OBTAINING RENEWABLE ENERGY BY OPTIMIZATION OF THE PERFORMANCE AND EMISSION RESPONSES OF THE DIESEL ENGINE WITH RSM USING ENVIRONMENTALLY FRIENDLY FUEL BLENDS

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I certify that in my opinion the thesis submitted by Haider Nashaat Hassen TAHA titled “OBTAINING RENEWABLE ENERGY BY OPTIMIZATION OF THE PERFORMANCE AND EMISSION RESPONSES OF THE DIESEL ENGINE WITH RSM USING ENVIRONMENTALLY FRIENDLY FUEL BLENDS” is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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““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.”

Haider Nashaat Hassen TAHA

ABSTRACT

M. Sc. Thesis

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In this study, the effects of using biodiesel produced from waste frying oil in a diesel engine on engine responses were examined and an optimization study was carried out with response surface methodology (RSM) so that it can be used under the best conditions. First, experimental studies were carried out with fuel mixtures containing different amounts of biodiesel (10, 20, 30, and 40% by vol.) at different engine electrical loads (500, 1000, 1500, 2000, 2500, and 3000 W) using a single-cylinder diesel generator. According to the test results, the best biodiesel ratio, especially in terms of emissions, was determined to be 30%. The lowest carbon monoxide (CO), hydrocarbon (HC) and smoke emissions were obtained with a fuel mixture containing 30% biodiesel. Then, optimization was made based on the experimental data obtained. While biodiesel ratio and engine load were selected as factors in the optimization study, CO, HC, carbon dioxide (CO_2), nitrogen oxides (NO_x), smoke and brake specific fuel consumption (BSFC) were selected as responses affected by the factors. According to the optimization results, the optimum factor levels were 26% and 1080 W for biodiesel ratio and engine load, respectively. The optimum responses obtained depending on the optimum factors are 500.1059 g/kWh BSFC, 0.4175% smoke, 375.1013 ppm NO_x, 3.9134% CO_2, 13.6162 ppm HC, 0.0404% CO. In addition, according to the verification study conducted to prove the reliability and accuracy of the optimization results, the lowest error rate between the optimum results and the experimental results was found in CO emission with 2.51%, while the highest error rate was obtained in HC emission with 7.83%. Accordingly, the fact that the maximum error is lower than 10% indicates that the optimization application can be trusted.

As a result, it was concluded that waste frying oil biodiesel can be an alternative fuel for diesel engines and can be used efficiently in diesel engines with RSM optimization.

Key Words : Waste frying oil biodiesel, response surface methodology, diesel engine, emissions.
Science code : 91413

ÖZET

Yüksek Lisans Tezi

ÇEVRE DOSTU YAKIT KARIŞIMLARI KULLANILARAK DİZEL MOTORUN PERFORMANS VE EMİSYON YANITLARININ RSM İLE OPTİMİZE EDİLMESİYLE YENİLENEBİLİR ENERJİ ELDE EDİLMESİ

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Bu çalışmada atık kızartma yağlarından üretilmiş biyodizelin dizel motorda kullanımının motor yanıtlarına etkileri incelenmiş ve en iyi şartlarda kullanılabilmesi için RSM ile optimizasyon çalışması gerçekleştirilmiştir. Öncelikle tek silindirli dizel jeneratör kullanılarak farklı motor yüklerinde (500, 1000, 1500, 2000, 2500 ve 3000 W) farklı oranlarda (10, 20, 30 ve %40) biyodizel içeren yakıt karışımları ile deneysel çalışmalar gerçekleştirilmiştir. Deney sonuçlarına göre özellikle emisyonlar açısından en iyi biyodizel oranı %30 olarak tespit edilmiştir. En düşük karbonmonoksit (CO), hidrokarbon (HC) ve is emisyonu %30 biyodizel içerikli yakıt karışımı ile elde edilmiştir. Daha sonra elde edilen deneysel verilere dayanarak optimizasyon yapılmıştır. Optimizasyon çalışmasında biyodizel oranı ve motor yükü faktör olarak seçilirken, CO, HC, karbondioksit (CO_2), azot oksit (NO_x), is ve fren özgül yakıt tüketimi (BSFC) faktörlerden etkilenen yanıtlar olarak seçilmiştir. Optimizasyon sonuçlarına göre optimum faktör seviyeleri biyodizel oranı ve motor yükü için sırasıyla %26 ve 1080 W olarak ortaya çıkmıştır. Optimum faktörlere bağlı olarak elde edilen optimum yanıtlar ise 500.1059 g/kWh BSFC, 0.4175% is, 375.1013 ppm NO_x, 3.9134% CO_2, 13.6162 ppm HC, 0.0404% CO'dur. Ayrıca, optimizasyon sonuçlarının güvenilirliğini ve doğruluğunu kanıtlamak amacıyla yapılan doğrulama çalışmasına göre optimum sonuçlar ile deney sonuçları arasındaki en düşük hata oranı %2,51 ile CO emisyonunda bulunurken en yüksek hata oranı %7,83 ile HC emisyonunda elde edilmiştir. Buna göre, en yüksek hatanın %10'dan daha düşük olması optimizasyon uygulamasına güvenilebileceğini göstermektedir.

Sonuç olarak, atık kızartma yağı biyodizelinin dizel motorlar için alternatif bir yakıt olabileceği ve RSM optimizasyonu ile verimli bir şekilde dizel motorlarda kullanılabileceği sonucuna varılmıştır.

Anahtar Sözcükler : Atık kızartma yağı biyodizeli, yanıt yüzey metodolojisi, dizel motor, emisyonlar.

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SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

NaOh: Sodium hydroxide salt
KOh : Potassium hydroxide salt
O : Oxygen
OH : Hydroxide

ABBREVITIONS

ANOVA	: Analysis of variance
BSFC	: Brake specific fuel consumption
CO	: Carbon monoxide
CO_2	: Carbon dioxide
DoE	: Design of experiments
D100	: Fossil diesel fuel
HC	: Hydrocarbon
NO	: Nitrogen oxide
NO_x	: Nitrogen oxides
PM	: Particle matter
RSM	: Response surface methodology
3D	: three dimensions

PART 1

INTRODUCTION

As a result of the increasing demand for energy due to the increase in humanity and the continuous development of the requirements of life, the consumption of fossil fuels that are destined for depletion has increased, with the resulting harmful effects on the environment due to the processes of oil extraction and its uses [1]. The need arose to find available alternatives that are less costly and sustainable for energy production. Figure 1.1 shows energy sources and types. Renewable energy Biomass is the largest and cheapest option for obtaining clean energy, including biofuels [2-5].

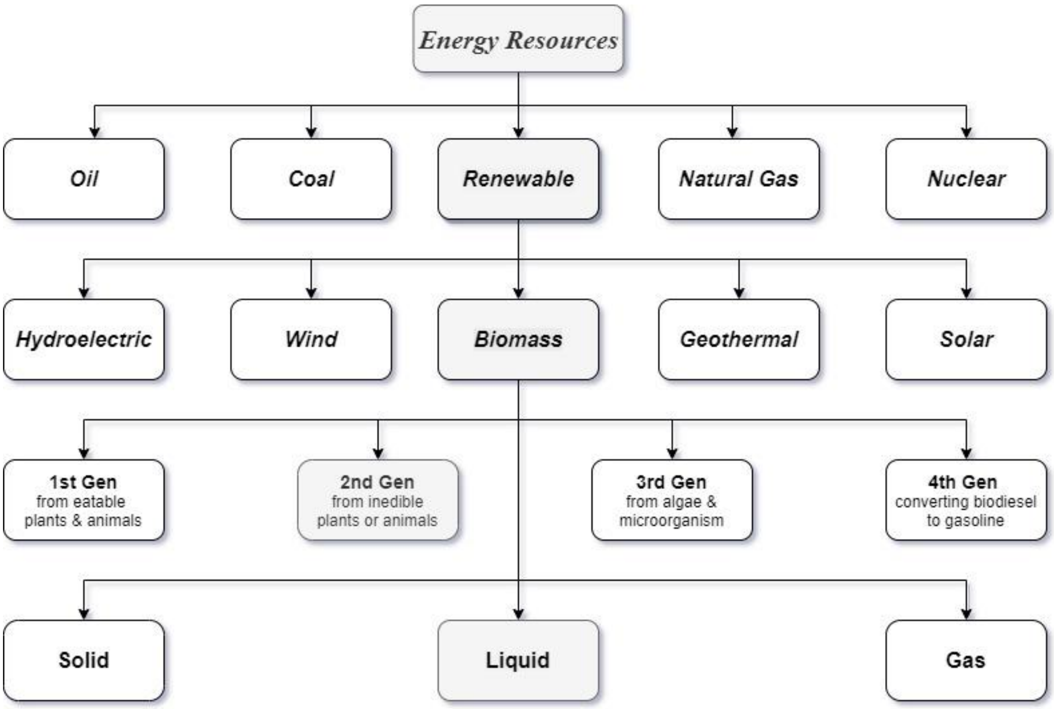


Figure 1.1. Types of energy sources

The efficiency of diesel engines has made them widespread and versatile, which has made them one of the sources of harmful emissions and environmental pollution [6].

The possibility of using biofuel to operate internal combustion diesel engines has been researched due to its specifications being close to those of fossil fuels without the need to bear the costs of making modifications to the engine, which facilitates the production of sufficient energy at a lower cost. Reducing emissions harmful to the environment [7,8].

Biofuel is a term consisting of two words: fuel, which means an energy substance that can be transported and used according to need, and bio, which means the product of plant or animal (biomass) ,Where plants store the energy of sunlight in chemical bonds, where they release their stored energy when breaking the bonds of molecules through physical or chemical processes such as combustion, digestion, decomposition, and others . The use of biomass for energy production represents a carbon dioxide recycling process, while the use of fossil fuels produces additional new carbon dioxide for the environment [9]. It is considered one of the most important sources of renewable energy due to its abundance, diversity, and cheapness. There are four generations of biofuel [10,11];

- **First generation:** fuel produced from edible plants.
- **Second generation:** fuel produced from inedible plants.
- **Third generation**: fuel produced from algae and some microorganisms.
- **Fourth generation:** converting vegetable oil and biodiesel into gasoline.

(Biodiesel) A liquid fuel produced from vegetable oils or animal fats by the transesterification method using alcohol (methanol or ethanol) with a base salt (NaOH or KOH) and, as a by-product, producing glycerides. Biodiesel is an environmentally friendly fuel with properties like conventional diesel fuel [12,13].

Biofuel is a clean and renewable fuel produced from plants and its derivatives. The energy of sunlight is stored through the leaves of plants in chemical bonds. When the bonds of molecules are broken by digestion, combustion or decomposition, their stored energy is released. It is environmentally friendly, being non-toxic, does not contain sulfur and aromatics, its properties vary according to the raw material and method. used in biodegradable production and its use reduces carbon monoxide, hydrogen carbonate and smoke emissions and the use of waste frying oil as a raw material in production reduces costs and secures the environment and local sources of energy and creates new job opportunities [14].

The advantages of biodiesel are high cetane number with the property of increasing engine lubrication with the presence of the oxygen molecule and its characteristics are close to fossil diesel fuel and it is biodegradable. The disadvantages of biodiesel are its higher viscosity and low calorific value with low thermal efficiency of the brakes and increased braking energy consumption [15,16].

God Almighty said in the Holy Qur’an: And We have revealed to you the Book explaining everything (Surat An-Nahl, verse 89). Fuel has already been mentioned in the Holy Qur’an (the holy book of Muslims) in eleven verses, five of which are about biofuels, and as indicated (10- Al-Imran, 17- Al-Baqarah, 24 Al-Baqarah, 64 Al-Ma’idah, 17- Al-Ra’d, 35- Al-Nur, 38- Al-Qasas, 80- Yasin, 6- Al-Tahrim, 5- Al-Buruj, 6- Al-Humazah) [17,18].

In this study, we investigate to obtain clean energy by improving the performance, emissions, and responses of a diesel engine (using the Response Surface Methodology (RSM)) using a mixture of fossil diesel and environmentally friendly fuel extracted in (home laboratory) by recycling waste vegetable frying oil through transesterification. Where the used frying oil goes through several processes (primary filtration, heating and secondary filtration to get rid of impurities and water and heating and then adding a mixture of methanol alcohol and (potassium or sodium) hydroxide salt (KOh or NaOh) with a certain rotating and moving mechanism and a very slow speed and washing with distilled basic water and then left for a certain period will produce a liquid consisting of two layers 96% of the primary biofuel is relatively transparent and 4% of the crude glycerine is dark in colour, then the biofuel is separated and reheated for a specific period of time to get rid of excess water and alcohol, and the result is 100% biofuel obtained in a simple and low-cost way (which will be explained in detail in this research. It is worth noting that the first use of biodiesel fuel of vegetable origin was documented by the inventor of the engine, the German scientist Rudolf Diesel in 1900 at the Paris International Exhibition.) [19,20].

A computer program was used to study the engine performance because its results are faster and less expensive, and its results are of close accuracy than the traditional methods that are very expensive and very slow (using the RSM) [21] by making a laboratory model consisting of a single-cylinder four-stroke diesel engine with Direct injection and air cooling Through the use of several models of a mixture of diesel and bio-fuel with different proportions to run a model A laboratory consisting of a single-cylinder, four-stroke, direct-injection, air-cooled diesel engine linked to an electric generator to deliver different electrical loads with the use of performance measurement devices and emissions analysis of the model under standard working conditions (70% diesel + 30% biodiesel).

PART 2

LITERATURE REVIEW

Sheinbaum and others studied the effect of using biofuels made from vegetable frying oil at a rate between 1.5% and 3.3% of diesel fuel used in public transportation in Mexico on reducing CO_2 emissions by 1.0% to 2.7%. Governments should set policies that support the recycling of waste, including waste frying oil, to increase economic, security, and environmental feasibility and raise awareness of the harms of used and expired cooking oil waste and the benefits of collecting and recycling [22].

By studying the results reached by the researchers, whose research was reviewed in this chapter, it was found that the performance of the diesel engine is affected by the use of biofuel mixtures, with a 74% increase in BSFC, while in terms of emissions coming out with the exhaust gas of the engine, it was found that there was a 77% increase in CO_2 and 75% increase in NO_x and 87% decrease in CO and 86% decrease in HC and 86% decrease in smoke, which means that the results reached in this research are close to what others have achieved as shown below .

No.	**Authors**	**Fuel**	**Engine Specifications**	**Engine Performance**	**Emissions**
1	searched by (M.S.Gad) et al. [23]	(WCO)Biodiesel + Gasoline BD92%+G8%	Diesel	BSFC (g/kWh) was increase BTE was decreases EGT (ºC) was increases	CO: decreases, NO_x: increases, HC: decreases, Spot: decreases
2	Searched by (Murat Kadir Yesilyurt) et al. [24]	biodiesel from peanut oil by transesterification technique (catalyst (KOH)+Methanol)	Diesel (3.5 kW) single cylinder, four-stroke, direct-injection, water-cooled 1500 rpm	Energy efficiency values: decreases Fuel consumption due to lower calorific value: increases	Mentioned gas emissions as values without comparison
3	Searched by (H. Sanli) et al. [25]	waste frying oil-based methyl and ethyl ester biodiesel fuels 20% MEBD+80% diesel & 20%EEBD+80% diesel& MEB & EEB & PbD	Diesel, 6 cylinders, 4 stroke, Direct injection, turbocharged, intercooled water cooled.	BSFC (g/kWh): increases BTE:(MEB or EEB): increases	CO: decreases CO_2: increases HC: decreases NO_x: increases
4	Searched by (Suleyman Simsek) et al. [26]	biodiesel obtained from Canola, safflower oils and waste oils	Diesel engine single cylinder, four-stroke direct injection, air-cooled fixed speed 3000 rpm	BSFC (g/kWh): increases BTE: increased for BD10, BD20 and BD30 blends. Decreased for BD50, BD75 and BD100 blends	CO: decreases CO_2: increases HC: decreases NO_x: increases

5	searched by (Medhat Elkelawy) et al. [27]	Biodiesel production from sunflower and soybean oils homogeneous transesterification method 70%BD30%D	Diesel engine single cylinder, four-stroke direct injection naturally aspirated, water cooled	BSFC (g/kwh): increases BTE: decreases	CO: decreases CO_2: increases HC: decreases NO_x: increases
6	Searched by (Suleyman Simsek) et al. [21]	Canola, Safflower and Waste Vegetable Oil Based Biodiesel RSM	diesel engine a single cylinder, four-stroke, direct-injection with a 3000-rpm constant speed naturally aspirated, air-cooled	BTE: decreased EGT (℃): decreases	CO_2: increases NO_x: increases Smoke: decreases
7	Searched by (S. Chandra Sekhar) et al. [28]	Biodiesel from Pithecellobium dulce seed oil	Diesel engine four stroke, single cylinder, constant speed (1500 rpm), water cooled, vertical, naturally aspirated, and DI engine	BTE: decreased BSFC (g/kWh): increases EGT (°C): decreases	CO_2: increases CO: decreases HC: decreases NO_x: decreases Smoke: increases
8	Searched by (Suleyman Simsek) et al. [2]	waste vegetable oil and waste animal oil-based biodiesel	diesel engine a 3000-rpm constant speed air cooled, naturally aspirated, four-stroke, single cylinder, and	BTE: decreased BSFC (g/kWh): increases	CO: decreases CO_2: increases HC: decreases

			direct injection		Smoke: decreases NO_x: increases
9	Searched by (Suleyman Simsek) et al. [29]	biodiesel/2-ethylhexyl nitrate B97.5E2.5, B98.5E1.5, B99.5E0.5 Taguchi	internal combustion, compression ignition diesel engine (2000, 2500, 3000 watt)	BTE: increased BSFC (g/kWh): decreases Due to loads and B.D. ratio	CO: increases with B.D ratio decreases with load, HC: increases with B.D ratio decreases with load, NO_x: increases with B.D ratio decreases with load, Smoke: increases Due to loads and B.D. ratio
10	Searched by (Suleyman Simsek) et al. [30]	animal waste fat-derived biodiesel ANN and RSM technique	single cylinder diesel engine makes by Katana KM 178 FE, power 6.7 hp, 3000 rpm engine loads (500, 1000, 2000, 2500 and 3000 Watt).	BTE (%): decreases BSFC (g/kWh): increases Due to loads	NO_x (ppm): increases HC (ppm): increased CO (%): decreases CO_2 (%): increases Smoke (%): increases Due to loads
11	Searched by (Samet Uslu) et al. [31]	cerium dioxide/diesel blends using 4 amounts of CeO_2	diesel engine, single-cylinder Antor 3LD510 compression ignition engine, 1800 rpm	BTHE: increases EGT: increases	HC (ppm): decreased CO (%): decreases

		(25,50,75 and 100 ppm) nanoparticles to the diesel fuel	engine loads (8, 12, 16, 20, and 25 Nm)		NO_x: increases Smoke (%): decreases
12	Searched by (Samet Uslu) et al. [32]	diethyl ether	in a single cylinder diesel engine	BTE: increases BSFC (g/kWh): increases EGT: decreases	HC (ppm): decreased CO (%): decreases NO_x: increases Smoke (%): decreases
13	Searched by (Suleyman Simsek) et al. [33]	graphene oxide (GO) dosed sesame oil (SO)/diesel fuel blend GO (25, 50, 75 and 100 ppm) to the fuel blend (30% SO/70% diesel) RSM	single-cylinder diesel engine engine loads (500, 1000, 1500, 2000, 2500 and 3000 W)	BSFC (g/kWh): decreases BTE (%); EGT: decreases due to increasing (GO) ratio	CO: decreases HC: decreases NO_x: decreases due to increasing (GO) ratio
14	Searched by (Jagannath B. Hirkude) et al. [34]	waste fried oil methyl ester-diesel blend using RSM	Direct injection CI diesel engine, 4 Stroke, 1 cylinder, power: 3.78kW (5 HP)	BTE (%): increases Due to (IP, IT) BSFC: decreases when CR (16-18) and increasing of IP. EGT (℃); increases due to CR, IP increases and IT decreases	Smoke: decreases Due to CR, IT, IP, and biodiesel ratio

				Due to compression ratio (CR), injection time (IT) and injection pressure (IP)	
15	Searched by (R. Rohith Renish) et al. [35]	neem oil biodiesel-diesel blends B5, B10, B15, B20 and B25 (%vol.)	Diesel engine, Compression ignition, 4-stroke, multifuel, VCR-engine, 1- cylinder, 1500 rpm, Compression ratio: 12:1–18:1	BTE (%): decreases close to diesel at CR 18:1 and increases according to CR increasing BSFC (kg/kWh): increases except B25 at CR 18:1 and close to diesel. EGT (℃): increases Due to engine load (%)	CO (%): decreases at CR 18:1 HC (ppm): decreases at CR 18:1 NO_x (ppm): increases at CR 18:1 Due to engine load (%)
16	Searched by(Suleyman Simsek) et al. [36]	biodiesel/2-ethylhexyl nitrate (EHN) fuel blends by RSM	Diesel compression ignition engine with single cylinder power: 6.7hp speed: 3000 rpm	BTE: increases BSFC (g/kWh): decreases	HC: increased CO: decreases CO_2: increases NO_x: increases Smoke: increases
17	Searched by (Abhishek Sharma) et al. [37]	tobacco (Nicotiana Tabaccum) for biodiesel using (RSM)	4-stroke, DI diesel engine (Single Cylinder)	BTE decreases EGT slight increase	HC: decreases

18	Searched by (Abhishek Sharma) et al. [38]	biodiesel/diesel blends raw biogas–diesel dual fuel	diesel engine Single cylinder, four stroke, CI, air cooled, naturally aspirated, direct injection, constant speed 1500rpm	BTE decreases BSFC (g/kWh): increases	Smoke: decreases
19	Searched by (Medhat Elkelawy) et al. [39]	acetone organic additives into the diesel/biodiesel mixture	DI, CI diesel engine, Single cylinder, Cooling system water-evaporative 1600 rpm four stroke, horizontal, and swirl chamber	EGT increases BTE decreases BSFC (g/kWh): increases	CO: decreases CO_2: increases NO_x: increases HC: decreases O_2: increases Smoke decreases
20	Searched by (Shiv Kumar Ray) et al. [40]	Waste Vegetable Oil biodiesel	single cylinder diesel engine, make Kirlosker TV1 1500 rpm.	BSFC (g/kWh): increases	CO: decreases NO_x: increases CO_2: increases
21	Searched by (Murat Kadir Yesilyurt) et al. [41]	waste cooking oil biodiesel-diesel blends (B5 ،B10 ،B20، B30)	single cylinder diesel engine the fuel injection pressure (170–220 bars)	BSFC (g/kWh): increases BTE: decreases at (210 bar) increases.	CO: decreases CO_2: increases

				Engine torque: decreased at (210 bar) increases EGT(C): increases	HC: decreases NO$_x$: increases
22	Searched by (Saravanan Subramani) et al. [42]	diesel-biodiesel-higher alcohol blends percentage of biodiesel blend, percentage of Butanol, pentanol and propanol, RSM	Single cylinder 4.4 kW Direct Injection 1500 rpm	BSFC (g/kWh): decreases	NO$_x$: decreases Smoke: decreases CO: decreases
23	Searched by (Osama Khan) et al. [43]	blends of biodiesel, hydrogen, and cerium oxide nanoparticles	PETTER -AV1 DI, 4-stroke, DI, water cooled. 5 BHP at 1500 rpm	BTE: increases BSEC: increases	NO$_x$: increases HC decreases
24	Searched by (Md. Nurun Nabi) et al. [44]	Biodiesel from cotton seed oil	Diesel engine. single cylinder, water-cooled, 4-stroke, DI	BTE: decreases BSEC: increases	CO: decreases CO$_2$: increases NO$_x$: increases Smoke: decreases
25	Searched by (Bhupendra	Jatropha biodiesel oil and its blends	A Kirloskar diesel engine, single cylinder, air cooled, direct injection,	BTE: decreases BSEC: increases	CO: decreases CO$_2$: increases

