Republic of Iraq

Ministry of Higher Education

And scientific Research

University of Babylon

College of Engineering

Mechanical Engineering Department

Experimental Study for the Effect of Exhaust Gas Recirculation on the Performance and Emission of Diesel Engine Fueled with Waste Cooking Oil Biodiesel

A Thesis

Submitted to University of Babylon College of Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Sciences in Mechanical Engineering

By

Noor Ali Zead Abed

(B.Sc. - 2010)

Supervised by

Assist. Dr. Duraid F. Maki

Department of Mechanical Engineering College of Engineering of the Babylon University

2023 A.D.   **1445 A.H**

(بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ)

(وَمَا تَوْفِيقِي إِلَّا بِاللَّهِ ۚ عَلَيْهِ تَوَكَّلْتُ وَإِلَيْهِ أُنِيبُ)

(صَدَقَ اللهُ العلي العَظِيمُ)

(سورة هود:88)

Dedication

For those who helped me especially

And to my family, my loved ones, and my friends

ACKNOWLEDGMENTS

First, thanks be to God who enabled me to achieve this work.

I would like to express my deepest gratitude and sincere thanks to my supervisor, Dr. (Duraid F. Maki) for the invaluable daily guidance and continuous discussions , direct supervision of the practical and scientific section of the thesis and constructive comments, which helped and greatly improved the structure and presentation of the thesis.

I would like to extend my deep thanks to the staff of the mechanical engineering laboratories and the employees of the Chemical Engineering Laboratories / University of Babylon.

I register my sincere gratitude to my husband and children for their love, patience and support during the study preparation period. Finally, I am grateful to everyone who helped or advised me in this work.

Noor

2023

Abstract

In this study, the transesterification process was used to synthesize biodiesel from waste cooking oil. It is the reaction of triglycerides in 1 liter of waste cooking oil (WCO) with methoxide (4 g of NaOH catalyst dissolved in 130 ml of methanol alcohol). The experiment was carried out at different temperatures (58, 60, 62, 64) °C, to obtain different percentages of biodiesel production (86, 90, 94, 92)% in sequence. Thus, the optimum temperature for mixing all materials is at a temperature of 62°C, the mixture was left for 24 hours to obtain a biodiesel yield of 94% opposite 6% glycerol.

The results obtained from the examination of biodiesel properties using American Standards for Testing and Materials (ASTM) standards showed that the viscosity of biodiesel is approximately three times greater than the viscosity of pure diesel, for pure diesel a higher calorific value and less density of 0.08% than biodiesel. The resulting biodiesel has a sulfur content lower than pure diesel by 96%, which makes it environmentally friendly. The sulfur dioxide produced from the combustion of pure diesel is a toxic gas that poses a threat to human health.

However, after running an engine Single-cylinder diesel at a speed of 1500 rpm under different loads (0, 0.25, 0.5, 0.75, 1)% and with variable compression ratios and diesel and biodiesel mixtures. A mixture of biodiesel fuel was used with diesel in proportions B0(0% WCO biodiesel, 100% diesel),B10 (10%WCO biodiesel , 90% diesel),B20(20% WCO biodiesel , 80% diesel) and B30(30% WCO biodiesel , 70% diesel). It was found that at B20, the Brake Thermal Efficiency(BTE) decrease was 15.5% compared to pure diesel at high loads and compression ratio 15.5. At the same conditions, Specific Fuel Consumption (SFC) increased by 15%. Emissions of (CO_2 and HC) decrease by (23 and 48)%, compared to an increase in nitrogen oxides by 40%. B20 is considered

the best mixing ratio, because it gives engine characteristics closer to pure diesel compared to B10 and B30.

NO_X emissions, which have a negative impact on global warming, are one of the problems faced when using biodiesel. Therefore, Exhaust Gas Recirculation (EGR) technology was added. In this study, 5% and 10% of EGR were used . The results showed that at a mixture ratio of B20 and a compression ratio of 15.5, BTE, with an increase in EGR and a decrease in SFC by 25% when EGR = 10%. The results showed a decrease in nitrogen oxides by (60 to 78)% due to a decrease in the exhaust gas temperature (EXT) by 30% and a decrease in the amount of oxygen by 15%, in exchange for an increase in carbon dioxide and hydrocarbon emissions by (12 to 20). % and (11 to 20)%, respectively. BTE values are close when changing the EGR ratio, with a decrease in SFC by (18)% compared to none use of the EGR.

It was proved that 10% of EGR is better than 5%, to increase the decrease of NO_X emission and decrease of SFC. Slight difference in CO_2 and HC emission between 10% and 5% of EGR.

In this work, the compression ratio(CR) being changed three times (14.5, 15.5, 16.5), where the present results showed an increase in BTE and SFC by (14, 25)%, in sequence, with an increase in the compression ratio at the mixing ratio B20 at high loads. With an increase in the compression ratio from 15.5 to 16.5, the volumetric efficiency (VOL.eff) value and the air to fuel ratio (A/F) were close between the two ratios.

The optimum exhaust temperature which achieves the best performance and engine emissions was achieved when the diesel engine run on B20 fuel with 100% EGR applied (100% of the maximum 15% of the total exhaust flow intake). It was also approved seen that for each compression ratio, there is an optimum EXT at 3/4 load. They were 92 °C as the best EXT when CR = 14.5, 98.7 °C as the best EXT when CR = 15.5, and 130 °C as the best EXT when CR = 16.5, respectively.

NOMENCLATURE

Symbols	Description	Unit
A	area of orifice	mm
A_1	The pipe area	m^2
A_2	The orifice area	m^2
ASTM	American Standards for Testing and Materials	-
A/F	Air to fuel ratio	-
B_x	bias errors	-
BTE	Brake Thermal Efficiency	(%)
BP	Brake Power	KW
CR	Compression Ratio	-
CN	cetane number	-
C_d	Coefficient of discharge	-
DOE	Design of experiment	-
EGR	Exhaust Gas Recirculation	(%)
EXT	Exhaust Gas Temperature	(°C)
FAME	fatty acid methyl ester	-
ha	The head pressure of air	mm
h_w	The head pressure of water	mm
h_g	The head pressure of exhust gas	mm
IP	Input Power	KW
LCV	Lower Calorific Value of fuel	MJ/kg
n	number of measurements	-
Pa	Atmospheric pressure	kN/m2
p	confidence	-

