that the engine power and torque of the SO-diesel fuel blend are comparable to those of diesel fuel, but exhaust pollutants are reduced. This indicates that the combination of SO and diesel fuel may be effectively utilized as an alternative fuel in diesel engines without any changes and is also an eco-friendly fuel in terms of performance and emission [22].

The research done by H.K. Rashedul et al. investigated the effects of additives on the characteristics, performance, and emissions of a biodiesel-fueled CI engine. The report emphasizes the significance of biodiesel as a means of conserving fuel supplies and reducing CO_2 emissions. The author observed that the lower heating value and low temperature features of biodiesel compared to diesel led to a drop in engine power. Moreover, the low-temperature attributes of biofuels were discovered to be inferior to those of diesel fuels [23].

M. Habibullah et al, conducted an experiment to assess the performance of biodiesel blends derived from coconut, palm, and a mixture of the two in a diesel engine with a single cylinder. The objective of this study was to produce, characterize, and assess the impact of biodiesel blends derived from two principal feedstocks: palm and coconut (PB30 and CB30) on engine performance and emissions. The biodiesel blends were produced using an alkali-catalyzed transesterification technique. They also investigated the impact of combining the high ignition quality of palm with the high oxygen content of coconut to develop a superior blend of biodiesel. The findings of the experiment indicate that, in terms of engine performance and emissions, the blend of palm and coconut oil surpasses the blends of coconut oil and biodiesel separately [24].

According to Mehra et al, the rising expense of petroleum fuels have prompted a comprehensive search for alternative fuels. The feasibility of utilizing SO as a biodiesel feedstock was investigated. Using the trans-esterification method, market-purchased SO was turned to biodiesel in a laboratory environment. The maximum biodiesel production was attained when the esterification process was completed at 60 °C for 90 minutes with a 10:1 ratio of ethanol to oil and 2.3% sodium hydroxide. Using different experimental apparatus, the thermo-physical characteristics of SO biodiesel were investigated, and it was determined to be an acceptable alternative fuel for compression-ignition engines, based on comparison with the Bureau of Indian Standards (IS 15607:2016). Various mixes of SO biodiesel and diesel fuel (SO20, SO40, SO60, SO80, and SO100) were evaluated alongside mineral diesel and unrefined SO to establish their viability as diesel engine fuels [25].

Simsek et al. aim to use RSM to determine the optimum engine parameters for both performance and emissions of diesel engine. The optimization procedure was created to enhance BTE, EGT, NO_x, and CO_2 emissions. To examine the impact of biodiesel blends on engine performance and emissions, this study conducted experiments with varying concentrations of a biodiesel mixture created from canola, safflower, and waste vegetable oil. Using the experimental study's results, an RSM model was developed to assess the viability of biodiesel in diesel engines. The ideal engine running parameters were determined to be a load of 1484.85 watts, an IP of 215.56 bar, and a biodiesel ratio of 25.79%. The results for BTE, EGT, smoke, NO_x, and CO_2 were 20.54%, 199.88 ^oC, 0.26% , 558.44 ppm, and 4.52%. The study shows that RSM is a useful method for predicting and optimizing the performance and emission values of biodiesel-powered diesel engines [26].

Using RSM, Singh et al, investigated the effects of engine load, injection pressure, and IT on the performance and exhaust emissions of a diesel engine powered with pongamia biodiesel and diesel blends. Based on their optimization results, they determined the best operating parameters to be a fuel spraying pressure of 196.36 bar, a 40% biodiesel mix, and a 53% engine load. The researchers discovered error rates of less than 5% and concluded that RSM is an efficient strategy for optimizing diesel engine parameters and attaining high performance [27].

Sakthivel et al, the study aim to identify the ideal engine operating parameters for a diesel engine running on waste biomass pyrolysis oil using a RSM model. As input factors, the RSM model comprised compression ratio, fuel blend, and engine load. As output variables, the model included BTE, BSFC, NO_x, HC, CO, and smoke emissions. While doing their research, they discovered that the best CR was 18:1 CR, BTE improved by 5%, BSFC decreased by 3%, and CO and unburnt HC decreased by 58.3% and 38.5%, respectively [28].

Thokchom et al, the purpose of the study was to evaluate the performance of Spirulina microalgae combined with conventional diesel fuel in a variables, engine under various loads, CR, and blend concentrations. Using a complete factorial technique, a L64 orthogonal array was utilized to create trials, and RSM was applied to analyze numerous responses. The study explored the relation between performance indicators, including BSFC and BTE, and emission parameters, including CO_2, PM, and NO_x. The process was described by the regression model's R^2 response variable, which was more than 80%. The model indicated that a load of 64.634, a CR of 16.50, and a blend concentration of 20% would yield the best results, with a BTE of 31.357%, a BSFC of 274.97 g/kWh, and lower levels of CO_2 (869.075 g/kWh), PM (0.2807 g/kWh), and NO_x (1804.97 ppm). The confirmation test revealed that the projected outcomes closely matched the experimental values [29].

Krishnamoorthi et al. The focus of the research was on three input parameters: IP, CR, and IT. Three values were employed for each input parameter throughout the experiment: 210 bar, 230 bar, and 250 bar for IP, 16, 17, and 18 for CR, and 21°, 23°, and 25° bTDC for IT. As a statistical technique, the DoE was utilized to arrange the experimental trials and evaluate the output parameters of performance and emissions. The objective was to optimize the input parameters to reduce emissions pollution and enhance performance. RSM was employed to create models, and confirmatory tests were conducted to validate the models. The analysis determined that the optimal combination for fuel consisted of an IP of 230 bar, a CR of 18, and an IT of 23°bTDC, yielding a maximum BTE of 30.5%. The study indicated that the lowest levels of CO were recorded at an IP of 230 bar, a CR of 18, and an IT of 25°bTDC for fuel, whereas the maximum levels of NO_x were detected at an IP of 250 bar, a CR of 16, and an IT of 25°bTDC [30].

Yashvir Singh et al, the purpose of this study is to apply the RSM optimization approach to identify the parameters that influence the performance and emissions of a direct injection diesel engine while utilizing cassia tora biodiesel mixes. The study evaluates four input factors, including engine load, IT, IP, and blend percentage, with five levels for each variable. To maximize engine output variables such as NO_x, BTE. RSM is used to determine the ideal combination of these components. By utilizing cassia tora biodiesel blends, the environmental performance of the engine may be enhanced, leading in an increase in commercial value. A central composite rotating design matrix underpins the experimental design. 15^o bTDC IT of fuel, 221 bar IP of fuel, 40% cassia tora blending with diesel, and 47% engine load were determined to be the optimal combination of input parameters, resulting in maximum BTE and NO_x emissions of the engine [31].

Parida et al. performed a study with engine load, CR, and biodiesel blends as input variables. For modeling and assessing response parameters, they employed RSM with full factorial design within Minitab. To validate the proposed models, data regression, significance analysis, and individual model coefficients were applied. The desirability function was then used for multi-objective optimization to produce replies. The results were confirmed by conducting confirmation tests with the following input parameters are load 9.8 kg, CR 18.0, and blend of 20%. The mathematical modeling output solutions were derived using a D-optimal test with composites desirability of 0.97009. Except for the CO model, RSM predictions matched with experimental data with errors of less than 5%. BTE, BSFC, CO, HC, and NO_x were derived via mathematical modeling as output responses [32].

In an experiment done by R. Sakthivel, the ideal engine operating conditions (CR, load, and fuel blend) for a diesel engine utilizing pyrolysis oil derived from waste biomass were determined. RSM was utilized to create multiple regression models for various engine performance and emissions-related output response variables. It was determined that the models were statistically significant, and optimization was conducted using a desirability technique to increase BTE and CO_2 while reducing other emissions. The optimal parameters were determined to be a CR of 18:1, a fuel mixture of 20%, and a 100% engine load. The models were tested by confirmatory experiments and found to be accurate to within 5% prediction error. Overall, the study underlines the promise of advanced biofuels of the third generation for a cleaner and more sustainable environment [33].

Krishnamoorthi M. Using a mix of experimental inquiry and RSM, the purpose of this work is to optimize a direct injection, single-cylinder diesel engine with an emphasis on brake power, fuel efficiency, and exhaust emissions. At various engine loads, the diesel-biodiesel-DEE mix exhibited a marginally reduced BSFC and substantial emission reductions. RSM was utilized to establish the ideal mix ratio of the three fuels, which was determined to be 25% biodiesel, 5% DEE, and 70% diesel. The study discovered that RSM is an effective technique for improving biodiesel blends as fuel in diesel engines, and the mathematical models utilized in the study provide forecasts for untested factor quantities. Brake power was constant across all mixes, although BSFC rose as a result of decreased heating values. NO_x, CO, and HC emissions also decreased significantly [34].

PART 3

FUELS, COMBUSTION AND EMISSIONS IN DIESEL ENGINES

3.1. Specifications of Diesel Fuel

Diesel fuel is the type of fuel utilized by diesel engines. It is derived from a range of crude oils and is often darker than gasoline. Diesel fuel has a greater energy density than gasoline, meaning it contains more energy per volume unit. It also has a greater flash point than gasoline. The flash point is the temperature at which a substance will ignite. Diesel fuel is widely utilized in the transportation business, particularly in cars, buses, and trucks. It is also utilized in the maritime, construction, and agricultural industries. Diesel fuel regulations vary by state or locale, but sulfur content, cetane number, and density are typically required to fulfill specified standards [35].

3.1.1. Cetane Number of Fuel

The cetane number is one of the most important characteristics affecting the engine's output power, combustion behavior and harmful emissions and provides a measure of the ignition characteristics. It symbolizes a fuel property closely related to automatic ignition, especially at low temperatures. The cetane number of the fuel also depends on the aromatic content and boiling point. Low cetane number delays the auto-ignition of the fuel, increases the density and causes noise in the engine. It also contains heavy HC [36].

Fuel with a low cetane number causes late combustion in the engine and due to the long ignition delay, there is difficulty in the first start in cold weather conditions. There are also negative effects in terms of emissions. The high cetane number of the fuel reduces engine noise, improves cold weather performance, engine runs smoother and improves emissions. For these reasons, fuels with very high or very low cetane numbers affect the operation of the engines, so the cetane number should be in certain ranges. The cetane number in a diesel engine should be between 40-60. If it is desired to increase the cetane number, cetane increasing additives can be used, but these additives may damage some properties of the fuel. If the cetane number is high, the ignition delay is short, and if the cetane number is low, it is long [35,36].

The cetane number of biodiesel fuel changes depending on the distinctive properties of the fatty acid in the oil used as raw material. Due to its higher cetane number compared to diesel fuel, biodiesel positively affects the combustion efficiency. Since the raw material used affects the cetane number, the cetane number value generally varies between 46-60 values [36].

3.1.2. Kinematic Viscosity of Fuel

Kinematic viscosity is a measurement of a fluid's resistance to flow. It is defined as the ratio of the fluid's dynamic viscosity (a measure of the fluid's internal resistance to flow) to its density. At 40 °C, the kinematic viscosity of diesel fuel is normally between 2.0 and 6.0. Depending on the quality and kind of diesel fuel used, this might vary. Diesel fuel's kinematic viscosity is crucial since it impacts the ease with which the fuel flows through fuel lines and fuel injectors [36].

A fuel with a greater kinematic viscosity may not atomize as smoothly, resulting in incomplete combustion, which can lead to problems with the fuel delivery system and poorer fuel efficiency. On the other side, a fuel with a lower kinematic viscosity may result in increased atomization and combustion, resulting in better fuel efficiency. The kinematic viscosity of diesel fuel has a substantial impact on its performance and handling. According to EN ISO 3104, the kinematic viscosity of SO is 34.97 mm^2 /s at 40 °C [37].

3.1.3. Flash Point of Fuel

The flash point is the temperature at which a fuel will ignite when exposed to an ignition source and generate a flash. When handling and storing fuels, the flash point is a significant safety issue since a fuel with a low flash point is more likely to ignite and cause a fire or explosion. Diesel fuel has a greater flash point. it is less flammable and less prone to burst into flames under normal circumstances [38].

The flash point of diesel fuel is between 55 ^{o}C and 66 ^{o}C. The flash point for safety is typically between 65 ^{o}C and 150 ^{o}C and should never go below 36 ^{o}C. The biodiesel fuel's flash point is fairly good and does not significantly affect engine performance. A decrease or rise in the flash point has no effect on the properties of combustion. The high flash point of fuels makes them excellent for transportation and storage. The flash point of biodiesel fuel is approximately 220 °C [36,38].

3.1.4. Cloud Point of Fuel & Pour Point of Fuel

At the cloud point, tiny wax crystals begin to form in diesel fuel. These crystals can block gasoline filters and limit fuel flow to the engine, resulting in engine failure or malfunction. When operating in cold weather, it is crucial to remember the cloud point of diesel fuel, as the fuel may become less fluid as the temperature decreases. The point of solidification or flow becomes important during the start-up of an engine at low temperatures. In the case of solidification, the necessary fuel flow cannot be provided, and the engine will not run. The flow point temperature should be 5 ^{o}C to100 ^{o}C below the ambient temperature to ensure the engine operates properly [35,36].

3.1.5. Density of Fuel

The density of a fuel offers basic information on its structure, carbon-hydrogen content, fragmentation, and ignition ability. In diesel engines, injection systems dispense fuel on a volumetric basis, therefore the specific gravity of the fuel has a direct effect on the amount of fuel injected. In general, the specific gravity of a molecule falls as the number of hydrogen atoms increases [36].

Fuel density is an important factor in NO_x emissions and particulate formation [39]. When diesel fuel density is raised, the mass of the injected fuel rises, resulting to an increase in smoke emissions. In addition, low fuel density also increases fuel consumption. When the density of diesel fuel is raised, the volume of fuel injected may rise, which may have detrimental impacts on smoke emissions.

3.1.6. Distillation Range of Fuel

The diesel fuel's distillation range can also alter its behavior under varying temperature conditions. For instance, diesel fuel with a lower distillation range may perform better in colder weather due to its greater vapor pressure, which aids in its evaporation and burning. Due to its greater vapor pressure, diesel fuel with a higher distillation range may be more susceptible to vapor lock (when the fuel vaporizes and clogs the fuel line) in hot weather. At general, the distillation range of diesel fuel is a crucial consideration when selecting a fuel for a certain purpose or for use in varying temperatures [40].

The presence of heavy HC in the fuel makes it difficult to ignite and evaporate.it is useful in preventing smoke emissions. Reducing the maximum distillation temperature reduces the quantity of heavy HC in the fuel. This guarantees clean ignition. Additionally, the viscosity and density of the fuel will drop. Distillation is essential for easing the initial movement in cold weather and reducing the quantity of NO_x, smoke emitted by burning. High distillation fuels minimize smoke production, fuel usage, and exhaust temperature [41].

3.1.6. Biodegradability of Fuel

Diesel fuel is not biodegradable, meaning it does not breakdown in the environment. It is made up of complex HC that are resistant to decomposition by bacteria and other natural processes. Diesel fuel may harm plants and animals, and the environment. which contributes to its environmental effect. There are initiatives to generate more diesel fuels that are biodegradable. These initiatives include the use of alternative feedstocks, such as algae or waste products, to produce biodiesel, a biodegradable fuel derived from renewable resources. Even though biodiesel is usually regarded to be more environmentally friendly then diesel fuel, it still has certain negative environmental implications, but it is essential to decrease diesel fuel usage and dispose of it correctly in order to lessen its environmental implications [42].

3.1.7. Cold Flow Feature

The cloud point is the temperature at which crystallization of the fuel first occurs. The cloud point for diesel is -15^{o}C. If this number goes below, the flowability of the gasoline will diminish. The pour point is the final temperature at which the fluidity of the fuel ceases. The pour point for diesel is -19^{o}C. Fuel with poor pour point characteristics flows slowly and can ice up injectors, resulting in injector blockage. When biodiesel fuel has an abundance of saturated fatty acids, the fuel crystallizes faster. Misting in biodiesel fuel further demonstrates that the cloud point may occur at positive temperatures. The effects of climate change include quick freezing, difficulties with fuel flow, and fuel storage. To ensure the fuel's ability to adjust to climate circumstances, the cold filter plugging point, cloud point, and pour point must be managed and recognized [40].

3.1.8. Sulfur Content and Corrosion Effect

Sulfur is a harmful substance found in the content of diesel fuel, which causes particles and corrosion. At the same time, sulfur has lubricating properties in fuels. As a result of studies, biodiesel fuels are chosen due to their reduced sulfur content. Lubrication is required to avoid this deterioration. To decrease emissions, the sulfur level of diesel fuels is kept low. As an outcome, diesel fuel's lubricating properties diminish. Biodiesel fuel is an excellent lubricant [40].

3.1.9. Aromatics of Fuel

Aromatics are a class of chemical compounds that contain aromatic rings which are rings of atoms with alternating double bonds. Aromatics are added to diesel fuel to increase its performance and decrease its environmental effect. Aromatics are generally used to reduce the cetane number [43]. The cetane number is a measure of the fuel's ability to ignite and burn effectively in a diesel engine. Aromatics may also increase the energy density of the fuel, which is the amount of energy that can be extracted from a given volume of fuel [44].

3.1.10. Lubricity of Fuel

Diesel fuel must have sufficient lubricity to guarantee the smooth running of the engine and avoid the early wear and failure of its components [45]. The superior lubricating quality of biodiesel compared to diesel fuel helps reduce engine wear and extends engine life.

3.1.11. Freeze Point of Fuel

The freeze point of diesel fuel is typically around (-19 to -40°C) but its vary depending on the specific type and quality of the diesel fuel. To ensure proper performance, it is recommended to store diesel fuel at temperatures above its freeze point. There are various elements that can influence the freezing point of diesel fuel, including the diesel fuel type and its chemical composition, the presence of additives.

3.1.12. Oxygen Content of Fuel

Due to biodiesel's high oxygen content and high cetane number, the incorporation of biodiesel into diesel fuel has reduced CO and HC emissions [40].

3.1.13. Ash Content of Fuel

The ash content in diesel fuel is the quantity of inorganic material present in the fuel. It is composed of ash and small solid particles, as well as metallic components in the fuel or oil. One of the most significant issues with diesel fuel is that it contains a significant amount of ash content. It can give severe damage to the engine's mechanical components and build on the surfaces of the exhaust valves, causing valve burning. Fuels with excessive ash content can also cause corrosion [40].