	SinghChauhan) et al. [45]		1500 rpm	EGT: decreases	HC: decreases NO$_x$: increases Smoke: decreases
26	Searched by (Orkun Özener) et al. [46]	soybean biodiesel D2, B10, B20, B50 and B100	Diesel engine direct injection, 4 stroke, 1-cylinder, air-cooled diesel, 8.1 kW at 3000 rpm	Torque (Nm): decreases BSFC (g/kWh): increases ignition delay (sec.): decreased Due to engine speed	NO$_x$: increases CO$_2$ (%): increases CO (%): decreases HC: decreases Due to engine speed
27	Searched by (Cengiz Öner) et al. [47]	Biodiesel production from inedible animal tallow	Rainbow LA186, direct injection diesel engine, single cylinder, four-stroke, force air-cooling, naturally aspired.	BTE: decreases BSEC: increases EGT: increases except B50 decreases	CO: decreases NO$_x$: decreases when speeds were more than 2500 rpm SO$_2$ (ppm): decreases Smoke: decreases
28	Searched by (Avinash Kumar Agarwal) et al. [48]	Karanja biodiesel blends	DI diesel engine, single cylinder, max power 6 kW, 1500 rpm	BSEC: increases BTE: increases (with respect to fuel injection press. and start of injection	CO: decreases except KOME50 increases HC: decreases except KOME50 increases

				deg.)	NO_x: increases (with respect to fuel injection press. and start of injection deg.)
29	Searched by (Luka Lešnik) et al. [49]	diesel, biodiesel, and their blends biodiesel from rapeseed oil at Biogoriva, Rače, Slovenia, and mineral diesel fuel D2	DI diesel engine, 4 stroke, 6 cylinders, Natural aspirated	BSFC: increases	CO: decreases except B25 NO_x: decreases except B25
30	Searched by (A.S.Silitongaab) et al. [50]	Ceiba pentandra biodiesel blends	the single cylinder four stroke diesel engines	BSFC (g/kWh): increases except B10 Torque (Nm): decreases except B10 Break Power (kW): decreases except B10 EGT (°C): increases (with respect to speed)	NO_x (ppm vol.): increases HC (ppm vol.): decreases CO (% vol.): increases except B10 CO_2 (% vol.): increases except B50 decreases Smoke (% HSU): decreases (with respect to speed)
31	Searched by (Paramvir Singh) et al. [51]	Biodiesel from Aamla oil (Phyllanthus Emblica L.) extracted from seeds of	Kirloskar make diesel engine, Direct injection, single cylinder, naturally	BTE: decreases except B50 BSFC (g/kWh): increases except B50	CO (% vol.): decreases when loads were more than 45% HC (ppm vol.): decreases

		aamla	aspirated, water cooled and 4-stroke	EGT (°C): decreases except B50, B60 (with respect to load)	except B100, B90 Smoke (%): decreases NO_x: decreases except B50, B60 (with respect to load)
32	Searched by (Ahmed Sanjid) et al. [52]	A blend of kapok and moringa biodiesel	diesel engine, 4-cylinder, Water cooled	BSFC (g/kWh): increases (with respect to speed-rpm)	NO_x (ppm vol.): increases HC (ppm vol.): decreases CO (% vol.): decreases CO_2 (% vol.): increases (with respect to speed-rpm)
33	Searched by (M.Mohamed Musthafa) [53]	Bio diesel from the refined palm oil blends (LPG)	diesel engine, Single cylinder 4-stroke engine, power 2.6, KW /3.5 HP, 1500 rpm, direct injection, Water cooling	BTE: increases BSFC (g/kWh): decreases EGT (°C): increases except LPG-Biodiesel with DTBP (with respect to load-%)	CO (%vol.): increases except LPG-Biodiesel with DTBP HC (ppm vol.): increases NO_x (ppm vol.): increases (with respect to load-%)
34	Searched by (Pankaj Dubey) et al. [54]	dual bio-fuel (Jatropha biodiesel and turpentine oil)	5 HP at 1800 rpm diesel engine	BTE (%): decreases (with respect to compression	CO (g/kWh): decreases CO2 (g/kWh): increases

				ratio)	HC (g/kWh): decreases NO_x (g/kWh): increases except B50 Smoke (%): decreases (with respect to compression ratio)
35	Searched by (T. Senthil Kumar) et al. [55]	Biodiesel of Kapok methyl ester and its blends	Single cylinder four strokes, direct injection, water cooled, compression ignition, 4 kW 1500 rpm	BTE: decreases except B20 BSFC (g/kWh): increases EGT (°C): increases (with respect to load-%)	CO (g/kWh): decreases except B100, B80 NO_x (g/kWh): increases HC (g/kWh): decreases except B100, B80 Smoke (%): decreases except B100, B80 (with respect to load-%)
36	Searched by (A. Sanjid) et al. [56]	combined palm and jatropha biodiesel blends	single-cylinder diesel engine, 4 – stroke DI, 7.7 kW, Radiator cooling	BSFC (g/kWh): increases (with respect to speed-rpm)	CO (% vol.): decreases CO_2 (% vol.): increases HC (ppm): decreases NO_x (ppm): increases

					Sound (db): decreases (with respect to speed-rpm)
37	Searched by (Hwai Chyuan Ong) et al. [57]	Bio diesel from high free fatty acid Calophyllum inophyllum oil	CI, Direct injection diesel engine, 1- Cylinder, Water cooling, Maximum power 7.7 kW , 2400rpm	BSFC (g/kWh): increases except B10 BTE (%): decreases except B10 EGT (°C): increases except B10 (with respect to speed-rpm)	CO (%vol.): increases except B10 NO_x (ppm vol.): increases Smoke (%): decreases (with respect to speed-rpm)
38	Searched by (Yaser Noorollahi) et al. [58]	different diesterol (diesel–waste oil biodiesel–ethanol) blends (D100, D97B2E1, D94B4E2, D91B6E3)	small air-cooled diesel engine, 1- Cylinder, Direct Injection, Compression Ignition,	Torque (Nm) increases BSFC (g/kWh): increases except D97B2E1 (with respect to speed-rpm)	CO (% vol.): decreases CO_2 (% vol.): decreases except D91B6E3 HC (ppm): decreases NO_x (ppm): decreases except D91B6E3 (with respect to speed-rpm)
39	Searched by (Mohamad A. Hasan Altaie) et al.	Enriched palm oil biodiesel	diesel engine, 1-Cylinder, 4-cycle, Direct injection, Air cooled	Brake Torque (Nm): decreases Brake power (kW): decreases	CO (% vol.): decreases HC (% vol.): decreases

	[59]			BSFC (g/kWh): increases EGT (°C):decreases (with respect to speed-rpm)	NO_x: increases (with respect to speed-rpm)
40	Searched by (Sachin Muralee Krishna) et al. [60]	optimally blended biodiesel-diesel-ethanol	diesel engine, 4- strokes, 4-cylinders, 3- phases	BSFC (g/kWh): increases	CO (% vol.): decreases except at full load BDE 7, BDE 8 and DBE 9 blends were higher CO_2 (% vol.): increases NO_x: increases
41	Searched by (E.A. El Shenawy) et al. [61]	water-diesel emulsion	DEUTZ FL 511/W" which is a single-cylinder, four-stroke, Water cooling, power; 5.7 kW, 1500 rpm using partially premixed charge compression ignition (PPCCI) combustion at premixed ratio (PR = 30%).	BSFC (g/kWh): decreases BTE (%) : increases Due to engine loads	CO: decreases, UHC: decreases smoke: decreases NO_x: decreases Due to engine loads
42	Searched by (E.A.	pure diesel fuel.	1 cylinder, 5.7 kW, Water cooling, direct injection,	BSFC (g/kWh): decreases	CO: decreases,

	El Shenawy) et al. [62]		compression ignition diesel engines using partially premixed charge compression ignition (PPCCI) combustion fuelled with (100% and 30%) pure diesel fuel on the combustion	BTE (%): increases at (PPCCI) 30% premixed ration. Due to engine loads	UHC: decreases smoke: decreases NO_x: decreases Due to engine loads
43	Searched by (Mustafa Aydın) et al. [63]	biodiesel-diesel 4-blends (100D,20B,40B, 60B) ANN and RSM methods The optimized values 32% biodiesel ratio	compression ignition diesel engine I.P. 200–400–600 bar engine loads (500, 750, 1000, 1250, 1500 W). ANN and RSM methods The optimized values 816-W engine load and 470 bar injection pressure	BTE: 14.54%, BSFC (g/kWh): 783.95 EGT: 184.14 °C Due to optimized values engine load, biodiesel ratio, injection pressure optimum operating	NO_x (ppm): 120.05 CO (%): 0.079% HC (ppm): 120.30 Smoke (%): 9.95% Due to optimized values engine load, biodiesel ratio, injection pressure
44	Searched by (K. Sivaramakrishnan) et al [64]	biodiesel	diesel engine	BTE: decreases BSFC: increases due to CR increasing When decreasing the fuel	CO: decreases, HC: decreases when CR from 17.5 to 18.1

				blend ratios	
45	Searched by (Subhash Lahane) et al. [65]	different percentages of biodiesel–diesel blends (B5 ،B10 ،B15 ،B20 ، B25 ،B50 ،B100)	direct injection diesel engine speed :(1500 rpm)	injection duration (sec.): increases Torque (Nm): decreases except at B20 BSFC (g/kWh): increases	CO (%): decreases HC: decreases smoke: decreases NO_x: increases Best biodiesel–diesel blends: B15-B20
46	Searched by (Ekrem Buyukkaya) [66]	neat rapeseed oil biodiesel (5%, 20% and 70%) its blends with diesel fuel.	Diesel engine, 6 cylinders, 4-stroke, turbocharged direct injection , power 164kW at 2100rpm.	Power (kW): decreases Torque (Nm): decreases BSFC (g/kWh): increases BTE (%): increases at B20 Due to engine speed (rpm) The preferred percentage of biodiesel in environmentally friendly fuel is approximately (20%).	NO_x: increases CO: decreases, HC: decreases smoke: decreases Due to engine speed biodiesel blend is friendly to environment when used with diesel engine without changing
47	Searched by (I.M.	antioxidant + palm biodiesel blends	diesel engine turbocharged four-cylinder, water cooled,	BTE (%): increases	NO_x (ppm): increases

	Rizwanul Fattah) et al. [67]		4 stroke, Indirect injection, power: 42kW at 4000rpm adding separate tanks with (2-way valves)	EGT(K):increases Power(kW): decreases BSFC (g/kWh): increases Due to engine speed (rpm)	CO (%): decreases HC (ppm): decreases Due to engine speed (rpm)
48	Searched by (Hwai Chyuan Ong) et al. [68]	Jatropha curcas, Ceiba pentandra and Calophyllum inophyllum biodiesel blends 10%, 20%, 30% and 50%	CI diesel engine single cylinder, four stroke, water cooling, Maxpower 7.7 kW at 2400 rpm and direct injection engine	Torque (Nm): decreases BTE (%): decreases except (JCB 10) Brake power (kW): decreases except (JCB 10) J. curcas BSFC (g/kWh): increases except (B10 at all types) EGT (°C): increases Due to engine speed (rpm)	NO_x (ppm vol.): increases HC (ppm vol.): increases except (B10 at all types) CO_2 (% vol.): decreases except (JCB 10) CO (% vol.): increases except (JCB 10) Smoke (%): decreases Due to engine speed (rpm) Diesel engine working by using biodiesel
49	Searched by (Nadir Yilmaz) et al. [69]	biodiesel–butanol fuel blends (5%, 10%, and 20%)	diesel engine: 2-cylinders, 4-stroke, water-cooled, naturally aspirated, indirect injected , Rated power (6.5	BSFC (g/kWh): increases EGT (°C): decreases	NO_x (ppm.): decreases CO (%): increases

		butanol in volume basis (B95Bu5, B90Bu10, B80Bu20).	kW)	Due to engine load (kW)	HC (ppm): decreases Due to engine load (kW)
50	Searched by (Alpaslan Atmanli) [70]	diesel–waste oil biodiesel and propanol, n-butanol or 1-pentanol blends	diesel engine: 4- cylinders, 4-Cycle, naturally aspirated, indirect injected , Air cooled	BSFC (g/kWh): increases BTE (%): increases EGT (°C): increases Due to engine load (kW)	NO_x (ppm.): decreases, CO (%): increases except at (9kW) load HC (ppm): increases at mostly Due to engine load (kW)
51	Searched by (Li Li) et al. [71]	diesel/biodiesel/pentanol fuel blends D70P30 (70% diesel, 30% pentanol), D70B30 (70% diesel, 30% biodiesel) and D40B30P30 (40% diesel, 30% biodiesel and 30% pentanol)	diesel engine: 1- cylinder, 4-stroke diesel engine retrofitted from a four-cylinder engine	BTE (%): increases except at B30 BSFC (g/kWh): decreases except at B30	NO_x (ppm.): increases, Smoke: decreases CO: decreases HC: decreases
52	Searched by (Erkan Öztürk) et al. [72]	canola oil–hazelnut soap stock biodiesel mixture diesel (D100) and biodiesel blends (B5 and B10).	DI-diesel engine, natural aspirated, air cooled, 1-Cylinder, power 5.4 (kW) at 3000rpm engine loads (25, 50, 75 and 100%)	BTE (%): decreases close to B5 BSFC(g/kWh): increases close to B5 EGT (°C): increases	CO (%): decreases with B5 at full load HC (ppm): increases except with B5 at full load Smoke: increases except with B5 at full load

				Due to engine load (%)	Due to engine load (%)
53	Searched by (PankajShrivastava a) et al. [73]	Roselle and Karanja biodiesel	CI diesel engine 4-stroke, 1-cylinder, direct injection and water cooling	EGT (°C): decreases BSFC(g/kWh): increases BTE (%): decreases Due to engine load	NO_x (ppm.): decreases, CO_2 (%): increases Smoke: decreases Due to engine load
54	Searched by (Nadir Yilmaz) et al. [74]	biodiesel–butanol fuel blends	diesel engine 2-cylinder, 4-stroke, liquid cooled, naturally aspirated, indirect injected Kubota GL7000	BSFC(g/kWh): increases EGT (°C): decreases compared to neat biodiesel. Due to engine load	NO_x (ppm.): increases at load90% except B80, CO (%): decreases except B80 HC (ppm): decreases except B80, B95 compared to neat biodiesel. Due to engine load
55	Searched by (H.K. Imdadul) et al. [75]	C4 and C5 alcohol treated diesel–biodiesel blends	diesel engine 1- cylinder, 4-stroke, water-cooled, naturally aspirated-direct injection	BSFC (g/kWh): increases Due to engine speed(rpm)	NO_x (ppm.): increases CO (%): decreases CO_2 (%): increases HC (ppm): decreases Due to engine speed(rpm)

56	Searched by (Hüseyin Aydin) et al. [76]	cottonseed oil methyl ester B5, B20, B50 and B75 blends	diesel engine 1- cylinder, 4-strokes, air cooled	Power (kW): decreases Torque (Nm): decreases except B5 BSFC (g/kWh): increases except B20 at low speed Due to engine speed (rpm)	NO_x (ppm): decreases except B5 SO_2 (ppm): decreases CO (% vol.): decreases Smoke (%): increases except B20 Due to engine speed (rpm)
57	Searched by (M.S. Shehata) et al. [77]	Corn and soybean biodiesel blends 20% biodiesel (C20 and S20)	diesel engine 4-stroke, 1-cylinder, air cooled direct injection (DI) diesel engine at different engine speeds, loads and IP (180, 190 and 200 bar)	Power (kW): increases at S20 and 83%load BSFC (g/kWh): decreases at S20 and 83%load BTE (%): increases at S20 and 83%load with high speeds EGT (°C):decreases at S20 and 83%load with high speeds Due to engine speed (rpm)at IP (200 bar) engine performance	Effect of fuel injection pressure on the injection, combustion and performance characteristics of a DI diesel engine fueled with canola oil methyl esters-diesel fuel blends

				parameters were better when injection pressure increased	
58	Searched by (M. Mofijur) et al. [78]	Moringa oleifera biodiesel and diesel fuel blends (B10 and B20) ASTM D6751	diesel engine indirect injection Radiator cooling 4-Cylinder. Power (78 kW) at Speed 4200 rpm	Brake power(kW): decreases BSFC (g/kWh): increases BTE (%): decreases Due to engine speed (rpm)	CO (%): decreases HC (ppm): decreases NO_x (ppm): increases Due to engine speed (rpm)
59	Searched by (A.M. Liaquat) et al. [79]	coconut biodiesel blended fuels DF (100% diesel fuel), CB5 (5% coconut biodiesel and 95% DF), and CB15 (15% CB and 85% DF)	diesel engine 1-cylinder, 4-stroke	Torque (Nm): decreases Brake power (kW): decreases BSFC (g/kWh): increases EGT (°C): increases Due to engine speed	CO (%): decreases CO_2 (%): increases HC (ppm): decreases NO_x (ppm): increases Due to engine speed (rpm)
60	Searched by (Y.H. Teoh) et al. [80]	Moringa oleifera biodiesel-diesel blends (MOB10, MOB20, MOB30 and MOB50)	a common-rail diesel engine injection pressure 140 MPa 4-Cylinder	Torque (Nm): decreases Brake power (kW): decreases BSFC (g/kWh): increases BTE (%): increases except at speed 1500 rpm	CO (%): decreases NO_x (ppm): increases Smoke (%): decreases Due to engine speed (rpm)

				Due to engine speed (rpm)	
61	Searched by (Ahmet Necati Ozsezen) et al. [81]	canola and waste palm oil methyl esters	Diesel engine Water-cooled, direct injection, naturally aspirated, 4- stroke, 6-cylinders and 81 kW at 2600 rpm	Brake power (kW): decreases BSFC (g/kWh): increases Due to engine speed (rpm)	CO (%): decreases CO_2 (%): decreases HC (ppm): decreases NO_x (ppm): increases Smoke (%): decreases Due to engine speed (rpm)
62	Searched by (Alpaslan Atmanli) et al [82]	diesel–vegetable oil–n-butanol ternary blends n -butanol (nB), crude canola (Cn), soybean (Sb), sunflower (Sf), corn (Cr), olive (Ol), and hazelnut oil (Hn), diesel fuel (D)-vegetable oil (D70nB10Cn20, D70nB10Sb20, D70nB10Sf20, D70nB10Cr20, D70nB10Ol20 and D70nB10Hn20) blends.	Land Rover 110 diesel engine 4-cylinder, 4-stroke, turbocharged, direct injection	BTE (%): decreases BSFC (g/kWh): increases EGT (℃): decreases Due to engine speed (rpm)	CO (%): increases CO_2 (%): decreases HC (ppm): decreases except in 1800 rpm NO_x (ppm): increases Due to engine speed (rpm)
63	Searched by	carbon nanotubes additives to diesohol-B2	diesel engines	Torque (Nm): increases	CO (%): decreases

	(Khadijeh Heydari-Maleney) et al. [83]	fuels D100, B2, B2E2, B2E4, and B2E6	1-cylinder, 4-stroke, direct injection, air-cooled, 9kW power at 2300rpm, max. speed 3000 rpm engine speed (1700, 2300, and 2900 rpm)	except B2 power(kW): increases except B2 EGT (°C): decreases BSFC (g/kWh): decreases except B2 BTE (%): increases at except B2 Due to engine speed (rpm)	HC (ppm): decreases NO_x (ppm): increases Smoke (%): decreases Due to engine speed (rpm)
64	Searched by (A.M. Ruhul) et al. [84]	Millettia pinnata and Croton megalocarpus biodiesel blends (MP20, MP15CM5, MP10CM10, MP5CM15 and CM20) ASTM D975 (diesel) and ASTM D6751-08 (biodiesel) specification.	diesel engine 4 Stroke DI, 1-cylinder, Radiator cooling	Brake power(kW): decreases BSFC (g/kWh): increases BTE (%): decreases EGT (°C): increases Due to engine speed (rpm)	CO (%): decreases CO_2 (%): decreases HC (ppm): decreases NO_x (ppm): increases Due to engine speed (rpm)
65	Searched by (Pankaj Shrivastava) et al. [85]	biodiesel from Roselle oil (B20, B40 and B100) blends	CI engine 1- cylinder compression ignition engine at a constant	BSFC (g/kWh): increases BTE (%): decreases	CO_2 (%): increases NO_x (ppm): decreases

			engine speed of 1500 rpm injection pressure (180, 200, 220, 240 and 260 bars), loading (25%, 50%, 75%, 100%)	EGT (℃): increases Due to engine load (%)	Smoke (%): decreases Due to engine load (%)
66	Searched by (Mustafa Atakan Akar) et al. [86]	Hydrogen enriched waste oil biodiesel (D, B10 and B20) of waste oil biodiesels	Diesel engine compression ignition naturally aspirated, water cooled, 4- stroke and 1-cylinder	BSFC (g/kWh): increases but decreases with Hydrogen. BTE (%): decreases but increases with Hydrogen Due to engine speed (1500 rpm)	CO (%): decreases and more decreases with Hydrogen CO_2 (%): increases but decreases with Hydrogen NO_x (ppm): increases and more increases with Hydrogen Due to engine speed (1500 rpm)
67	Searched by (Narendra Krishania) et al. [87]	spirulina, waste cooking and animal fats blended biodiesel fuel	auto-ignition diesel engine rail 1 cylinder, 4-stroke, and direct injection diesel engine.	EGT (℃): decreases BSFC (g/kWh): increases BTE (%): decreases Due to engine speed (1500 rpm)	NO_x (ppm): increases at mostly Smoke (%): decreases Due to engine speed (1500 rpm)

68	Searched by (GökhanTüccar) et al. [88]	microalgae biodiesel–butanol blends D70B20But10, D60B20But20, D80B20 and 100% diesel fuel	diesel engine 4- stroke, 4-cylinder. Water cooled	Torque (Nm): decreases Brake power (kW): decreases BSFC (g/kWh): increases Due to engine speed (rpm)	CO (%): decreases except engine speed more than 2600 rpm NO_x (ppm): decreases except B20 Smoke (%): decreases Due to engine speed (rpm)
69	Searched by (Jagannath Hirkude) et al. [89]	waste fried oil methyl ester blend (B0 وB50 وB70)	CI, 1- cylinder diesel engine	EGT (℃): increases BSFC (g/kWh): increases BTE (%): increases Due to brake load (kW)	CO (%): decreases NO_x (ppm): increases Due to brake load (kW)
70	Searched by (Upendra Rajak) et al. [90]	hydrogen enriched n-butanol, diethyl ester and Spirulina microalgae biodiesel	diesel engine The 4-stroke, 1-cylinder, direct injection, water cooled, naturally aspirated,	BSFC (g/kWh): decreases with Hydrogen BTE (%):increases with Hydrogen Due to engine load (%)	Smoke (%): decreases with Hydrogen CO_2: decreases with Hydrogen NO_x (ppm): increases with Hydrogen Due to engine load (%)
71	Searched by (Mostafa M. El-	Ethanol biofuel extracted from jatropha oil using a heterogeneous catalyst	diesel engine 1- cylinder	EGT (℃) : decreases	CO (%): increases