P_X	accuracy errors	-
R	Gas constant	J/kg.K
rpm	Revolution per minute	1/min
SFC	Specific Fuel Consumption	(kg/sec)
TG	Triglycerides	-
Ta	Atmospheric temperature	K
u_x	uncertainty	-
VCR	Variable compression ratio	-
VOL.EFF	Volumetric Efficiency	(%)
WCO	Waste Cooking Oil	-
X1	true value	-
X_i	tested value	-

GREEK SYMBOLS

Abbreviation	Definition	Units
ρ_d	Density of diesel	kg/m^3
ρ_{bio}	Density of biodiesel	kg/m^3
ρ_a	Density of air	kg/m^3
ρw	Density of water	kg/m^3
$\dot{m}_f$	Flow rate of fuel mass	kg/s
$\dot{m}_{f1}$	The initial weight of fuel	kg
$\dot{m}_{f2}$	The final weight of fuel	kg
$\dot{Q}_a$	The flow of actual air	m^3/sec
$\dot{Q}_s$	The flow of theoritac	m^3/sec
$\dot{Q}_g$	The flow of EGR	m^3/sec

CONTENTS

CHAPTER ONE
INTRODUCTION

1.1 Overview

The demand for energy is rising quickly due to the ongoing growth in the global population. By 2030, the world's energy demand is expected to have increased by 53% from 2001 levels. The continued usage of fossil fuels will eventually lead to the depletion of non-renewable fossil fuels and increase global warming issue. The primary end-uses of fossil fuels are transportation, manufacturing, and energy generation. Environmental problems caused by the burning of these fuels include carbon emissions and climate change .

There is a need to solve these problems. Therefore, high efforts and an investigation were carried out to find new alternate energy sources such as solar, wind, nuclear, hydro, and biofuels. The most potential renewable energy source is biofuel. Biofuel is merely similar to the diesel fuel in terms of characteristics and its cleaner burning in compression ignition engine. Alternative fuels must be practical, accessible, and environmentally friendly. Biodiesel has been proven to be this most suitable promising replacement for diesel fuel. Numerous researchers and scientists have experimented with various renewable bio fuels such as the biodiesel, hydrogen, liquefied petroleum gas, compressed natural gas, and alcohol and others [1].

Favorable renewable liquid fuels include alcohols and bio oils, vegetable oils, the Animal grease, algae oil, and its biodiesel. Generally, alcohol has low cetane number makes it unsuitable for diesel engines. Although it was used as a fuel, It is not recommended to use vegetable oils directly in diesel engines due to their high viscosity, low volatility, and low octane rating. Therefore, vegetable oils must be converted to biodiesel through a variety of processes. Scientists were attracted to sources of inedible oils as vegetable seed oil crops

can be grown in arid lands, thus costing less to grow. The oils contain a high percentage of Free Fatty Acids , and thus these inedible oils need multiple chemical steps to be synthesized into fuel biodiesel, which increases production cost and lowers ester yield.

Therefore in the current study methyl esters are synthesized from waste cooking oil which has a very low Fatty acids content. A wide range of studies have been carried out on the combustion characteristics and obtaining emissions of a biodiesel diesel engine from a WCO. The studies on engine testing indicated in a decrease in particulate matter, carbon monoxide and hydrocarbons with clean or blended biodiesel compared to pure diesel fuel[1].

The chart below shows the Iraqi per capita consumption of cooking oils over several years, which shows a clear increase in consumption over the years figure(1.1) [4].
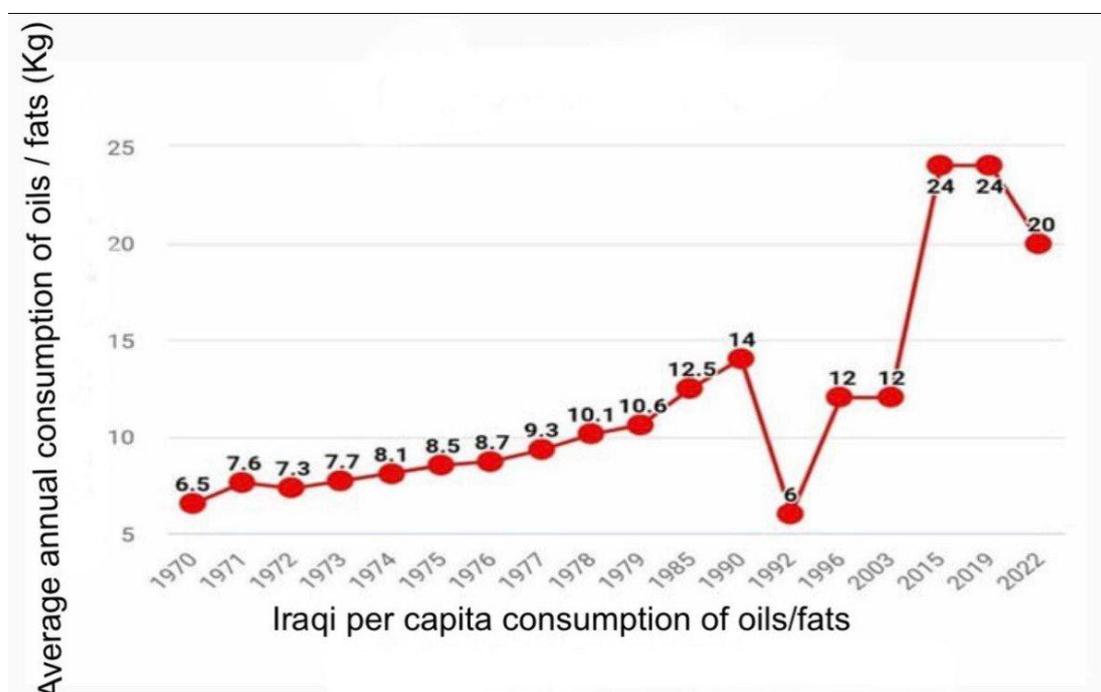
Figure (1.1) Annual Iraqi per capita consumption of oils [4].

Expansion of WCO production leads to serious waste. The majority of the time, this leftover oil is dumped into the ocean. It lowers the quality of the water, which can lead to pollution .So, it leads to numerous health issues. By using WCO as a biodiesel feedstock, issues like water contamination and sewage system obstructions that necessitate further cleaning can be lessened. Because of the high-temperature mixing of the water from the nutrients and the oil during the frying process, WCO has a high water and Fatty acidscontent. Therefore, the viscosity and acidity of the oil increases after use, these quantities should be less to reach the desired values. To solve these problems, the most common method, transesterification, was resorted to in the presence of an alcohol and a catalyst.