3.2. Combustion and Mixture in Diesel Engines

In a diesel engine, the injection of fuel into the compressed air in the combustion chamber initiates combustion. The high temperature and pressure produced by the compression process ignites this fuel-air mixture. Diesel cycle describes the combustion process in a diesel engine. It comprises four phases:

- Induction
- Compression
- Combustion
- Expansion

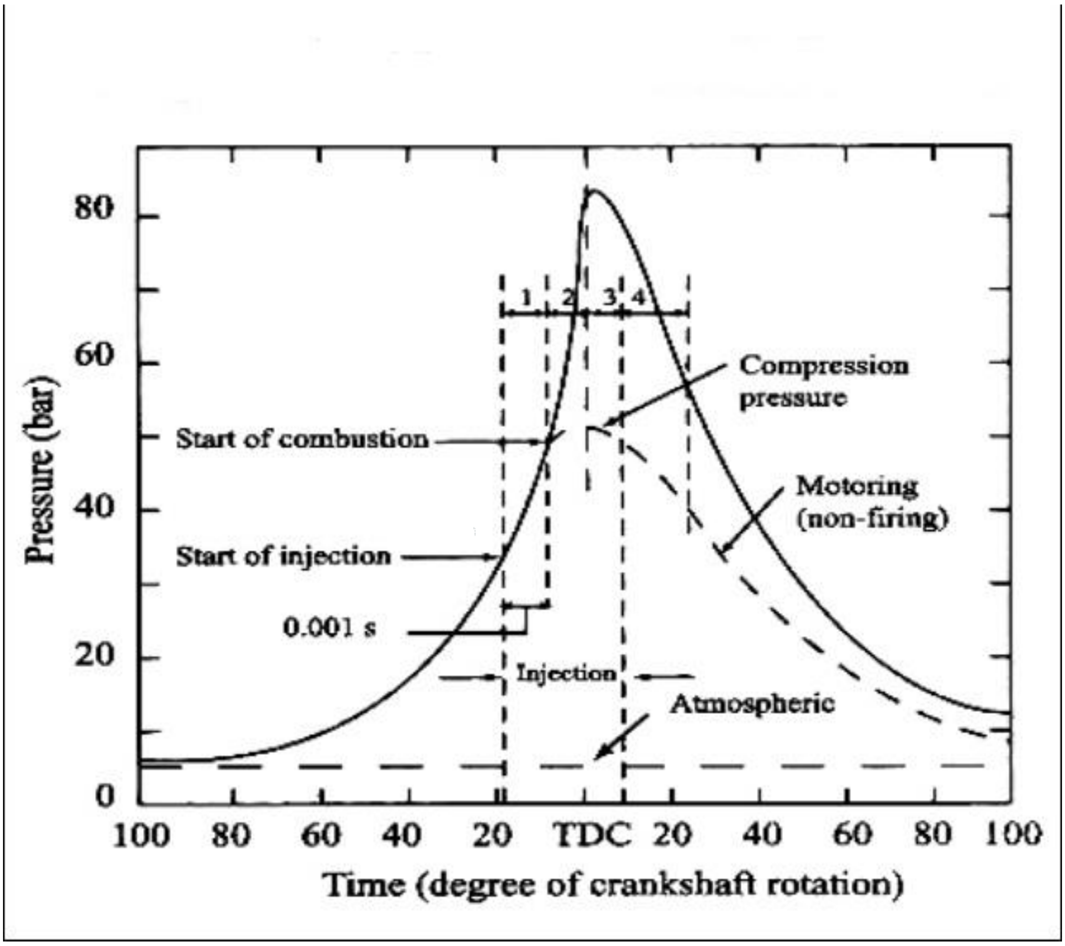

Figure 3.1. Combustion diagram in diesel engines.

During the induction phase, the intake valve draws air into the engine cylinder. The air is then compressed, increasing its temperature and pressure, during the compression step. During the combustion stage, compressed air is injected with fuel and ignited by the high temperature and pressure. This results in a fast expansion of the gases, which pushes the piston down and turns the crankshaft of the engine. During the last phase of the cycle, the gases continue to expand and push the piston back up, thereby completing the cycle. A diesel engine's fuel-to-air ratio is essential for effective combustion. Too much fuel will result in incomplete combustion and higher emissions, while insufficient fuel will lower power production and increase fuel consumption. The fuel injection system of a diesel engine controls the fuel-to-air ratio by adjusting the amount of fuel injected based on engine speed and load. This enables for optimal engine combustion and performance [46].

3.2.1. Combustion Stages in Diesel Engines

A diesel engine's combustion process may be separated into four phases.

3.2.1.1. Ignition Delay

The ignition delay in a diesel engine is the amount of time between the injection of fuel into the cylinder and the beginning of combustion at point 1 as shown in Figure 3.1. The fuel droplets are evaporated and combined with air during this period. A diesel engine's efficiency and performance are significantly impacted by the ignition delay interval. If the ignition delay is too long, partial combustion and lower engine performance may occur. Alternatively, if the ignition delay is too short, knocking and pre-ignition might occur, culminating in engine damage. Several factors, including fuel quality, injection time, and engine temperature, can influence the ignition delay. The ignition delay of a diesel engine can be affected by the size and form of the fuel droplets, the chemical composition of the fuel, and the pressure and temperature within the cylinder [46].

To optimize the ignition delay and enhance engine efficiency, diesel engines are fitted with sophisticated fuel injection systems that precisely regulate the time and quantity of fuel injected into each cylinder. diesel engines are outfitted with sensors and control systems that monitor and alter the ignition delay in real time to optimize performance.

The delay time of ignition is determined by the temperature and air pressure, the atomization and quality of the fuel, the injection timing, and the turbulence. The ambient pressure affects the ignition delay. The ignition delay diminishes as the ambient pressure rises. The chemical components of the delay in ignition are governed by the pre-combustion reactions of the fuel. Despite the fact that ignition occurs in the vaporization stage, oxidation events can also occur in the liquid part between the fuel droplets and oxygen-dissolving fuel molecules. Additionally, big HC molecules are broken down into smaller molecules. These chemical processes are dependent on the fuel components, filling temperature, and pressure of the cylinder.

In diesel engines, intake air temperature has a favorable influence on reducing the ignition delay. As the temperature of the intake air rises, the ignition delay reduces. Since the fuel ignition characteristic impacts the ignition delay, this characteristic is crucial for the operational characteristics of diesel engines; it affects qualities such as fuel conversion efficiency, knock-free operation, non-ignition, exhaust pollutants, noise, and ease of operation. Increasing the CR will cause the temperature and pressure to rise. Consequently, the ignition delay will diminish [47].

The cetane number characterizes the capacity of fuel to ignite. For fuels with a low cetane number, the ignition delay will be prolonged, and the majority of fuel will be injected without igniting. This results in extremely quick burning and unexpected rises in pressure. This phenomenon is characterized by an audible knocking sound and is known as "diesel knock."

3.2.1.2. Uncontrolled Combustion

Uncontrolled Combustion, also known as Pre-ignition, is the stage in a diesel engine where fuel droplets begin to ignite and burn prior to the completion of the fuel injection process at point 2 as shown in Figure 3.1. Pre-ignition can result in knocking, which is a loud knocking or pinging sound created by the fuel in the cylinder igniting early. Multiple causes, including high engine temperature, a high compression ratio, and poor fuel quality, can induce pre-ignition. Pre-ignition may cause significant damage to a diesel engine by causing banging and engine failure.

To prevent pre-ignition, diesel engines are fitted with sophisticated fuel injection systems that precisely manage the IT and volume. Additionally, the fuel injection system may be modified to accommodate various operating situations, such as load and speed. In order to maintain optimal performance, diesel engines are also fitted with sensors and control systems that monitor and alter the fuel injection process in real time [46,47].

pre-ignition in a diesel engine can be caused by a variety of factors including high engine temperature, high compression ratio, and poor fuel quality. Diesel engines are equipped with advanced fuel injection systems and control systems that carefully monitor and control the fuel injection process to prevent pre-ignition and ensure optimal performance. Regular maintenance and keeping the engine temperature within a safe range can also help prevent pre-ignition [46].

3.2.1.3. Controlled Combustion

Controlling the rate of heat transfer after uncontrolled combustion is the air/fuel mixture that is sensitive to combustion at point 3 as shown in Figure 3.1. At this step, processes such as liquid fuel atomization, air and vaporized fuel mixture, and vaporization occur. Among them, the mixture of air and vaporized fuel has the largest impact on this curve. Controlled combustion in a diesel engine refers to the management of fuel injection and ignition to enhance engine performance and efficiency. In a diesel engine, the fuel is ignited by the high temperature of the cylinder's air, which takes longer to achieve the required ignition temperature. In order to achieve maximum performance and efficiency, the ignition delay in a diesel engine is a crucial variable that must be properly managed. Advanced fuel injection systems are used to precisely manage the time and amount of fuel injected into the cylinder of a diesel engine in order to produce controlled combustion. Additionally, the fuel injection system may be modified to accommodate various operating situations, such as load and speed. In addition, diesel engines are outfitted with sensors and control systems that monitor and alter the ignition delay in real time to optimize performance [46,47].

3.2.1.4. Delayed Combustion

Exhaust, or delayed combustion, is the final stage of the combustion process of a diesel engine at point 4 as shown in Figure 3.1. At the conclusion of the spray phase, combustion does not instantly cease. Unburned or partially burnt fuel particles that have accumulated in the combustion chamber make contact with oxygen and ignite. The delayed combustion phase begins about after the controlled combustion period finishes and the maximum combustion end temperature is attained and lasts until a portion of the expansion time. As the expansion time approaches, the rate of heat release during the delayed combustion interval drops. This is because extremely little quantities of unburned fuel and smoke particles or rich combustion products offer heat release during the delayed combustion phase. During this time, the average temperature of the gas within the cylinder decreases [47].

3.2.2. Working Principle of Diesel Engines

Using the heat of compressed air, diesel engines ignite fuel delivered into the combustion chamber. The process begins when the engine's starting motor rotates the crankshaft, causing the pistons in the cylinders to rise and fall. As the pistons descend, they pull air and fuel mixture with the intake valve as shown in figure 3.2 at point A. The intake valve then closes, preventing the mixture from escaping the cylinder. The cylinder is then shut off from the remainder of the engine, and the rising piston compresses the mixture as shown in figure 3.2 at point B. When the air and fuel combination reaches a certain temperature and pressure, the fuel injector injects the fuel into the combustion chamber. The fuel is ignited by the heat of the compressed air, causing a controlled explosion as shown in figure 3.2 at point C. This explosion pushes the piston down, turning the crankshaft and generating power. The exhaust gases produced by the explosion are then expelled through the exhaust valve as shown in figure 3.2 at point D. The process is repeated in each cylinder in the engine, generating the power needed to drive the vehicle [46,47].

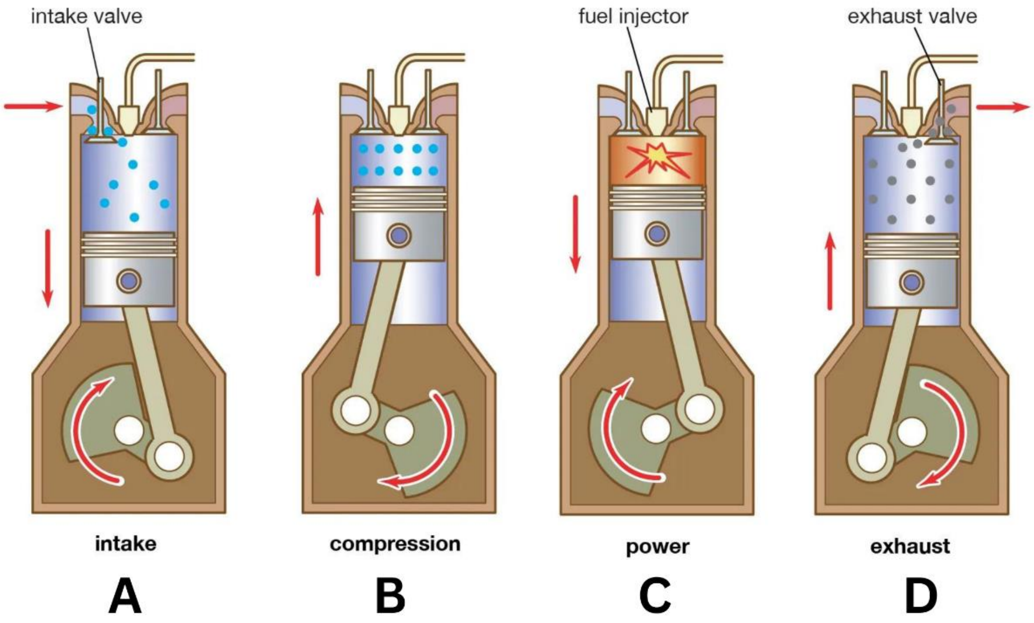

Figure 3.2. Working Principle of Diesel Engines.

3.3. Emissions in Diesel Engines

Air pollution is caused by various sources in both developed and developing countries. These sources vary depending on the level of industry and the presence of motor vehicles. There are a huge number of chemicals in the form of gases, liquids, and particulate matter in air pollution emissions. Previous studies have indicated that approximately 50% of air pollution is caused by motor vehicles. Additionally, 12% of harmful pollutants are attributed to motor vehicles [48].

Diesel engines are renowned for their efficiency and sturdiness, but they can have detrimental environmental effects. NO_x are one of the primary causes of emissions from diesel engines. NO_x is a set of gases created by the combustion of fuel at high temperatures, and it is a major contributor to air pollution and smog. Another cause of diesel engine emissions is PM. PM is composed of minute particles created by the combustion of fuel, and it can be breathed to cause respiratory issues. In addition to CO_2 and methane, diesel engines release greenhouse gases (CH_4). By trapping heat in the Earth's atmosphere, these gases contribute to global warming [48].

In recent years, major efforts have been made to minimize diesel engine emissions. This includes the use of cleaner fuels, such as biodiesel, and the development of new technologies, such as EGR systems and selective catalytic reduction (SCR) systems, which aid in the reduction of emissions. Diesel engines continue to contribute to air pollution and climate change despite these efforts; thus, it is crucial to continue reducing their emissions.

3.3.1. Hydrocarbon (HC) Emission

HC emissions refer to the discharge of incomplete combustion or partially burned HC into the atmosphere during a diesel engine's combustion process. These emissions are caused by the incomplete burning of fuel and can contribute to air pollution and have negative health impacts. There are several factors that can contribute to HC emissions in diesel engines, including engine design, fuel quality, and operating conditions. Some ways to reduce HC emissions include using a fuel with a higher cetane rating, improving the air-fuel mixture in the engine, and using EGR systems to reduce combustion temperatures [48].

HC emissions in diesel engines are composed of fragmented fuel molecules. Some HC contain carcinogenic properties. HC emissions are formed from unburned fuel particles. When the mixture in the combustion chamber is insufficient to ignite, HC are produced. It results from incomplete combustion or evaporation of the fuel. Complete combustion requires a sufficient amount of oxygen; when this oxygen is lacking, HC emissions will increase. HC emissions occur in several ways. These include incomplete combustion, carbon particles in the cylinder, flame extinguishment that occurs in the cylinder, problems with the injection system, and liquid fuel remaining in the cylinder can cause HC emissions [49].

Limits on HC emissions have been established by regulatory bodies across the world in an effort to decrease their detrimental influence on the environment and public health. These limitations vary according on the kind of vehicle and engine, as well as the operating zone. Diesel engine manufacturers must design their engines to fulfill these emission requirements for lawful sale and operation. Other methods for reducing HC emissions from diesel engines include improving the timing of fuel injection, utilizing catalytic converters, and employing sophisticated emission control technology such as diesel particulate filters. In addition to these steps, frequent engine maintenance and correct operation can assist decrease HC emissions. This involves replacing the air filter on a regular basis, ensuring the engine is properly oiled, and preventing engine overload [48,49].

Alternative fuels are an essential part of lowering HC emissions from diesel engines. These may include biofuels such as biodiesel and renewable diesel, which are derived from renewable resources and can aid in reducing the carbon footprint of transportation. While alternative fuels cannot remove HC emissions entirely, they can dramatically lower them compared to conventional fossil fuels. Alternative fuels and vehicle electrification are further potential strategies for minimizing HC emissions. Biodiesel is an alternative to traditional fossil fuels derived from vegetable oils and animal fats [57]. Biodiesel has the ability to minimize HC emissions since it creates less pollutants and burns cleaner than conventional diesel fuel. It should be emphasized, however, that biodiesel production can also result in HC emissions, since it needs the processing of raw materials such as vegetable oils and animal fats [50,51].

3.3.2. Nitrogen Oxide (NO_x) Emission

There are several methods available for reducing NO_x emissions from diesel engines. Using biofuels, which can have lower NO_x emissions due to their lower combustion temperatures, and enacting stronger emissions rules and standards are two more potential techniques for decreasing NO_x emissions from diesel engines. In addition, diesel engines must be properly maintained and serviced to ensure that they operate effectively and release as little NO_x as feasible. This involves routinely inspecting and repairing old or broken components, as well as utilizing premium fuels and lubricants.

Biodiesel provides additional environmental advantages. It creates less greenhouse emissions than conventional diesel fuel and is biodegradable. It may also be employed without modification in current diesel engines, making it a practical and cost-effective option. It is crucial to highlight, however, that biodiesel is not a perfect answer, as its combustion still creates some pollutants. Biodiesel is a potential alternative for lowering NO_X emissions and enhancing air quality, but it should be utilized in conjunction with other techniques to maximize its advantages [49].

3.3.3. Carbon Monoxide (CO) Emission

During burning, alternative fuels such as biodiesel, ethanol, and natural gas can also create carbon monoxide. However, these fuels often have lower CO emissions than conventional diesel. Biodiesel, which is derived from renewable sources such as vegetable oils and animal fats, has been demonstrated to lower CO emissions by up to 20% compared to conventional diesel. Ethanol, a biofuel derived from maize and other crops, may lower CO emissions by up to 50%. Alternative fuels can minimize CO emissions from diesel engines and contribute to a healthier and cleaner environment [51].

3.3.4. Formation of Particulate Matter (PM) Emission

Governments throughout the world restrict PM emissions to safeguard public health and the environment. There are a number of methods for reducing PM emissions from diesel engines, including increasing fuel quality, utilizing cleaner-burning fuels, and putting particle filters in the exhaust system [49].