	Sheekh) et al. [91]	(CaO) and soybean and sunflower oils with wheat straw hydrolysate blends (D50B50, BE10D45B45, BE20D40B40)	air-cooled direct injection. speed 1500 rpm	BSFC (g/kWh): decreases BTE (%): increases Due to engine brake power (kW)	HC (ppm): increases CO_2 (%): increases NO_x (ppm): decreases Due to engine brake power (kW)
72	Searched by (Phobkrit Kanokkhanarat) et al. [92]	ethanol biodiesel blends	Isuzu 4JJ1-TC make direct Injection diesel engine	BSFC (g/kWh): increases BTE (%): increases Due to engine speed (rpm)	NO_x (ppm): increases Smoke (%): decreases Due to engine speed (rpm)
73	Searched by (M. Ghanbari) et al. [93]	nano particles additives in biodiesel-diesel blends	CI diesel engine	Torque (Nm): increases Brake power(kW): increases BSFC (g/kWh): decreases BTE (%): increases Due to engine speed (rpm)	CO (%): decreases HC (ppm): decreases CO_2 (%): increases NO_x (ppm): increases Due to engine speed (rpm)
74	Searched by (AbhishekPaul) et al. [94]	Diesel-ethanol-biodiesel blends D100, D45E5B50, D40E10B50, D35E15B50, D30E20B50	CI diesel engine 1- cylinder, 4- stroke, water cooled, naturally aspirated, stationary DI engine	BSFC (g/kWh): decreases at D35E15B50 BTE (%): increases at D35E15B50	CO (%): decreases HC (ppm): decreases NO_x (ppm): increases

			maximum power of 3.6 kW at 1500 rpm.	Due to engine load (%)	Due to engine load (%)
75	Searched by (AnkurNalgundwar) et al. [95]	dual biodiesel blends of palm and jatropha Pure diesel, D90JB5PB5, D80JB10PB10, D70JB15PB15, D60JB20PB20, D50JB25PB25, D40JB30PB30, D20JB40PB40, D0JB50PB50	CI diesel engine 1-cylinder, 4-stroke, naturally aspirated, air cooled, direct injection	Brake power(kW): increases at D90JB5PB5. EGT (℃): decreases except at high biodiesel blends with high loads. BSFC (g/kWh): decreases at D60JB20PB20 and D90JB5PB5 BTE (%): increases at except for higher biodiesel blends at higher loads. Due to engine load (watts)	CO (%): decreases at (D90JB5PB5, D80JB10PB10) CO_2 (%): decreases except at (D90JB5PB5 and D80JB10PB10 at 500,1500 Watts engine load) NO_x (ppm): increases Due to engine load (watts)
76	Searched by (B. Ashok) et al. [96]	zinc oxide and ethanox as additives with biodiesel	CI diesel engine, Direct injection (DI) 2- cylinder, 4-stroke, Water cooled ,	BSFC (g/kWh): decreases BTE (%): increases Due to engine loads (%)	CO (%): decreases HC (ppm): decreases Smoke (%): decreases NO_x (ppm): increases except at Ethanox Due to engine loads (%)

77	Searched by (M. Annamalai) et al. [97]	ceria nanoparticle blended emulsified biofuel diesel, LGO, LGO Emulsion , LGO Nano Emulsion	Kirloskar diesel engine , 4- stroke, 1- cylinder, Water cooling compression ignition	BSEC (MJ/kWh): increases BTE (%): decreases Due to brake power (kW)	CO (%): decreases HC (ppm): decreases NO_x (ppm): increases except at LGO Nano Emulsion Smoke (%): decreases Due to brake power (kW)
78	Searched by (UpendraRajaka) et al. [98]	microalgae Spirulina D100, D80B20, AB100	direct injection diesel engine 1- cylinder, 4- stroke, water cooled and power 3.7 kW	Torque (Nm): decreases EGT(K): decreases BSFC (g/kWh): increases Due to compression ratio (%)	CO_2 (%): decreases NO_x (ppm): increases Due to compression ratio (%)
79	Searched by (S. Prasanna Raj Yadav) et al. [99]	hydrocarbon fuel derived through recycling of waste transformer oil standard diesel, B25 (25% HCF + 75% diesel by volume) and B100 (100% HCF by volume)	compression ignition diesel engine , single cylinder, four stroke, constant speed, vertical, water cooled and direct injection	BSFC (g/kWh): decreases BTE (%): increases Due to brake power (kW)	CO (%): decreases HC (ppm): decreases Smoke (%): decreases NO_x (ppm): increases Due to brake power (kW)

80	Searched by (G. Najafi) [100]	nanoparticles in biodiesel-diesel blends D, BD, BDAG40, BDAG80, BDAG120, BD+CNT40, BD+CNT80 and BD+CNT120	Diesel engine CI engine, 6- Cylinder, 4 -stroke, water cooled	Torque (Nm): increases power(kW): increases BSFC (g/kWh): decreases BTE (%): increases Due to engine speed (rpm)	CO (%): decreases CO_2 (%): increases HC (ppm): decreases with AG nanoparticles. NO_x (ppm): increases Due to engine speed (rpm)
81	Searched by (PankajShrivastava a) et al. [101]	blends of diesel, karanja and roselle biodiesel B1 (D50KB45RB5) ‹B2 (D50KB40RB10) and B3 (D50KB30RB20)	diesel engine 1- cylinder, 4-stroke, water cooled and direct injection compression ignition engine.	EGT (℃): decreases BSFC (g/kWh): increases BTE (%): decreases Due to engine load (%)	CO_2 (%): increases Smoke (%): decreases NO_x (ppm): decreases Due to engine load (%)
82	Searched by (M. Arunkumar) et al. [102]	castor biodiesel blends (B20, B40, B60, B80 and B100) of biodiesel	CI diesel engine, single cylinder, four-stroke and direct injection	EGT (℃) : decreases BSFC (g/kWh): increases BTE (%): decreases	CO (%): decreases HC (ppm): decreases Smoke (%): decreases at B20

				Due to Brake power (kW)	NO_x (ppm): increases Due to Brake power (kW)
83	Searched by (NadirYilmaza) et al. [103]	biodiesel, higher alcohols, and vegetable oil DB, DBVOPro and DBVOPen	compression ignition diesel engine	EGT (℃) : increases BSFC (g/kWh): increases Due to engine load (kW)	CO (%): increases HC (ppm): increases NO_x (ppm): decreases at propanol and pentanol Due to engine load (kW)
84	Searched by (Farhad M. Hossain) et al. [104]	microalgae fuel components 100D, 75D5×5B and 50D5×10B	diesel engine 6-cylinder turbocharged	BSFC (g/kWh): increases BTE (%): decreases Due to engine load (%)	Smoke (%): decreases NO_x (ppm): increases Due to engine load (%)
85	Searched by (R.Senthil) et al. [105]	Annona methyl ester and its blends	Vertical, 4-stroke, 1- cylinder	BSFC (g/kWh): decreases at A20 BTE (%): decreases Due to engine load (kg)	CO (%): decreases HC (ppm): decreases at A20 Smoke (%): decreases NO_x (ppm): close Due to engine speed (rpm)

86	Searched by (Gvidonas Labeckas) et al. [106]	ethanol–diesel–biodiesel blends (DF), (E5), (E10), (E15) blends with anhydrous (99.8%) ethanol (E).	direct injection diesel engine 4-stroke, 4-cylinder, naturally aspirated and 60 kW diesel engine three ranges of speed.1400, 1800 and 2200 rpm	BSFC (g/kWh): increases at E15, E15B BTE (%): =E15B , decreases Due to engine speed (rpm)	NO_x: decreases HC: decreases CO: decreases Smoke: decreases Due to engine speed (rpm)
87	Searched by (Md. Nurun Nabi) et al. [107]	diesel- waste cooking oil biodiesel blends D100, B2(20B80D2+2%O_2), B4(40B60D+4%O_2), B6(40D60B+6%O_2)	diesel engine 4-stroke, High-pressure common rail fuel injection, 6-cylinder, Turbocharged, three ranges of speed at loads of 0, 25, 50, 75 and 100%.	Brake power(kW): increases BSFC (g/kWh): decreases at B2 Due to engine load (%) and speed (rpm)	CO (%): decreases HC (ppm): decreases Smoke (%): decreases NO_x (ppm): increases closed to B6 Due to engine load (%) and speed (rpm)
88	Searched by (M. Krishnamoorthi) et al. [108]	diesel/aegle marmelos oil/diethyl ether blends neat diesel (F0), diesel+bael oil +diethyl ether (DEE) in the (% vol.) 80:15:5 (F1) and 60:30:10 (F2)	KIRLOSKAR DI compression ignition diesel engine, VCR multi fuel, vertical, water cooled, direct injection, 4-stroke, 1-cylinder and naturally	BTE: increases F (1) at IP of 230 bar, CR18 and IT of 23 ° bTDC IT. BSFC (g/kWh): decreases Due to engine CR, IP, IT	CO and HC: decreases at compression ratio ranges (16.5 - 17.5). NO_x: decreases (with DEE) Smoke: decreases (with DEE)

		RSM	aspirated engine		Due to engine CR, IP, IT
89	Searched by (Ümit Ağbulut) et al. [109]	diesel–biodiesel–alcohol blends D: neat diesel C:cottonseed methyl ester E: ethanol (D100), (D80C20), (D90E10) and (D70C20E10)	diesel engine at engine speeds (1750, 2250, 2750 and 3250) rpm under full load.	Torque (Nm): decreases power(kW): decreases EGT (°C): decreases Due to engine speed (rpm)	CO (%): decreases HC (ppm): decreases Smoke (%): decreases NO_x (ppm): decreases Due to engine speed (rpm)
90	Searched by (E. A. Elsharkawy) et al. [110]	Biodiesel (castor oil methyl-ester) –Diesel (CD10, CD20, CD30) and Biodiesel –Kerosene Blends (CK10, CK20, CK30)	CI diesel engine direct injection, 4-stroke, 1-cylinder , air cooling engine power/load (0%, 20%, 40%, 60%, and 80% load) with engine speed of 2000 rpm.	BSFC (g/kWh): increases at mostly BTE (%): decreases at mostly Due to engine loads (%)	NO_x (ppm): decreases at CK blends CO (ppm): decreases at CD blends Due to engine loads (%)
91	Searched by (Márcio A. S. de Carvalho) et al. [111]	biodiesel, ethanol, and diethyl ether blends fossil diesel (D100), - B20 (20% biodiesel + 80% diesel) - B20E (90% B20 + 10%	MWM 229.4 diesel engine power: 54 kW, mechanical fuel injection, 4- cylinder, in line; aspirated , Max. power 54 kW at 2500 rpm and Mechanical direct injection	Torque (Nm): decreases BSFC (g/kWh): increases BTE (%): increases with	CO (%): decreases with engine load increasing. HC (ppm): decreases with engine load increasing. Smoke (%): decreases at

		ethanol) B20E + DEE (95% B20E and 5% DEE)	with (25%, 50% and 75%) of engine brake power	engine load increasing Due to engine loads (kW)	mostly NO$_x$ (ppm): increases with engine load increasing Due to engine loads (kW)
92	Searched by (Yuvarajan Devarajan) et al [112]	(BD100) and different proportions of cyclohexanol blends (BD90COH10, BD80COH20, BD70COH30) and diesel D100	(AVL 5402). diesel engine 4-stroke, 1-cylinder, air cooled type, naturally aspirated, Direct Injection (DI)	EGT (°C) : decreases Due to engine loads (kW)	CO$_2$ (%): increases CO (ppm): decreases at same speed and increases with engine load increasing HC (ppm): decreases at same speed and increases with engine load increasing Smoke (%): decreases at same speed and increases with engine load increasing NO$_x$ (ppm): increases Due to engine loads (kW)
93	Searched by (M.A. Asokan) et al [113]	Juli flora biodiesel and its diesel blends (B20, B30, B40, and B100) compared with diesel (D100).	4- stroke, 1- cylinder diesel engine	BSFC (g/kWh): increases BTE (%): decreases Due to engine loads (%)	CO (%): increases except B100 at load more than 60% HC (ppm): decreases Smoke (%): increases

					NO_x (ppm): increases close to D100 Due to engine loads (%)
94	Searched by (ChandraKishore) et al. [114]	Karanja Kusum and Mahua methyl esters karanja methyl esters, kusum methyl esters and mahua methyl (10%, 20% and 40%) blending.	DI diesel engine 4- stroke, Water cooled	BSFC (g/kWh): increases except at low load BTE (%): decreases except at low load Due to engine loads (kW)	Studied the performances
95	Searched by (Abhishek Sharma) et al. [115]	Raw Pongamia seed oil biodiesel-diesel blends (B10, B20, B30, and B40). Taguchi and utility theory	diesel engine 4-stroke, 1-Cylinder, power 5.2 kW at 1500 rpm and CI engine	BTE (%): decreases Best blending of Pongamia (biodiesel 10%) at fuel injection timing 23°bTDC, and injection pressure 22 MPa.	HC (ppm): decreases NO_x (ppm): increases Smoke (%): decreases
96	Searched by (K.A. Abed) et al. [116]	Biodiesel from Jatropha, palm, algae, and waste cooking oils blends (B10, B20)	diesel engine 4-stroke, 1-cylinder, Direct injection, air cooling	Studied the emissions	CO (%): decreases at (B20, 20kW) load the most decreasing. CO_2 (%): decreases except at (WCOB) load the most decreasing

					HC (ppm): decreases Smoke (%): decreases NO$_x$ (ppm): increases Due to engine loads (kW)
97	Searched by (Murari MohonRoya) et al. [117]	canola oil biodiesel–diesel, biodiesel–diesel-additive (A) Wintron XC 30 (2 vol.%) and kerosene (K)–biodiesel blends volume percent of biodiesel(B) (B0,B5,B10,B20,B50,B100) Additive Wintron XC 30 (2 vol.% of B): (A) (B5A,B10A,B20A,B50A, B100A) kerosene (K) (K0,K5,K10,K20,K50,K100)	diesel engine direct injection (DI) , 4-stroke , 2- cylinder and power 11.2kW at 1800rpm engine loads (5%, 50% and 95% of rated load) at the rated speed of 1800 rpm	BSFC (g/kWh): increases at low load except at (K blends) with medium and high loads Due to engine loads (%)	CO(g/kWh): decreases except at (K blends) HC(g/kWh): decreases except at (K blends); At high loads all blends decreases NOx(g/kWh): decreases at all (K blends) with all loads, except NO$_2$ at med load Due to engine loads (%)
98	Searched by (K.V. Yatish) et al. [118]	bauhinia variegata biodiesel and diesel blends B10, B20, B30, B40 and	Kirloskar make diesel engine. 1- cylinder , 4-stroke , water cooled , direct injection CI	EGT (℃): decreases BTE (%): decreases	CO$_2$ (%): increases CO (%): decreases

		B100 RSM	engine , power 4.4kW at 1500 rpm (0%, 25%, 50%, 75% and 100%). of engine load	BSFC (g/kWh): increases Due to engine loads (%)	HC (ppm): decreases NO$_x$ (ppm): increases Due to engine loads (%)
99	Searched by (M.Krishnamoorthia) et al. [119]	diesel - aegle marmelos oil - diethyl ether (DEE) blends 100:0:0 (D), 70:20:10 (B1), 60:30:10 (B2), 50:40:10 (B3)	Kirloskar VCR diesel engine, 1- cylinder, 4-stroke, direct injection, variable, water cooled, and naturally aspirated engine compression ratio (CR14, CR15, CR16, CR17.5) 0%, 25%, 50%, 75% and 100% engine load at constant speed	BTE (%): increases at B2 Due to engine loads (%)	CO (%): decreases best at B2 HC (ppm): increases less than CR14 best at B2 Smoke (%): increases less than CR14 NO$_x$ (ppm): increases at more than CR18 best at B2 Due to engine loads (100%) B2 (60% diesel: 30% bael oil: 10% DEE)
100	Searched by (Abhishek Paul) et al. [120]	diethyl ether (DEE) and ethanol(E) blends DEE and ethanol together with Diesel(D).	Kirloskar, Model TV-1 VCR diesel engine, Direct injection, CI engine, 1-cylinder, 4- stroke, max. power 3.6 kW and water	BTE (%): increases at DEE (5%) except D90DEE10 BSFC (g/kWh): decreases at DEE (5%) except	CO (%): decreases at D90DEE10 HC (ppm): decreases

		6- blends D95DEE5 and D90DEE10 blends. D90DEE5E5 D85DEE5E10 D85DEE10E5 and D80DEE10E10	cooled. At 6 - different loads engine (kW) speed of 1500 rpm	D90DEE10 Due to engine load (kW) D80DEE10E10 blend was the best BTE increases, BSFC , NO_x, HC, CO at high loads and smoke decreases	Smoke (%): decreases NO_x (ppm): decreases at D85DEE5E10 D85DEE10E5 and D80DEE10E10 Due to engine load (kW)

PART 3

PARTS OF COMBUSTION AND EMISSIONS IN DIESEL ENGINES

In this section, the parts of combustion in a diesel engine and post-combustion emissions will be discussed.

3.1. PARTS OF COMBUSTION IN DIESEL ENGINES

3.1.1. Ignition Delay Period

The fuel line pressure or the amount of injector needle lift is used to calculate when fuel is injected into the cylinders. The rate of heat release or the second derivative of the in-cylinder pressure curve can be used to predict when ignition will start. The ignition delay is the period that passes between the injection of fuel into the combustion chamber and the beginning of its ignition. In Figure 3.1, the region I located in between regions a and b expresses this portion. In this area, a denotes the start of the injection process, while b denotes the initial point of ignition. Figure 3.1 provides a clearer picture of the conditions in the area between these two scenarios. The physical elements influencing the production of the fuel jet and conditions in the engine's suction line (pressure, temperature, and speed) also have an impact on the ignition delay. These elements change based on the engine's operating conditions, the architecture of the combustion chamber and fuel injection system, and other factors.

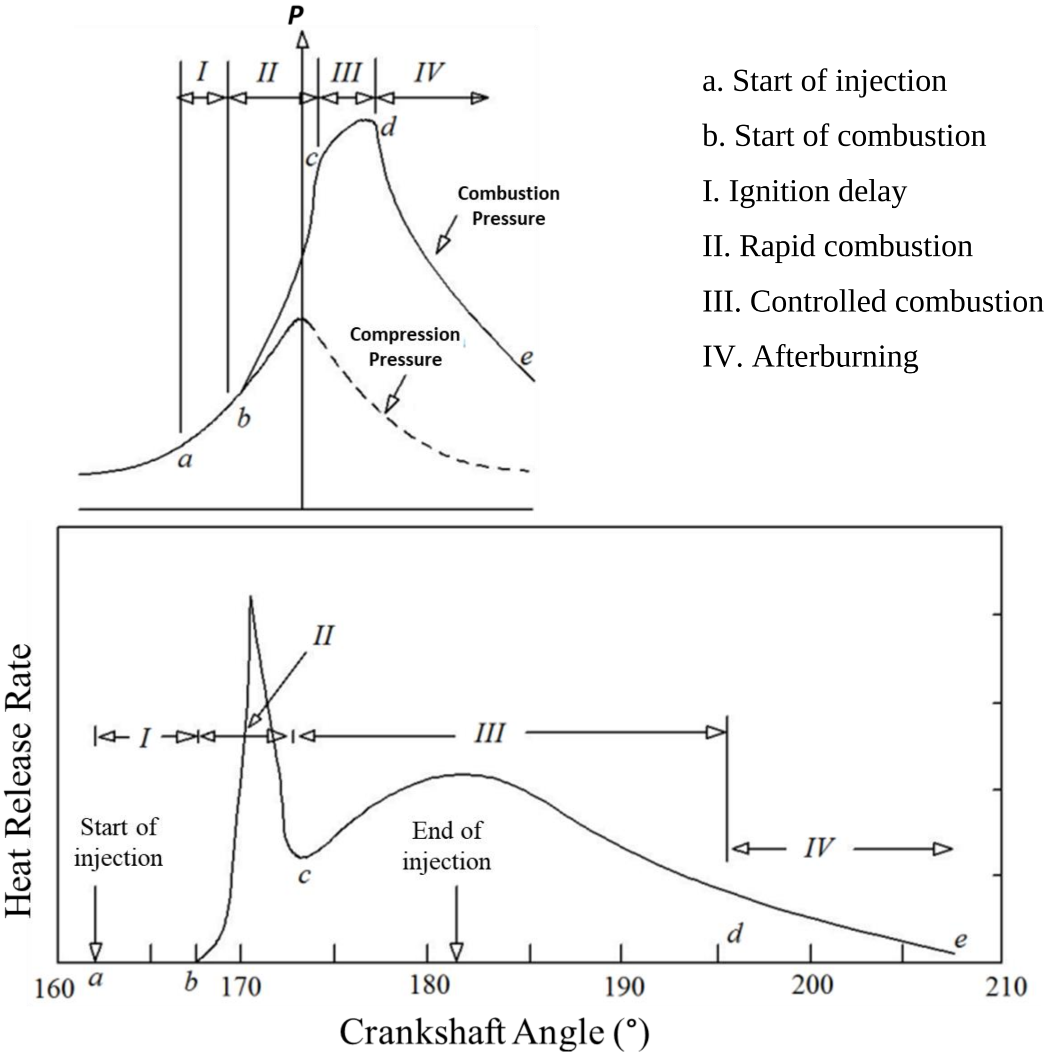


Figure 3. 1. Combustion periods in compression ignition engines

The timing (advance) of the injection, injector spray pressure, volume of fuel sprayed from the injector, velocity of fuel spray, shape of the spray jet, and droplet diameter are fuel system variables that have a significant impact on the creation of the fuel jet. The combustion design, intake pressure and temperature, compression ratio, injection advance, cooling water and lubrication temperature, engine speed, and waste gas conditions in the cylinder all affect the engine's suction or charging conditions. There are two types of ignition delay: chemical and physical. The period between the injection of fuel and the time it takes for the fuel to reach conditions favourable for the initiation of chemical reactions is known as the physical ignition delay. The sprayed fuel atomizes, evaporates, mixes with the air, and achieves the auto-ignition temperature in the physical ignition delay section.

The type and physical characteristics of the fuel affect the physical ignition delay. In heavy fuels, the physical igniting delay is greater than in light fuels. Increasing spray pressure, high end-combustion temperatures, strong turbulence, and atomization can all help shorten the physical ignition delay. Reactions begin slowly during the chemical ignition delay and pick up speed until ignition or ignition happens. Usually, a chemical reaction takes longer to ignite than a physical one does. However, in-cylinder temperatures have a significant impact on the delay in chemical ignition. The chemical ignition delay gets shorter as in-cylinder temperature rises, and the physical ignition delay might also get shorter.

3.1.2. Rapid Combustion Period

The instantaneous combustion time is the interval from the beginning of ignition in the combustion chamber to the first trough after the heat release rate reaches its highest value. The fuel-air mixture burns quickly during the instantaneous combustion period, creating a mixture that is combustible during the ignition delay interval. Region II in Figure 3.1 is the region that explains the sudden combustion period. The section between regions b and c is referred to as this segment. The beginning of combustion is in region b. The pressure and temperature immediately rise, and the initial spark instantly ignites the entire mixture in the cylinder, signalling the conclusion of this section. The sudden combustion period is when the heat release rate is at its highest. The ignition delay has a significant impact on the maximum in-cylinder pressure and heat release rate during the flash combustion period. The amount of fuel injected into the cylinder before to the instantaneous combustion period builds up throughout the lengthy ignition delay period and burns quickly during the instantaneous combustion period, raising the cylinder pressure and heat release rate. The end-combustion temperatures and pressures rise together with the pressure increase rates in this circumstance.