The following are the advantages of biodiesel:

- Biodiesel is nontoxic and decomposes 4- times nearer than diesel as pure biodiesel degrades 85 - 88% in water.

- Oxygen content in biodiesel advances the combustion process and reduces the possibility of oxidation, so it reduces the formation of CO_2, CO, HC, in addition of being sulfur-free. Mixing biodiesel and pure diesel rises engine success.

 - The lower vapor pressure of biodiesel creates it harmless to handle and store.

 - Because biodiesel has better lubricating properties compared to diesel, using it can increase the lifespan of a diesel engine.

- Produced from agricultural and plant resources, this resource is local, renewable, and non-exhaustible.

-Biodiesel is an alternative fuel linked to sustainable development, energy conservation, management, and environmental preservation.

 - An energy source having roughly the same amount of energy as diesel fuel.

 - The term "carbon neutral" is used to describe biodiesel as payment. Plants absorb more CO_2 from the atmosphere during photosynthesis than they do when It is burned in compression ignition engines as a fuel.

- Biodiesel may be used by itself or combined with petroleum diesel fuel in any amount.

- By generating employment and market opportunities, it helps agriculture and lessens the nation's dependency on imported crude oil. Biodiesel is safer to handle, move, and store than gasoline and diesel.

-Biodiesel does not contain aromatics or polycyclic aromatic hydrocarbons.

- A transesterification by product of crude glycerol that can be used in medical and industrial manufacturing in the cosmetics industry .

On the contrary, biodiesel has disadvantages which are summarized in the following points:

 -Higher viscosity.

-High corrosion of the copper strip.

- Slightly lower fuel economy on power fundamentals .

- Low temperatures cause it to start gelling, which can clog filters or thicken to the point where It is not pumpable from a fuel tank.

- Greater density than pure diesel.

- Oxidation-prone than pure diesel and in advanced phases, biodiesel fuel can become acidic as a result; creating insoluble gum and sediment that can clog filters.

-It was observed that biodiesel blends have higher specific fuel consumption than diesel fuel, and that biodiesel blends have lower thermal efficiencies than diesel fuel.

- An increase in NO_X emissions. Nitrogen oxide is one of the gases responsible for the formation of smog and ozone.

To achieve optimal performance of the variable compression ratio engine, EGR technology is added to reduce NO_X emission and obtain better performance characteristics. [2]

1.2 Biodiesel Production Feedstock

Biodiesel can be made from a variety of different feedstocks. The most important aspect of the biodiesel value chain is the raw materials. Consequently, their maximum possible oil content is of the utmost importance. The greater fat percentage, the greater the yield of biodiesel. This ranges from 15% (soybean) to 70% (microalgae) depending on the source material. Table (1.1) provides an overview of the biodiesel raw materials currently in use and their oil content.

Table (1.1) The oil content of the most important biodiesel feedstocks[3]

Type of Oil	Feedstock	Oil Content (%)
Edible	Soybean	15–20
	Rapeseed	37–50
	Palm	20–60
Nonedible	Jatropha seed	35–60
Other sources	Microalgae	30–70

1.2.1 First Generation Biodiesel Feedstock

Feedstocks for first-generation biodiesel include oilseed, sugarcane including (sugarcane and sugar beet), corn, , and certain other oil producing food and feed crops. Currently, maize and sugarcane crops account for 80% of bioethanol production, with raw ground corn accounting for 20% of ethanol conversion [5].

After using vegetable oils, fatty acid, ethyl, or methyl esters can undergo a variety of transformations [6].

1.2.2 Second Generation Biodiesel Feedstock

The second generation biodiesel is a biofuel comprising a natural proportion of municipal waste and forest residue that has a high octane number and a low cetane number [7]. Biodiesel created by mixing jatropha oil and crank oil in addition to diesel has proven to be capable of making energy [8] It is expected that inedible biodiesel crops will be grown on largely undeveloped lands, especially in poor areas and damaged forests . Furthermore, inedible oil plants are well adapted to arid and semi-arid environments, and require little fertilizer and water[9]. 26 plant species that contain oil in their seeds or kernels and produce inedible oils are potential sources for biodiesel production. Figure (1.3) shows a part of these plants.

The most important source of the second generation, which is characterized by lower costs, is WCO compared to pure vegetable oil . WCO is gaining traction as a potential biodiesel favorite. The widespread use of WCO in biodiesel production will help reduce reliance on petroleum fuels while alleviating the difficulty of discharging waste oil and potential pollution of land and water sources, and as a result, a carbon neutral approach to combustion-based energy sources is being pursued. One way to combat environmental degradation and

energy scarcity is to produce biodiesel from WCO to fully or partially replace pure diesel. In addition, the WCO is an excellent option for reducing the cost of biodiesel production All of these features make WCO a desirable renewable resource [11].

pongamia pinnata (karanja)   calophyllum inophyllum (polanga)   madhuca indica (mahua)

hevea brasiliensis (rubberseed)   cotton seed   simmondsia chinensis (jojoba)

nicotiana tabacum (tobacco)   azadirachata indica (neem)   Linseed

Jatropha

Figure (1.3) Varied non-edible vegetable oils as biodiesel feedstock[10]

1.2.3 Third Generation Biodiesel Feedstock

Due to their rapid expansion, and better photosynthesis than other terrestrial plants, algae are now considered one of the most promising feedstocks for biofuels containing up to 70% lipids by dry weight [9].

Algae perform photosynthesis and convert sunlight, water, and (CO2) into algal biomass, microalgae have long been recognized as potential sources of biodiesel [12].

1.2.4 Fourth Generation Biodiesel Feedstock

Fourth-generation biodiesel, like third-generation biodiesel, is produced on non-arable land. However, unlike the third generation, it does not entail the destruction of biomass. Waste transformer oil is a source belonging to the fourth generation. Waste transformer oil can be used as a substitute for petroleum oils. It is known that transformer oil is mainly used for insulation in electrical transformers, and after its expiration date, this oil is not used for anything else. Currently, 100% transformer oil is not used to drive the engine instead of diesel fuel [13]. Waste transformer oil are usually made from wax-free naphthenic oils [14].

1.3 Methods of Biodiesel Production

Some methods have been used to overcome the major difficulties associated with the usage of plant oils due to its little volatility and great viscosity. Some of these methods are (pyrolysis/cracking, dilution with hydrocarbons (blending), micro-emulsification, and transesterification) .