Biodiesel is a fuel created from renewable resources, such as vegetable oil or animal fat, and may be used in diesel engines in place of standard diesel fuel. In comparison to conventional diesel fuel, biodiesel emits less particulate matter particles. Because biodiesel has a higher flash point, which means it takes more heat to ignite, its PM emissions are generally lower than those of conventional diesel fuel. This may result in a more thorough burning of the fuel, hence decreasing PM emissions. Biodiesel can be an efficient strategy to minimize PM emissions from diesel engines, but it is important to consider all factors [49,50].

3.4. Alternative Fuels for Diesel Engine

Diesel engines may run on alternative fuels including biodiesel, compressed natural gas, and propane to reduce pollution and minimize reliance on non – renewable [50]. It is possible to decrease air pollution, lower greenhouse gas emissions, and increase fuel efficiency by using alternative fuels in diesel engines. Utilizing alternative fuels in diesel engines has environmental advantages as well as possible financial advantages. The use of alternative fuels can help to reduce reliance on foreign oil, which can increase energy security and lower the chance of price fluctuations in the global oil market. Many alternative fuels are less expensive than conventional diesel fuel, which can help to reduce operating costs for businesses and individuals. As an alternative to using fossil fuels, biofuels made from natural materials are believed to have great thermal efficiency and low exhaust emissions [51].

While using alternative fuels in diesel engines has many advantages, there are some drawbacks as well. Since many gas stations do not offer alternative fuel sources, one of the major obstacles is the absence of infrastructure for alternative fuels. it might be expensive and not always feasible to convert a diesel engine to run on an alternate fuel. Despite these difficulties, using alternative fuels in diesel engines offers a viable way to cut emissions and improve sustainability in the transportation industry [52].

3.4.1. Biodiesel

Diesel engines may run on biodiesel, an alternative fuel. It has a reduced carbon footprint than conventional diesel fuel because it is made from renewable resources like animal or vegetable oils. Biodiesel can be used as a standalone fuel or in mixes with conventional diesel. It provides a number of advantages, including as better air quality, less reliance on fossil fuels, and higher energy security. By lubricating the engine and lowering wear, biodiesel can also enhance the efficiency of diesel engines. Despite its advantages, biodiesel is not yet a commonly utilized fuel for transportation since it requires more infrastructure and is more expensive than conventional diesel. However, it is expected that biodiesel will play a bigger part in transportation in the future as the need for alternative fuels increases [50].

Due to its ability to be produced from used cooking oil, biodiesel is a more waste- and pollution-free fuel option. It can also be produced from waste materials that would normally be thrown away, like leftover cooking oil and animal fat. Utilizing biodiesel, which emits fewer pollutants when burned than petrodiesel, can also aid in lowering greenhouse gas emissions [52]. Although not all vehicles or engines can use biodiesel, it is a promising alternative fuel for diesel engines and has the potential to drastically lessen transportation's impact on the environment. Overall, biodiesel can help us become less dependent on fossil fuels and increase the sustainability of transportation [53].

One potential drawback of biodiesel is that it can be more expensive than traditional diesel fuel. This is caused in part by how much raw materials cost and how biodiesel is manufactured. However, it is probable that the price of biodiesel will eventually drop as the demand for alternative fuels increases. A lot of governments also provide incentives or subsidies to encourage the use of alternative fuels, which can help to reduce the cost. Due to its lubricating qualities, which can help to prolong engine life and lower maintenance costs, using biodiesel in some situations can also result in cost savings. We may utilize biodiesel in diesel engines as a promising alternative fuel to lessen our reliance on fossil fuels and increase the sustainability of transportation [51-53].

3.4.2. Bio Alcohols

Due to their renewable nature and low emissions, bio alcohols like ethanol and methanol have attracted interest as alternative fuels for diesel engines [54]. Biomass sources like corn, sugarcane, and even waste materials like sawdust and agricultural byproducts can be used to make these bio alcohols. Bio alcohols can drastically lower emissions of dangerous pollutants including CO_2 and particulate matter when utilized in a diesel engine. bio alcohols have a high octane rating and can boost a diesel engine's power and efficiency to improve performance. But one drawback of employing bio alcohols in diesel engines is that they have a lower energy density than regular diesel fuel, which may lead to a shorter commuting distance. Despite this, the use of bio alcohols in diesel engines has the potential to aid in the shift to a transportation industry that is more environmentally friendly and low carbon [55].

It is possible to readily combine bio alcohols with conventional diesel fuel to produce a more environmentally friendly fuel combination when using them in diesel engines. For instance, it has been demonstrated that adding 20% ethanol to diesel fuel dramatically lowers emissions of dangerous pollutants such CO, HC, and particulate matter. compared to diesel fuel, bio alcohols have a greater cetane number, which might enhance the ignition and combustion processes in a diesel engine. This may result in the engine running more smoothly and effectively [55].

For usage in diesel engines, bio alcohols present a possible substitute for conventional diesel fuel. Although they have some drawbacks, such as a lower energy density, the advantages of lower emissions and better performance make them a good choice for the transportation industry. Future acceptance of bio alcohols as a fuel for diesel engines is projected to expand as long as this field of study and development is pursued. For usage in diesel engines, bio alcohols present a possible substitute for conventional diesel fuel. Although they have some drawbacks, such as a lower energy density, the advantages of lower emissions and better performance make them a good choice for the transportation industry. Future acceptance of bio alcohols as a fuel for diesel engines is projected to expand as long as this field of study and development is pursued [56].

3.4.3. Natural Gas

Due to its many advantages, natural gas has been employed as an alternative fuel in diesel engines more frequently in recent years. Low carbon emissions make natural gas a cleaner and more environmentally friendly fuel option, which is one of its key benefits. Additionally, because natural gas has a higher octane rating than gasoline, the engine may run at a greater compression ratio, enhancing efficiency and performance. Because it is produced domestically and in greater abundance, natural gas encourages energy security by lowering our dependency on foreign oil [57]. Although converting a diesel engine to run on natural gas may cost more up front, the long-term cost savings and environmental advantages make the investment worthwhile. natural gas has the potential to be an effective fuel substitute for diesel engines, resulting in a more environmentally friendly and effective transportation system. The advantage of using natural gas as an alternative fuel for diesel engines is that it is less expensive than either diesel or gasoline. Since natural gas is often less expensive than these other fuels, it is a more affordable choice for both individuals and businesses. Additionally, natural gas may be kept in storage for a longer period of time without degrading than gasoline. This is particularly helpful in emergency situations where gasoline availability can be restricted [58,59].

However, using natural gas as an alternative fuel for diesel engines comes with significant drawbacks. One problem is that there isn't enough infrastructure for natural gas filling stations, which makes it harder for drivers to get gasoline. The high pressure and temperature at which the fuel is stored and consumed may also necessitate greater maintenance on the fuel system for natural gas engines. Despite these difficulties, natural gas is a promising alternative fuel for diesel engines and a viable option for the transportation of the future [60].

3.4.4. Biogas

Due to its renewable and ecological attributes, biogas has drawn interest as a potential replacement fuel for diesel engines. Methane and CO_2 make up the majority of biogas, which is created when organic material, like sewage sludge or agricultural waste, is digested anaerobically. Biogas can drastically lower emissions of dangerous pollutants such particulate matter, NO_x, and CO when utilized in a diesel engine [61]. Biogas also has a higher octane number than diesel fuel, which may enhance engine efficiency and performance. Diesel engines can run on pure biogas or a mixture of biogas and diesel fuel. Biogas can help to lessen the engine's overall carbon emissions and dependence on fossil fuels when utilized as part of a blend. The use of biogas in diesel engines has the potential to be advantageous for both producers and consumers economically as well as environmentally. Local production of biogas can eliminate the need for fossil fuel distribution and transportation while also giving farmers and other producers who make biogas from their trash a means of income. In conclusion, biogas is a possible replacement fuel for diesel engines with the potential to lower emissions, increase sustainability, and bring financial benefits to both producers and consumers [61].

The requirement for specialized fuel handling and storage equipment could be a barrier to biogas's widespread use as a diesel engine fuel. In order to endure the high pressure and temperature needed for its usage in engines, biogas must be stored and delivered in specially engineered containers. A diesel engine's fuel system must also be changed to allow for the usage of biogas, which can be an expensive procedure. Despite these difficulties, the advantages of using biogas as a fuel far exceed them because it can greatly lessen the negative environmental effects of diesel engines and promote a more sustainable future. The variable nature of biogas as a fuel is another possible issue. Depending on the materials used in its production and the anaerobic digestion conditions, the quality and composition of biogas might change. Although studies have shown that biogas may be used effectively in diesel engines with the right alterations to the fuel system, this may have an impact on the engine's performance. Although there are now significant barriers preventing biogas from being widely used as a diesel engine fuel, such as the requirement for specialized fuel handling and storage equipment, the benefits could make it an attractive alternative fuel source in the future [61].

PART 4

MATERIAL AND METHOD

The materials used in the experimental study are listed below in order, along with their corresponding figures, tables, and charts.

4.1 Experimental Area

The Test Engine analyses were carried out in the Automotive Laboratory of the Faculty of Engineering at Karabuk University. The entire view of the experimental equipment is shown in Figure 4.1.

Figure 4.1. Shows the overall view of the experimental setup.

4.2. Experimental Engine

The LUTIAN brand 3GFF-ME model diesel generator was used for the combustion and analysis of test fuels. the diesel generator set used in the experiments is shown in Figure 4.2. The engine speed was maintained at 3000 rpm throughout the experiments. Different loads were applied to the diesel engine to examine the engine's performance under various load conditions. No modifications were made to the engine during the tests. In Table 4.1, the technical specifications of the diesel engine generator unit are given.

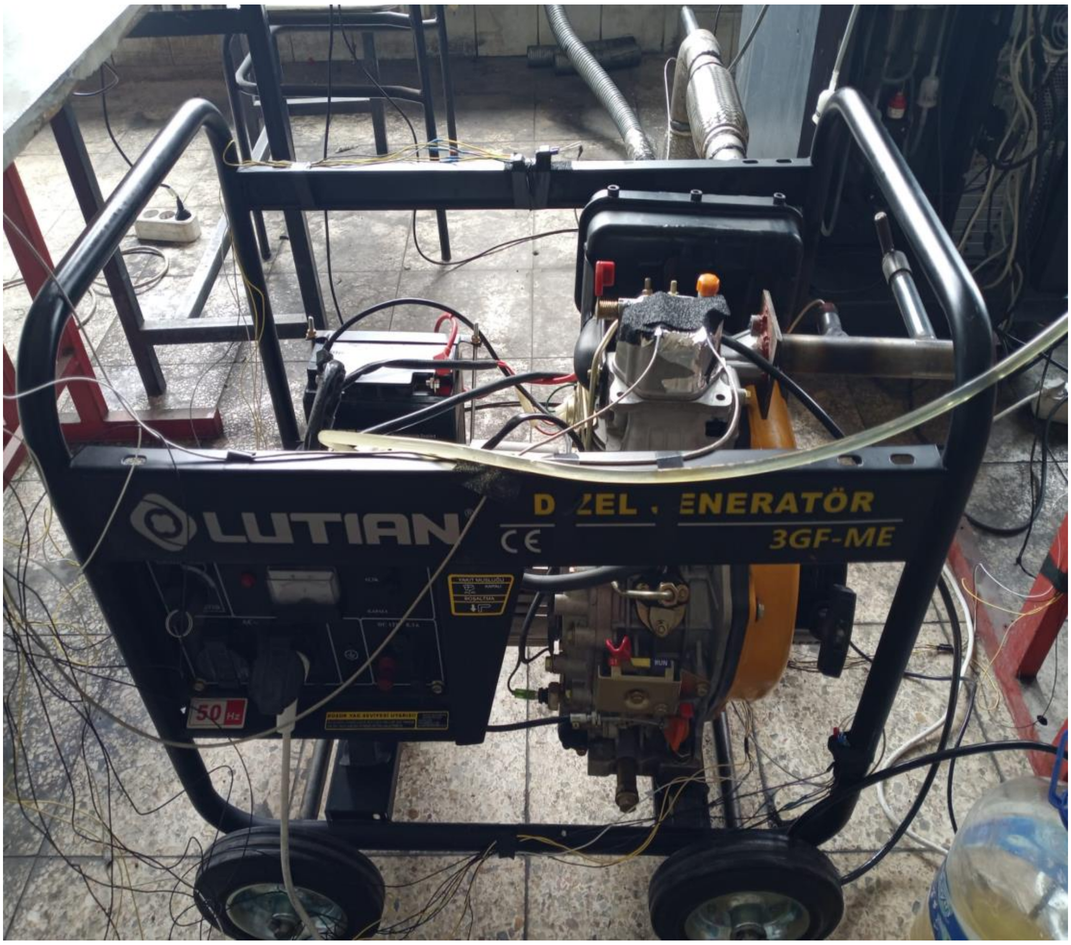

Figure 4.2. The engine were used in the experiment.

Table 4.1. The technical specifications of the engine

Maximum Output Power	3.2 KW
Continuous Output Power	2.9 KW

Frequency	50 (Hz)
Output Voltage	220 V
Engine Power	7 HP
Fuel Type	Diesel
Engine Type	178F
Fuel Tank	15 Lt.
Oil Capacity	1.10. lt.
Noise Level	80 dBA 7m
Dimensions	690x470x570mm
Weight	69 Kg

4.3. Engine Load Units

In experimental studies, in order to examine the combustion characteristics of different fuels used on the engine at different engine loads, an electrical load was connected to the generator coupled to the engine. This electrical loading of the motor was carried out using a system created by adding a loading unit consisting of 500, 1000, 1500, 2000, 2500 and 3000-watt halogen bulbs to the generator. It is made over a control panel that enables the change of load stages to be opened and closed with a switch and the computer system. A photograph of the loading set is given in Figure 4.3.

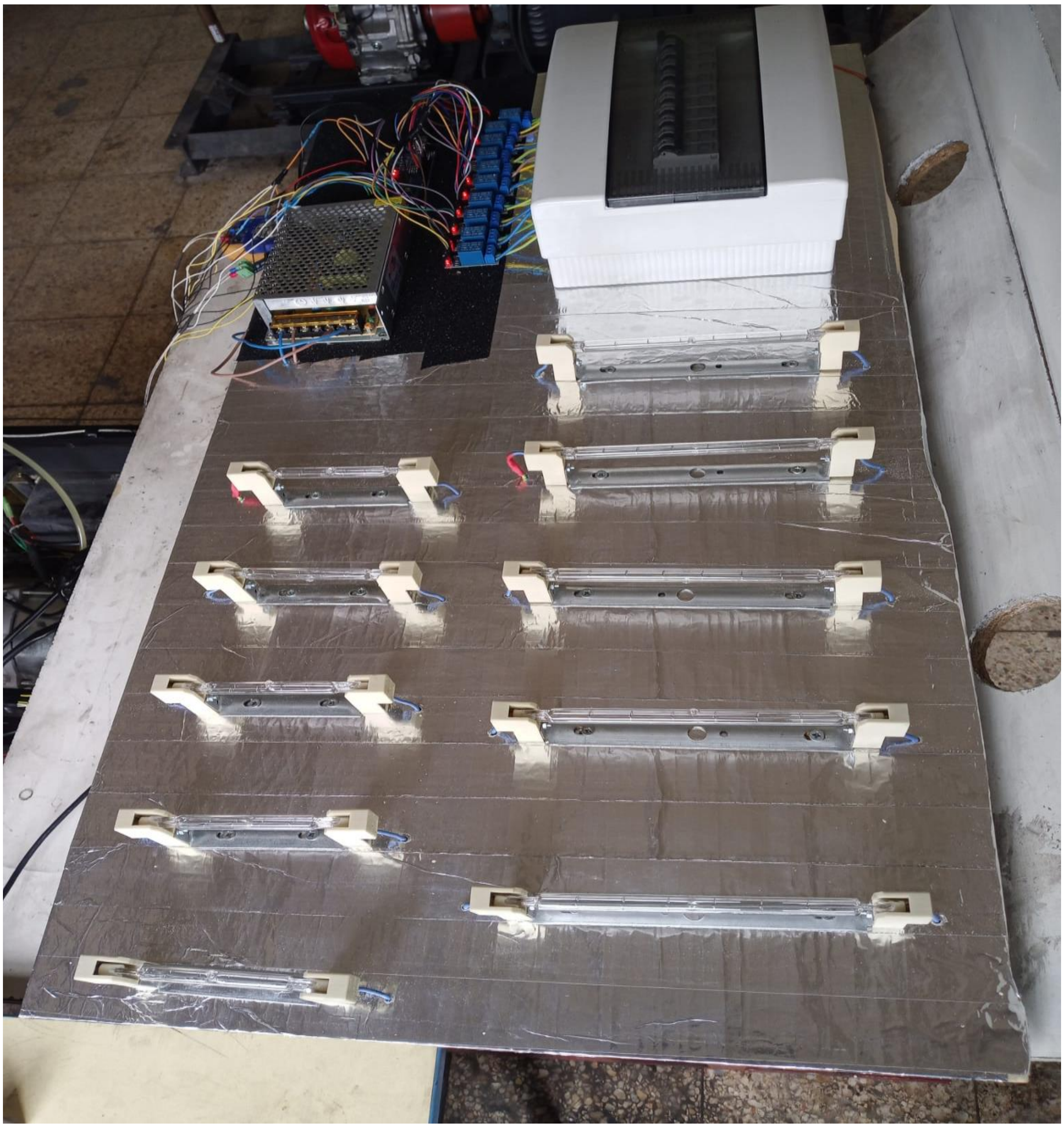

Figure 4.3. Loading unit

4.4. Experimental Fuel

In the experiment, pure diesel, SO and DEE blends will be used as test fuels. The diesel fuel, SO and DEE used in the experiments were obtained from commercial companies. The test fuels are given in Figure 4.4.

Tests have been conducted using diesel, SO biodiesel, and biodiesel- DEE blends. Diesel fuel and DEE have been mixed volumetrically. The DEE-biodiesel fuel blends obtained from Figure 4.4 are shown. The magnetic stirrer was used to mix the fuels in the mixture completely homogeneously given in Figure 4.7.

Figure 4.4. Testing fuels

The properties of the SO, DEE and diesel fuel, used in the experiments can be seen in Table 4.2.

Table 4.2. Properties of fuels.