3.1.3. Controlled Combustion Period

This section, shown in region III in Figure 3.1, starts with section c. The flash combustion phase is completed in section c. The pressure drops in the d portion, which is where it happens. The fuel-air mixture quickly burns during the instantaneous combustion period after forming a mixture in the flammable range during the ignition delay interval. The unburned fuel-air combination left over from the flash combustion period or the fuel that is still being pumped control the diffusion-controlled combustion period. The conclusion of the instantaneous combustion period marks the beginning of the diffusion-controlled combustion period, which lasts until the heat release rate reaches 90–95 percent or, more generally, until the end-combustion temperatures are at their highest.

3.1.4. Afterburning Period

The termination of the injection phase does not immediately bring an end to combustion. Fuel particles that are still unburned or only partially burned in the combustion chamber encounter oxygen and start to burn. The maximum end-of-combustion temperature and the beginning of the diffusion-controlled combustion period mark the beginning of the afterburning period, which lasts until a portion of the expansion time. As expansion time approaches, the afterburning period's heat release rate slows down. Because rich combustion products or soot particles from a very little amount of unburned fuel produce heat during the afterburning process. The cylinder's typical gas temperatures drop during this time. Nitrogen oxide (NO) emissions typically happen during the rapid combustion phase, whereas soot emissions generally happen during the diffusion-controlled combustion phase. Pollutant emissions that are created and may be observed in engine exhaust are directly proportional to the duration of combustion.

3.2. EXHAUST EMISSIONS IN DIESEL ENGINES

3.2.1. Hydrocarbon (HC) Emission

Fuel evaporation or insufficient combustion result in HC emissions. Complete combustion needs enough oxygen, and HC emissions rise when this requirement is not met. There are several causes for HC emissions. HC emissions may be brought on by incomplete combustion, carbon particles in the cylinder, flame extinction in the cylinder, issues with the injection system, or liquid fuel that is still present in the cylinder. HC emissions are those brought on by insufficient fuel combustion. Insufficient oxygen levels or insufficient temperature are the main contributors to this emission. Although unburned fuel-air mixtures are the main source of HC emissions, there are other ones as well. These sources include incompletely burnt lubricants, engine oil mixing into the cylinder, and prolonged ignition delay. Lean fuel/air combinations might result from malfunctions like vacuum leaks and seal leaks, which will boost HC emissions once more. A fuel with hydrocarbon components is diesel fuel. The fuel doesn't burn entirely due to issues including flame extinguishment brought on by heat losses in the cylinder and the mixture failing to ignite, which results in hydrocarbon emissions from the exhaust [121]. Increased hydrocarbon emissions are caused by fuel particles that have accumulated on the cylinder walls [122].

3.2.2. Carbon Monoxide (CO) Emission

Diesel engines need higher compression ratios than petrol engines because they need more air to operate than the latter. Diesel engines produce fewer CO emissions than other types of engines because of the high amount of oxygen in the combustion chamber. The air excess coefficient is one of the most crucial factors in CO production [123] . It is possible for deposits to accumulate because carbon monoxide is an odourless gas that is heavier than air. The main cause of CO formation in the cylinder because of combustion is a lack of oxygen during combustion. Uneven fuel-air mixing can result in a lack of oxygen in a particular region of the cylinder, which can result in the creation of CO. If the extra air coefficient is high, CO production in diesel engines is minimal [124].

3.2.3. Carbon Dioxide (CO_2) Emission

CO_2, which is a component of the entire combustion products produced by diesel engines, is not regarded as a polluting fuel at levels of reasonable concentration. The impact of global warming is growing when CO_2, the most significant greenhouse gas, reaches higher quantities. It is one of the primary elements of any fuel with a hydrocarbon base that is burned to produce emissions. The number of things that contribute to CO_2 production, such as the number of industries and cars, must be decreased or at the very least made more efficient if major reductions in CO_2 are to be achieved [125].

3.2.4. Nitrogen Oxide (NO_x) Emission

Nearly 90% of NO_x produced by diesel engines is NO, 5% is NO_2, and the remaining 20% is made up of various nitrogen oxides [126].The nitrogen molecule in the air disintegrates and mixes with oxygen to generate NO_x when the local temperatures in the combustion chamber are higher than 1800 K. Oxygen concentration and high temperature are the primary causes of NO_x emissions. The fuel also contains nitrogen, which oxidises during combustion to produce nitrogen oxides. Regardless of the flame's temperature, the air's N_2 bonds can easily break the carbon-nitrogen bonds in the fuel. As a result, when compared to thermal creation, NO_x formation is easier and more often when the amount of nitrogen in the fuel is high. Additionally, during combustion, a fuel-rich mixture and a flame zone abruptly form NO. Nearby oxygen (O) and hydroxide (OH) produce NO_x emissions. This is why temperature has less of an impact on the abrupt production of NO_x [127].

The extended burning of quickly flammable fuels causes an increase in NO_x emissions. Due to the oxygen, they contain, biodiesel fuels may result in higher nitrogen oxide emissions when compared to diesel fuel. The addition of oxygen improves combustion efficiency, raises the temperature at which combustion ends, and triggers the oxidation of nitrogen gas into nitrogen oxide emissions [128].Additionally, because of the high viscosity of biodiesel fuel, it has poor atomization quality and produces more NO_x emissions at high temperatures due to uncontrolled combustion brought on by the buildup of fuel in cold areas [129].

3.2.5. Particulate Matter

Carbonaceous soot particles, volatile organic compounds, and trace amounts of carbonaceous ash make up most of the particulate matter (PM) released by diesel engines [130].PM has a wide range of detrimental consequences, including those on visibility, the environment, and human health. Numerous studies show a weak but enduring link between human health and the amount of PM (mainly microscopic carbon particles) in the environment. Additionally listed are much more severe complications include breathing problems, lung cancer, heart failure, and stroke [131].The EURO emission regulations for diesel engines have had the greatest requests to be lowered in the past ten years, along with NO_x and PM emissions.

The three main causes of PM emissions are rich combustion, lubricating oil, and fuel composition. According to their chemical makeup, PM emissions can be categorised as organic or inorganic, or according to their physical states, as solid, volatile, or semi-volatile PM [132].The type of fuel utilised, and the combustion procedure must be modified to lower these emissions. Additionally, technology for exhaust aftertreatment like diesel particulate filters and EGR must be developed. Fuel must have the right viscosity and surface tension levels in addition to having a high cetane number, a high oxygen content, a low aromatic content, and a low sulphur content to limit PM emissions [133].

Direct fuel injection into the cylinder or pre-combustion chamber of a diesel engine causes high particle emissions. Because of the relatively sluggish mixing, some fuel is left in contact with the hot, fuel-rich gases for long enough to make high molecular weight HCs, which eventually form soot. Despite the substantial amount of air that is generally present in a diesel engine, subsequent mixing is slow enough for many particles to avoid oxidation.

PART 4

ALTERNATIVE FUELS FOR DIESEL ENGINE

Fossil fuels are the most prevalent type of energy in use today [134]. Fossils are the remains of extinct animals that have endured for a very long time without degrading. Energy sources known as fossil fuels are created when dead animals and plants decompose under high pressure. Additionally, they endure millions of years underground in an oxygen-poor environment. It can be used in a wide variety of industrial settings. Fossil fuels can be utilized for a variety of purposes, including running factories, producing electricity, powering internal combustion engines, and providing heat [135]. Fossil fuel consumption has constantly increased, especially since the early 20th century, because of rising population and technological advancements worldwide [136]. This increased usage of fossil fuels depletes reserves and harms the environment. Because burning fossil fuels releases CO_2, which hastens climate change [137]. Fossil fuels are the main source of these emissions, which are what primarily contribute to climate change by releasing greenhouse gases like CO_2 into the atmosphere [138]. Climate change is the biggest hazard to human health in the twenty-first century, according to the World Health Organization. To find solutions to these problems related to global warming and dependence on fossil diesel, a green and sustainable fuel needs to be discovered [139-141]. There are many different alternative fuels used for this purpose. The most preferred fuel type, on which research continues, is biofuels. The development process for biofuels shown in Figure 4.1 has gone through four generations based on various production methods as detailed in Table 4.1.

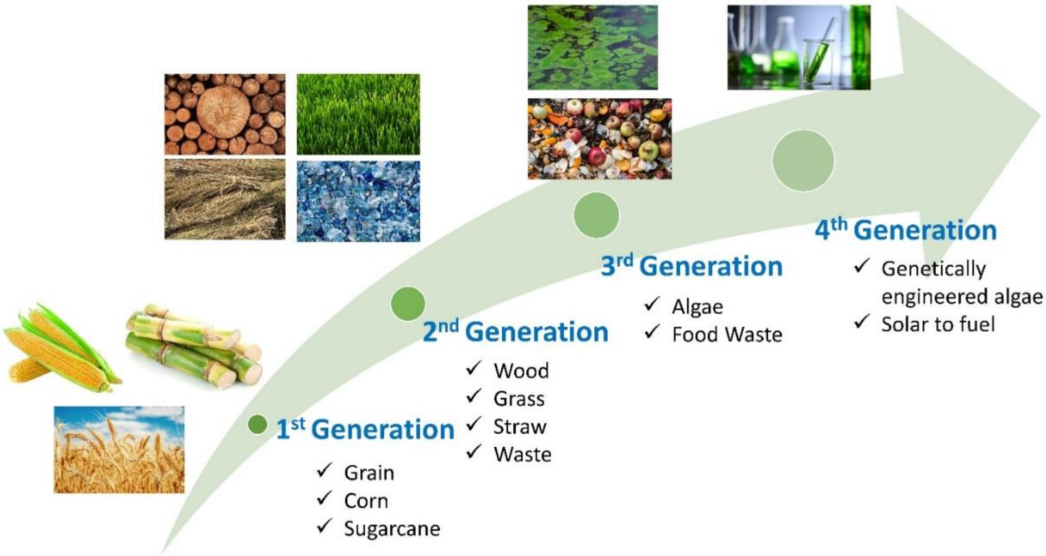


Figure 4. 1. The four distinct generations of biofuels' development.

Table 4. 1. Biofuel classification.

	First Generation	**Second Generation**	**Third Generation**	**Fourth Generation**
Raw materials	• Corn • Sugarcane • Animal fats • Vegetable oils • Grain	• Wood • Grass • Straw • Waste • Inedible plants	• Algae • Food waste	• Genetically engineered algae
Products	• Bio-alcohol • Biodiesel • Biogas • Solid biofuels	• Cellulosic • Ethanol • Methanol • Biodiesel	• Biodiesel • Gasoline • Butanol • Jet fuel • Methane	• Biodiesel • Bio-alcohol
Processes	• Transesterification • Anaerobic digestion • Biodegradation • Fermentation	• Gasification • Pyrolysis • Biochemical conversion	• Biochemical transformation • Thermochemical transformation • Chemical reaction	• Metabolic engineering technology

Typically made from plant or animal fats, biodiesel is a type of biofuel that can be used in place of conventional diesel fuel that is based on petroleum. Because it is made from renewable resources and has the potential to lower greenhouse gas emissions and reliance on fossil fuels, it is regarded as an environmentally beneficial substitute for conventional diesel.

The choice of suitable feedstocks, or the initial supply of the raw ingredients used to make the fuel, is the first step in the manufacture of biodiesel. Vegetable oils (like soybean, canola, or palm oil), animal fats (like tallow or poultry fat), and waste products are frequently used as feedstocks for the manufacturing of biodiesel. The characteristics of the biodiesel produced can vary depending on the feedstock used. Transesterification is the main chemical procedure used to turn these feedstocks into biodiesel. This process involves combining the triglycerides (fats and oils) in the feedstock with an alcohol, commonly methanol or ethanol, in the presence of a catalyst (often sodium or potassium hydroxide). The major constituents of biodiesel are glycerol and fatty acid methyl or ethyl esters, which are produced by this method from triglycerides. The mixture usually goes through separation after transesterification to separate the biodiesel from glycerol and other byproducts. This is frequently accomplished using techniques like centrifugation, decanting, or settling. The resulting biodiesel is next cleaned and refined to get rid of any contaminants, catalyst residues, or water that may have remained.

Once refined, biodiesel has traits that are comparable to those of diesel fuel made from petroleum. It burns cleanly and has a high cetane rating, a sign of strong ignition quality. Because biodiesel contains less sulphur, it emits less sulphur compounds when burned. Additionally, it possesses effective lubricating qualities that can increase the lifespan of engine parts and fuel system components. It is possible to mix biodiesel with conventional diesel fuel. B5 (5% biodiesel and 95% diesel) and B20 (20% biodiesel and 80% diesel) are examples of common blends. The specific mix ratio may differ by location and be governed by legal requirements.

Compared to petroleum-based diesel, biodiesel is frequently thought to be more environmentally benign. It can be produced domestically and is renewable, which lessens reliance on foreign oil. Because the carbon absorbed by the plants that provide the feedstock balances out the carbon released during burning, it often results in lower levels of CO_2 emissions. While biodiesel has many benefits, it also has drawbacks, including limited feedstock supply, rivalry with food production, and worries about shifting land usage. Additionally, biodiesel and petroleum diesel may have distinct cold flow characteristics, which may be a factor in colder climates.

In conclusion, biodiesel, which is created through the transesterification of vegetable or animal fats, is a renewable and cleaner-burning substitute for conventional diesel fuel. Environmental issues, energy security, and initiatives to cut greenhouse gas emissions in the transportation sector are the driving forces behind its development.

After biodiesel, another preferred alternative fuel is alcohols. Alcohols, especially ethanol and methanol, can be utilized in a variety of ways in diesel engines, mostly as additives or as blends with diesel fuel. As oxygenate additives, alcohols like ethanol and methanol can be added to diesel fuel. These oxygenates raise the fuel's oxygen content, which aids in improving combustion efficiency. Reduced emissions of some pollutants, such as CO and PM, may result from improved combustion. Additionally, oxygenates can raise the fuel's cetane number, which impacts how well it ignites. Alcohols like ethanol and methanol are being researched and developed as potential replacement fuels for compression-ignition (diesel) engines. These alcohols, which have higher octane ratings, can be utilized in dual-fuel engines or adapted diesel engines, which can run on both alcohol and diesel fuel. Diesel fuel can be supplemented with methanol to reduce gelling and enhance cold-weather performance. Diesel fuel can gel or become overly viscous in colder regions, which can cause problems with engine starting and performance. Diesel fuel can have its freezing point lowered by methanol, making it more appropriate for usage in colder climates.

It's significant to highlight that using alcohols in diesel engines may present certain difficulties and issues. Corrosion problems, fuel compatibility problems, and the requirement for engine modifications or unique fuel formulations to accommodate alcohol-blended fuels are a few of these. Additionally, different regions and nations may have different laws restricting the usage of diesel fuels combined with alcohol.

Considering local conditions and requirements, the usage of alcohols in diesel engines should be carefully assessed.

PART 5

MATERIAL AND METHOD

5.1. PREPARATION OF BIOFUELS FROM USED COOKING OIL OR WASTE

The preparation process was carried out in several stages (collection, filtration, separation, chemical treatments, separation, washing, separation, heating, filling) as shown in Figure 5.1 below:

Figure 5. 1. Waste cooking oil biodiesel production

1. Collecting used oil from kitchens, restaurants, potato gypsum factories, and shops that use cheap vegetable oils to fry vegetable or animal materials, such as oils expired or unfit for human consumption due to poor storage or rejected by laboratory tests of the Central Agency for Standardization and Quality Control approved in the Republic of Iraq or other similar examination centres in each country, and others in plastic or metal containers.

2. Keep the waste cooking oil used in other plastic or glass containers in a quiet place for more than a day to deposit suspended substances from frying vegetables, foods, etc. Leave the precipitates at the bottom of the bowl and collect the top layer of used oil in other plastic or glass containers.
3. Filter what is collected from the above paragraph with a metal mesh filter to remove coarse plankton from other foods and collect the resulting oil after filtering in transparent glass containers that can be heated.
4. Heat the filtered oil from the above paragraph to a temperature of more than 70 centigrade degrees to make the fluid light.
5. Use a paper filter to get rid of fine impurities and collect the resulting oil in a flask of a heated glass vessel listed in a standard fixed and even volume scale.
6. Calculate the amount collected after filtration to prepare the reducing substance of the waxy substance (glycerol) from one litter of oil produced by exchange esterification.
7. Prepare the auxiliary material according to the following steps:
    - A glass jar divided in equal degrees is used for the unit of volume measurement of millilitres, where 250 millilitres of laboratory methanol of purity (99.95%) are used per 1 litter of waste oil extracted.
    - We use an electronic balance for weighing (5 g of potassium hydroxide per 250 ml of methanol alcohol) and mix them in a transparent glass jar and dissolve well in methanol using a recycling device and for a period of time (hour) to form the auxiliary solution potassium hydroxide is stored in a closed container as the material is fluidized and absorbs moisture, which prefers mixing quickly to avoid absorption of water vapor from ambient air.
8. The total oil is reheated in a glass container that can be heated to 110 degrees Celsius using a heating and mixing device and a glass heater to get rid of the water contained in the oil obtained after paper filtration.
9. Monitoring the temperature of the fluid until it reaches a temperature of 60 degrees Celsius using a mercury thermometer to measure the temperature.
10. Adding the auxiliary substance above the measured amount of oil depending on the amount of sample to be prepared.

11. The prepared quantity is rotated and mixed in a transparent glass container that can be heated for up to 30 minutes to ensure the mixing of the mixture using a device.
12. The mixture is left in a conical transparent glass container with a lock at its lower end for a period of up to 4 hours or more to ensure the process of separation of the waxy substance from the prepared oil.
13. After the liquid in the pot has become composed of two semi-transparent upper layers and a dark lower one, a smaller amount represents the waxy substance, where a separation flask or other tool is used to collect the upper oil in the separation flask by extracting all the dark-coloured wax with a high density.
14. The product is left in a transparent glass container for more than another hour to make sure that there is no waxy substance that may precipitate again.
15. The prepared product is washed with the addition of salt-free base water using 1 litter of water per 1 litter of the product in a transparent plastic package and shaken with the technique of light and very slow rotation and in a cylindrical shape to extract insoluble alcohol in the second process and for a period until the colour of the product change.
16. The product mixed with water is placed in the glass separation flask again and waited for the process of separation of water from the fuel where it becomes softer for a while.
17. The upper part is separated from the coloured low-density fuel about denser water.
18. The product is heated in a transparent glass container that can be heated to 102 degrees Celsius with rotation using a device to get rid of water until the colour of the product changes to a visible transparent shape .
19. Biofuels are filled with packages for physical and chemical laboratory tests to identify the properties of the prepared fuel and are considered ready for use in mixing operations with diesel fuel or the use of a unit in the operation of diesel engines as an alternative fuel.
20. After conducting laboratory tests on samples of the extracted fuel, the results were obtained in comparison with the characteristics of conventional oil fuel, the standard standards or specifications that were adopted.

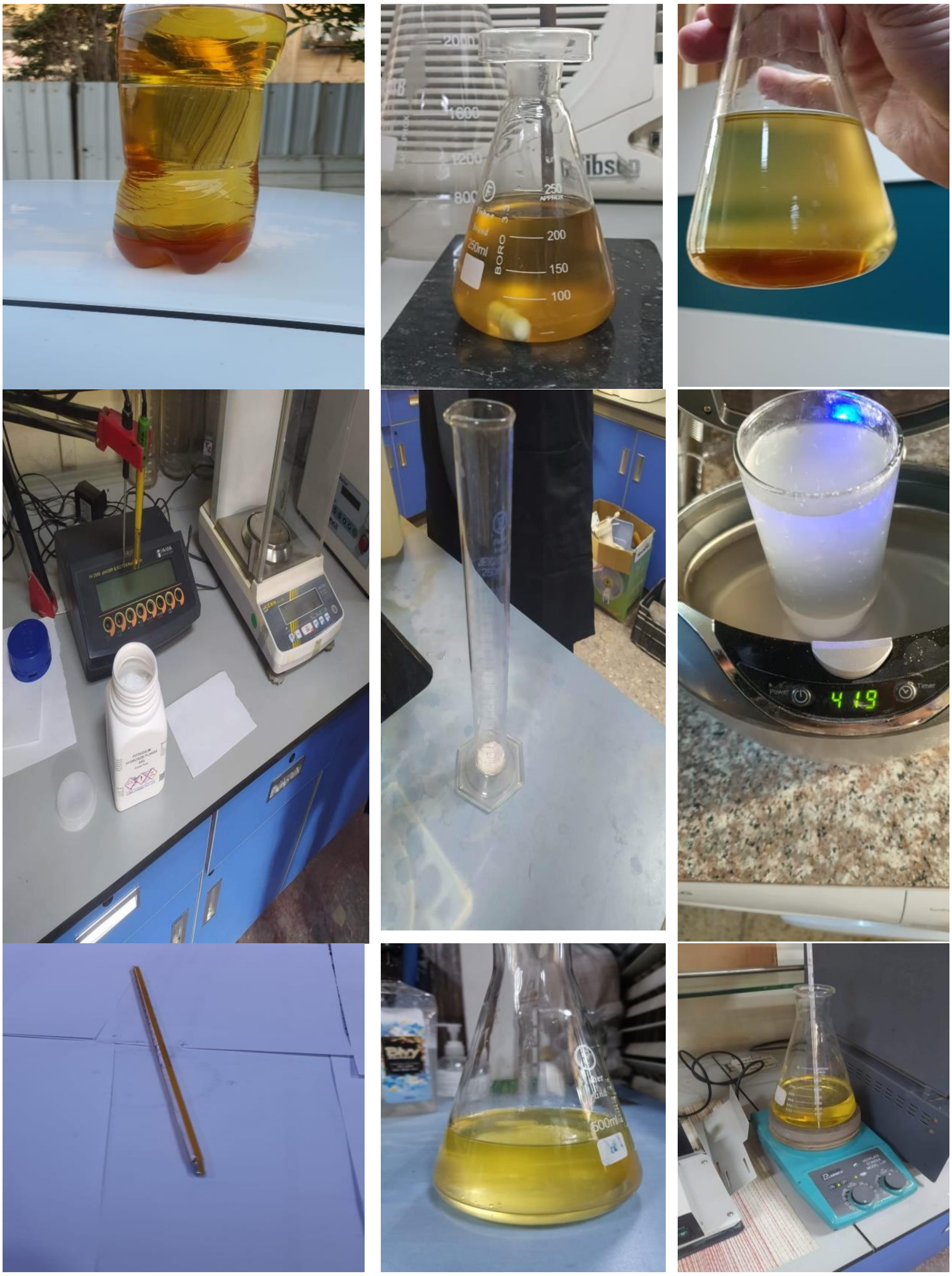


Figure 5. 2. Photos of biodiesel production stages

Figure 5. 3. More photos of biodiesel production stages

Some fuel properties of produced biodiesel and diesel are tabulated in Table 5.1.