1.3.1 Thermal cracking (Pyrolysis)

It is the heating, with or without the use of a catalyst, of a single organic material into a multitude of tiny molecules. The majority of triglycerides (TG) is found in vegetable oils and animal fats . Sulfur, water, and sediment levels in pyrolyzed vegetable oils are acceptable .

Many studies have shown that pyrolysis of (TG) can create compounds appropriate for diesel engines. Though pyrolysis-produced biodiesel fuel is appropriate for diesel engines, the absence of oxygen reduces the environmental benefits of oxygenated fuels. The pyrolyzate (pyrolysis product) is less viscous, has a lower flash point. Furthermore, pyrolysis biodiesel's applicability may be limited due to undesired qualities such as decreased heating value, turbulence, and unstable . Pyrolysis is a rather expensive production process ,It requires complex equipment, such as distillation equipment, and is consequently very energy intensive [2] [15].

1.3.2 Blending (Dilution with hydrocarbons)

Dilution with hydrocarbons is the second method . Burning vegetable oils is generally regarded as inefficient and undesirable for both direct and indirect injection diesel engine. Using vegetable oils directly in diesel engines has two major drawbacks: oil degradation and incomplete combustion.

The dilution process is the process of diluting vegetable oils or waste oils by mixing them with a solvent or diesel fuel in certain proportions. This will reduce the viscosity of lubricants, improve engine performance, and reduce diesel use. However, this process is constantly limited due to the following factors:

• High viscosity, acidic composition and abundance of free fatty acids.

• Carbon deposits and thick lubricating oil. Gum formation during storage and combustion due to oxidation and polymerization [16].

As a result, substantial engine modifications, such as a change in the piping and injector construction materials, are necessary for the usage of plant oils in diesel engine .Otherwise, increasing wear and the danger of engine failure would result in higher engine maintenance costs.

1.3.3Microemulsification

Microemulsification, or the formation of micro-emulsions, could be a solution to the excessive viscosity of vegetable oils . Microemulsions contain three elements: a surfactant, an oil part, and an aqueous part. They are transparent, stable, and isotropic liquids. The precise quantities of pure diesel , plant oil, alcoho1, surfactant, and cetane enhancer compose a biodiesel microemulsion. Methanol and ethano1 are viscosity-reducers, whereas higher alcohols and alkyl nitrates are cetane promoters. Butanol, hexanol, and octanolmicroemulsions can all satisfy the maximal viscosity requirement for diesel engine. Microemulsion enhances spray efficacy and reduces biodiesel viscosity while also increasing CN . Continuous usage of micro emulsified fuel in engines, however, reasons issues such as injector needle sticking, excessive carbon deposits, and inefficient combustion [17].

1.3.4 Transesterification

The most widely used biodiesel production process is transesterification, Where reaction occurs when a fat or oil reacts with an alcohol to form esters and glycerol . Transesterification converts oils and (TG) into alkyl esters, which have a viscosity similar to diesel fuel. As a result, the material possesses similar qualities to diesel fuel, allowing it to be used as a dropable fuel in existing petroleum DIes without modification. The first step is to convert triglycerides

into fats by using ethanol alcohol in the presence of an alkaline catalyst such as NaOH or KOH [18] or methanol [19].

This is followed by the transformation of a diglyceride to a monoglyceride and a monoglyceride to a glycerol, giving one methyl ester molecule at each step from each glyceride.

Triglycerides are composed of three long-chain fatty acids linked to a molecule of glycerol. The type of fatty acid attached to the glycerol determines the oil's composition and characteristics. The type of fatty acid can influence the biodiesel's properties.

The viscosity of the vegetable oil changes dramatically during the transesterification process. Because the high viscosity component glycerol is eliminated, the result has a low viscosity, similar to that of fossil fuels.

In whatever proportion, the biodiesel generated is completely miscible with pure diesel. After transesterification, the biodiesel's flash point is reduced and the cetane number is increased.

1.4 Factors Affecting Biodiesel Production

Several process parameters influence biodiesel yield in the transesterification process, including the presence of water and free fatty acids, reaction time, reaction temperature, catalyst, and the alcohol-to-oil molar ratio ,are the primary parameters impacting transesterification [2].

1.4.1 Reaction temperature

Transesterification can be performed at a variety of temperatures, As a result, the temperature rises from room temperature to the boiling point of

alcohol (68°C for methanol), most literature recommends a temperature of 60–65 °C for transesterification. When the reaction temperature approaches or reaches the methanol's boiling point (68 °C), the methanol evaporates and produces a large number of bubbles. Since high reaction temperatures promote

saponification of triglycerides, in addition to increasing the reaction temperature above the acceptable limit,it reduces biodiesel production.The transesterification may well be performed at room temperature but requires a lengthier reaction time [5].

1.4.2 Reaction time

The reaction time determines whether the primary catalytic transesterification process has completed. Excess reaction time has been shown to cause a reverse reaction (hydrolysis of esters), which leads to a loss in product yield. After one hour of treatment, the highest yield of methyl esters can be obtained. Increasing reaction time does not lead to higher biodiesel/ monoalkyl ester yields. Moreover, As a result of the reversible reaction of transesterification, esters are lost and soaps are formed, the longer reaction time reduces the final product biodiesel [6].

1.4.3 Mixing Intensity

Transesterification is a somewhat slow process because it can only occur in the interfacial region between the liquids and because fats and alcohols are not completely miscible. To increase the contact area between the two immiscible phases, vigorous mixing is required . In the transesterification process, mechanical mixing is widely used. Depending on the need for mixing in the trans-esterification process, the strength of the blending could be adjusted. To guarantee good and consistent blending of the feedstock, the mixing intensity should be increased in general. When high kinematic viscosity vegetable oils

are utilized as the feedstock. Due to agitation of the oil and catalyst combination increases the reaction. Agitation speed is significant in the synthesis of the final product (mono alkyl ester or biodiesel). The mixing speeds were (200 rpm , 400 rpm , 600 rpm, and 800 rpm) while all other variables remained unchanged. At 400 rpm, a greater final product conversion was achieved. Because of the

slower stirring speed, less substance is generated . Higher stirring speeds, on the other hand, enhance soap production [20].