Properties	**Diesel**	**Sesame Oil**	**DEE**	**Analysis Method**
Density at 15°C (kg/m3)	830.2	921.9	713	EN ISO 12185
Kinematic viscosity @ 40°C (mm²/s)	2.861	30.93	0.23	ASTM D 445
Lower calorific value (Kj/kg)	43015	38075	33900	D240
Cetane number	56.2	52.2	125	EN ISO 5165

4.5. Equipments Used In Experiments

4.5.1. Exhaust Emission Analyzer And Smoke Opacity Measurement Device

The BİLSA MOD 2210 WINXP-K brand exhaust gas analyzer given in Figure 4.5 was used to measure exhaust emissions during the experiments. The exhaust gas analyzer is capable of measuring CO, HC, CO_2, NO_x, O_2, smoke opacity, engine speed, and lambda (λ air excess coefficient) variables. In addition, smoke opacity measurements are determined for diesel engines. After the measurement, the values can be obtained as output. The technical specifications of the exhaust gas analysis device are given in Table 4.3. The emission measurement was performed with the BILSA emission measurement device and indicator adapter, as seen in Table 4.3. The smoke measurement device shows the measurement information on the display of the indicator adapter with a data cable, and the values can be obtained as output.

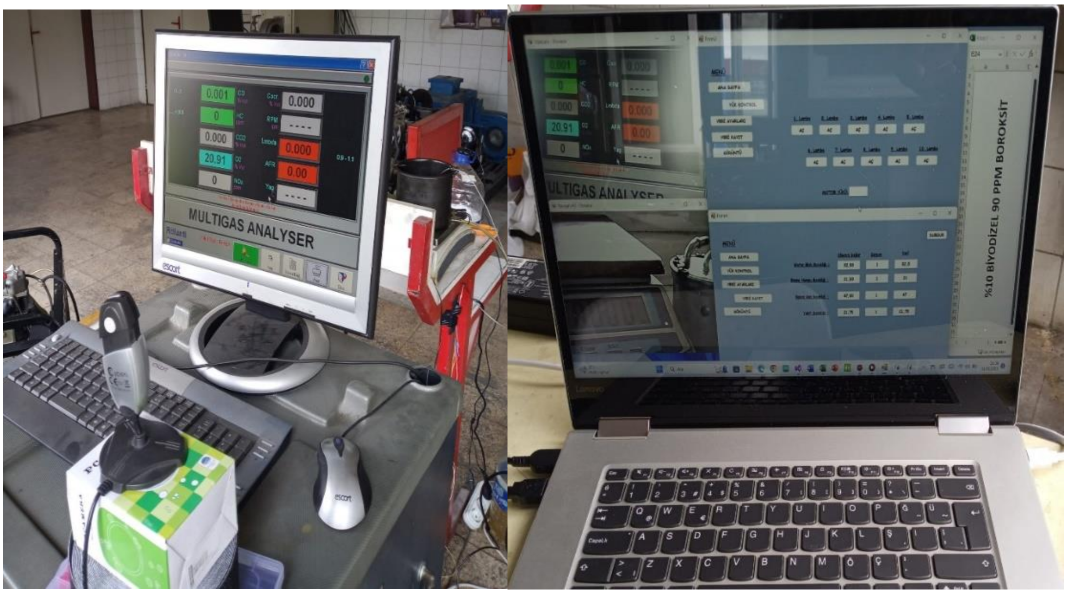

Figure 4.5. BİLSA brand exhaust gas analyzer.

Table 4.3. Exhaust emission device measurement ranges and accuracy.

No.	parameters	Measurement Range	Accuracy
1	HC	0-10000	1 ppm
2	NO_x	0-5000	1 ppm
3	CO	0-10(%)	0.01 %
4	CO_2	0-20(%)	0.01 %

4.5.2. Fuel Consumption Measuring Device

In the study conducted using SO and DEE, a mass-based method was used to measure fuel consumption. the use of different biodiesels at a determined ratio and in the determination of time-dependent fuel consumption in engine tests. Fuel consumption values were determined by recording fuel consumption based on time with the help of a stopwatch. The electronic precision balance used in the experiments can weigh with a precision of 1 g. The electronic precision balance used to determine fuel consumption is given in Figure 4.6.

Figure 4.6. Electronic Scales

4.5.3. Fuel Mixture Instrument

The WEIGHTLAB instrument’s magnetic stirrer was used to mix the fuels in the mixture completely homogeneously. The device can perform the tasks of heating and mixing simultaneously or separately. The device specifications include a closed heating tray with flame protection, fast heat-up, and durability. Temperature and mixing speed should be adjusted with two different buttons, which are shown in Figure 4.7. The specifications for the magnetic stirrer are given in Table 4.4.

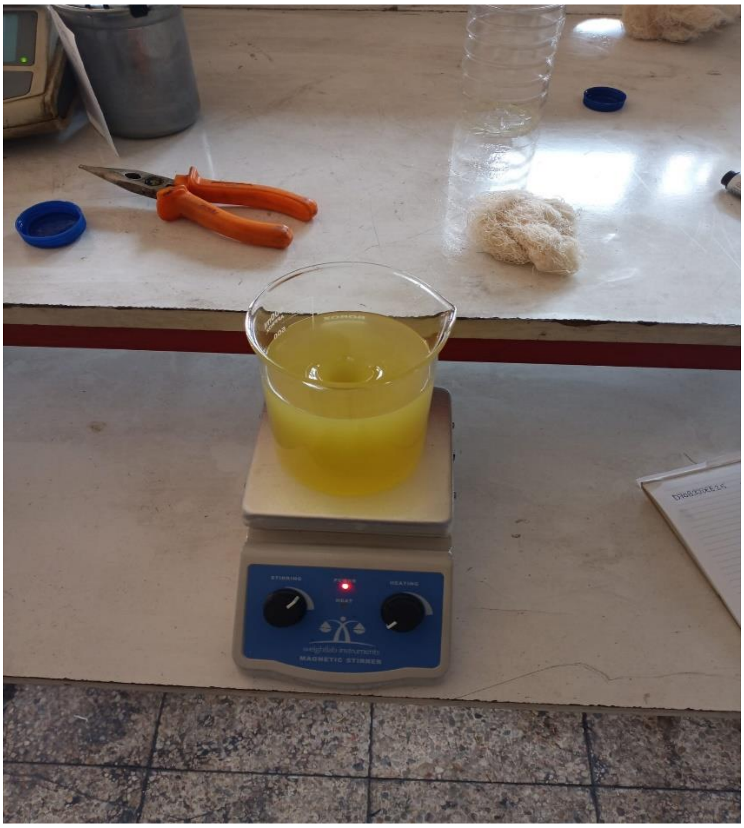

Figure 4.7. Analog Heated Magnetic Stirrer WF-MIA1.

Table 4.4. Specifications of analog heated magnetic stirrer WF-MIA1

Device Type	Analog, Table top
Heating Range	Ambient Temperature to 380°C
Mixing Speed Range	100 – 2000 Rpm
Maximum Mixing Capacity	2 litre (H20)
Table Dimensions	115 x 115 mm
Weight	1,9 kg
Device Dimensions	200 x 120 x 90 mm
Power	180 W

4.5.4. Stopwatch

When calculating the duration of time needed to consume fuel, we used a Coston ST-613D stopwatch. The digital stopwatch has a measuring accuracy of 0.01 seconds, making it ideal for timing events to the millisecond as shown in Figure 4.8.

Figure 4.8. Stopwatch.

4.5.5. Digital Thermometer

A digital thermometer TT T-ECHNI-C A930C, was used to measure the temperatures. It is connected to this engine block temperature sensor so that we can find the temperature of the engine separately or as the difference of two points. The thermometer is given in Figure 4.9.

Figure 4.9. Digital thermometer

4.6. Conducting the Experiments

4.6.1. Experimental Setup

The experimental setup consists of four parts. These are the fuel mixture, generator unit, load unit, and emission measurement unit.

Fuel mixture: The magnetic stirrer was used to mix (diesel fuel, SO, and DEE) in the mixture completely homogeneously and creating fuel blends known as (D100%, D70SO30, D70SO30DEE15, D70SO30DEE20, and D70SO30DEE25).

Generator unit: It consists of a testing engine, engine block temperature sensor, intake air temperature sensor, exhaust gas temperature sensor, and fuel temperature sensor.

Load unit: This electrical load system was created by adding a loading unit consisting of 500, 1000, 1500, 2000, 2500, and 3000-watt halogen bulbs to the generator.

Emission measurement unit: It consists of an exhaust emission measurement device and a computer.

4.6.2. Engine Experiments

Engine maintenance and adjustments were carried out before the engine testing experiments began. After the engine was brought to an operating temperature of 50^{o}C.

The engine testing experiments were initially conducted using pure diesel fuel (D100) and biodiesel fuel (D70SO30). The tests continued by adding DEE to biodiesel in different proportions. DEE was added to biodiesel at volumetric ratios of 15%, 20%, and 25%, creating fuel blends known as (D100%, D70SO30, D70SO30DEE15, D70SO30DEE20, and D70SO30DEE25). The loading of the engine was performed by applying a load to the generator. The engine was loaded using a unit consisting of 500, 1000, 1500, 2000, 2500, and 3000-watt halogen bulbs. The generator operated at a constant speed (3000 rpm), allowing the engine tests to be conducted at a steady speed under varying loads. The test engine was tested with standard IP (200 bar) using diesel, SO, and specific ratios of biodiesel-DEE blends

(DEE15, DEE20, and DEE25) at different engine loads (500, 1000, 1500, 2000, 2500, and 3000 watts). After each test stage, after the engine reached a steady state of operation, BSFC, CO, HC, CO_2 , and NO_x emissions were recorded. BSFC (g/kWh) were measured and calculated.

PART 5

RESULTS AND DISCUSSION

5. RSM Explanation

RSM is in engineering applications used to reduce the number of experiments and to save both time and money. Sometimes engineering applications require a lot of experimentation. These can be tedious and time-consuming. RSM is one of the applications used to reduce or minimize experiment, and it has proven itself in this regard. As we have our experiment's data in the Excel file, We have 3 factors and 5 responses that are affected by these 3 factors. We will make an RSM application using this set of experiments by using the Minitab program.

Select the Stat - DoE - Response Surface, - Create Response Surface Design options, respectively.

You will see other options, which will be in passive mode, not active. A new interface appears when we click on the Create Response Surface Design option. There are two different options available. Here, the design type is asked. -Central Composite, -Box -Behnken.

The Central Composite can be used for factors 2-10, while Box-Behnken can be used for factors 3-10. As we have the 3 factors in our Excel file. Therefore, both design types here are suitable for us. we will choose a Central Composite design and make an application. After choosing the design type, we choose the number of factors. We have 3 factors: SO %, DEE %, and engine load. When we select the display of available design types, we see a module that shows how many experiments each design type needs. According to the central composite design, 20 experiments are required for 3 factors, so I chose 20. It was designed according to 20 experiments.Then, we select Stat - Design of Experiment - Response Surface - Analyze Response Surface Design, respectively. Now our model is run to make predictions, and the Response Surface Regression sheet open.

The important factors in the Response Surface Regression sheet are:

- Model summary
- Analysis of variance
- Regression equation in uncoded units
- Pareto chart of the standardized effects

The closer the R^2 value found in the model summary is to 100% or 1, the higher the model's success.

In the (ANOVA) Model results, there are 3 important columns in the ANOVA table. percentage Contribution, F-value, and P-value. there values indicate that the effect of a p-value factor higher than 0.05 is insignificant. The factor with a low p-value and a high contribution should have a large f-value and will be the most effective factor.
A regression equation is used to compare the optimization value of RSM with the experimental value and to find how close the values are.

We also had a Pareto chart. It shows how influential these factors are. As you will see in this study, the model has derived a value indicated by a vertical red dashed line. Those to the left of this line are ineffective, and those to the right are effective. and an ANOVA should support these results.

This experiment will explain four main results: ANOVA results, the Pareto chart, Surface Plot Three-dimensional graphs, and optimization application with RSM.

Table 5.1. The experimental values which were used for Minitab RSM.

Sesame Oil (%)	**DEE (mL)**	**Engine Load**	**CO (%)**	**HC (ppm)**	**CO_2 (%)**	**NO_X (ppm)**	**BSFC (g/kWh)**

		(W)					
0	0	500	0.105	18.00	2.70	180.67	773.55
0	0	1500	0.076	46.67	3.85	269.33	360.00
0	0	2000	0.061	49.67	4.41	335.13	311.69
0	0	3000	0.081	81.33	6.78	545.50	320.00
30	0	500	0.076	7.00	3.72	271.33	855.29
30	0	1500	0.039	27.00	5.26	451.00	533.33
30	0	2500	0.042	42.00	7.24	693.67	366.00
30	0	3000	0.057	48.67	8.65	780.67	382.35
30	25	1000	0.095	42.00	3.19	183.67	1198.75
30	25	2000	0.069	63.33	4.64	302.87	1151.82
30	25	2500	0.071	77.33	5.22	395.83	1123.13
30	25	3000	0.086	116.00	5.92	484.50	1085.32
30	20	1000	0.081	20.00	4.04	315.67	1164.05
30	20	2000	0.053	39.00	5.61	550.67	1080.66
30	20	2500	0.051	49.67	6.48	654.00	1081.19
30	20	3000	0.059	62.00	7.64	729.33	1044.10
30	15	1000	0.047	14.33	4.54	380.00	1071.88
30	15	1500	0.038	18.67	5.27	496.33	1050.59
30	15	2500	0.032	32.67	7.37	761.33	998.40
30	15	3000	0.045	39.33	8.74	860.67	964.06

5.1. Impact of SO Ratio, DEE Ratio, and Load on Engine Performance Response.

5.1.2. Brake Specific Fuel Consumption (BSFC)

In Figure 5.1 show, the Consumption of biodiesel specific to braking and the effect of engine in which operating parameters on BSFC are expressed as a percentage contribution, Table 5.1 presents the ANOVA results for BSFC. Figure 5.2 shows the 3D diagrams for BSFC at various engine loads, DEE ratios, and SO ratios.

The DEE (43.01%) and SO ratio (39.34%) have the greatest impact, as shown by ANOVA in Figure.5.1 and Table 5.2. The ratio of SO * engine load (0.25%) has the least impact on BSFC. Clearly, Figure.5.1 demonstrates a significant relationship between BSFC and the SO and DEE ratios. BSFC shows the amount of fuel consumed per unit of power [54]. The thermal value of the fuel is one factor affecting the BSFC.

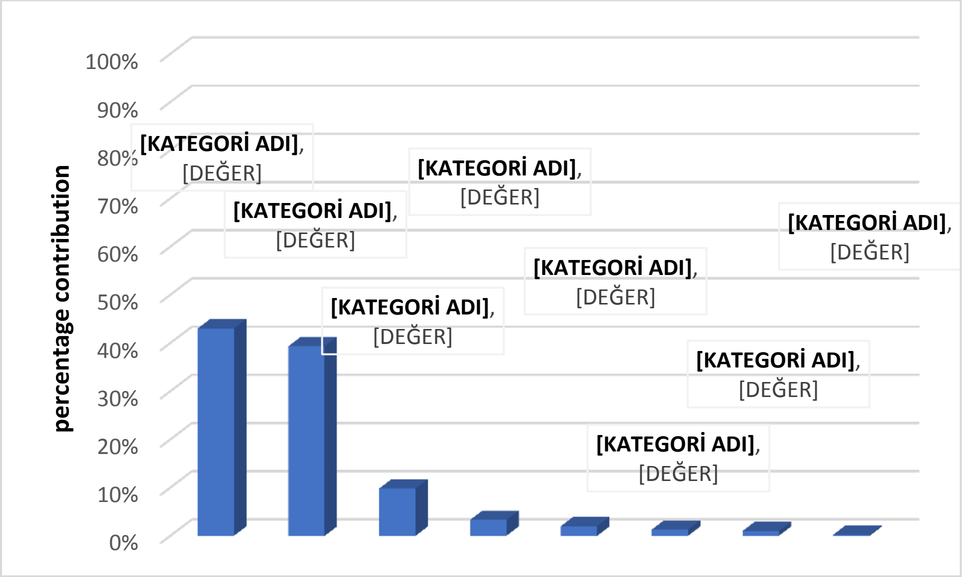

Figure 5.1. Impact of engine operating percentage contribution on BSFC.

In terms of linear coefficients, the DEE, biodiesel SO ratio, and engine load p-values in Table 5.2 are less than 0.05. Regarding terms of second-order coefficients, however, the value of p for engine load and DEE is again less than 0.05. The interaction p-value between SO percentage and engine load is greater than 0.05, and the error in this RSM is 1.28%. This indicates that nearly all factors have a greater impact on BSFC optimization.

Table 5.2. ANOVA for BSFC

Analysis of Variance for BSFC

Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	7	2052961	98.72%	2052961	293280	131.81	0.000
Linear	3	1916874	92.17%	1166326	388775	174.73	0.000
Sesame Oil (%)	1	818087	**39.34%**	22358	22358	10.05	**0.008**

DEE (mL)	1	894372	**43.01%**	726535	726535	326.52	**0.000**
Engine Load (W)	1	204415	**9.83%**	106114	106114	47.69	**0.000**
Square	2	110133	5.30%	87785	43893	19.73	0.000
DEE (mL)*DEE (mL)	1	41717	**2.01%**	51763	51763	23.26	**0.000**
Engine Load (W)*Engine Load (W)	1	68416	**3.29%**	39810	39810	17.89	**0.001**
2-Way Interaction	2	25955	1.25%	25955	12977	5.83	0.017
Sesame Oil (%)*Engine Load (W)	1	5219	**0.25%**	120	120	0.05	0.820
DEE (mL)*Engine Load (W)	1	20736	**1.00%**	20736	20736	9.32	0.010
Error	12	26701	1.28%	26701	2225		
Total	19	2079662	100.00%				

When discussing the efficiency of engines in terms of fuel consumption, BSFC is an important consideration. Figure 5.2 shows the combined impact on BSFC of the ratio of SO, the ratio of diesel exhaust fluid, and the load on the engine. As the load on the engine increases, there is a corresponding rise in the temperature of combustion within the cylinder. This increase in temperature leads to an improvement in the fuel combustion process and a reduction in the chance of incomplete combustion; therefore, the BSFC gradually decreases. Conversely, the amount of BSFC has increased significantly as the proportion of DEE, which has a lower heating value than diesel fuel, has increased. Because more fuel are required to produce the same amount of output energy. Although the change in the SO ratio did not significantly impact BSFC, the increase in the SO ratio led to a slight rise in BSFC. When the load increases, the BSFC first starts decreasing to some range and then increases with increasing the load.