Table 5. 1. Properties of diesel and waste frying oil biodiesel

	Diesel	**Biodiesel**
Flash point (°C)	175	179-184
Density (g/cm^3)	0.883	0.898
Oxygen content (wt. %)	56	64
Calorific value (kJ/kg)	43199	35236
Sulphur (ppm)	5.5	< 15
Kinematic viscosity (mm^2/s)	4.24	5.421

5.2. EXPERIMENTAL SETUP

Experiments have been performed in Engine Research Laboratory, Karabuk University. to evaluate the performance and emission of diesel and biodiesel fuels blends.

5.2.1. Diesel Generator

Experimental studies were carried out using the Lutian 3GF-ME brand diesel generator shown in Figure 5.4. The characteristics of the diesel engine and generator are shown in Table 5.2 and Table 5.3 respectively.

Figure 5. 4. Diesel generator

Table 5. 2. Specifications of diesel engine

Model	LT-178F/FA	
Engine Type	single cylinder,4 stroke, Air Cooled diesel engine	
Combustion system	Direct injection	
Bore x Stroke	78x62/78x64 mm	
Displacement	296/305 cc	
Engine Speed	3000 rpm	3600 rpm
Max. Output	5.7 HP	7HP
Continuous Output	5.2 HP	6HP
Power Take Off	Crankshaft or camshaft (camshaft PTO rmp is1/2)	
Starting System	Recoil or Electric	

Table 5. 3. Specifications of generator

Frequency (Hz)	50
Max. AC Output (Kva)	3
Rated AC Output (Kva)	2.8
DC Output (V-A)	12.7A
Rated Voltage (V)	230
Rated Current (A)	7.8 / 15.6
Rated Speed (rpm)	3000
Phase	Single Phase
Start Type	Recoil/Battery Start
Dimensions (L x W x H)	695 x 470 x 540
Weight (kg)	56
Engine Type	Single-cylinder, Vertical, 4-Stroke
Displacement	211
Engine Power	7HP
Fuel Tank Capacity (lt)	12.5

5.2.2. Gas Analyzer

In this study, the BİLSA MOD 2210 WINXP-K gas analyser was used for emission measurements. BİLSA MOD 2210 WINXP-K is following TS ISO 3930 standards for gasoline, LPG, and CNG-powered vehicles with a positive ignition engine, and with TS ISO 11614 standards for diesel-powered vehicles. BİLSA MOD 2210 WINXP –K is with Type Approval Certification from the Republic of Turkey Ministry of Industry and Technology Compliance with ISO 3930 and OIML Class Standards. For gasoline-powered vehicles, this device is used to measure the values of (CO, CO_2, HC, O_2, NO_x, Lambda, and AFR,) using a Non-dispersive Infrared System. For diesel-powered vehicles, this device functions with an Opacity method. The Opacity of Exhaust Gas is measured in K, %, gr/m^3. Figure 5.5 shows the gas analyser. The technical specifications of the gas analyser are tabulated in Table 5.4.

Figure 5. 5. Gaz analyser

Table 5. 4. Measuring ranges and sensitivities of gas analyser

Variable	Measuring Range	Accuracy
CO	0-10.0 %vol.	0.001%
Lambda	0.5 – 2.00	0.001
NO_x	0-5000	1 ppm
O_2	0-10 % vol.	0.01%
HC	0-10.000 ppm vol.	1 ppm
CO_2	0-20.0 % vol.	0.001%
Speed	0 – 9990 rpm.	10 rpm.

5.2.3. Smoke meter

Through it, the density of smoke coming out of the internal combustion engine as a result of its operation, its extent and opacity is measured, and through it shows the efficiency of combustion of the fuel used to operate the engine to ensure the engine is working well and contributes to improving fuel economy and protecting the environment (the device used is from the Turkish company Bilsa). Figure 5.6 shows the smoke meter.

Figure 5. 6. Smoke meter

5.2.4. Laptop

For monitoring and controlling, collecting the results of laboratory experiments, and performing mathematical calculations and graphs to facilitate discussing the results and arriving at the conclusions of the research study. Figure 5.7 shows the laptop.

Figure 5. 7. Laptop

5.2.5. Electrical load panel with control unit

It requires conducting experiments on a single-cylinder, four-stroke, direct injection, air-cooled diesel engine and operating it using fossil fuel diesel and fuel mixtures with biodiesel to place different electrical loads that include ten halogen lamps arranged in two rows, each row consisting of five halogen lamps, each lamp in first row with a capacity of (500 watts), and the second row also consists of five halogen lamps, each lamp with a capacity of (1000 watts), all of which are connected to circuit breakers (10) and connected to a small control unit to control the loads placed on the engine by connecting it to the laptop, as shown. With pictures and illustrative diagrams. Figure 5.8 shows the electrical load panel with control unit.

Figure 5. 8. Electrical load panel with control unit

5.2.6. Small laptop cameras

We use two small cameras for monitoring, the first to monitor the electronic weighing scale for fuel weight and the second camera to monitor the gas analyser and connect the two cameras to the laptop to control, collect and record the results of the experiments. Figure 5.9 presents the laptop camera.

Figure 5. 9. Laptop camera

5.2.7. Magnetic Stirrer

Weightlab Instruments offers fast and smooth mixing in its analog-controlled Desktop WF-MIA1 Magnetic Stirrer model. It can perform mixing simultaneously or separately while heating the samples with its aluminium alloy and 115x115 mm sized heating plate. The speed range is 100 - 2000 rpm in the WF MIA1 Magnetic Stirrer, where the temperature and mixing speed can be adjusted sleeplessly with only two buttons. The temperature setting of the device can be adjusted in ambient temperature to 380 °C temperature conditions, thus meeting the mixing needs in the best way, the magnetic stirrer device with heater realizes a suitable power consumption of 180 W, which provides energy efficiency. The IP21 protection of the device provides long-lasting use to the user. Figure 5.10 presents the magnetic stirrer.

Figure 5. 10. Magnetic stirrer

5.2.8. Accessories

Laboratory glassware included in various sizes are shown in Figure 5.11.

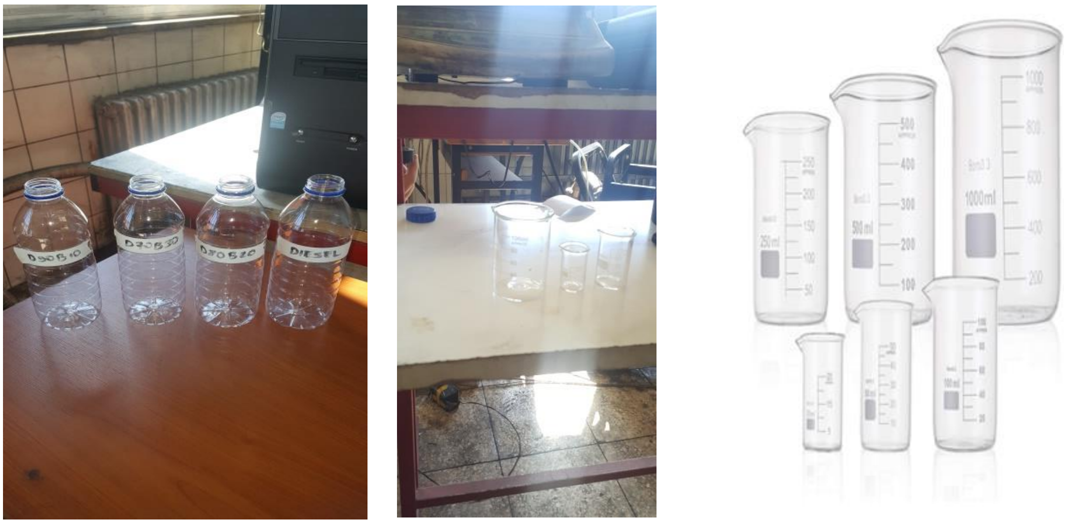
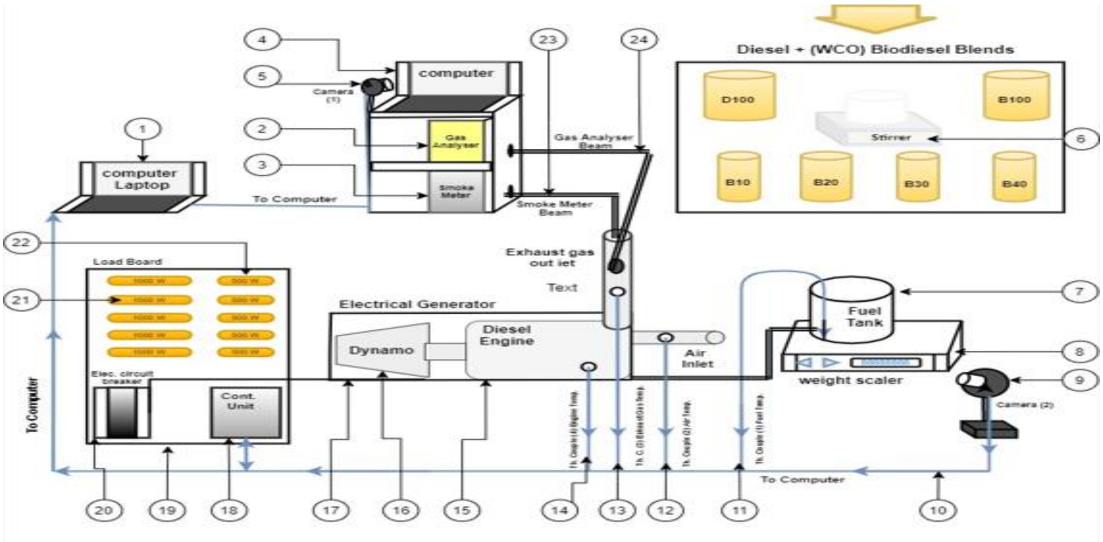


Figure 5. 11. Accessories

5.3. CONDUCTING THE EXPERIMENTS

To conduct laboratory experiments, we built a network of devices and equipment as shown in Figure 5.12, connected them, checked the connection, calibrated the measuring devices and sensors, and ensured that they worked correctly in standard weather conditions. We carried out the following procedures:



1. Computer laptop	13. Thermo couple (3) for gas exhaust.
2.Gas analyser	14. Thermo couple (4) for engine temp
3. Smoke meter	15. Diesel engine
4. Computer	16. Dynamo

5. Camera (1)
6. M. stirrer
7. Fuel tank
8. Weight scale
9. Camera (1)
10. Data wire
11. Thermo couple (1) for fuel temp.
12. Thermo couple (2) for air temp.
17. Electrical generator
18. Control unit
19. Load board
20. Circuit breaker
21. Halogen lamp (500 W)
22. Halogen lamp (1000 W)
23. Smoke meter beam
24. Gas analyser beam

Figure 5. 12. Experimental setup

Biofuel mixtures were prepared from waste cooking oils and conventional diesel in different proportions (100% diesel, 90% diesel + 10% biodiesel, 80% diesel + 20% biodiesel + 70% diesel + 30% + 60% diesel + 40% Biodiesel) and all packaged in plastic containers. We put traditional diesel fuel (100% diesel) in the fuel tank after cleaning it and place it on a weighing scale to operate the diesel engine connected to the dynamo to generate electricity, which feeds the electrical load board. After (15 minutes) and the engine operation and temperature stabilize (52 degrees Celsius), the engine is loaded with a load (500 watts) and after (15 minutes) the temperatures sensed by thermocouples placed to measure the temperatures of (fuel, engine, air entering the engine, etc.) are recorded. Exhaust gas coming out of the engine. All the above steps are repeated for each type of biodiesel fuel mixture from waste cooking oil and conventional diesel (90% diesel + 10% biodiesel, 80% diesel + 20% biodiesel, 70% diesel + 30%, 60% diesel + 40% diesel) blends. All readings and results are recorded on the laptop computer connected to the laboratory testing network.

5.4. RESPONSE SURFACE METHODOLOGY

The field of experimental design and optimization use the statistical and mathematical technique known as RSM. It is especially helpful when attempting to optimize systems or processes whose performance is influenced by numerous variables or causes.

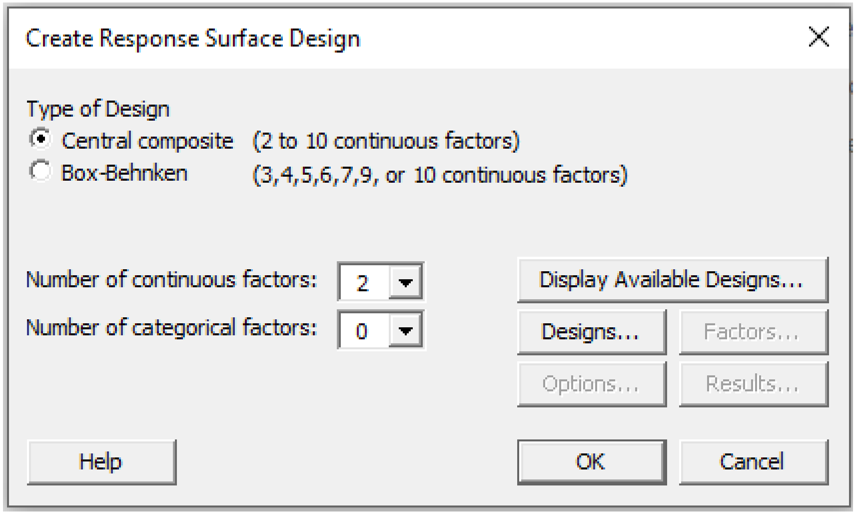
The following are the main elements and ideas of the RSM:

- **Designing an experiment**: RSM begins with the design of experiments (DOE), in which various input factors or variables are systematically changed to understand their effects on an interest-precise response or output variable. The response variable is the dependent variable, whereas these input components are frequently referred to as independent variables or factors.
- **Modelling:** In RSM, the link between the input variables and the response variable is modelled mathematically. Usually, these models are polynomial equations that simulate the behaviour of the system under investigation. Higher-order models can also be employed if necessary, however second-order models are the most frequently utilized form.
- **Optimization:** RSM seeks to identify the ideal set of input factor values that maximizes or minimizes the response variable after the mathematical model has been built. The settings that produce the desired result are found using optimization approaches like gradient ascent or descent.
- **Response surfaces and contour plots:** RSM frequently uses response surface plots and contour plots to display its results. These graphical depictions make it easier to understand how adjustments to the input variables impact the response variable. Response surface plots offer a three-dimensional perspective of the relationship whereas contour plots display regions of equal response values.
- **Validation:** In order to confirm that the anticipated optimum is actually possible and that the model adequately represents the system, it is crucial to validate the results with additional experiments after determining the ideal circumstances.
- **Applications:** In many different industries, including engineering, manufacturing, chemistry, pharmaceuticals, agriculture, and more, RSM has a wide range of applications. By methodically analysing and enhancing complicated systems, it is utilized to optimize operations, raise product quality, lower costs, and increase efficiency.

Overall, RSM is an effective method for experimental optimization, enabling scientists and engineers to quickly investigate and improve systems or processes with numerous variables and intricate interconnections. It is especially helpful when conducting trials is expensive or time-consuming because it lowers the quantity of experiments needed to find the best solution.

5.4.1. RSM application

In order to perform RSM application, a certain number of experimental data is required. The number of experiments is determined by the number of factors. In this study, there are two factors: biodiesel ratio (%) and engine load (watt). Accordingly, RSM application is started by clicking "Stat → Doe → Response Surface → Create Response Surface Design". When the specified commands are selected respectively, the interface shown in Figure 5.13 below appears.

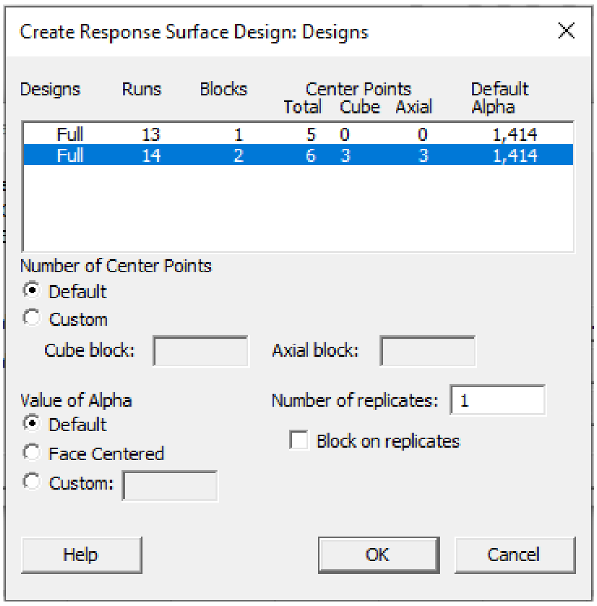

Create Response Surface Design

Type of Design
● Central composite (2 to 10 continuous factors)
○ Box-Behnken (3,4,5,6,7,9, or 10 continuous factors)

Number of continuous factors: 2
Number of categorical factors: 0

Figure 5. 13. Interface for Response Surface Design

Then, by clicking "Design" in the opened interface, the new interface shown in Figure 5.14 opens, where the design type will be selected. Here, the design type that represents 14 experiments is selected.



Create Response Surface Design: Designs

Designs	Runs	Blocks	Center Points Total	Center Points Cube	Center Points Axial	Default Alpha
Full	13	1	5	0	0	1,414
Full	14	2	6	3	3	1,414

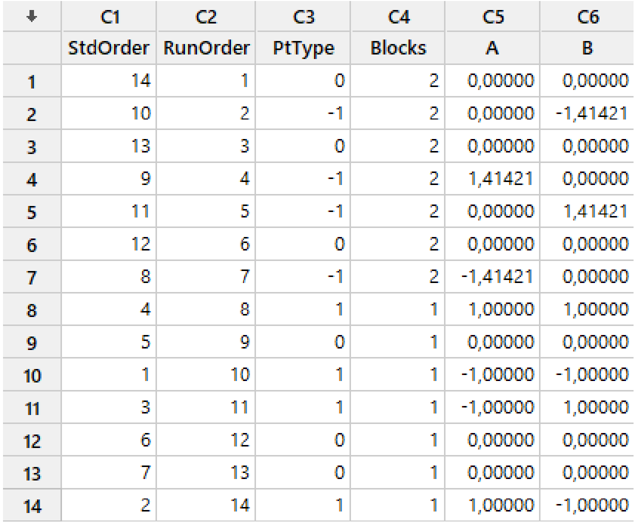
Number of Center Points
● Default
○ Custom
Cube block: Axial block:

Value of Alpha
● Default
○ Face Centered
○ Custom:

Number of replicates: 1
☐ Block on replicates

Figure 5. 14. Selection of design type

Once the design type is approved, a central composite design with two factors and 14 experiments shown in Figure 5.15 is created.



↓	C1	C2	C3	C4	C5	C6
	StdOrder	RunOrder	PtType	Blocks	A	B
1	14	1	0	2	0,00000	0,00000
2	10	2	-1	2	0,00000	-1,41421
3	13	3	0	2	0,00000	0,00000
4	9	4	-1	2	1,41421	0,00000
5	11	5	-1	2	0,00000	1,41421
6	12	6	0	2	0,00000	0,00000
7	8	7	-1	2	-1,41421	0,00000
8	4	8	1	1	1,00000	1,00000
9	5	9	0	1	0,00000	0,00000
10	1	10	1	1	-1,00000	-1,00000
11	3	11	1	1	-1,00000	1,00000
12	6	12	0	1	0,00000	0,00000
13	7	13	0	1	0,00000	0,00000
14	2	14	1	1	1,00000	-1,00000

Figure 5. 15. Central composite design with two factors and 14 experiments

After the design is created, we can now move on to the analysis phase. To do this, first of all, a new "worksheet" is opened on Minitab and the experiment data containing all factors and answers is copied here. Data transcribed for this study are shown in Table 5.5.

Table 5. 5. Experimental data

Number of Run	**Biodiesel Percentage (%)**	**Engine Load (W)**	**CO (%)**	**HC (ppm)**	**CO_2 (%)**	**NO_x (ppm)**	**Smoke (%)**	**BSFC (g/kWh)**
1	0	1000	0.090	20.03	3.33	293.53	0.59	383.35
2	0	1500	0.075	27.25	3.94	389.40	0.59	307.01
3	0	2000	0.060	38.74	4.69	498.08	0.60	293.46
4	40	500	0.065	9.85	2.58	232.46	0.45	886.50
5	40	1000	0.049	17.73	3.55	332.27	0.45	506.57
6	40	1500	0.042	19.70	4.23	434.06	0.46	403.61
7	30	2000	0.029	21.67	6.37	652.73	0.41	344.75
8	30	2500	0.030	25.28	7.34	750.24	0.43	322.36
9	30	3000	0.038	32.83	8.73	782.42	0.46	315.20
10	20	1000	0.044	16.09	3.78	336.21	0.42	466.58
11	20	1500	0.034	17.73	4.47	444.24	0.44	354.60
12	20	2000	0.032	23.64	5.52	568.67	0.45	329.86
13	10	2500	0.047	37.43	5.68	633.68	0.51	295.50
14	10	3000	0.064	42.36	6.79	721.02	0.55	332.44

Then, the "Stat → Doe → Response Surface → Analyze Response Surface Design" commands are selected, and the analysis begins. After these commands are selected respectively, the interface in Figure 5.16 opens.

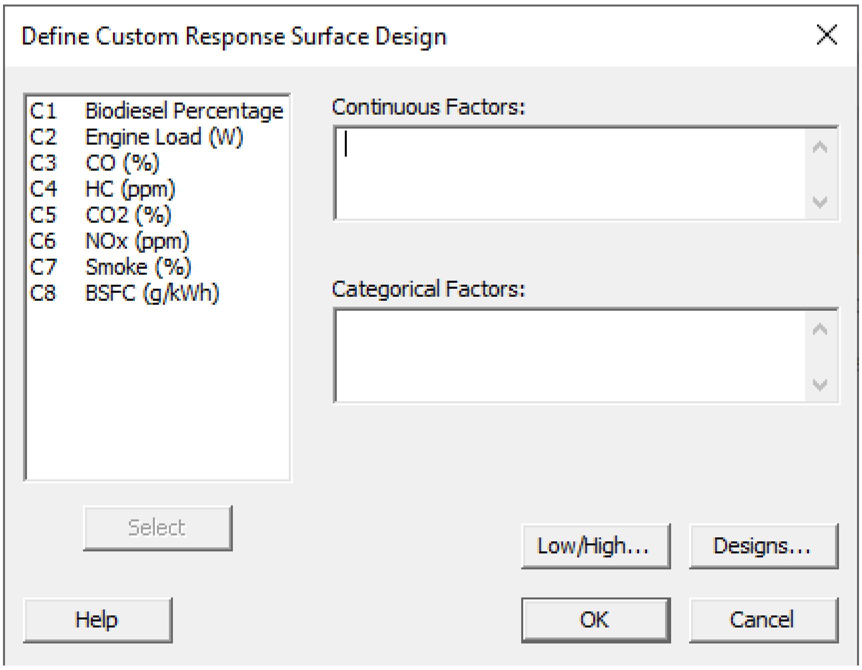
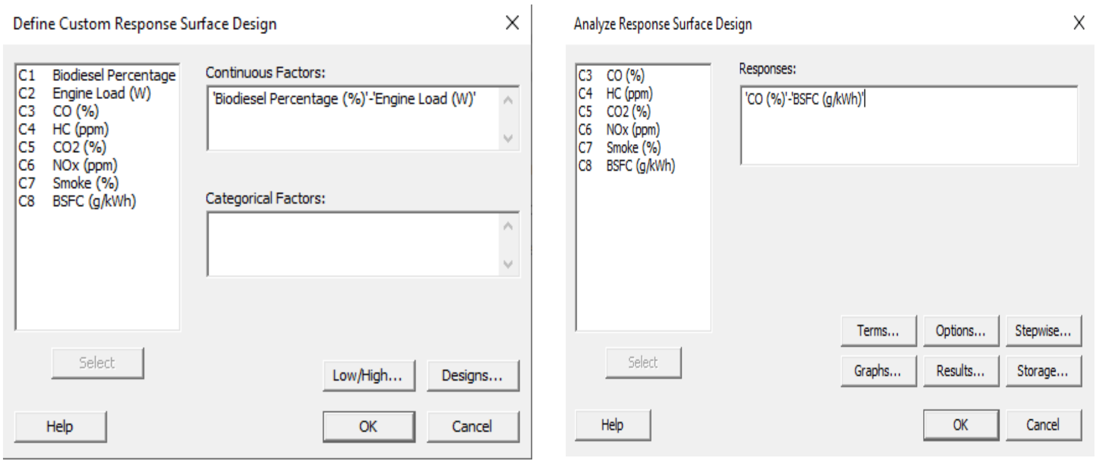


Figure 5. 16. Response surface design definition

In this interface, first the factors "biodiesel rate and engine load" are selected and confirmed, as shown in Figure 5.17. Then, the responses "from CO to BSFC" are selected and confirmed, again as shown in Figure 5.17.