1.4.4 Methanol to Oil Molar Ratio

The molar ratio of alcohol to triglycerides is one of the most important factors affecting biodiesel production. In the trans-esterification reaction, methanol, ethanol, propanol, butanol , and amyl alcohol can all be utilized; however, methanol is used more often, due to its lower price and stronger physical and chemical advantages than the other alcohols, it is the most popular. The effect of methanol and ethanol volumetric ratios on oil was studied. The maximum biodiesel yield was about 99.5% when the oil/methanol ratio was 1:6. Thus, biodiesel production with methanol tended to rise with higher molar ratio of methanol [2], while some researchers found that the maximum conversion occurred with 1: 7 [3].

1.4.5 Type and Amount of Catalyst

The concentration of the catalyst has an impact on biodiesel production. (NaOH) or (KOH) are the most commonly used catalysts for biodiesel generation [2]. The concentration of the catalyst has an impact on biodiesel production. Due to the cost of the catalyst, a large amount of catalyst may not be economically feasible and also affects the yield of biodiesel. As a result, similar to the oil-to-alcohol ratio, finding the optimal amount of catalyst

required for the transesterification process varies between researchers and by biodiesel feedstock [21].

1.5 Effect of Properties of Biodiesel on Diesel Engine

Physical, chemical, and thermal properties are present in diesel and biodiesel. (Viscosity, density, cloud point, spill point, flash point, boiling range, freezing point, and thermal coefficient) are examples of physical properties.

A product's chemical properties, such as(acid value, saponification value, iodine value, total heating value, ash, sulfur, and copper content, corrosion, and flammability) are determined by its chemical composition. Thermal characteristics include (distillation temperature, thermal decomposition temperature, carbon residue, specific heat and thermal conductivity) [2].

One of the most important of these characteristics is the kinematic viscosity that must be taken into account to maintain engine performance. As the high viscosity hinders fuel flow in the engine combustion chamber during the intake stroke and takes a long time to mix with air, the viscosity must be reduced. Hence, it causes delayed combustion. It has been demonstrated that fuel viscosity reduces as temperature rises.

The cetane number directly affects the combustion quality and the fuel ignition quality is measured through it. The higher it is, the shorter the ignition delay.

Calorie value is one of the factors that determine the heating efficiency and combustion of the engine; it is a measurement of the energy content of the used fuel.

The flash point characteristic should be taken into account when evaluating the flammability of a fuel. At this point, the burning of steam stops if the ignition source is removed. Many factors affect the change of biodiesel flash point, one of them being the residual alcohol content. Also, it is affected by the

chemical composition of biodiesel. Including the number of double bonds, the number of carbon atoms, and others.

Fuel density influences engine performance and combustion quality by varying the amount of fuel injected by the injector. The increased density enlarges the fuel droplets in the combustion chamber, resulting in elevated particulate matter and NO_X emissions from the DI. The decreased density

increases the efficiency of atomization. Accruing to the variable fuel injection mass, variations in density impacts the output power of the engine.

Pour point is lowest temperature that the diesel reaches in the flow, and it is an indicator of the temperature at which the fuel can be easily pumped, after which the fuel stops flowing and begins to freeze. It is a measure of the quality of the diesel. The lower it is, the more desirable the fuel becomes.

Ash content is the remnants of non-combustible inorganic materials that remain after fuel combustion in air at a specified high temperature [22].

1.6 Treatment of NO_X Emissions

Mainly, the use of biodiesel is to reduce the hydrocarbons emissions but not NOX. NO and NO_2 combined are referred to as NO_X emissions. In the high temperature region of the flame post-combustion process, nitrogen oxide is produced. The primary source of nitrogen oxide formation is the oxidation of atmospheric nitrogen.

The primary causes of biodiesel's increased NO_X emissions are:

1- The viscosity and density of biodiesel, resulting in the delivery of a greater quantity of fuel under the same injection preparation conditions, as well as a more advanced combustion process, and consequently higher cylinder pressure and temperature. Since combustion occurs in a shorter time period, less time is likely available for cooling via heat transfer.

2- High availability of oxygen in the combustion chamber when biodiesel is used, which may lead to enhance nitrogen oxide formation reactions [25].

The emission of nitrogen oxides is reduced by several techniques, the researchers stopsat some of them.

1.6.1 Emulsified biodiesel

In this method, water molecules absorb a portion of the heat produced during combustion, thereby lowering the temperature of combustion and reducing NO_X emissions. An emulsion is a blend of two partly liquid substances, one of which (water) is spread inside the other is (biodiesel). Adding water to biodiesel increases its power, thereby improving the brake thermal efficiency of the. Corrosion is one of the primary issues associated with emulsified biodiesel due to its water content behavior. Using a water vapor injection system with electronic control can reduce the corrosion issue caused by emulsion fuels. Due to its lower combustion temperature, this technology produces more hydrocarbon and carbon dioxide emissions. Additionally, it lacks stability. Emulsified biodiesel necessitates an integrated emulsion system, which raises costs. Because pure diesel has a smaller boiling range than biodiesel, it is less difficult to combine with water.

1.6.2 Low temperature burning

It is usually accepted that soot and NO_X emissions are potential if the burning heat is maintained below 1800 K. A fuel is pre-compressed and premixed before to auto-ignition. This helps to lessen the temperature of combustion. When NO_X and particulate matter emissions drop, HC and CO emissions rise. Due to the difficulties of creating a homogenous combination of low-volatile diesel and air, external mixing equipment is utilized.

1.6.3 Fuel processors

Biodiesel characteristics play a significant role in NO_X emissions. Biodiesel fuels with a high density and a low cetane number emit a considerable amount of NOx. With the addition of a suitable additive, NOx emissions from biodiesel can be reduced significantly. Cetane number enhancers like ethyl hexyl nitrate are among these fuel additives , and antioxidants such as nickel and magnesium are of great importance, and are important in reducing NO_X emissions. Adding antioxidants has the added benefit of increasing storage stability , improve combustion efficiency and engine protection against wear and wax deposition. NO_X emissions are decreased by adding acetone , butanol and ethanol.

1.6.4 Exhaust gas recirculation (EGR)

Through the inlet valve, A minor amount of exhaust gases are recycled back into the combustion chamber. During combustion, these recycled exhaust gases replace a portion of the available oxygen. Since the specific heat of EGR exceeds that of ambient air. EGR increases the temperature of the mixture of fresh air and reduces the amount of oxygen, Thus, the combustion temperature is lowered for the same amount of heat output, and NO_X emissions are reduced. However, as EGR rates increase, the emission of HC, CO, CO, and smoke increases. This is caused by lacking oxygen for complete combustion, which lowers the burning heat. The brake thermal efficiency also declines as the EGR rate rises. It also increases the fuel consumption. It can be corrected by improving the EGR percentage. The effective air-fuel ratio is lower due to lack of oxygen for combustion.