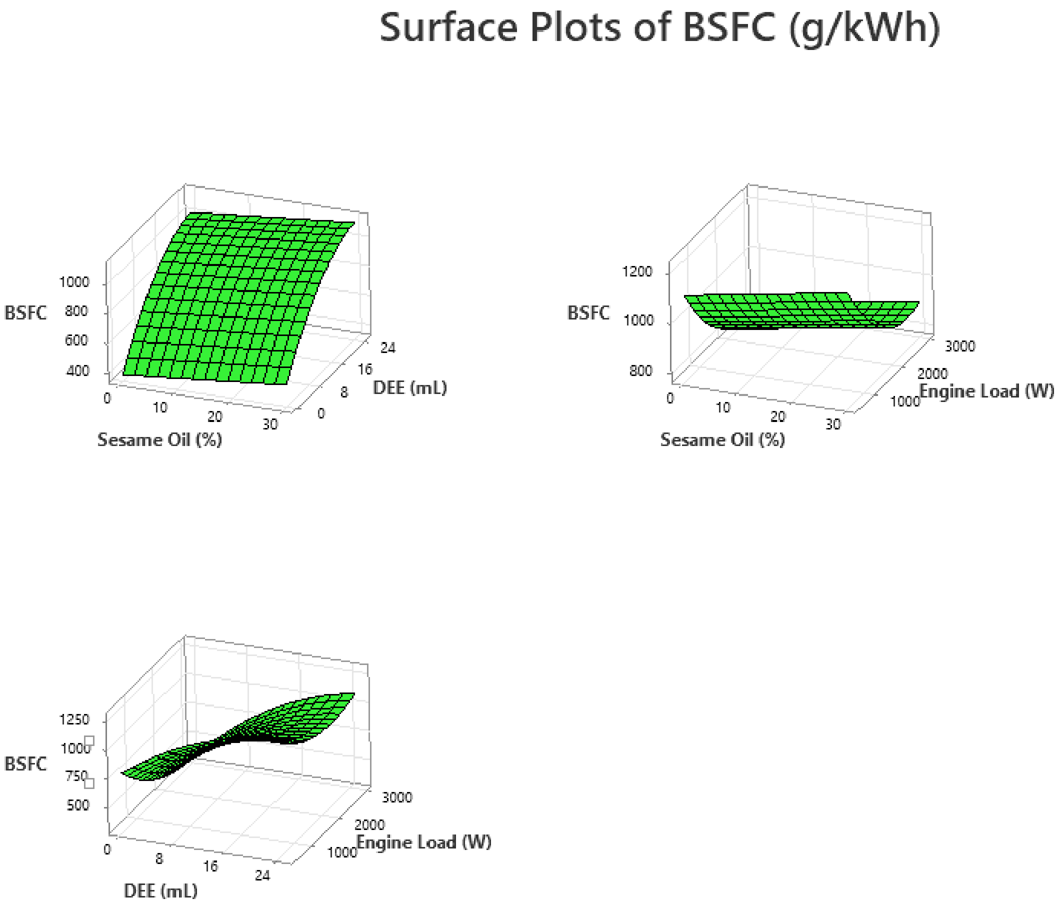

Figure 5.2. 3D Surface plots for BFSC at different SO (%), DEE ratio, and load.

Pareto charts were better used to show how big and important the impacts of the factors are. The Pareto chart represents the absolute values of the standard impacts, from greatest to least important of the factors. A reference line is also drawn on the graph to show which effects are statistically important. Bars that cross the reference line on a Pareto chart are statistically important. Figure 5.3 shows Pareto charts for the BSFC. In the BSFC Pareto chart, the bars representing variables B, C, BB, CC, A, and BC cross the 2.18-point reference line. By the extant model terms of Pareto chart of the standardized effects, these variables are statistically important.

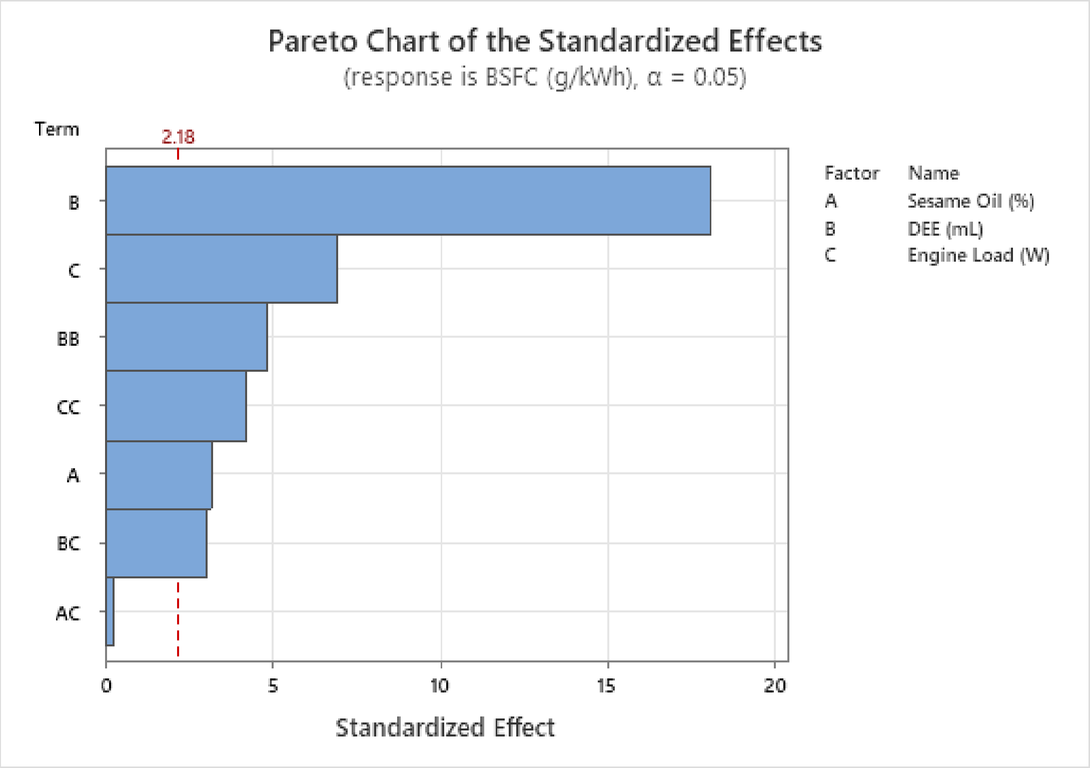

Figure 5.3. Pareto Chart of engine performance parameters.

5.2. Impact of SO Ratio, DEE Ratio, and Load Interaction on Engine Emission Response

5.2.1. Carbon Monoxide (CO) Emission

When the cylinder does not have enough time for combustion and does not have enough oxygen, CO emissions occur [54]. Figures 5.4 show the influence that different engine operating parameters have on CO emission as well as surface plots for CO emission based on those varied engine operating parameters. The results of the ANOVA for CO emission are presented in Table 5.3. Fig. 5.5. 3D Surface plots for CO at various loads, DEE ratios, and SO ratios.

The square DEE has the greatest impact (27.60%) on the CO emission of the engine, as shown by ANOVA Table.5.3 and Fig.5.4, followed by the square load (23.70%) and SO% (19.50%). The SO%*Load value of 0.01% has the least impact on CO emissions.

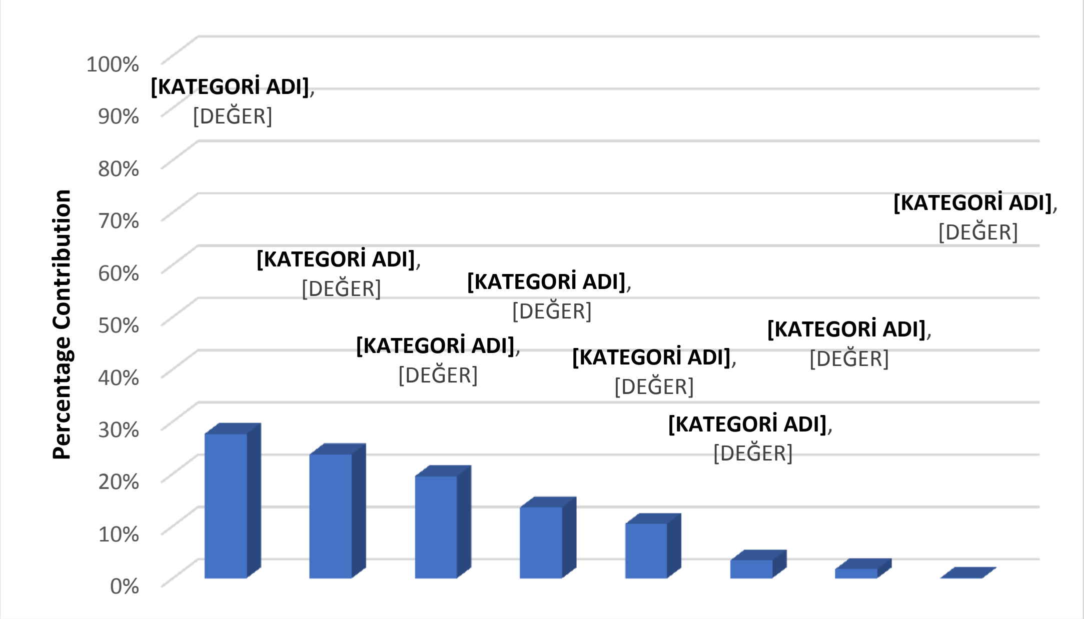

Figure 5.4. Impact of engine operating percentage contribution on CO.

In terms of linear coefficients, the p-values of DEE, SO ratio, and engine load are all less than 0.05 in Table 5.3. The p-values for engine load and DEE are once again both less than 0.05 in terms of second-order coefficients. as well as the error that led to 3.41% in this RSM. This indicates that the majority of the contributing components have a bigger influence on CO emissions.

Table 5.3. ANOVA for CO

Analysis of Variance for CO

Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	7	0.007661	96.59%	0.007661	0.001094	48.51	0.000
Linear	3	0.003450	43.49%	0.003659	0.001220	54.06	0.000
Sesame Oil (%)	1	0.001547	**19.50%**	0.001658	0.001658	73.48	0.000
DEE (mL)	1	0.001077	**13.57%**	0.002731	0.002731	121.04	0.000
Engine Load (W)	1	0.000826	**10.41%**	0.001248	0.001248	55.34	0.000
Square	2	0.004068	51.29%	0.004171	0.002085	92.44	0.000
DEE (mL)*DEE (mL)	1	0.002189	**27.60%**	0.001996	0.001996	88.48	0.000
Engine Load (W)*Engine Load (W)	1	0.001879	**23.70%**	0.001993	0.001993	88.35	0.000

2-Way Interaction	2	0.000143	1.80%	0.000143	0.000072	3.17	0.078
Sesame Oil (%)*Engine Load (W)	1	0.000005	**0.06%**	0.000017	0.000017	0.74	0.408
DEE (mL)*Engine Load (W)	1	0.000138	**1.74%**	0.000138	0.000138	6.13	0.029
Error	12	0.000271	**3.41%**	0.000271	0.000023		
Total	19	0.007932	100.00%				

Figure 5.5 depicts the combined effect of SO percentage, DEE percentage, and load on CO emissions. As the increased in the ratio of DEE in the fuel mixture, CO emissions initially decreased and then began to rise again after a certain ratio range [55]. CO emissions are the result of incomplete combustion. Oxygen deficiency and low cylinder temperature are the primary causes of CO emissions [54]. Since DEE has a high cetane number and evaporation heat value, combining it with SO biodiesel to a certain extent enhanced combustion and ensured complete combustion. Due to the extremely high evaporation heat value of the mixture, thus incomplete combustion occurred with increased mixing, and the CO emissions rise again. As CO emissions continue to rise.

Due to the formation of a rich mixture in the cylinder during moderate loads, when the SO ratio increases, CO emissions decrease. However, CO emissions continue to decrease when the load increases, and DEE ratio, CO emissions start to increase after a certain amount of time, when the engine load and DEE ratio increases.

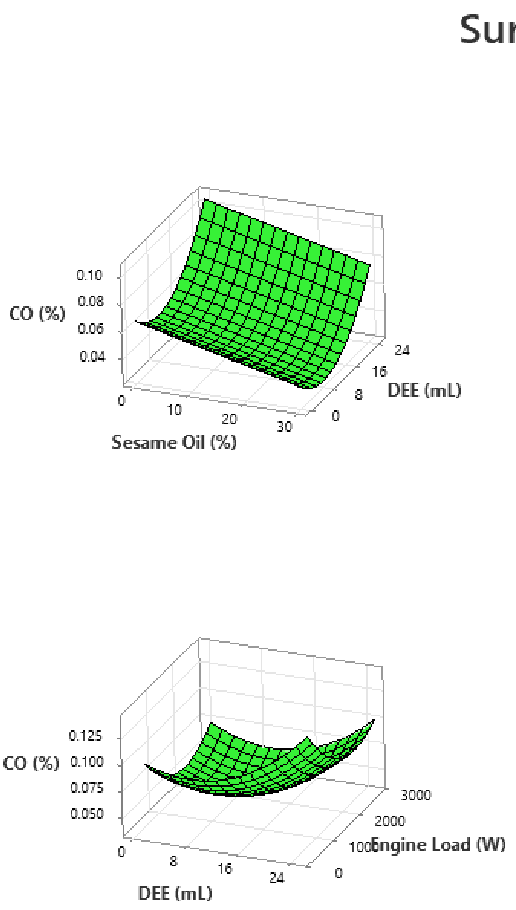

Figure 5.5. 3D Surface plots for CO at different SO (%) , DEE ratio and load.

The Pareto charts for CO are shown in Figure 5.6. The bars representing the variables B, BB, CC, A, C, and BC on the CO Pareto chart cross the reference line at 2.18. It means that these factors are statistically significant when considering the terms of the present model.

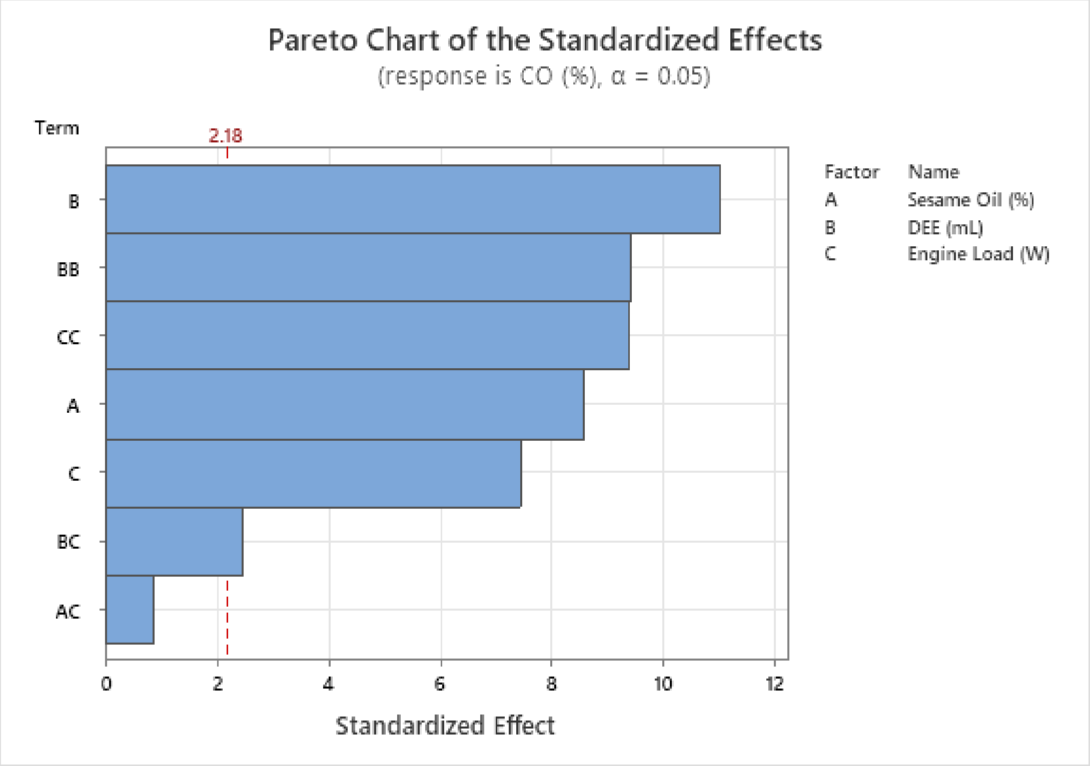

Figure 5.6. Pareto Chart of engine performance parameters.

5.2.2. Hydrocarbon (HC) Emission

Incomplete combustion in the cylinder is what causes HC emission, which happens when there is not enough oxygen or air [54]. The HC emission ANOVA results are shown in Table 5.4. Figures 5.7 and 5.8 show the effect of engine operating parameters on HC emission in terms of percentage contribution and three-dimensional graphs for various engine operating parameters.

ANOVA Table 5.4 and Figure 5.7 show that the amount of engine load has the greatest impact (47.83%) on the amount of HC emissions produced by the engine. This is followed by the square of DEE (21.96%), and then DEE (21.19%). The lowest effect that engine load has on HC emission is the square of the engine load which is 0.34%. The production of HC emissions is caused by the incomplete combustion at the engine.

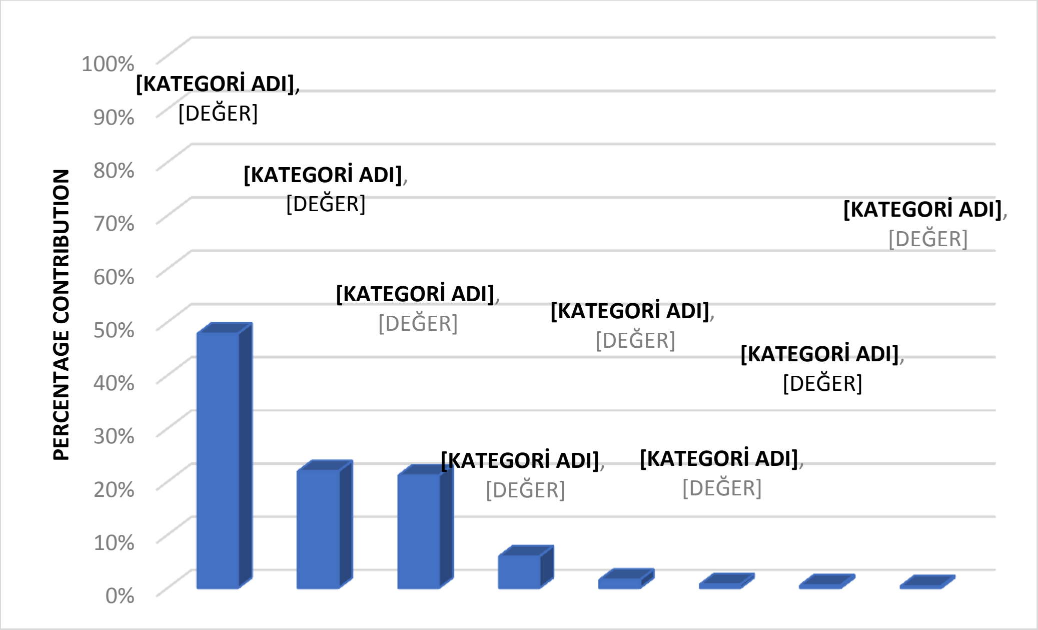

Figure 5.7. Impact of engine operating percentage contribution on HC.