Continuous Factors: 'Biodiesel Percentage (%)'-'Engine Load (W)'

Responses: 'CO (%)'-'BSFC (g/kWh)'

Figure 5. 17. Selection of factors and responses

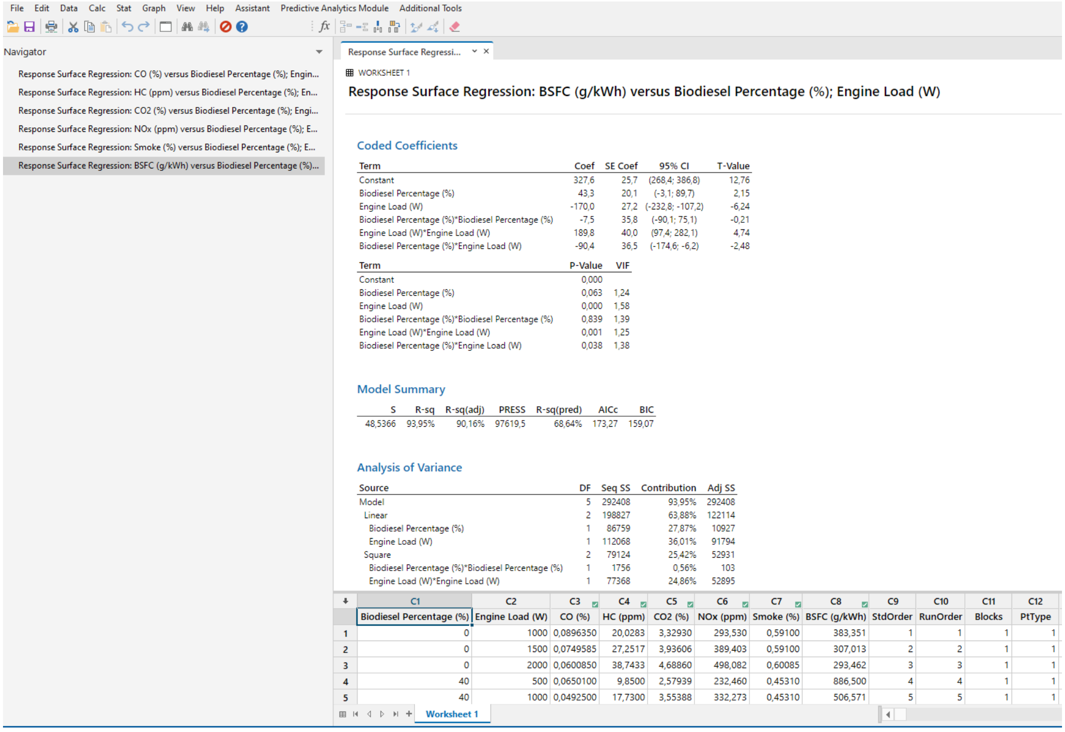
Then click on the "Terms" option and select the "full quadratic" expression, where all conditions are taken into account. On the other hand, "Pareto" is selected from the

"Graphs" option to shape the degree of influence of factors on the responses. Analysis starts once all selections are confirmed.

As a result of the analysis, individual results for each response are listed in tabs as shown in Figure 5.18. With the analysis, the following results are obtained for each answer.

- Coded Coefficients
- Model Summary
- Analysis of Variance
- Regression Equation in Uncoded Units
- Fits and Diagnostics for Unusual Observations
- Pareto Chart

The analysis results in this study will be mentioned in the following parts.



Response Surface Regression: CO (%) versus Biodiesel Percentage (%); Engin...
Response Surface Regression: HC (ppm) versus Biodiesel Percentage (%); En...
Response Surface Regression: CO2 (%) versus Biodiesel Percentage (%); Engi...
Response Surface Regression: NOx (ppm) versus Biodiesel Percentage (%); E...
Response Surface Regression: Smoke (%) versus Biodiesel Percentage (%); E...
Response Surface Regression: BSFC (g/kWh) versus Biodiesel Percentage (%)...

Response Surface Regression: BSFC (g/kWh) versus Biodiesel Percentage (%); Engine Load (W)

Coded Coefficients

Term	Coef	SE Coef	95% CI	T-Value
Constant	327,6	25,7	(268,4; 386,8)	12,76
Biodiesel Percentage (%)	43,3	20,1	(-3,1; 89,7)	2,15
Engine Load (W)	-170,0	27,2	(-232,8; -107,2)	-6,24
Biodiesel Percentage (%)*Biodiesel Percentage (%)	-7,5	35,8	(-90,1; 75,1)	-0,21
Engine Load (W)*Engine Load (W)	189,8	40,0	(97,4; 282,1)	4,74
Biodiesel Percentage (%)*Engine Load (W)	-90,4	36,5	(-174,6; -6,2)	-2,48

Term	P-Value	VIF
Constant	0,000	
Biodiesel Percentage (%)	0,063	1,24
Engine Load (W)	0,000	1,58
Biodiesel Percentage (%)*Biodiesel Percentage (%)	0,839	1,39
Engine Load (W)*Engine Load (W)	0,001	1,25
Biodiesel Percentage (%)*Engine Load (W)	0,038	1,38

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
48,5366	93,95%	90,16%	97619,5	68,64%	173,27	159,07

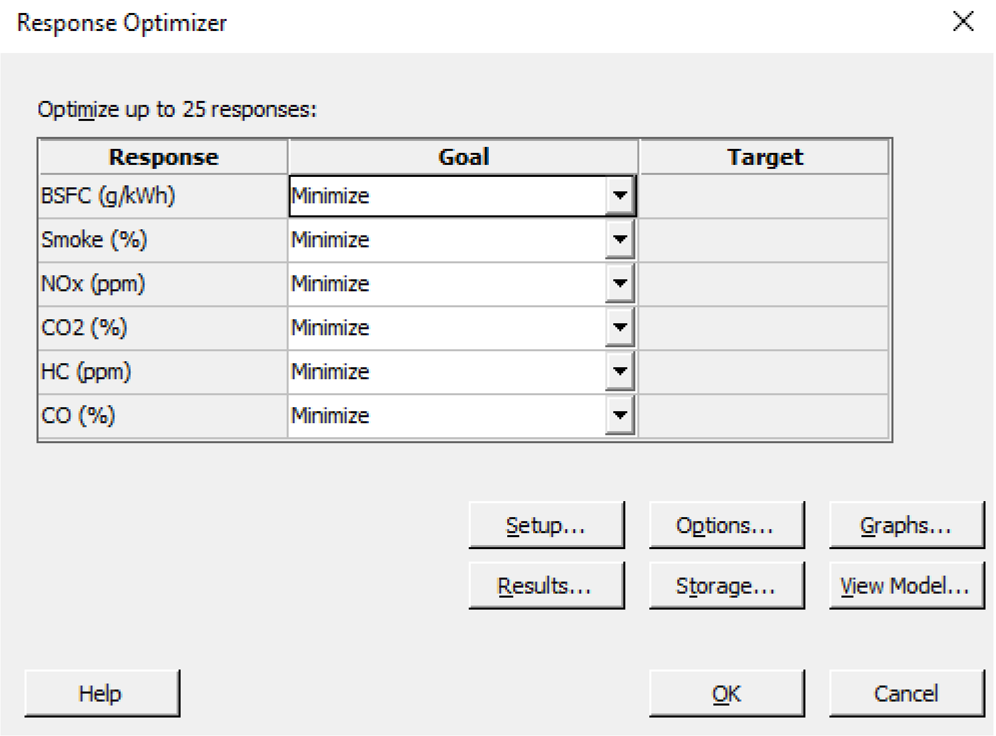
Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS
Model	5	292408	93,95%	292408
Linear	2	198827	63,88%	122114
Biodiesel Percentage (%)	1	86759	27,87%	10927
Engine Load (W)	1	112068	36,01%	91794
Square	2	79124	25,42%	52931
Biodiesel Percentage (%)*Biodiesel Percentage (%)	1	1756	0,56%	103
Engine Load (W)*Engine Load (W)	1	77368	24,86%	52895

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
	Biodiesel Percentage (%)	Engine Load (W)	CO (%)	HC (ppm)	CO2 (%)	NOx (ppm)	Smoke (%)	BSFC (g/kWh)	StdOrder	RunOrder	Blocks	PtType
1	0	1000	0,0896350	20,0283	3,32930	293,530	0,59100	383,351	1	1	1	1
2	0	1500	0,0749585	27,2517	3,93606	389,403	0,59100	307,013	2	2	1	1
3	0	2000	0,0600850	38,7433	4,68860	498,082	0,60085	293,462	3	3	1	1
4	40	500	0,0650100	9,8500	2,57939	232,460	0,45310	886,500	4	4	1	1
5	40	1000	0,0492500	17,7300	3,55388	332,273	0,45310	506,571	5	5	1	1

Figure 5. 18. Overview of analysis results for each response

After the analysis, an optimization study is carried out to determine the optimum factor levels and the optimum responses depending on these levels. "Stat → Doe → Response Surface → Response Optimizer" is selected respectively and the interface in Figure 5.19 appears. Here it is necessary to choose the purpose of optimization for each response. The "Minimize" option was selected for all of the selected responses in this study. Once the selections are confirmed, optimization takes place and the optimization graph shown in Figure 5.20 is obtained.



Optimize up to 25 responses:

Response	Goal	Target
BSFC (g/kWh)	Minimize	
Smoke (%)	Minimize	
NOx (ppm)	Minimize	
CO2 (%)	Minimize	
HC (ppm)	Minimize	
CO (%)	Minimize	

Figure 5. 19. Response Optimizer

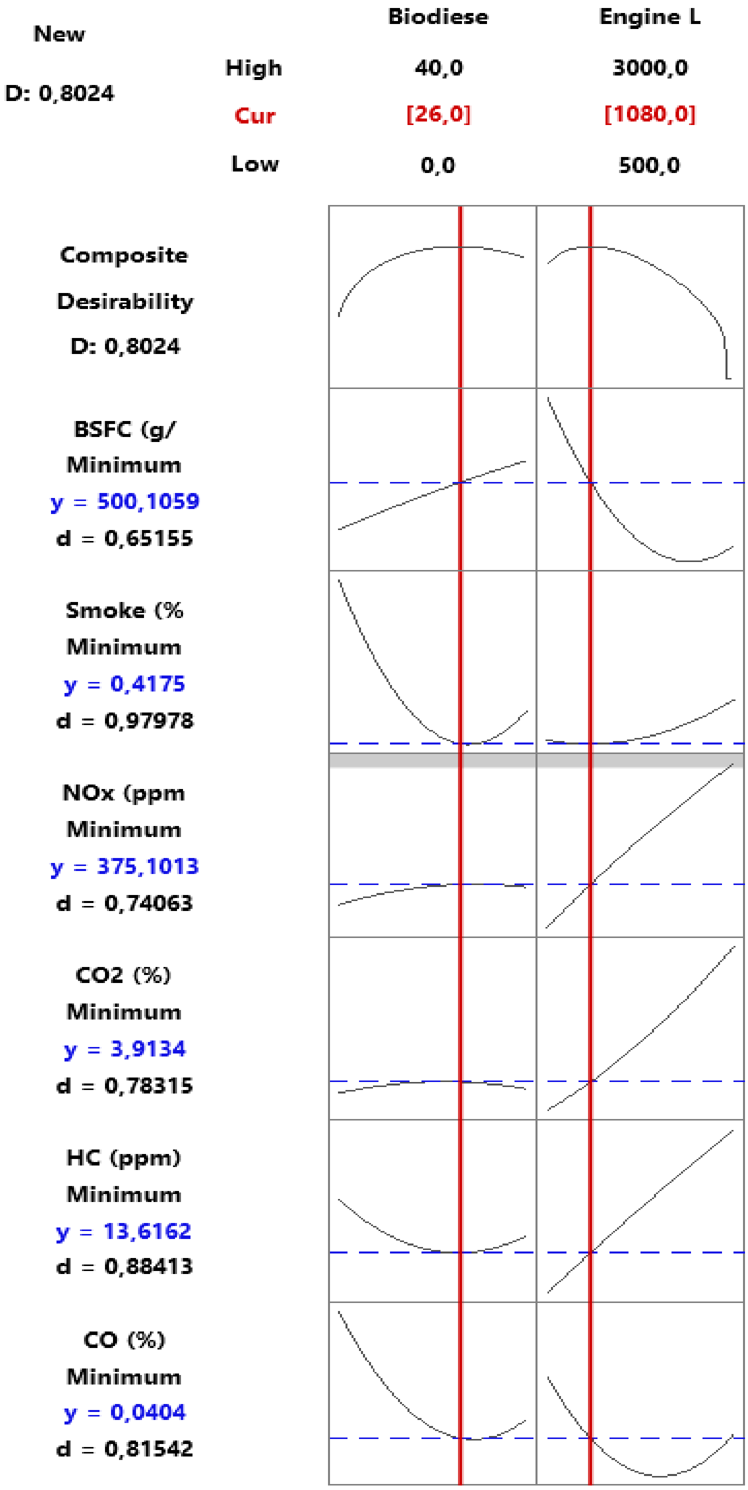


Figure 5. 20. Optimization Plot

PART 6

RESULTS AND DISCUSSIONS

6.1. ENGINE PERFORMANCE

6.1.1. Brake Specific Fuel Consumption

Through laboratory experiments on the performance of a diesel engine at a speed of (3000 rpm) using five types of fuel, blends of fossil diesel fuel with waste cooking oil biodiesel compared to diesel fuel, and different loads were applied to the engine. Graphic curves were drawn showing the results of the tests, which indicate the following:

Increasing of BSFC because of increasing in fuel consumption for all biodiesel blends compared to fossil diesel fuel (D100) as shown in Figure 6.1 and Figure 6.2, due to the low calorific value of biodiesel, which requires burning more fuel to produce the necessary energy. Increasing of BSFC due to an increase in the viscosity and density of the fuel with an increase in the percentage of biodiesel in the fuel mixture used in relation to D100. Decreasing of BSFC in all curves as the engine continues to operate and loads increase, due to rise of pressure and temperature of the combustion chamber, which increases the efficiency of fuel combustion and reduces combustion energy losses. We note the relative closeness of the engine fuel consumption results with all types of fuel at loads (2000-3000) watts. This is evidence of the good quality of biodiesel produced from waste cooking oils. Increasing rates of BSFC for a diesel engine using all types of biofuel blends produced from waste cooking oil (B40, B30, B20, B10) compared to D100 with all loads imposed on the engine and in full, in percentages, respectively (27%, 19%, 16%, 5%).

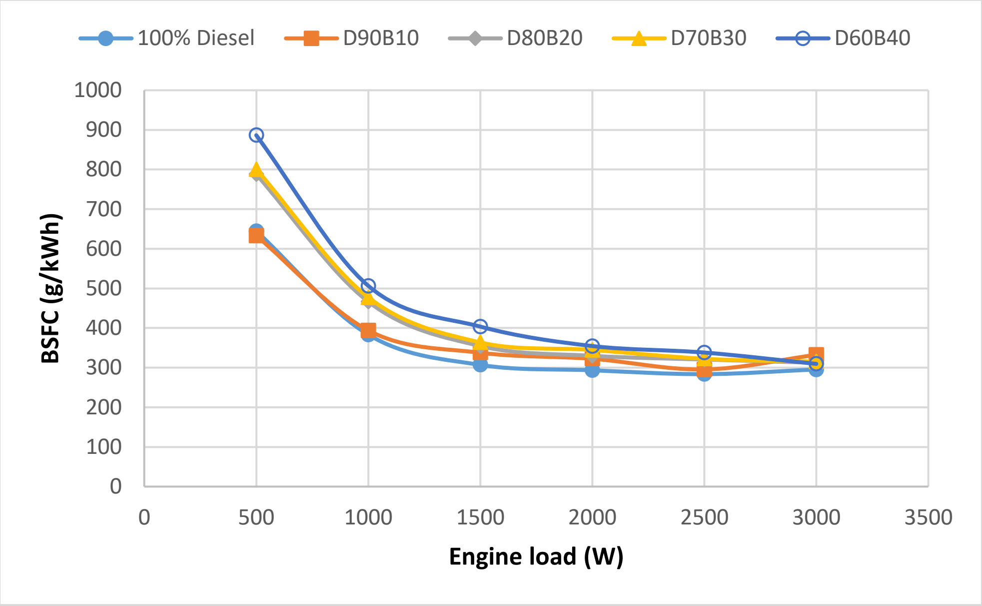


Figure 6. 1. Change of BSFC for different test fuel

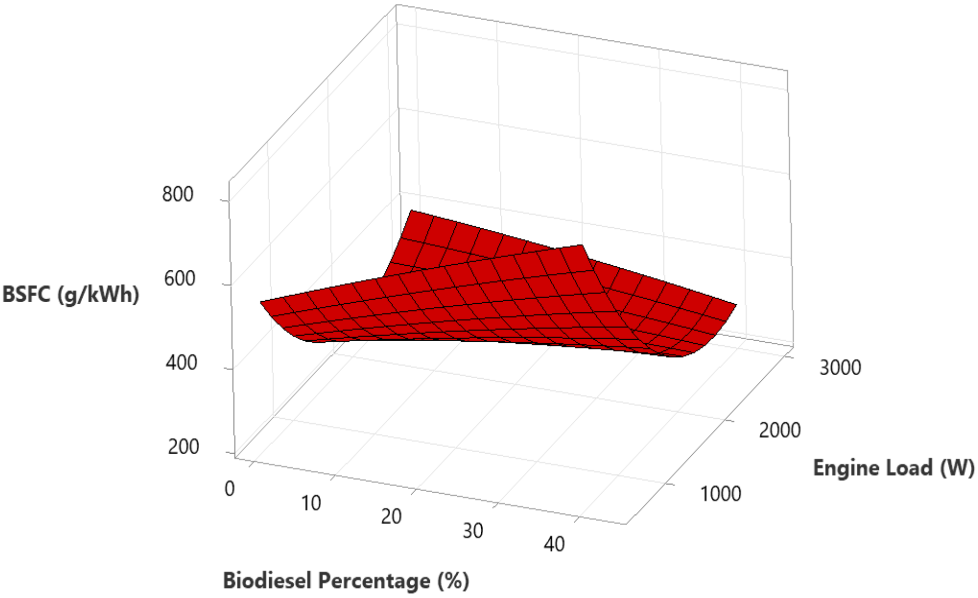


Figure 6. 2. 3D version of the variation of BSFC for different test fuels

6.2. ENGINE EMISSIONS

The process of operating a diesel engine is through injecting fuel consisting of (carbon, hydrogen, and in the presence of biodiesel, oxygen is added) into the combustion chamber in the presence of air consisting of (a large percentage of Nitrogen and Oxygen) and applying high pressure by the cylinder piston, which leads to the combustion of the fuel inside the engine. In operation, the incorrect combustion process of fuel in the combustion chamber releases the above unburned elements in varying proportions into the exhaust gas in the form of emissions.

6.2.1. Carbon emissions

Carbon is one of the components of fossil diesel fuel or biodiesel (in larger proportions), and its particles are emitted in the exhaust gas as a result of not being burned when operating the diesel engine using biofuel mixtures (B10, B20, B30, B40) compared to fossil D100 and applying different loads. Unburned carbon is produced with the exhaust gas in three forms: HC, CO, and CO_2, in different proportions. The results were converted and graphed in the form of curves to facilitate their study.

6.2.1.1. CO emissions

A clear decrease in CO emissions with using biodiesel fuel blends compared to fossil diesel as shown in Figure 6.3 and Figure 6.4 due to the increase in oxygen cetane in the biodiesel formula.

A continued decrease in CO levels for all types of fuel with increasing engine loads up to (2000 and 2500) watts due to the increase in combustion efficiency due to the increase in combustion chamber temperature and pressure with increasing loads. The engine operates at its best with all types of fuel at a load ranging between (2000 and 2500) watts. Then, CO emissions gradually increase at maximum engine load to increase the amount of fuel inside the combustion chamber at maximum load, which leads to the carbon fuel elements not burning properly. Decreasing rates of emissions of CO from the diesel engine using all types of biofuel blends produced from waste cooking oil (B40, B30, B20, B10) compared to D100 with all loads imposed on the engine and in full percentages on respectively (40%, 52%, 50%, 32%).