This technique is still preferred because of the simplicity in operation, compared to the economy of other techniques [25][26].

Some researchers have cooled the exhaust gas before it is re-circulated using a heat exchanger as shown in figure (1.4) , which lowers the combustion

temperature in the cylinder. Between the intercooler and the exhaust port of the engine, control valves are installed to regulate the amount of EGR that must be recalculated back into the engine. Brass is used to construct the control valve, so that it can withstand high temperatures. Placed after the intercooler and before the engine's intake port, the filter filters carbon particles

from the exhaust gas. Figure (1.3) shows the application of the EGR system for experimental investigation to the researcher[27].
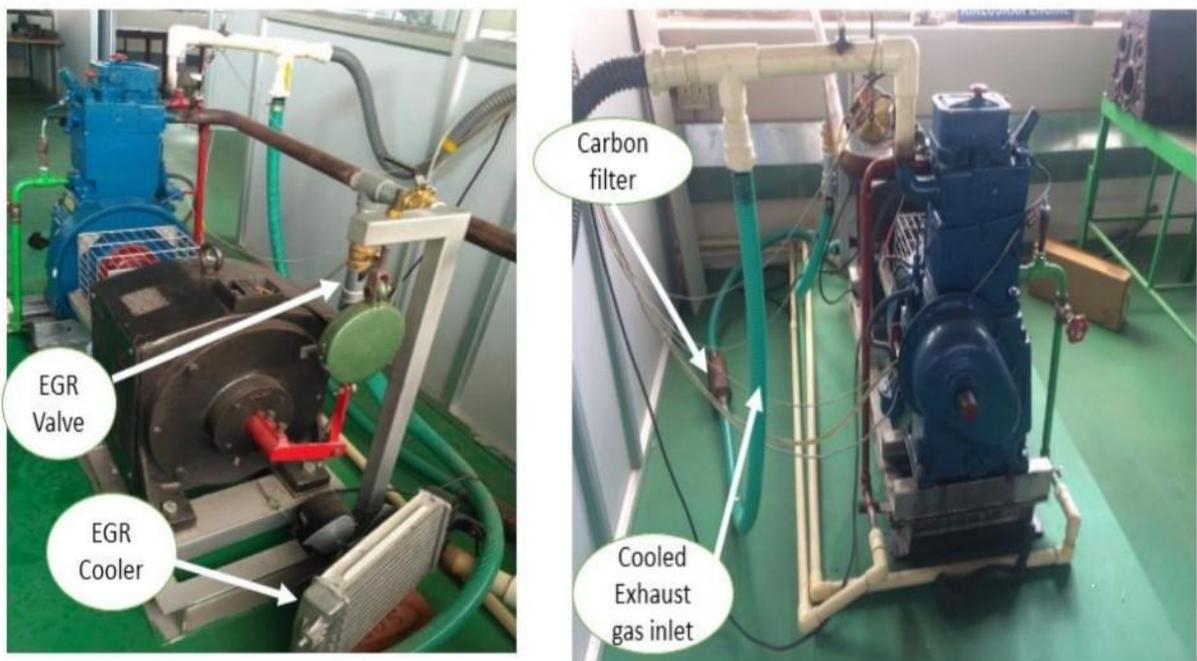

Figure (1.3) A picture of a diesel engine equipped with a system EGR [27]
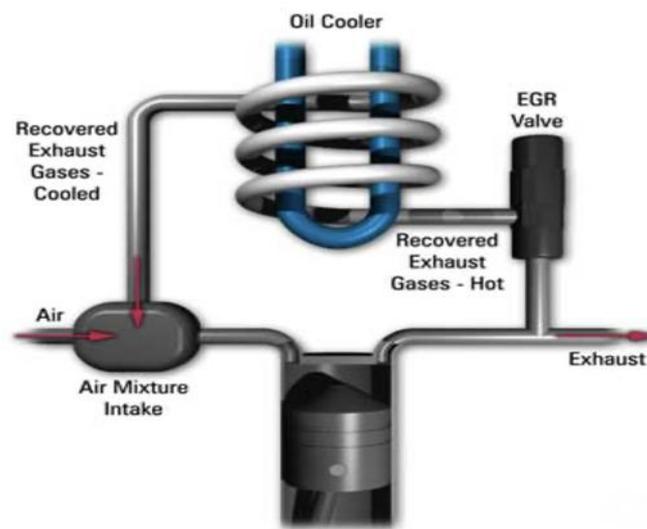
Figure (1.4) Scheme for cooled EGR[27]

1.7 Economic Evaluation

Transesterification is currently the most popular method for producing biodiesel, primarily due to its rapid reaction rate and low cost. Alcohol is combined with an alkaline stimulant. Methanol is widely utilised in this process because its low cost. NaOH or KOH is the common alkaline catalyst. Due to its relatively slow reaction rate, acid-catalyzed esterification (such as sulfuric acid) has received less attention.

Using waste cooking oil significantly reduces the cost of biodiesel because waste oil is relatively inexpensive. This eliminates the cost of the raw materials. Valuable was the production of a glycerol byproduct, which could add a tangible credit for a 10% reduction in total production costs.

The cost of producing biodiesel produced from any source includes the cost of purchasing raw materials, raw material processing, costs of equipment used, labor costs, costs of catalysts and alcohol.To improve the overall cost of biodiesel production, the cost of raw materials must be reduced.

1.8 Aims of the Study

The aim of this study can be summed up in a few points:

1- Preparing biodiesel from waste cooking oil WCO through the transesterification process. This helps environment by recycling waste, saving the climate at a reasonable price, and producing clean and renewable energy.

2- Fuel characterization to comply with ASTM international fuel standards.

3- Experimental investigation using a 4-stroke, single-cylinder, direct-injection diesel engine. It works in variable loads and can be controlled with variable compression ratios.

4- Determining the best mixing ratio that can be used to operate the diesel engine to give the best performance with the least engine exhaust emissions.

5- Reducing NO_X emissions resulting from mixing biodiesel with diesel by using the EGR technology.