In the ANOVA model for HC found in Table 5.4, The DEE, SO ratio, and engine load all have p-values less than 0.05, which is considered to be statistically important. On the other hand, when considering second-order coefficients, the p value for engine load is greater than 0.05, whereas the p-value for DEE is once again lower than 0.05. The error in this RSM, which show as to 5.95%. This indicates that linear parameters have a stronger influence on the emission of HC.

Table 5.4. ANOVA for HC

Analysis of Variance for HC

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	7	12305.7	94.05%	12305.7	1757.95	27.11	0.000
Linear	3	9117.6	69.69%	8472.6	2824.21	43.56	0.000
Sesame Oil (%)	1	87.5	**0.67%**	753.5	753.52	11.62	0.005
DEE (mL)	1	2772.1	**21.19%**	2253.3	2253.28	34.75	0.000
Engine Load (W)	1	6258.1	**47.83%**	4218.6	4218.62	65.07	0.000
Square	2	2917.9	22.30%	2749.1	1374.57	21.20	0.000
DEE (mL)*DEE (mL)	1	2873.0	**21.96%**	2708.6	2708.60	41.78	0.000
Engine Load (W)*Engine Load (W)	1	44.9	**0.34%**	16.8	16.76	0.26	0.620
2-Way Interaction	2	270.1	2.06%	270.1	135.07	2.08	0.167

Sesame Oil (%)*Engine Load (W)	1	67.4	**0.52%**	204.7	204.67	3.16	0.101
DEE (mL)*Engine Load (W)	1	202.8	**1.55%**	202.8	202.75	3.13	0.102
Error	12	778.0	**5.95%**	778.0	64.83		
Total	19	13083.7	100.00%				

Figure 5.8 shows how the percentage of SO, the percentage of DEE, and the load all affect HC emissions. As the percentage of DEE in the fuel mix increases, HC emissions decreases, but then they started to go up again after a certain range. HC emissions are a product of incomplete combustion [54]. Since DEE has a high cetane number and evaporation latent heat, mixing it with biodiesel can help it burn better and make sure it burns completely. But when the mixture was stirred more, partial combustion happened because the heat of evaporation was so high. Most of the HC emissions come from the flame dying out or going out at the walls of the combustion chamber [55].

As the DEE ratio increases, the HC starts to decrease due to the rich mixtures of the fuel, but it increases again with the increase in the DEE ratio. This increase occurs in HC because of the high evaporating value of the DEE and due to incomplete combustion in the cylinder. With increasing SO percentage, the HC emission decreases slowly, and with increasing engine load, the HC emission starts increasing.

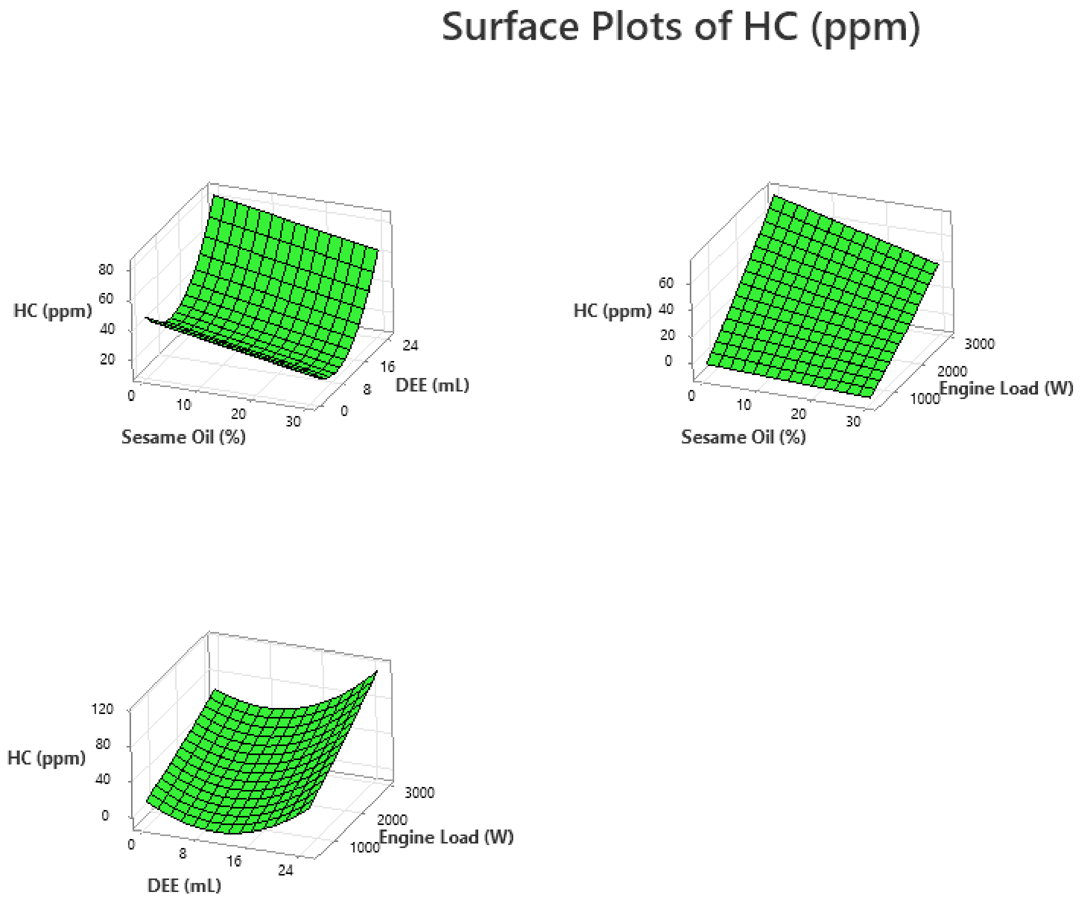

Figure 5.8. 3D Surface plots for HC at different SO (%), DEE ratio and load.

The Pareto charts for HC are presented in Figure 5.9. The bars C, BB, B, and A on the HC Pareto chart cross the reference line, which is 2.18, which is an interesting finding. This indicates that the working parameter mentioned above has a significant effect on HC emission, whilst the remaining factors have no influence on HC emission.

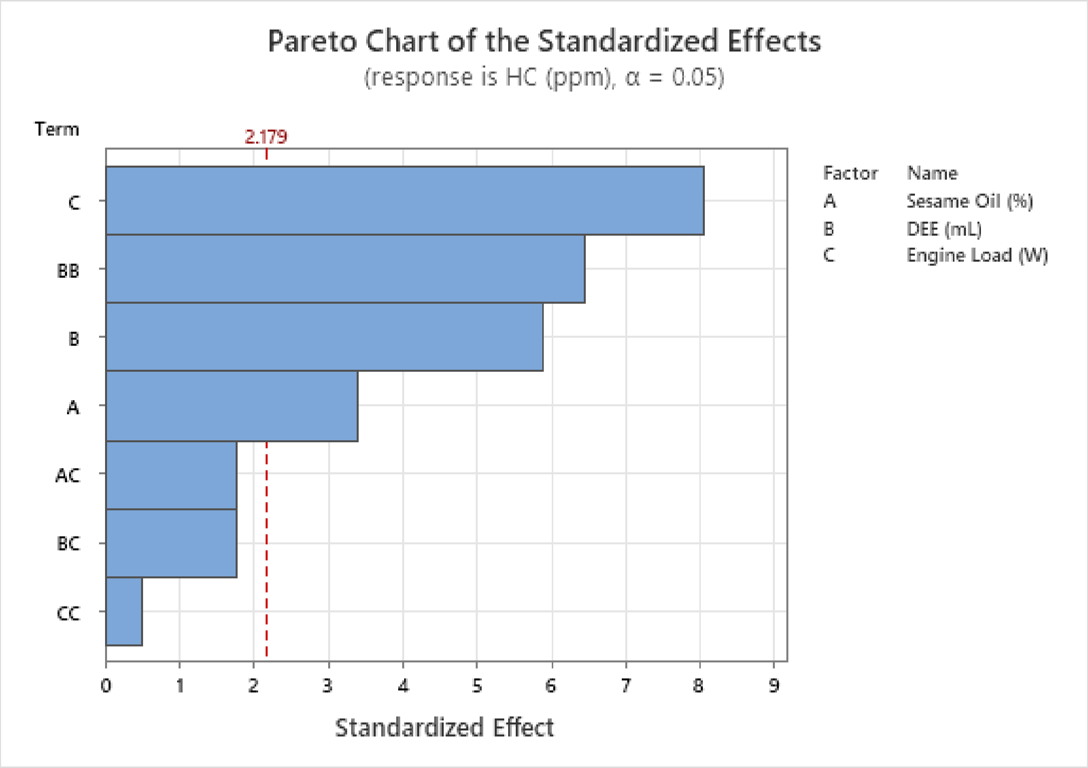

Figure 5.9. Pareto Chart of engine performance parameters.

5.2.3. Carbon Dioxide (CO_2) Emission

The efficient burning of fuel in diesel engines produces the production of CO_2 emissions, which are caused by the high temperature of the combustion process. CO_2 emissions are increased when sufficient oxygen is present for full combustion [54]. Table 5.5 presents the findings of the ANOVA performed on the CO_2 emission data. Figure 5.10 illustrates how engine operating parameters influence CO_2 emissions, and Figure 5.11 depicts surface plots of CO_2 emissions for a variety of engine operating parameter combinations.

Table 5.5 shows the findings of the ANOVA performed on the CO_2 emission data. The ANOVA Table 5.5 and Figure 5.10 shows that the engine load has the greatest influence (74.27%) on the CO_2 emissions produced by the engine, with the ratio of SO coming in second (10.91%). The effect of the SO percentage multiplied by the engine load (0.17%) is the least effect on CO_2 emission.

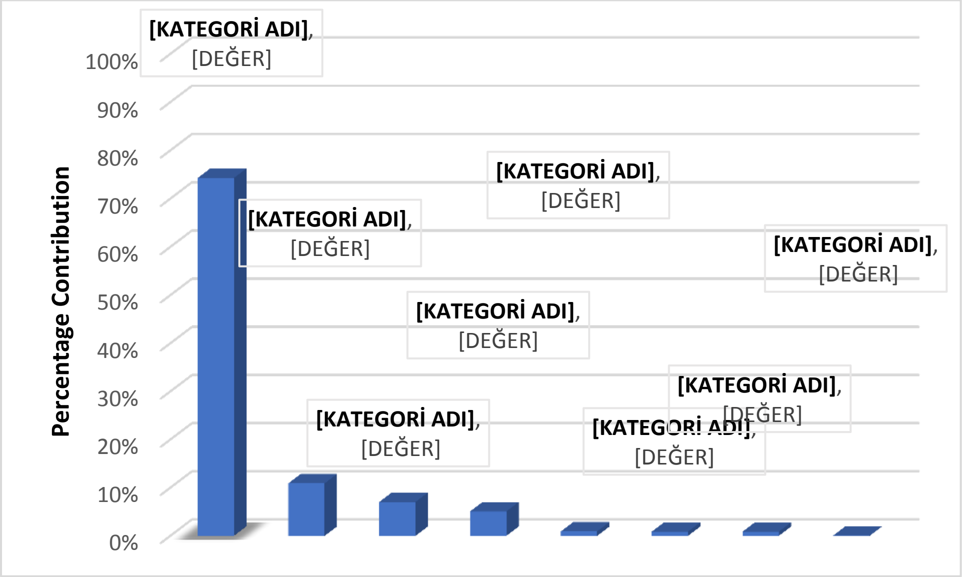

Figure 5.10. Impact of engine operating percentage contribution on CO_2.

In the ANOVA model for C02 shown in Table 5.5, The DEE, SO ratio, and engine load value all have p-values less than 0.05, and the p-values of engine Load and DEE are again less than 0.05 when measured in terms of second order coefficients. The error in this RSM was 0.86%. This indicates that each of the factors contributing has a more significant impact on CO_2 emissions.

Table 5.5. ANOVA for CO_2

Analysis of Variance

Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	7	57.9816	99.14%	57.9816	8.2831	197.89	0.000
Linear	3	52.7829	90.25%	19.8939	6.6313	158.43	0.000
Sesame Oil (%)	1	6.3819	**10.91%**	4.3744	4.3744	104.51	0.000
DEE (mL)	1	2.9636	**5.07%**	5.1273	5.1273	122.49	0.000
Engine Load (W)	1	43.4374	**74.27%**	15.8763	15.8763	379.29	0.000
Square	2	4.6131	7.89%	4.6131	2.3065	55.10	0.000
DEE (mL)*DEE (mL)	1	4.1097	**7.03%**	4.0631	4.0631	97.07	0.000
Engine Load (W)*Engine Load (W)	1	0.5034	**0.86%**	0.6867	0.6867	16.41	0.002
2-Way Interaction	2	0.5855	1.00%	0.5855	0.2928	6.99	0.010
Sesame Oil (%)*Engine Load (W)	1	0.0447	**0.08%**	0.3089	0.3089	7.38	0.019
DEE (mL)*Engine Load (W)	1	0.5408	**0.92%**	0.5408	0.5408	12.92	0.004
Error	12	0.5023	**0.86%**	0.5023	0.0419		
Total	19	58.4839	100.00%				

CO_2 is the primary contributor to the generation of greenhouse gases as well as the overall warming of our globe. As can be seen in Figure 5.11, as the load increases, so does the amount of CO_2 that is produced. In addition to this, because the amount of oxygen that is present in both SO and DEE helps oxygen-fuel reactions in the engine cylinder and the use of SO is advantageous.

According to the graph, with an increase in the DEE ratio, CO_2 also starts to increase up to its maximum, and with an increase in the DEE ratio, CO_2 starts to decrease. its mean, with a high DEE ratio, the CO_2 emission decreases. With the SO ratio increasing, CO_2 increases slowly. and CO_2 increases due to increases in engine load. If the engine load is maximum, the CO_2 will be maximum.

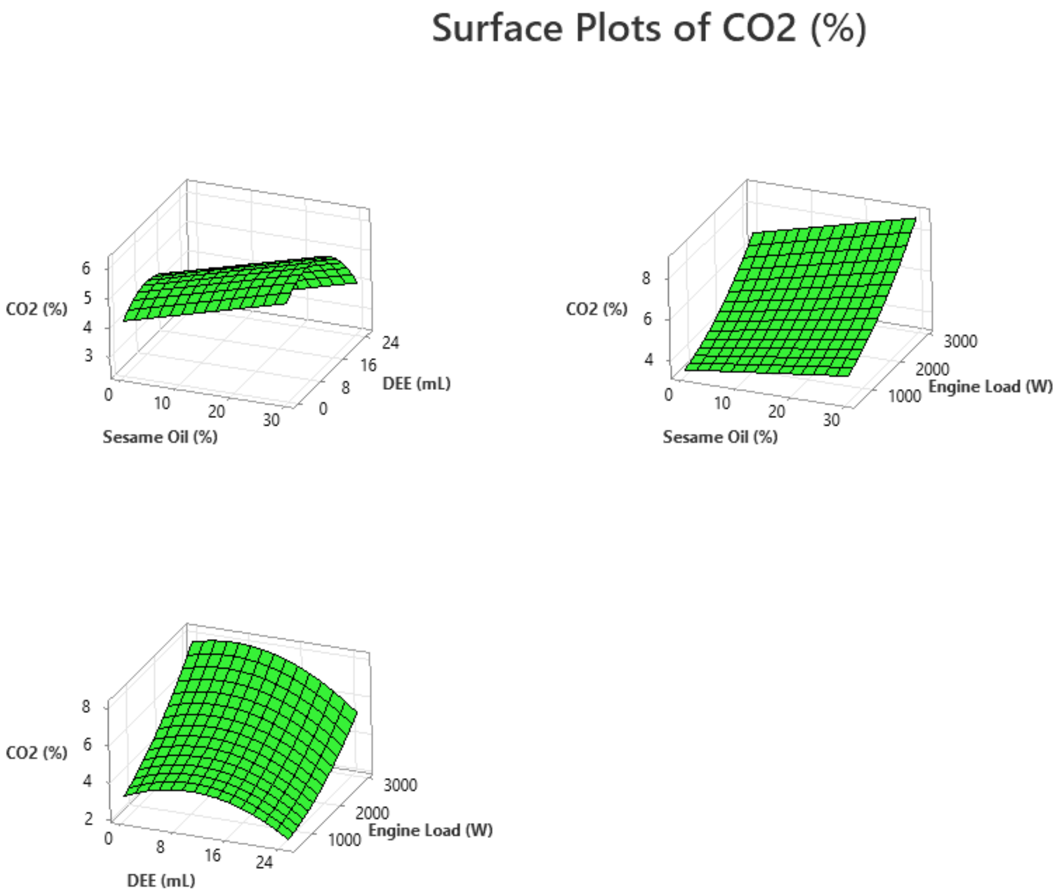

Figure 5.11. 3D Surface plots for CO_2 at different SO (%), DEE ratio and load.

The Pareto charts for CO_2 are shown in Figure 5.12. It's interesting to note that on the Pareto chart for CO_2, bars C, B, A, BB, CC, BC, and AC all pass the reference line that's set at 2.18. This indicates that all of the functioning parameters has a significant influence on the amount of CO_2 emitted.