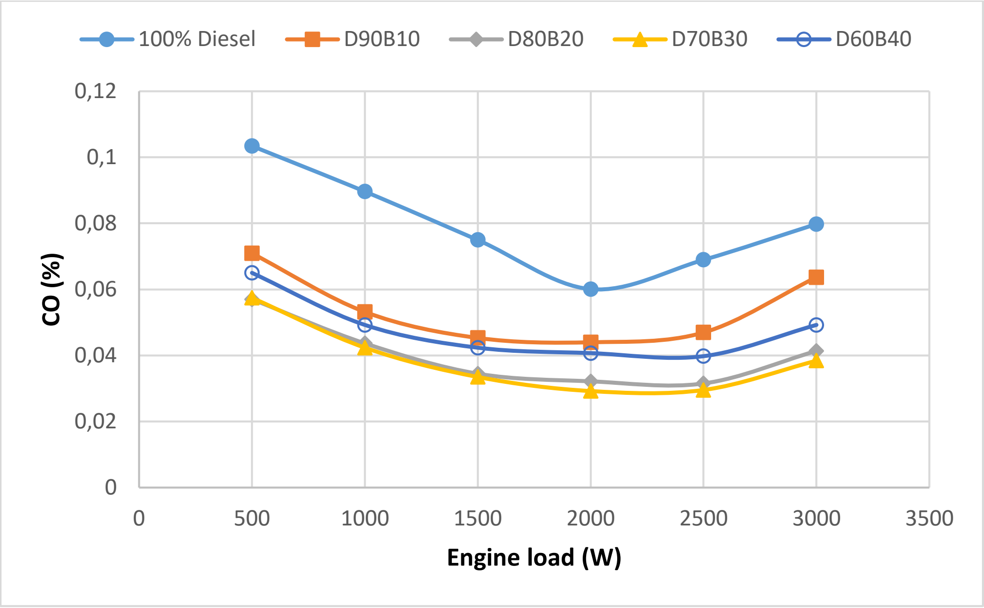


Figure 6. 3. Change of CO for different test fuel

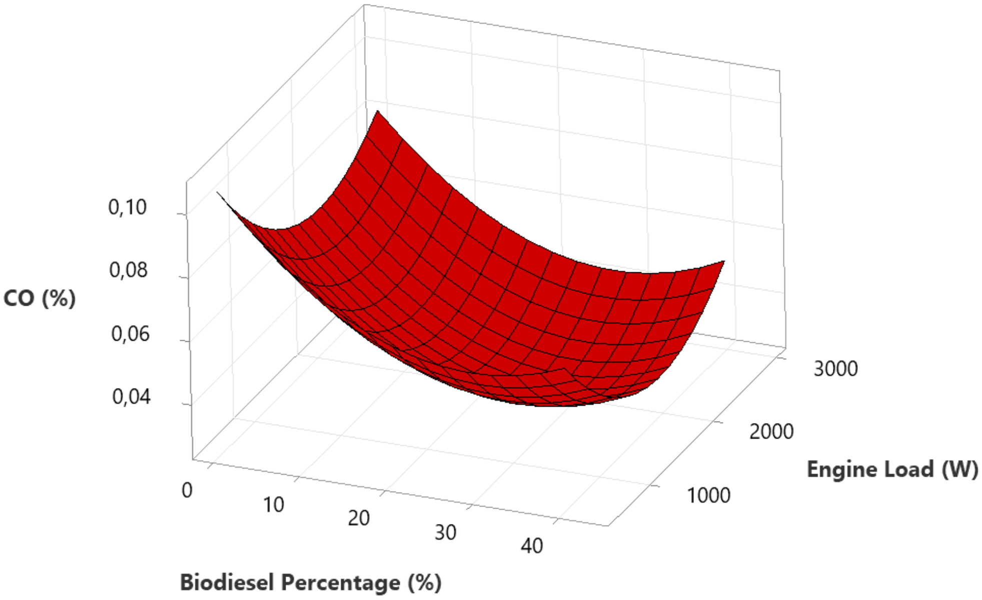


Figure 6. 4. 3D version of the variation of CO for different test fuels

6.2.1.2. CO_2 emissions

An increase in CO_2 emissions compared to using biodiesel fuel mixtures compared to fossil diesel due to the increase in the percentage of oxygen in the biodiesel composition, which led to a decrease in CO to be converted to CO_2 and a percentage increase in emissions of all proportions of biodiesel compared to D100.

CO_2 emissions continue to increase for all types of fuel with increased engine loads as shown in Figure 6.5 and Figure 6.6, due to the carbon elements not burning properly in the combustion chamber. We note the relative closeness of the engine CO_2 emissions results with (B10, B40 and D100) at loads (500-2000) watts. This is evidence of the good quality of biodiesel produced from waste cooking oils. Increasing rates of carbon dioxide emissions from a diesel engine using all types of biofuel blends produced from waste cooking oil (B40, B30, B20, B10) compared to D100 with all loads imposed on the engine and in full percentages on respectively (8%, 36%, 18%, 6%).

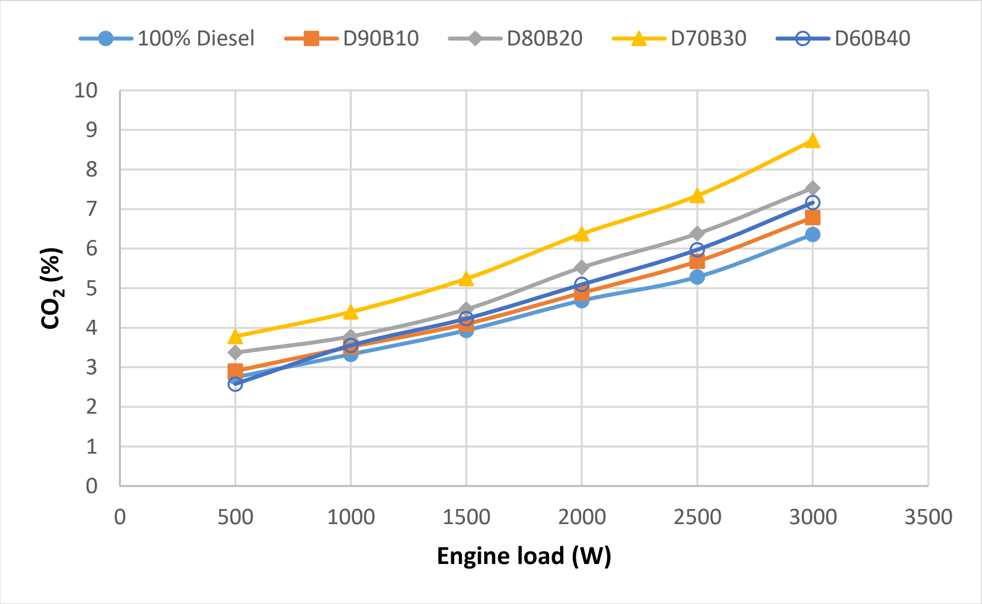


Figure 6. 5. Change of CO_2 for different test fuel

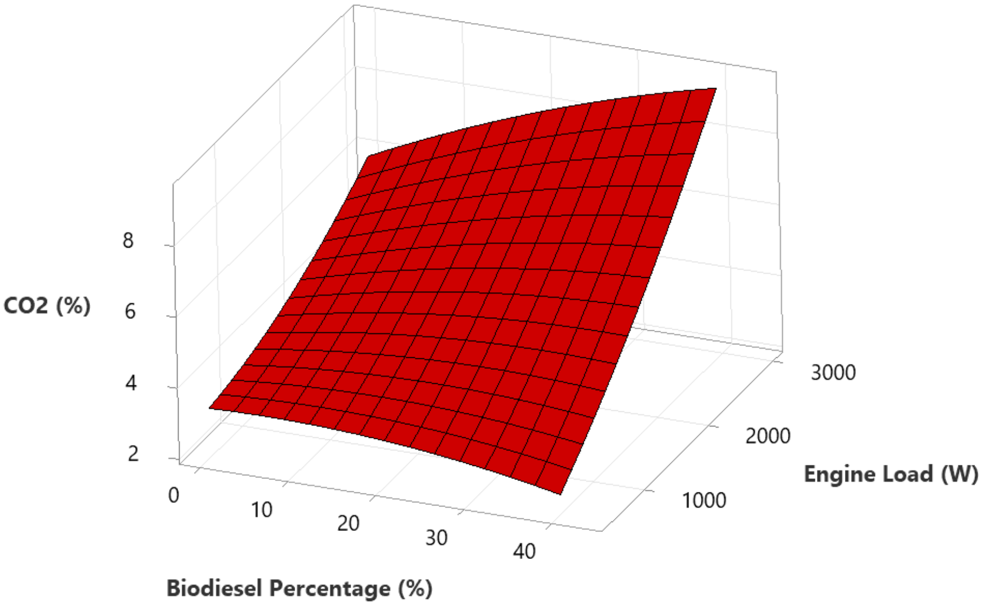


Figure 6. 6. 3D version of the variation of CO_2 for different test fuels

6.2.1.3. HC emissions

Hydrogen is one of the elements of fuel, and because of combustion, its elements are emitted in the exhaust gas in the form of hydrocarbon (HC), where carbon is bonded to hydrogen due to the lack of oxygen in the combustion chamber. In general, HC emissions are greatly reduced using all types of biodiesel mixtures compared to fossil diesel fuel and for all loads due to the high number cetane in biodiesel.

The results of HC emissions (B10, B20, B30, B40) are close to each other to increase the percentage of biodiesel as shown in Figure 6.7 and Figure 6.8. Increased HC emissions for all types of fuel with increasing loads placed on the engine because of incorrect combustion of hydrogen in the combustion chamber as the amount of fuel increases because of its density and viscosity, which affects the spraying and injection of fuel inside the combustion chamber and the decrease in the time required for combustion. Decreasing rates of HC emissions from a diesel engine using all types of biofuel blends produced from waste cooking oil (B40, B30, B20, B10) compared to D100 with all loads imposed on the engine and in full, in percentages, respectively (34%, 43%, 38%, 25%).

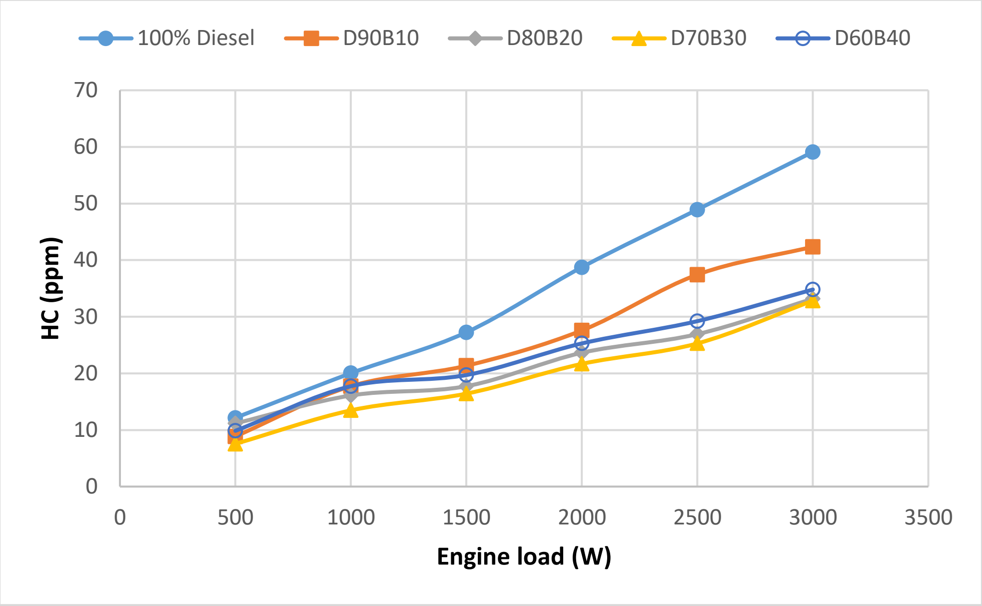


Figure 6. 7. Change of HC for different test fuel

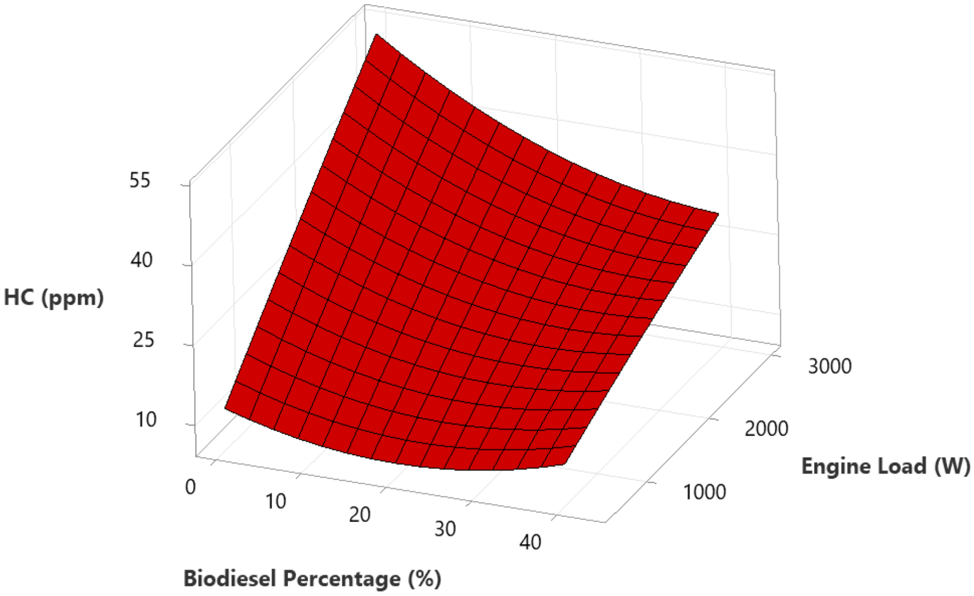


Figure 6. 8. 3D version of the variation of HC for different test fuels

6.2.2. Nitrogen oxides (NO_x) emissions

We have previously shown that nitrogen and oxygen are the largest components of the air, and it is known that nitrogen does not combust and is expelled from the combustion chamber of the engine with the exhaust gas in the form NO_x.

NO_x emission increases using all biodiesel mixtures compared to D100 as presented in Figure 6.9 and Figure 6.10 due to the increased density and viscosity of biodiesel relative to fossil diesel, which improves its quality in the combustion chamber and because of biodiesel containing a high percentage of unsaturated fatty acids and double bonds that increase the temperature of the chemical reaction with High aromatic content. NO_x emission increases for all types of fuel as the load on the engine increases due to the increase in pressure and temperature of the engine room as the load increases. We note the relative closeness of the engine NO_x emissions results with (B10, B20, B40 and D100) at loads (500-2000) watts. This is evidence of the good quality of biodiesel produced from waste cooking oils. Increased emissions rates of (nitrogen oxides) from a diesel engine using all types of biofuel blends produced from waste cooking oil (B40, B30, B20, B10) compared to D100 with all loads imposed on the engine and in full, in percentages, respectively (13%, 30%, 16%, 9).

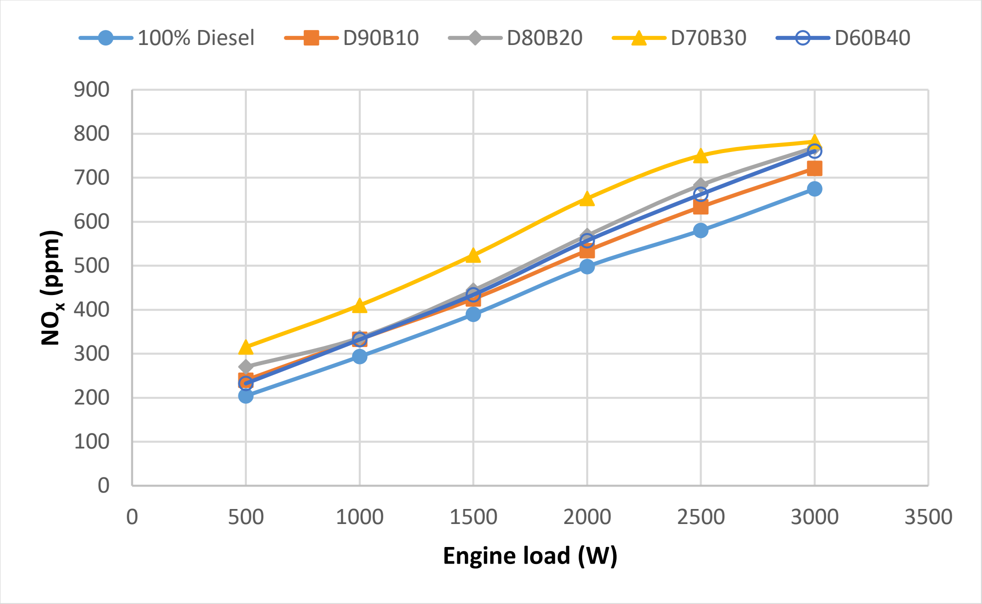


Figure 6. 9. Change of NO_x for different test fuel

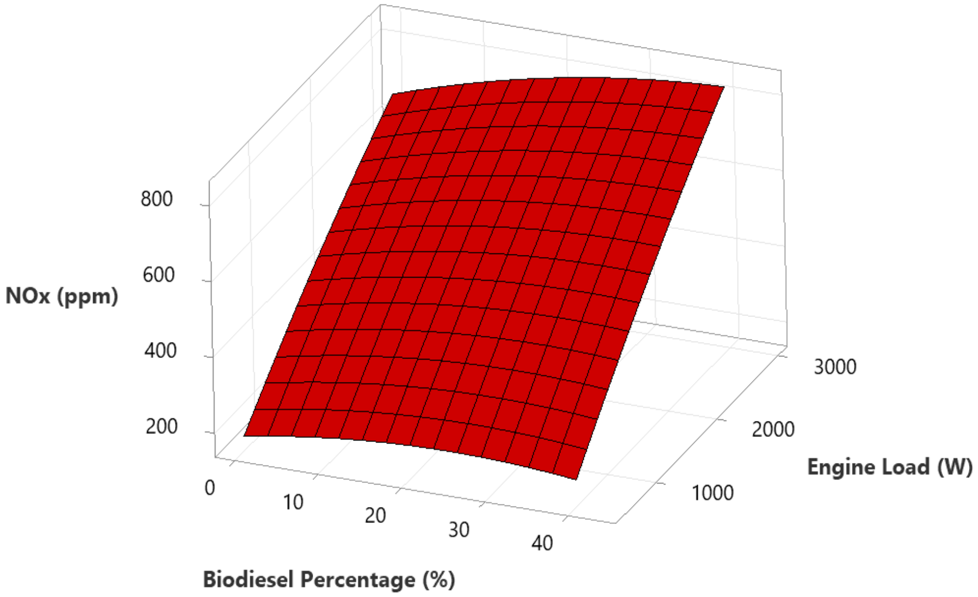


Figure 6. 10. 3D version of the variation of NO_x for different test fuels

6.2.3. Smoke emissions

Black smoke or soot is one of the forms of unburned carbon in the combustion chamber and is emitted with the exhaust gas along with a group of combustion impurities, and through the graph of the results it is evident.

The smoke emitted from the engine was reduced using biodiesel blends as revealed in Figure 6.11 and Figure 6.12, with a significant difference compared to fossil diesel, at all loads, due to the high cetane and oxygen numbers in the biodiesel blends. Convergence between the results of the combustion of biodiesel fuel from each other due to the similarity of its properties and their differences from the results of the combustion of fossil diesel. A slight increase in smoke for all types of fuel as the load on the engine increases. Decreasing rates (smoke emissions from the diesel engine using all types of biofuel blends produced from waste cooking oil (B40, B30, B20, B10) compared to D100 with all loads imposed on the engine and in the specified percentages, respectively (21%, 32%, 26%, 17%).

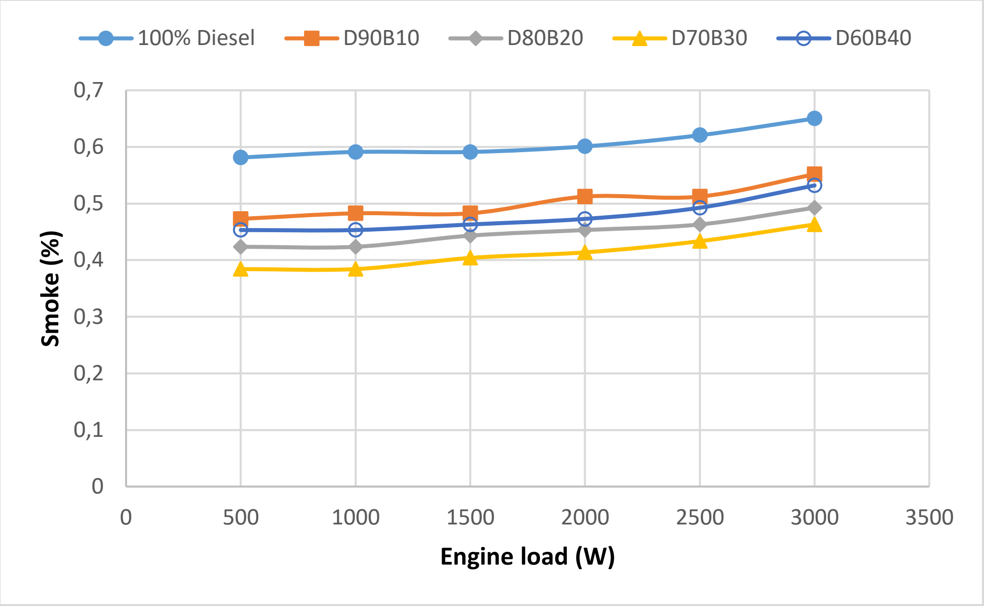


Figure 6. 11. Change of smoke for different test fuel

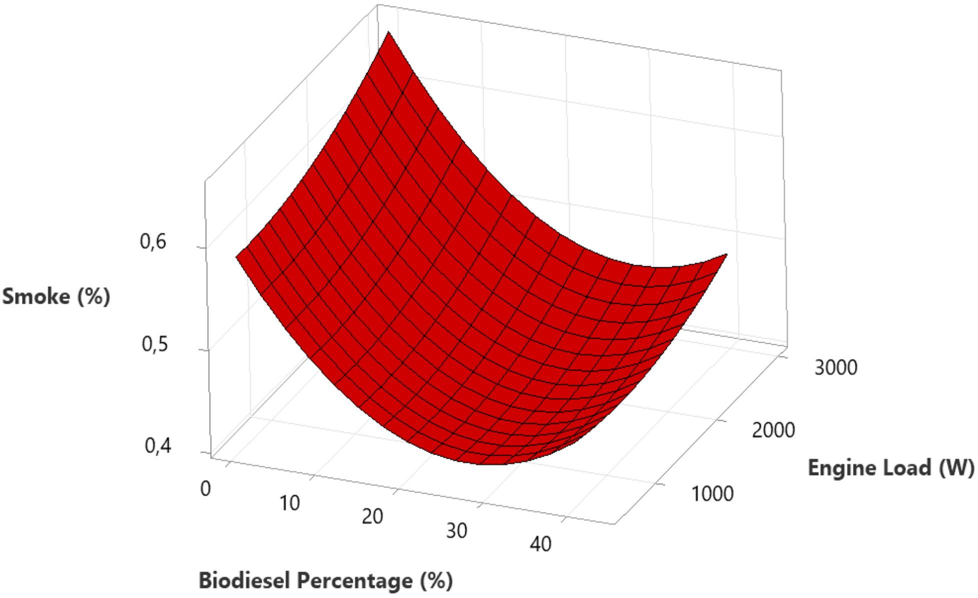


Figure 6. 12. 3D version of the variation of smoke for different test fuels

PART 7

OPTIMIZATION RESULTS

In this section, it is aimed to determine the optimum conditions of the selected factors and the responses that arise depending on these factors. In this study, biodiesel ratio and engine load were selected as operating parameters, while BSFC, CO, CO_2, HC, NO_x, and smoke were selected as the responses resulting from these parameters.

In this section, analysis of variance (ANOVA) table, Pareto chart and regression equation were created for each response. The important columns in the ANOVA table are contribution and p-value. Since this study was conducted with a 95% confidence level, it can be said that factors with a p-value lower than 0.05 are effective on the response. In the Pareto chart, which factor is effective is shown as a figure.

ANOVA table and Pareto chart for BSFC are given in Table 7.1 and Figure 7.1, respectively. According to the ANOVA table, the individual effect of biodiesel percentage on BSFC is 27.87%, while the individual effect of engine load is 36.01%. According to the Pareto chart, the effect of engine load appears to be more significant.