6- Finding out best EGR temperature that leads to enhance the performance and emissions of engine
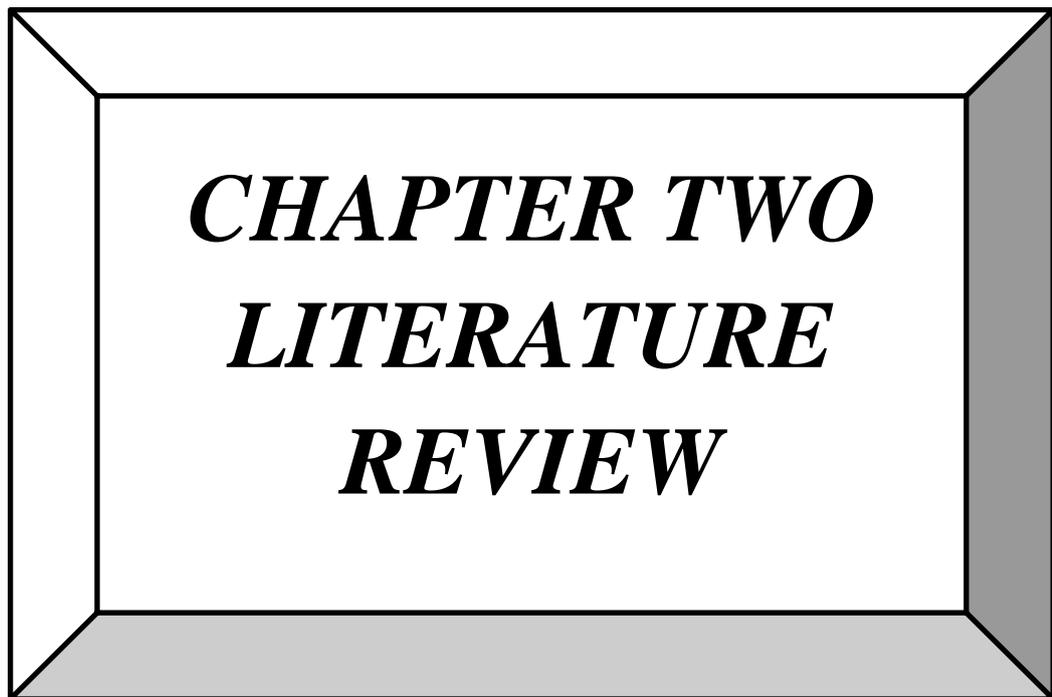
CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Revisions of previous studies are presented in this chapter. In 1885, Rudolf Diesel held the first patent for biodiesel as a fuel for compression ignition engines as a result of research conducted in the 1930s in Belgium, where pure vegetable oils were used in diesel engines for agriculture where petroleum diesel was not available. Biodiesel has played an important role in the world of fuels due to the depletion of fossil fuels and the increase in its emissions [28]. Recently, the transesterification process has been used to convert oils into alkyl esters of fatty acids to reduce their viscosity. The studies covered biodiesel production and its impact on the performance and emissions of the mechanical power generation engine in various sectors, such as agricultural, domestic, and transportation.

2.2 Biodiesel production from WCO

The waste cooking oil-derived biodiesel has been successfully used in diesel engine. Numerous techniques are adopted to convert the oil or fat to biodiesel [1], [36]. Recently, studies indicated that the production of biodiesel through the transesterification process is the most efficient and easiest technique.

Hosseinzadeh , et al. (2022) [29] said that turning in biodiesel production have the potential to solve the problem of providing clean and affordable fuel for future power and heat generation.

Liu, Yanbing, et al. (2021) [33] pointed out that the price of fuel is slightly greater than the cost of production. Together with the price of alcohol and catalysts, the production cost also included the cost of cleaning the spent oil to get rid of contaminants and high-density fatty acids. The researcher suggested that its use and sale should be strictly contrcontrolled in order to make the method commercially sustainable.

Zhao , et al. (2021) [34] either came to the conclusion that biodiesel had less of an impact on the environment than diesel. Due to greater purchases made by the WCO in China and the cost of the components needed in the transesterification process for biodiesel, the price of biodiesel is roughly 31% more than that of diesel. As a result, the researcher advised enhancing energy conversion rate, cutting transmission distance, and managing WCO purchase price.

Erchamo, et al. (2021) [35] synthesized biodiesel from WCO in a transesterification process using methanol alcohol, ethanol, and an improved CaO nanocatalyst from chicken eggshells using dehydration treatment followed by calcination. A biodiesel yield of 94% was achieved.

Singh , et al. (2020) [36] explained through his review that the transesterification process is the most economical and biodiesel fuel produced from this technology has similar characteristics with diesel. The researcher stressed the need to focus future research on identifying non-edible raw materials for the production of high-yield biodiesel fuel. There are wide research opportunities available in the field of reducing the cost of biodiesel production without affecting the quality of the fuel. The researcher also explained that the biodiesel production process must achieve economic feasibility, improve performance, and reduce emissions.

Park, et al. (2019) [37] turned to the production of biodiesel from WCO and grease resulting from cooking process of the campus restaurants. This eliminates campus expenses for off-campus shipping and handling of WCO and grease as well as operating diesel vehicles for processes, The college's maintenance and security workers and their potential cost reductions. Studies of the thermodynamics and viscosity of biodiesel testify to its suitability as a fuel, as it is not a source of concern because the level of pollutants is much lower than the level of environmental concern. Exhaust gas analysis indicates almost complete combustion of CO_2 and H2O with no residual hydrocarbons when experienced in a diesel engine.

Degfie , et al. (2019) [38] synthesized biodiesel from WCO by transesterification process with nano-catalyst (calcium oxide), at a temperature of 50 C° during 90 minutes of reaction. 96% of biodiesel have been produced with ASTM-compliant quality, this method has many benefits such as economic, environmental, and waste management.

Joshi, et al. (2019) [39] investigated the economic analysis of biodiesel production from the transesterification process of WCO collected from a campus restaurant. 93% of biodiesel was produced within 50 minutes at 60°C using methanol alcohol and KOH as a catalyst. The researcher concluded that biodiesel can be used as an alternative to diesel to solve the environmental problems related to it at a low production cost. The researcher conveyed some of the benefits of biodiesel production (sustainability, fuel diversity, increase in the number of rural areas, manufacturing jobs, increased investments in plant and equipment, international competitiveness and reduced dependence on imported diesel.