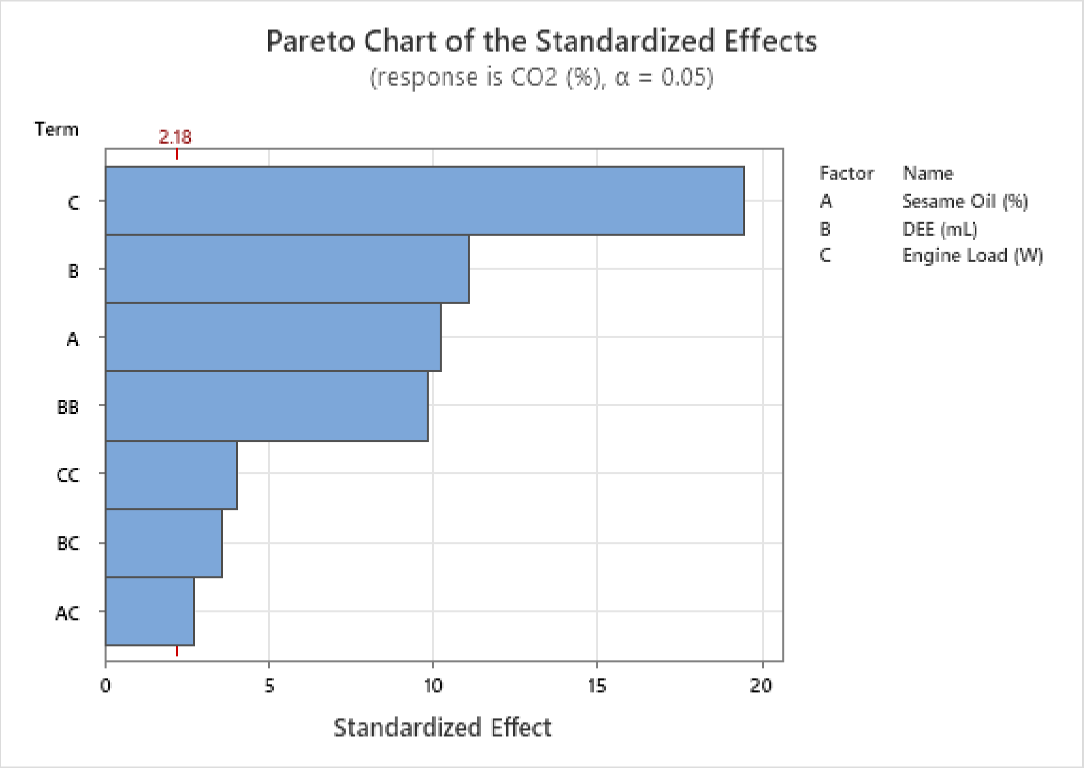

Figure 5.12. Pareto Chart of engine performance parameters.

5.2.4. Nitrogen Oxides (NO_x) Emission

Figure 5.13 shows how the percentage of SO, the DEE ratio, and the load all have an effect on NO_x emissions. The amount of oxygen in the fuel and the high temperatures inside the cylinder are the two most important factors in NO_x generation [26]. Incomplete combustion takes place as a result of a reduction in the amount of time that the air and fuel combination is exposed to one another [54]. This leads to an increase in the amount of emissions that are emitted. The results of the ANOVA for NO_x are shown in Table 5.6, and Figure 5.13 shows engine operating parameters and the impact on the NO_x emission as expressed as a percentage contribution. Figure 5.14 presents the NO_x 3D graphs for a variety of engine loads, DEE to SO ratios, and other variables.

Table 5.6's ANOVA reveals that the amount of engine load has the greatest influence on the amount of NO_x that is produced by the engine. This is followed by the square of the DEE ratio (15.96%) and the ratio of SO (13.54%). The DEE multiplied by the engine load has the smallest impact (0.33%) on NO_x emissions. NO_x is produced due to the temperatures of the cylinders, particularly at temperatures higher than 1500 °C [10].

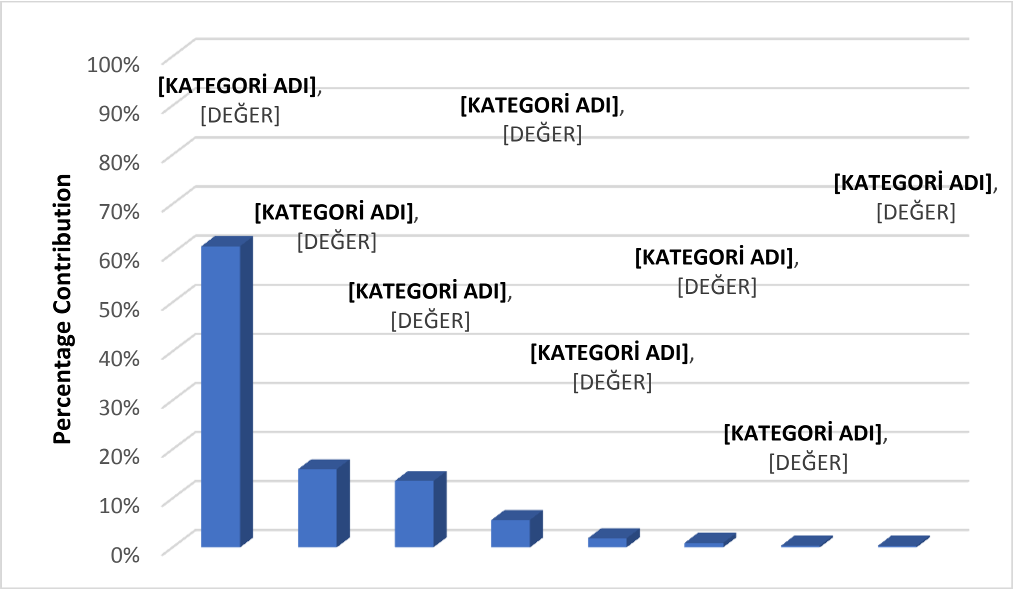

Figure 5.13. Impact of engine operating percentage contribution on NO_x.

In the ANOVA model for NO_x found in Table 5.6, The p-value for the DEE, SO ratio, and engine load linear coefficients is less than 0.05. However, The value of p for engine load is more than 0.05 in terms of second order coefficients, while the DEE p-value is once again less than 0.05. The error in this RSM is 1.86%. This indicates that the linear parameters have a more significant influence on the emission of NO_x.

Table 5.6. ANOVA for NO_x

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	7	809354	98.14%	809354	115622	90.63	0.000
Linear	3	664398	80.57%	252667	84222	66.02	0.000
Sesame Oil (%)	1	111677	**13.54%**	67616	67616	53.00	0.000
DEE (mL)	1	46092	**5.59%**	99547	99547	78.03	0.000
Engine Load (W)	1	506629	**61.43%**	179825	179825	140.95	0.000
Square	2	134622	16.32%	131379	65690	51.49	0.000
DEE (mL)*DEE (mL)	1	131604	**15.96%**	130135	130135	102.00	0.000
Engine Load	1	3018	**0.37%**	2596	2596	2.03	0.179

(W)*Engine Load (W)							
2-Way Interaction	2	10335	1.25%	10335	5167	4.05	0.045
Sesame Oil (%)*Engine Load (W)	1	7611	**0.92%**	10334	10334	8.10	0.015
DEE (mL)*Engine Load (W)	1	2724	**0.33%**	2724	2724	2.13	0.170
Error	12	15309	**1.86%**	15309	1276		
Total	19	824664	100.00%				

It has been proven that NO_x emissions will rise when the temperature inside the cylinder rises in response to an increase in the load placed on the engine. As can be observed in Figure 5.14, the ratio of SO and the load placed on the engine both contribute to an increase in NO_x emissions. This is due to the increase in the temperature of the cylinder that occurs as a result of the increased load and SO ratio. Figure 5.14 shows that as the DEE ratio increases, the amount of NO_x emissions first rises until they reach the midpoint, and then they begin to fall again.

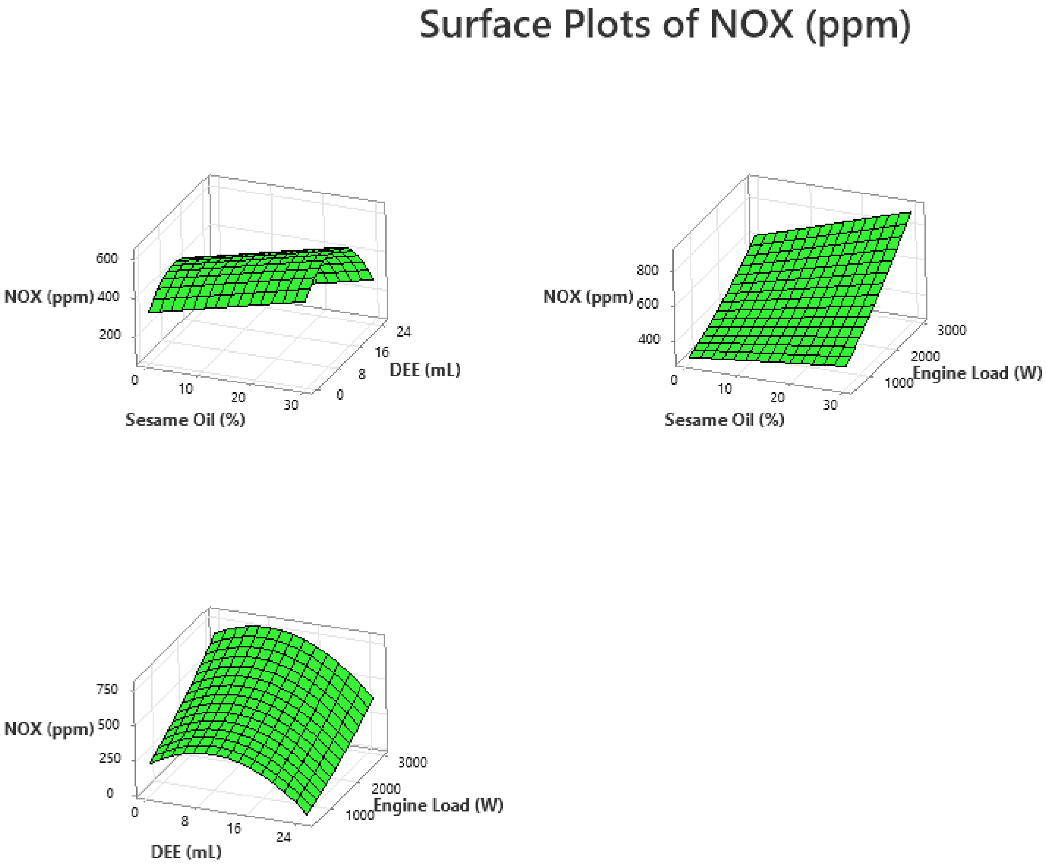

Figure 5.14. 3D Surface plots for NO_x at different SO (%), DEE ratio and load.

The Pareto charts for NO_x emission are shown here in Figure 5.15. The bar that represents the factor C, BB, B, C, and A, as well as AC, crosses the reference line that is located at 2.18 on the NO_x Pareto chart. All factors, with the except of CC and BC, have a significant impact on NO_x emissions.

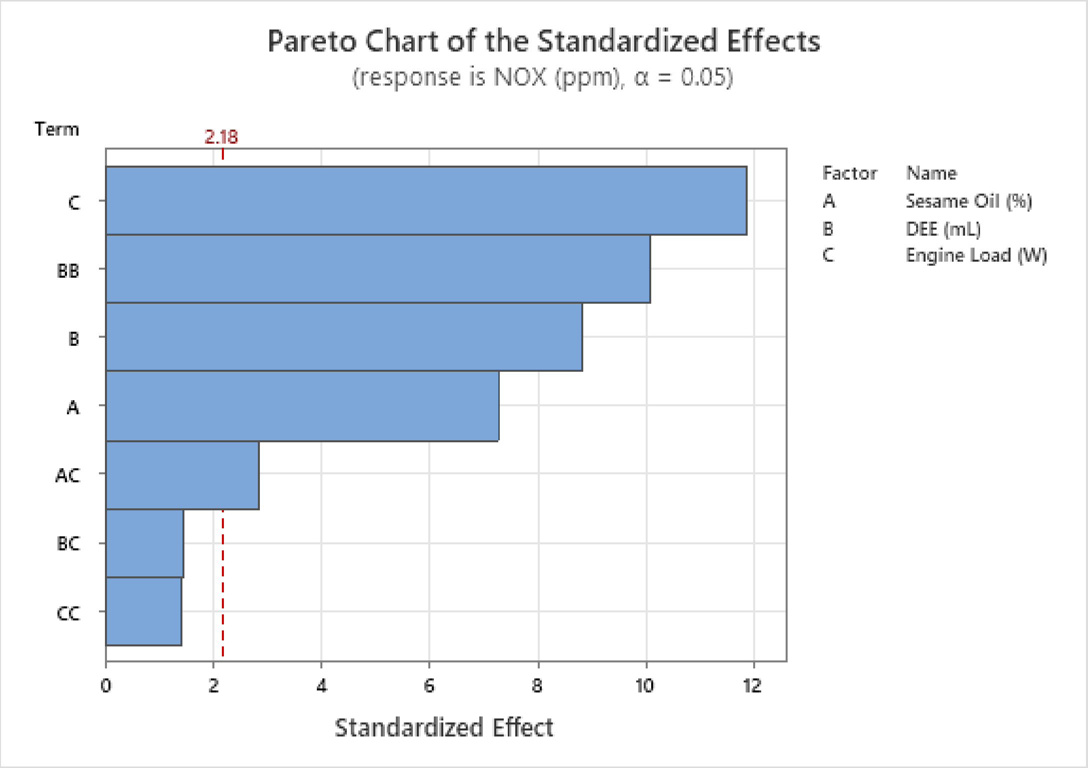

Figure 5.15. Engine performance parameter Pareto chart.

Table 5.7. Assessment of model

Model	**BSFC**	**CO**	**HC**	**CO_2**	**NO_x**
R^2 (%)	98.72	96.59	94.05	99.14	98.14
Adj. R^2 (%)	97.97	94.60	90.58	98.64	97.06
Pred.R^2 (%)	91.14	90.29	77.90	97.27	93.06

The success rate of the model is proportional to how near the R^2 value found in the model summary is to 1, or to 100%. It was determined that the R^2 values for the solutions BSFC, CO, HC, and NO_x were respectively 98.72%, 96.59%, 94.05%, and 99.14%, which demonstrates that the analysis was successful.

In Table 5.7, you'll find the R^2 values that resulted from the ANOVA that was carried out using RSM modeling. R^2 levels provide insight into the accuracy of the modeling approach. The fact that the R^2 values are very close to 1 or 100%, which shows the compatibility of the experimental model results, means the compatibility is high [26,54]. The optimization value of RSM is compared with the experimental value, and a regression equation is employed to determine how well the two sets of values match with one another. The following are the regression equation for: eq.1. CO, eq.2.CO, eq.3.HC, eq.4.CO_2, and eq.5.NO_x:

BSFC (g/kWh) = 933.8 + 4.02 SO (%) + 39.56 DEE (mL) - 0.4592 Engine Load (W) - 0.898 DEE (mL)*DEE (mL) + 0.000080 Engine Load (W)*Engine Load (W) - 0.00027 SO (%)*Engine Load (W) + 0.00459 DEE (mL)*Engine Load (W) (1)

CO (%) = 0.13939 - 0.001143 SO (%) - 0.002214 DEE (mL) - 0.000073 Engine Load (W) + 0.000176 DEE (mL)*DEE (mL) + 0.000000 Engine Load (W)*Engine Load (W) + 0.000000 SO (%)*Engine Load (W) - 0.000000 DEE (mL)*Engine Load (W) (2)

HC (ppm) = 9.6 - 0.026 SO (%) - 4.531 DEE (mL) + 0.0188 Engine Load (W) + 0.2055 DEE (mL)*DEE (mL) + 0.000002 Engine Load (W)*Engine Load (W) - 0.000357 SO (%)*Engine Load (W) + 0.000454 DEE (mL)*Engine Load (W) (3)

CO_2 (%) = 2.361 + 0.0253 SO (%) + 0.1732 DEE (mL) + 0.000446 Engine Load (W) - 0.007958 DEE (mL)*DEE (mL) + 0.000000 Engine Load (W)*Engine Load (W) + 0.000014 SO (%)*Engine Load (W) - 0.000023 DEE (mL)*Engine Load (W) (4)

NO_x (ppm) = 124.4 + 1.73 SO (%) + 29.21 DEE (mL) + 0.0736 Engine Load (W) - 1.424 DEE (mL)*DEE (mL) + 0.000021 Engine Load (W)*Engine Load (W) + 0.002535 SO (%)*Engine Load (W) - 0.00166 DEE (mL)*Engine Load (W) (5)

5.3. Optimization Responses

We use this study to investigate the effects of adding different amounts of DEE% in which SO 30% mixture are used as a fuel at different engine loads to find the performance characteristics and emissions in the diesel engine. The main goal and aim of this optimization study is to reduce emissions to below-minimum levels and the best condition. In which the SO%, DEE%, and engine load are the input variables, and the main goal for the optimization of this study is to minimize the values of the output variables, which are BSFC, CO, HC, and CO_2, and NO_x. The Table 5.8 contains information on the lower as well as the upper values.

Table 5.8. Setup For Optimization Parameters

Response	Goal	Lower	Upper
Engine load	In range	500	3000
Sesame oil (%)	In range	0	30
DEE (%)	In range	15	25
BSFC (g/kWh)	Minimum	311.688	1198.74
NO_x (ppm)	Minimum	180.667	860.67
CO_2 (%)	Minimum	2.699	8.74
HC (ppm)	Minimum	7.000	116.00
CO (%)	Minimum	0.032	0.10

For each response in Table 5.9, the RSM optimization value, the experimental value, and any errors are shown. The table's values and margin of error show that the RSM optimization and experimental findings are quite similar. The CO_2 reaction had a minimum error of 0.59%, however, the HC emission response had a maximum error of 7.185%.

Table 5.9. Validation of optimized and experimental results

Sesame Oil (%)	**DEE (mL)**	**Engine Load (W)**	**value**	**BSFC (g/kWh)**	**NO_X (ppm)**	**CO_2 (%)**	**HC (ppm)**	**CO (%)**
30	25	2500	Optimized	1102.024	414.78	5.25	82.89	0.0733
			Actual	1123.13	395.83	5.22	77.33	0.0710
			Error(%)	1.878	4.786	0.593	7.185	3.2394

The results that were obtained after optimizing result, which is shown in Figure 5.16, which is according to the requirements outlined in the study. The values that are written in red represent the optimal levels for each variable, and the values that are written in blue represent the responses that were reached using the optimal levels for each variable. The optimal values for the diesel engine were determined to be a SO percentage of 20.3030%, a DEE ratio of 0%, and a load of 1282.83 Watts. The calculated values for BSFC, HC, CO, CO_2, and NO_x were 551.371 g/kWh, 26.623 ppm, 0.0544%, 4.3566 %, and 353.650 ppm, respectively. when these variables were optimized to their full potential.