Table 7. 1. ANOVA table of BSFC

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	5	292408	93.95%	292408	58481.6	24.82	0.000
Linear	2	198827	63.88%	122114	61056.8	25.92	0.000
Biodiesel Percentage (%)	1	86759	27.87%	10927	10927.5	4.64	0.063
Engine Load (W)	1	112068	36.01%	91794	91793.6	38.96	0.000
Square	2	79124	25.42%	52931	26465.6	11.23	0.005
Biodiesel Percentage (%) * Biodiesel Percentage (%)	1	1756	0.56%	103	103.4	0.04	0.839
Engine Load (W)*Engine Load (W)	1	77368	24.86%	52895	52894.5	22.45	0.001
2-Way Interaction	1	14457	4.64%	14457	14456.9	6.14	0.038
Biodiesel Percentage (%) * Engine Load (W)	1	14457	4.64%	14457	14456.9	6.14	0.038
Error	8	18846	6.05%	18846	2355.8		
Total	13	311254	100.00%				

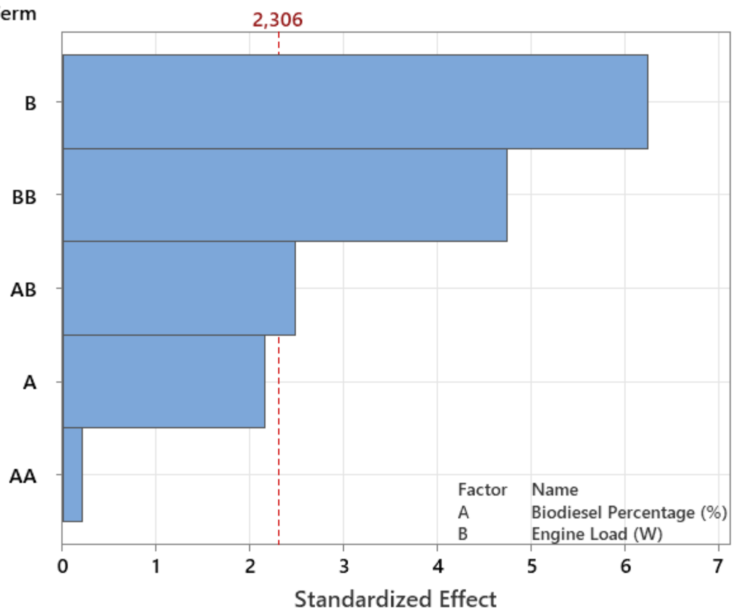


Figure 7. 1. Pareto chart for BSFC

ANOVA and pareto for CO emissions are shown in Table 7.2 and Figure 7.2. According to the ANOVA table, the highest effect level was linear. Among the individual factors, the highest impact on CO emissions was determined to be the biodiesel ratio. It can be seen that the effect level of biodiesel ratio is 31.57% while the engine load is 21.80%. The situation where the effect on CO emissions is not significant is the joint effect of the factors. The ratio of the joint effect of the factors was 0.18%. P-value and Pareto support this data.

Table 7. 2. ANOVA table of CO

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.004181	95.91%	0.004181	0.000836	37.53	0.000
Linear	2	0.002327	53.38%	0.001798	0.000899	40.33	0.000
Biodiesel Percentage (%)	1	0.001376	31.57%	0.001705	0.001705	76.53	0.000
Engine Load (W)	1	0.000951	21.80%	0.000335	0.000335	15.02	0.005
Square	2	0.001847	42.36%	0.001723	0.000862	38.67	0.000
Biodiesel Percentage (%) * Biodiesel Percentage (%)	1	0.001031	23.65%	0.000813	0.000813	36.46	0.000
Engine Load (W)*Engine Load (W)	1	0.000815	18.71%	0.000789	0.000789	35.42	0.000
2-Way Interaction	1	0.000008	0.18%	0.000008	0.000008	0.35	0.573
Biodiesel Percentage (%) * Engine Load (W)	1	0.000008	0.18%	0.000008	0.000008	0.35	0.573
Error	8	0.000178	4.09%	0.000178	0.000022		.
Total	13	0.004360	100.00%				

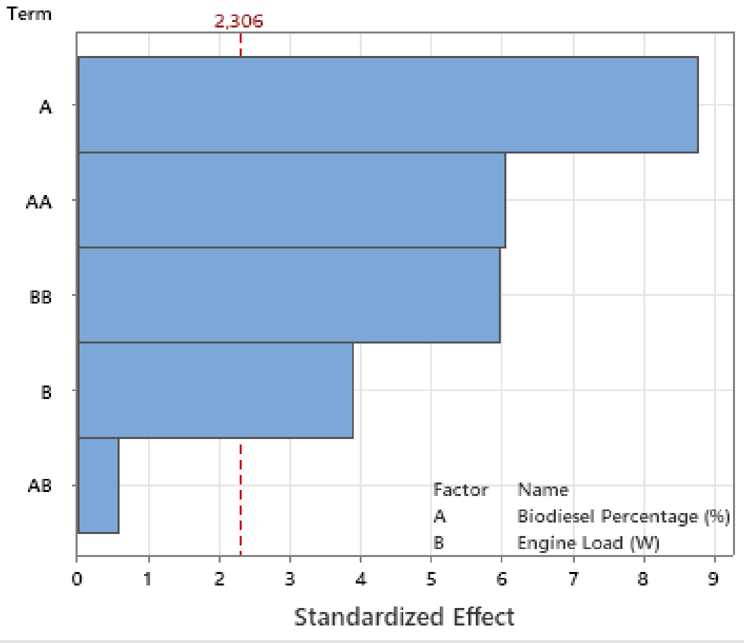


Figure 7. 2. Pareto chart for CO

The ANOVA table and Pareto chart of CO_2 emissions are presented in Table 7.3 and Figure 7.3, respectively. Contrary to what was revealed for CO emissions, the effect of engine load on CO_2 emissions was much higher compared to the biodiesel ratio. While the engine load effect is 91.53%, the effect of the biodiesel ratio is negligible (0.26%). The p-value shows that both engine load and biodiesel rate have an impact (even slightly) on CO_2 emissions. The Pareto chart also supports these statements.

According to Pareto, it is understood that all situations influence CO_2, except the square effect of both factors.

Table 7. 3. ANOVA table of CO_2

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	5	38.7205	98.11%	38.7205	7.7441	83.23	0.000
Linear	2	36.2258	91.79%	18.3424	9.1712	98.57	0.000
Biodiesel Percentage (%)	1	0.1030	0.26%	2.5108	2.5108	26.99	0.001
Engine Load (W)	1	36.1227	91.53%	17.8701	17.8701	192.07	0.000
Square	2	0.4014	1.02%	0.4343	0.2172	2.33	0.159
Biodiesel Percentage (%) * Biodiesel Percentage (%)	1	0.3869	0.98%	0.1676	0.1676	1.80	0.216
Engine Load (W)*Engine Load (W)	1	0.0145	0.04%	0.2960	0.2960	3.18	0.112
2-Way Interaction	1	2.0934	5.30%	2.0934	2.0934	22.50	0.001
Biodiesel Percentage (%) * Engine Load (W)	1	2.0934	5.30%	2.0934	2.0934	22.50	0.001
Error	8	0.7443	1.89%	0.7443	0.0930		
Total	13	39.4648	100.00%				

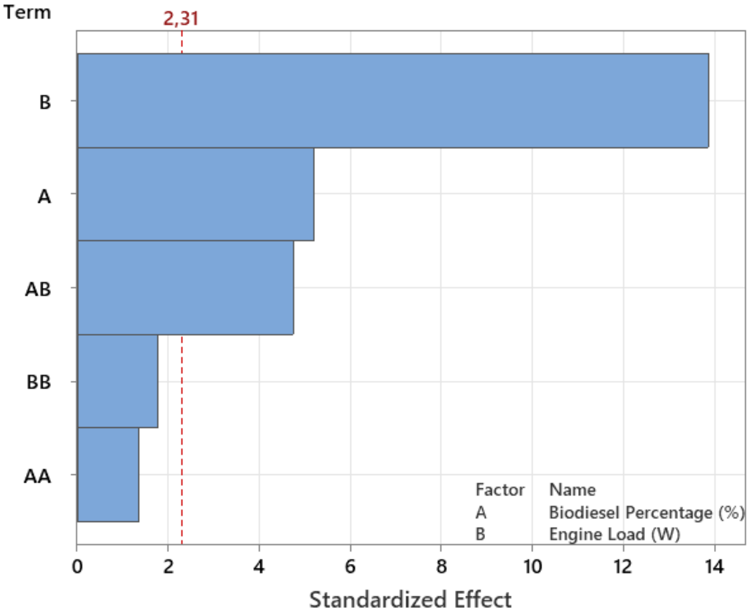


Figure 7. 3. Pareto chart for CO_2

According to Table 7.4, the factor that has the highest impact on HC emissions is engine load with 55.41%. The effect of the biodiesel ratio is 30.49%. According to the Pareto chart shown in Figure 7.4, the square effect of engine load does not have a significant effect on HC emissions. The fact that the p-value in the ANOVA table is higher than 0.05 proves the accuracy of this situation. Other situations need to be taken into account in the HC emission change.

Table 7. 4. ANOVA table of HC

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	5	1157.27	97.13%	1157.27	231.454	54.14	0.000
Linear	2	1023.43	85.90%	1084.74	542.368	126.86	0.000
Biodiesel Percentage (%)	1	363.25	30.49%	204.42	204.423	47.81	0.000
Engine Load (W)	1	660.18	55.41%	669.72	669.723	156.65	0.000
Square	2	73.34	6.16%	46.78	23.388	5.47	0.032
Biodiesel Percentage (%) * Biodiesel Percentage (%)	1	70.05	5.88%	46.77	46.767	10.94	0.011
Engine Load (W)*Engine Load (W)	1	3.29	0.28%	0.33	0.330	0.08	0.788
2-Way Interaction	1	60.50	5.08%	60.50	60.503	14.15	0.006
Biodiesel Percentage (%) * Engine Load (W)	1	60.50	5.08%	60.50	60.503	14.15	0.006
Error	8	34.20	2.87%	34.20	4.275		
Total	13	1191.47	100.00%				

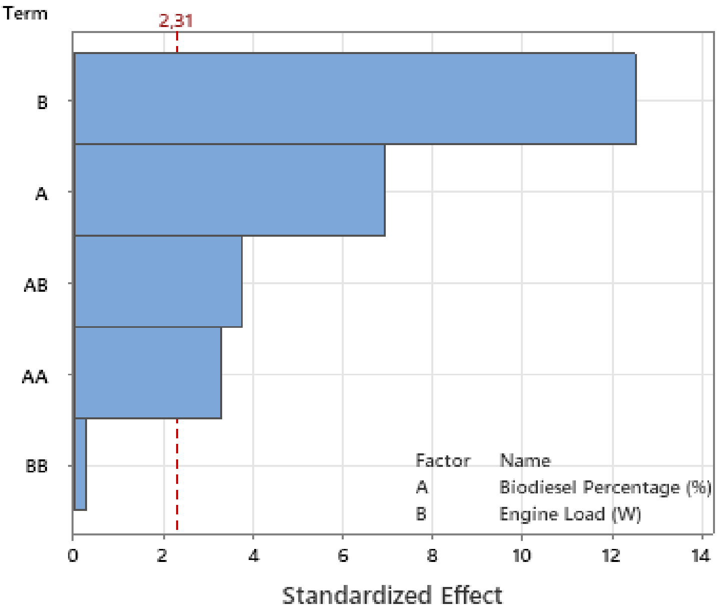


Figure 7. 4. Pareto chart for HC

According to the NO_x results tabulated in Table 7.5, the main factor affecting NO_x emissions is engine load with a rate of 96.11%. It is expected that NO_x emission, which occurs due to temperature, will be affected so much by the engine load, which has an increasing effect on the temperature. According to Pareto shown in Figure 7.5, the highest effect is due to engine load. It is understood from the Pareto chart that although the effect of the biodiesel ratio is much less than the engine load, it should not be ignored.

Table 7. 5. ANOVA table of NO_x

Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	5	416394	97.82%	416394	83279	71.88	0.000
Linear	2	409114	96.11%	242643	121321	104.71	0.000
Biodiesel Percentage (%)	1	52	0.01%	13906	13906	12.00	0.009
Engine Load (W)	1	409062	96.10%	242504	242504	209.30	0.000
Square	2	5284	1.24%	3046	1523	1.31	0.321
Biodiesel Percentage (%) * Biodiesel Percentage (%)	1	3388	0.80%	2048	2048	1.77	0.220
Engine Load (W)*Engine Load (W)	1	1896	0.45%	803	803	0.69	0.429
2-Way Interaction	1	1996	0.47%	1996	1996	1.72	0.226
Biodiesel Percentage (%) * Engine Load (W)	1	1996	0.47%	1996	1996	1.72	0.226
Error	8	9269	2.18%	9269	1159		
Total	13	425663	100.00%				

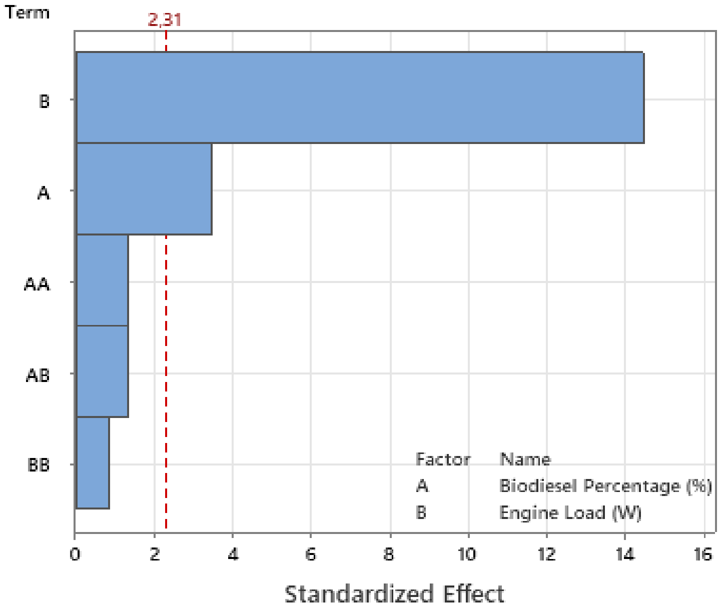


Figure 7. 5. Pareto chart for NO_x

ANOVA table and Pareto chart for smoke emission are shown in Table 7.6 and Figure 7.6 respectively. It can be clearly understood from both the table and Pareto that the highest impact on smoke emission is caused by the biodiesel ratio (68.09%) and the square effect of the biodiesel ratio (28.40%), respectively. The effect of engine load emerged, which should be taken into account, but at a low level (0.45%).

Table 7. 6. ANOVA table of Smoke

Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	5	0.057281	98.53%	0.057281	0.011456	107.02	0.000
Linear	2	0.039849	68.54%	0.037468	0.018734	175.01	0.000
Biodiesel Percentage (%)	1	0.039587	68.09%	0.030713	0.030713	286.92	0.000
Engine Load (W)	1	0.000263	0.45%	0.001795	0.001795	16.77	0.003
Square	2	0.017292	29.74%	0.015654	0.007827	73.12	0.000
Biodiesel Percentage (%) * Biodiesel Percentage (%)	1	0.016514	28.40%	0.014646	0.014646	136.82	0.000
Engine Load (W)*Engine Load (W)	1	0.000778	1.34%	0.000535	0.000535	5.00	0.056
2-Way Interaction	1	0.000140	0.24%	0.000140	0.000140	1.31	0.286
Biodiesel Percentage (%) * Engine Load (W)	1	0.000140	0.24%	0.000140	0.000140	1.31	0.286
Error	8	0.000856	1.47%	0.000856	0.000107		
Total	13	0.058137	100.00%				

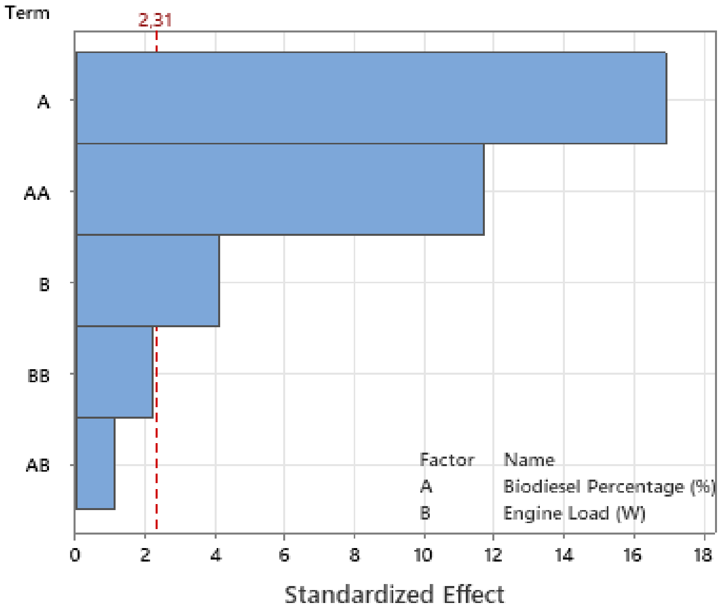


Figure 7. 6. Pareto chart for Smoke

Figure 7.7 shows the optimum factor values and the resulting optimum motor responses. The optimum biodiesel ratio was determined as 26% and the optimum engine load was 1080 W. The ideal engine responses resulting from these conditions are 500.1059 g/kWh BSFC, 0.4175% smoke, 375.1013 ppm NO_x, 3.9134% CO_2, 13.6162 ppm HC and 0.0404% CO, respectively.

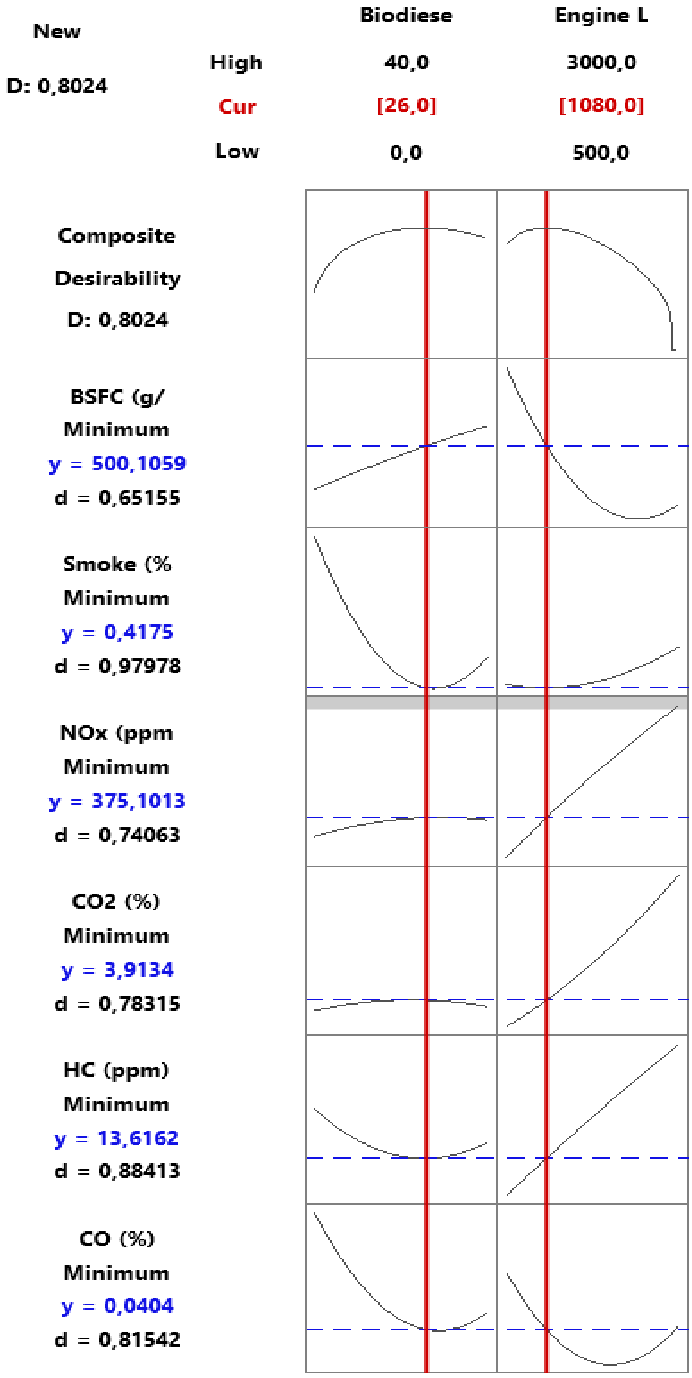


Figure 7. 7. Optimization

In Table 7.7, the results of the validation study conducted for the reliability of the optimum results are tabulated. If the error rates are within acceptable limits (below 10%), it means that the optimization results can be trusted. According to the verification study conducted to prove the reliability and accuracy of the optimization results, the lowest error rate between the optimum results and the experimental results was found in CO emission with 2.51%, while the highest error rate was obtained in HC emission with 7.83%. Accordingly, the fact that the maximum error is lower than 10% indicates that the optimization application can be trusted.

Table 7. 7. Validation of RSM results with an error percentage.

Load (W)	**BP (%)**		**BSFC (g/kWh)**	**CO (%)**	**CO_2 (%)**	**HC (ppm)**	**NO_x (ppm)**	**Smoke (%)**
1080	26	**Optimum**	500.11	0.0404	3.91	13.62	375.10	0.4175
		Test	480.16	0.0414	4.23	14.77	357.52	0.4031
		Error (%)	4.15	2.51	7.48	7.83	4.92	3.58

CONCLUSIONS

In this study, the effects of using biodiesel produced from waste frying oil in a diesel engine on engine responses were examined at different engine loads and mixture ratios, and an optimization study was carried out with RSM so that it can be used under the best conditions. Findings from experimental studies and RSM are as follows;

- BSFC increased with the use of biodiesel-containing fuel mixtures compared to D100. The highest increase was found to be 27% in the fuel mixture containing 40% biodiesel, and the lowest increase was 5% in the fuel mixture containing 10% biodiesel.
- Addition of biodiesel to diesel fuel had a positive effect on CO emissions. While the increasing rate of biodiesel up to 30% provided a further decrease in CO, after 30% CO started to increase. Therefore, the lowest CO emission was achieved with a fuel mixture containing 30% biodiesel, and a reduction of approximately 52% was recorded compared to D100.
- As a result of the addition of biodiesel increasing the combustion quality, CO_2, which is the product of complete combustion, increased. With the addition of 30% biodiesel, the highest CO_2 was reached, and a 36% increase was observed compared to D100. The increase in CO_2 emissions was limited to 6% with the addition of 10% biodiesel.
- Just like CO emission, HC emission also achieved a similar trend with the addition of biodiesel. In general, all biodiesel rates reduced HC emissions. The highest reduction was again achieved with 30% biodiesel. A 43% reduction was noted compared to D100.
- NO_x emissions increased with all biodiesel-containing fuel mixtures. The highest NO_x level was reached with 30% biodiesel, which improved the combustion quality the most. With the improvement of combustion, the in-cylinder temperature increased (because NO_x depends more on temperature).

- With 30% biodiesel content, NO_x increased by approximately 30% compared to D100.
- The addition of biodiesel had a positive effect on smoke emission and reduced it compared to D100. With 30% biodiesel, this reduction reached its maximum at 32%.
- According to the optimization results, the optimum factor levels were 26% and 1080 W for biodiesel ratio and engine load, respectively.
- The optimum responses obtained depending on the optimum factors are 500.1059 g/kWh BSFC, 0.4175% soot, 375.1013 ppm NO_x, 3.9134% CO_2, 13.6162 ppm HC, 0.0404% CO.
- According to the verification study, the lowest error rate between the optimum results and the experimental results was found in CO emission with 2.51%, while the highest error rate was obtained in HC emission with 7.83%.

As a result, according to the experimental results, it can be said that waste frying oil biodiesel will be successful in diesel engines, especially in reducing emissions, and can be an alternative fuel for diesel engines. In addition, according to the results of the verification study, it was concluded that the optimization application can be trusted as the maximum error is lower than 10% and waste frying oil biodiesel can be used efficiently in diesel engines with RSM optimization. Finally, a more precise optimization study by increasing the number of factors and responses should be included in future studies.

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RESUME

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