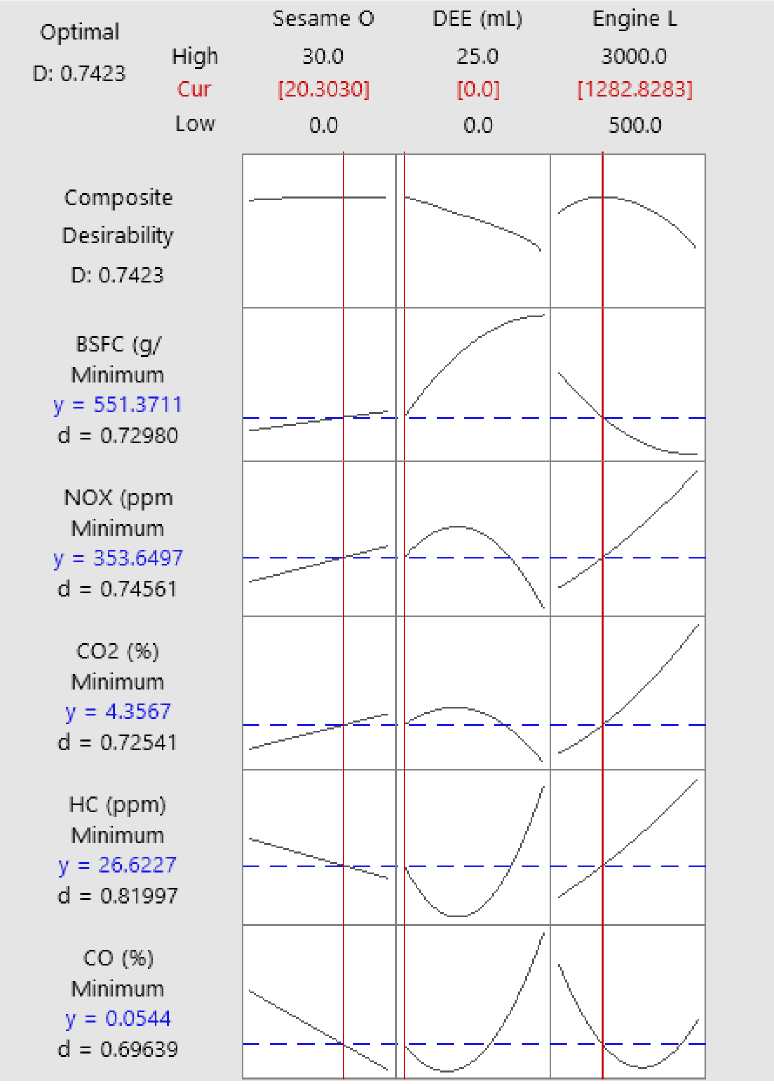

Figure 5.16. Optimization result

CONCLUSIONS

In this study, having chosen the optimal SO/diesel fuel blend through experimentation, the study aims to improve performance and emissions with adding different amounts of DEE ratio. Furthermore, the study expectations to determine the optimal amount of DEE with a minimum number of experiments by optimizing with RSM. This will be done by minimizing the number of experiments required to reach a conclusion.

In the present research study, an ANOVA-supported RSM was applied with the goal of determining and optimizing the impact of the percentage of SO, the percentage of DEE, and the load by finding the best performance and emissions of diesel engines. At six different (500, 1000, 1500, 2000, 2500 and 3000 W) engine loads, the experiments which were carried out by using (100% diesel fuel), biodiesel that contained (30% SO and 70% diesel fuel) of varying concentrations of DEE. For the RSM model, a configuration with three continuous factors was selected as the optimal one. The percentage of biodiesel used, the percentage of diesel exhaust emissions, and load were selected as the input components, and BSFC, CO_2, NO_x, CO, and HC were selected as the response factors. It was determined how successful the various input parameters were by creating Pareto charts and analyzing their effectiveness. The following is the most important findings from the recent research:

- In the optimization study where DEE ratio (15%, 20%, 25%), SO ratio (30%SO&70%DO), and engine load (500,1000,1500,2000,2500&3000W) were selected as input engine variables, BSFC, CO, HC, CO_2 and NO_x which were selected as the output response variables.
- The best engine operating parameters were a SO percentage of 20.30%, a DEE percentage of 0%, and a load of 1282.83-W.

- The BSFC, CO, HC, CO_2, and NO_x at the responses that observed under optimal conditions were 551.371 g/kWh, 0.0544%, 26.623 ppm, 4.3566%, and 353.650 ppm, respectively.
- The R^2 values for BSFC, CO, HC, CO_2, and NO_x emissions were 98.72%, 96.59%, 94.05%, 99.14%, and 98.14%, respectively, demonstrating the models' precision.
- The results showed that there is a good match between the optimization outcomes and experiment results, demonstrating an error rate of under 8%.
- Hence, the utilization of RSM can be used as an effective method to determine the optimum engine variables and responses.

This study clearly determined that the RSM method, as supported by our research findings, that can successfully model for diesel engines, and by using this method, we can save time, labor, and money that we use for the experiment.

REFERENCES

1. Simsek, Suleyman, Samet Uslu, and Hatice Simsek. "Response surface methodology-based parameter optimization of single-cylinder diesel engine fueled with graphene oxide dosed sesame oil/diesel fuel blend**."** **Energy and AI** 10 (2022): 100200.
2. Raimi, D., Campbell, E., Newell, R. G., Prest, B., Villanueva, S., & Wingenroth, J. (2022). **Global energy outlook 2022:** Turning points and tension in the energy transition. *Resources for the Future: Washington, DC, USA*.
3. Smil, V. (2016). ***China's Environmental Crisis****: An Enquiry into the Limits of National Development: An Enquiry into the Limits of National Development*. Routledge.
4. Trivedi, M. D., et al. "Review on performance and emission of CI engine fuel blended with sesame oil and diesel." ***International Journal for Scientific Research & Development*** *2 (10), 602* 604 (2014).
5. Ceviz, M. A., et al. "Analysis of combustion stability and its relation to performance characteristics in a compression ignition engine fueled with diesel-biodiesel blends." ***Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*** 33.10 (2011): 990-1003.
6. Stauffer, E., & Byron, D. (2007). Alternative fuels in fire debris analysis: biodiesel basics. ***Journal of forensic sciences***, *52*(2), 371-379.
7. Demırbas, A. (2017). The social, economic, and environmental importance of biofuels in the future. *Energy Sources, Part B:* ***Economics, Planning, and Policy,*** *12*(1), 47-55.
8. Ayoub, M., & Abdullah, A. Z. (2012). Critical review on the current scenario and significance of crude glycerol resulting from biodiesel industry towards more sustainable renewable energy industry. ***Renewable and Sustainable Energy Reviews***, *16*(5), 2671-2686.

9. Tickell, J. (2003). *From the fryer to the fuel tank: the complete guide to using vegetable oil as an alternative fuel*. **Biodiesel America**.
10. Datta, A., Hossain, A., & Roy, S. (2019). An overview on biofuels and their advantages and disadvantages.
11. Singh, v. K. (2020). Performance investigation of an egr based crdi diesel engine powered with blends of diesel and sesame oil methyl ester (Doctoral dissertation).
12. Sathyanarayanan, S., Suresh, S., Uslu, S., Shivaranjani, R. S., Chandramohan, V. P., & Simsek, S. (2023). Optimization of gasoline engine emission parameters employing commercial and sucrolite-catalyst coated converter using response surface methodology. ***International Journal of Environmental Science and Technology***, *20*(2), 1725-1738.
13. Samet, U. S. L. U. (2020). Multi-objective optimization of biodiesel and diethyl ether doped diesel engine by Taguchi method. ***International Journal of Automotive Science and Technology***, *4*(3), 171-179.
14. Myers, Raymond H., et al. "Response surface methodology: a retrospective and literature survey." ***Journal of quality technology*** 36.1 (2004): 53-77.
15. Yeşilyurt, M.K., Uslu, S. (2020) "response surface methodology based optimization of a diesel enginefueled with diethyl ether/diesel fuel blends", ***3. Uluslararası Akademik Araştırmalar Kongresi*** , (pp. 725-733), Bolu, Türkiye, (Temmuz 2020)
16. Altun, Ş., Bulut, H., & Öner, C. (2008). The comparison of engine performance and exhaust emission characteristics of sesame oil–diesel fuel mixture with diesel fuel in a direct injection diesel engine. ***Renewable Energy***, *33*(8), 1791-1795.
17. Shailaja, M., Aruna Kumari, A., & Sita Rama Raju, A. V. (2013). Performance evaluation of a diesel engine with sesame oil biodiesel and its blends with diesel. ***Int. J. Curr. Eng. Technol. Spec***, (1).
18. Dandu, M. S. R., & reddy Doddipalli, R. (2021). *Effect of Combustion Bowl Shape on Performance Combustion and Emission Characteristics of Diesel Engine Using Biodiesel with TiO 2 Nanoparticle Additive as Fuel* (No. 2021-28-0284**). SAE Technical Paper**.

19. Nilamkumar, Mr & Patel, S. Performance characterization of single cylinder diesel engine fuelled with Sesame oil -diesel and its blend with Ethanol (2012).
20. Balamurugan, T., & Nalini, R. (2014). Experimental investigation on performance, combustion and emission characteristics of four stroke diesel engine using diesel blended with alcohol as fuel. ***Energy***, *78*, 356-363.
21. Trivedi, M. D., et al. "Review on performance and emission of CI engine fuel blended with sesame oil and diesel." **International Journal for Scientific Research & Development 2** (10), 602 604 (2014).
22. Öner, Cengiz, and Şehmus Altun. "Biodiesel production from inedible animal tallow and an experimental investigation of its use as alternative fuel in a direct injection diesel engine." **Applied Energy** : 2114-2120,86.10 (2009).
23. Rashedul, H. K., et al. "The effect of additives on properties, performance and emission of biodiesel fuelled compression ignition engine." **Energy Conversion and Management:** 348-364, 8.8 (2014).
24. Habibullah, M., et al. "Biodiesel production and performance evaluation of coconut, palm and their combined blend with diesel in a single-cylinder diesel engine." **Energy Conversion and Management**: 250-257, 8.7. (2014).
25. Mehra, Kuber Singh, and Gaurav Pant. "Production Of Biofuel From Sesame Oil And Its Characterization As An Alternative Fuel For Diesel Engine." IOP Conference Series: **Materials Science and Engineering**. Vol. 1116. No. 1. IOP Publishing, 2021.
26. Simsek, S., & Uslu, S. (2020). Determination of a diesel engine operating parameters powered with canola, safflower and waste vegetable oil based biodiesel combination using response surface methodology (RSM). ***Fuel***, *270,* 117496.
27. Singh, Yashvir, et al. "Optimization of performance and emission parameters of direct injection diesel engine fuelled with pongamia methyl esters-response surface methodology approach." **Industrial crops and products** 126 (2018): 218-226.
28. Sakthivel, R., et al. "Prediction of performance and emission characteristics of diesel engine fuelled with waste biomass pyrolysis oil using response surface methodology." **Renewable energy** 136 (2019): 91-103.

29. Singh, Thokchom Subhaschandra, et al. "Optimization of performance and emission parameters of direct injection diesel engine fuelled with microalgae Spirulina (L.)–Response surface methodology and full factorial method approach." **Fuel 285** (2021): 119103.
30. Krishnamoorthi, M., R. Malayalamurthi, and P. Mohamed Shameer. "RSM based optimization of performance and emission characteristics of DI compression ignition engine fuelled with diesel/aegle marmelos oil/diethyl ether blends at varying compression ratio, injection pressure and injection timing." **Fuel 221** (2018): 283-297.
31. Singh, Yashvir, et al. "Optimization of diesel engine performance and emission parameters employing cassia tora methyl esters-response surface methodology approach." ***Energy*** 168 (2019): 909-918.
32. Parida, M. K., et al. "Multiple response optimizations to improve performance and reduce emissions of Argemone Mexicana biodiesel-diesel blends in a VCR engine." **Applied Thermal Engineering** 148 (2019): 1454-1466.
33. Sakthivel, R., et al. "Prediction of performance and emission characteristics of diesel engine fuelled with waste biomass pyrolysis oil using response surface methodology." ***Renewable energy*** 136 (2019): 91-103
34. Krishnamoorthi, M. (2015). Response surface methodology based optimization of diesel-mustard biodiesel-diethyl ether ternary blend ratios to improve engine performance. ***Journal of Chemical and Pharmaceutical Research,*** *7*(8), 249-256
35. Marcus, A. (1999). Diesel Fuel Basics. ***PassageMarker Inc. Magazine***.
36. Uslu, S., "The effect of using diethyl ether on engine parameters in a low power diesel engine", M.Sc., Karabuk University Institute of Science and Technology, Karabuk, 32-50 (2015).
37. Dodos, G. S., Zannikos, F., & Lois, E. (2011). Utilization of sesame oil for the production of bio-based fuels and lubricants. *School of Chemical Engineering, Laboratory of Fuel Technology and Lubricants,* ***National Technical University of Athens,*** *15780.*
38. llen, B., Baranescu, R., Diesel Engine **Reference Book Second Edition, Butterworth?Heinemann, Oxford, 100-102 (1999).**

39. Feng, H., Zheng, Z., Yao, M., Cheng, G., Wang, M., & Wang, X. (2013). Effects of exhaust gas recirculation on low temperature combustion using wide distillation range diesel. ***Energy,*** *51*, 291-296.
40. Karakuş N., "The Effect of Fuel Properties on Diesel Engine Performance and Emissions", PhD Thesis, Gazi University Institute of Science, Ankara, 11-23 (2000).
41. Feng, H., Zheng, Z., Yao, M., Cheng, G., Wang, M., & Wang, X. (2013). Effects of exhaust gas recirculation on low temperature combustion using wide distillation range diesel**.** ***Energy***, *51*, 291-296.
42. Sendzikiene, E., Makareviciene, V., Janulis, P., & Makareviciute, D. (2007). Biodegradability of biodiesel fuel of animal and vegetable origin. ***European Journal of Lipid Science and Technology,*** *109*(5), 493-497.
43. Corma, A., A. Martınez, and V. Martınez-Soria. "Hydrogenation of aromatics in diesel fuels on Pt/MCM-41 catalysts." ***Journal of Catalysis*** 169.2 (1997): 480-489.
44. Abdullah B, A., "Investigation Of The Effect Of The Addition Of Ceo2 Nano Particle In Diesel Fuel On Engine Performance And Emissions", M.Sc., Karabuk University Institute of Science and Technology, Karabuk, (2022)
45. Lacey, Paul I., and Steven R. Westbrook. "Diesel fuel lubricity." ***SAE transactions*** (1995): 214-225.
46. Heywood, John B. ***Internal combustion engine fundamentals***. McGraw-Hill Education, 2018.
47. Heywood J. B., "**Internal combustion engine fundamentals**", Mc Graw-Hill Book Company, Singapore, 930 (1988).
48. Bari, S. (Ed.). (2013). *Diesel Engine: Combustion, Emissions and Condition Monitoring*. **BoD–Books on Demand.**
49. Sercan, U., "The Effect of Pyrolytic Fuel Obtained from Waste Tires on Engine Performance and Emissions", M.Sc., Karabuk University Institute of Science and Technology, Karabuk, (2020)
50. Elkelawy, M., El Shenawy, E.A., Bastawissi, H.A.E., Shams, M.M. and Panchal, H., 2022. A comprehensive review on the effects of diesel/biofuel blends with nanofluid additives on compression ignition engine by response surface methodology. ***Energy Conversion and Management***: X, p.100177.

51. Bae, C., & Kim, J. (2017). Alternative fuels for internal combustion engines. ***Proceedings of the Combustion Institute***, *36*(3), 3389-3413.
52. Struben, J., 2006. Identifying challenges for sustained adoption of alternative fuel vehicles and infrastructure.
53. Uslu, S., Simsek, S., & Simsek, H. (2023). RSM modeling of different amounts of nano-TiO2 supplementation to a diesel engine running with hemp seed oil biodiesel/diesel fuel blends. ***Energy,*** 266, 126439**.**
54. Simsek, S. and Uslu, S., 2020. Experimental study of the performance and emissions characteristics of fusel oil/gasoline blends in spark ignited engine using response surface methodology. ***Fuel***, *277*, p.118182.
55. Simsek, S. and Uslu, S., 2020. Investigation of the effects of biodiesel/2-ethylhexyl nitrate (EHN) fuel blends on diesel engine performance and emissions by response surface methodology (RSM). ***Fuel,*** *275*, p.118005.
56. Upadhyay, Yogendra Prasad, and R. B. Sharma. "Biodiesel: An alternative fuel and its emission effect." ***IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*** 5.3 (2013): 01-04.
57. Trivedi, M.D., Patel, P.R., Patel, T.M. and Rathod, G.P., 2014. Review on performance and emission of CI engine fuel blended with sesame oil and diesel. ***International Journal for Scientific Research & Development*** 2 (10), 602, 604.
58. Agarwal, Avinash Kumar. "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines." ***Progress in energy and combustion science*** **33.3** (2007): 233-271.
59. Cernat, A., Pana, C., Negurescu, N., Lazaroiu, G., & Nutu, C. (2015, September). Aspects of the animal fat use at the diesel engine fuelling. In *2015* ***50th International Universities Power Engineering Conference (UPEC)*** (pp. 1-6). IEEE.
60. Semin, Rosli Abu Bakar. "A technical review of compressed natural gas as an alternative fuel for internal combustion engines." ***Am. J. Eng. Appl. Sci*** **1.4 (2008)**: 302-311.
61. Roubík, Hynek, et al. "Biogas quality across small-scale biogas plants: A case of central Vietnam." ***Energies*** 11.7 (2018): 1794.

RESUME

Zaid AHMAD has completed his high school education in Pakistan. After that, in 2016 he began his undergraduate bachelor's program and completed a BE in mechanical engineering at Karabuk University, Turkey. Then, in October 2020, he started an M.Sc. in mechanical engineering at Karabük University, Turkey.