Elgharbawy'sAbdallahSayed Ahmed Ali (2017) [85] explained "The implementation of such project enhances the national economy by providing about 150 direct jobs and 1,000 indirect jobs. After the researcher analyzed the

cost of producing biodiesel with a capacity of 100,000 tons per year, he found that the total capital expenditure required to build the plant is 4.121 million US dollars, where the cost of the purchased equipment is 1.3 million US dollars and the other capital expenditures are 2.8 million US dollars. The researcher concluded that the cost of producing one liter of biodiesel is $0.515, compared to $1 per liter for the price of pure diesel, so building biodiesel plants will undoubtedly reduce dependence on petroleum and diesel.

Sharma, et al .(2017) [40] mix 6 mixtures of pure diesel and biodiesel fuels to study the engine performance characteristics, B20 was chosen as the best ratio compared to the rest.

Hussain, et al .(2016) [41] studied for WCO biodiesel manufacturing in the United Arab Emirates. A survey of the local residential and commercial sectors was done. The researcher sought information regarding the type of oil and the quantity of WCO in order to identify the least sold and compare it to the current diesel price. Other benefits such as CO_2 emissions have been computed, and the results indicate a 23.1% decrease in emissions, as well as a reduction in the maintenance costs connected with the current drain obstruction due to WCO, so the government and waste management authorities are also gained. This has a really favorable effect on the environment.

M.F, Elkady, et al .(2015) [42] used the micro mixer in order to save time, increase product and better conversion, to produce biodiesel from waste vegetable oil by transesterification process in the presence of methanol at a ratio of 1:12 and by using a catalyst in 1% sodium hydroxide, acetic acid, and tetrahydroflurane at 120°C. The yield is up to 97%.

Subramaniam, et al .(2013) [2]explained that transesterification is the best process for producing clean, renewable, sustainable and environmentally friendly biodiesels, which are esters of long-chain fatty acids formed when

vegetable oils combine with a short-chain alcohol, in addition to producing a by-product (glycerol) for it commercial value.

Wang , et al . (2012) [43] described some methods for converting WCO into biodiesels (preheating, blending, microemulsion, pyrolysis or thermal cracking and transesterification). The biodiesel fuel that is produced from the transesterification process is non-toxic and sulfur-free (Which has a negative effect on human health [91]). As for the biodiesel that is produced from the rest of the processes, it causes problems in the engine due to the high viscosity of the oil and the incomplete combustion of the fuel.

Richard, et al . (2010) [15] demonstrated in several investigations to produce chemicals suitable for diesel engines. Although pyrolysis biodiesel is suitable for DIs, the lack of oxygen reduces the environmental benefits of oxygenated fuels. The pyrolysis product is less viscous than petroleum diesel, has a lower flash point, and contains less polypropylene. Moreover, the applicability of biodiesel pyrolysis may be limited by undesirable properties such as low heating value, turbulence and instability.

S.P., Singh, and Dipti Singh. (2010) [44] showed that the process of diluting vegetable oil with petroleum diesel to run the engine without any modifications to the engine is successful when mixing 20% vegetable oil and 80% diesel fuel. He also noted that it was impractical to replace 100% vegetable oil with diesel. As for the pyrolysis process, it is an expensive process that requires complex equipment such as distillation equipment and consumes a lot of energy. Therefore, researchers focused on the transesterification process to reduce production cost and high production capacity.

Meng, et al . (2008) [45] investigated the conditions affecting the production of WCO biodiesel from the transesterification process such as mole ratio of methanol/oil, amount of alkaline catalyst, duration and temperature of the reaction. These conditions are assumed to have a substantial effect on the

reaction's conversion efficiency. The ideal experimental parameters determined by the test were a methanol/oil molar ratio of 6:1, a NaOH concentration of 1.0%, a temperature of 50 degrees Celsius, and a reaction time of 90 minutes. Under these conditions, this resulted in a WCO conversion rate of biodiesel production of 89.8%.

2.3 Effect of Biodiesel on Diesel Engine Performance and Emissions

Yildiz, et al. (2022) [30] experimented with the exhaust emissions produced by the combustion of biodiesel in internal diesel engines. The researcher observed that more biodiesel than diesel is consumed as fuel. The use of biodiesel also affects emissions. To achieve the best outcomes for the engine and the environment, the researcher advised producing new varieties of biodiesel .

Sivarethinamohan, et al. (2022) [46]ran the diesel engine with a mixture of diesel and biodiesel produced from waste cooking oil by using solar energy. By using a thermal reactor consisting of a copper tube in the form of a spiral that was placed in a glass box to improve the area of heat absorption and transfer from the sun. The researcher used a stirrer to mix 0.75% of NaOH as a catalyst with 1:12 of methanol as a solvent at a speed of 300 rpm. The highest biodiesel production was obtained 82% at 56.5 °C in the month of April.The researcher noticed a decrease in BTE of the engine by (14.8%) at low engine load, and an increase in CO_2 emissions with a higher mixing ratio at high loads

Dangsunthonchai, et al. (2022) [47] Carried out a diesel engine test with a mixture of biodiesel fuels (0%, 30%, 100%) . The researcher noted that an increase in WCO in the mixture led to an increase in SFC and a slight decrease in the BTE under all loads, HC and particulate matter emissions were significantly reduced. Because of the high oxygen content of biodiesel contained in the fuel , Which leads to a longer combustion time, which stimulates additional time for the formation of nitrogen oxide. The researcher

recommends preparing new alternative fuels with advanced engine control strategies and exhaust gas after treatment systems to comply with increasingly stringent emissions legislation.

Singh , et al. (2021) [1] validated based on the most recent data on waste edible oil for the production of biodiesel and its efficient use in CI engines. Approximately 30% of the edible oil consumed per capita is discarded. The production of biodiesel from WCO decreases production costs and waste disposal plant labor. In comparisons between biodiesel and fossil fuels in CI engines, There was a rise in SFC and a drop in BET and BP. As the quantity of biodiesel in a diesel and biodiesel combination was raised, BTE lowers, SFC rises, and emissions of CO_2, HC, PM, and smoke are drastically reduced. There are significant efforts made to increase the yield without compromising the economic viability of the production procedure.

Balasubramanian, et al. (2021) [48] concluded that the mixing ratio B20 is the most suitable for the engine in terms of performance and emissions as shown in figure (2.1). It was found that the maximum reduction of HC was 17%, 30% for carbon monoxide, 14.08% for smoke, 7.35% for carbon dioxide and an increase of 16.46% for NO_X emissions. With the aim of reducing NO_X emissions (affecting human health), EGR was used at three rates (5%, 10%, and 15%). With increasing EGR rates, a significant proportion of NO_X was reduced. Yet, other emissions rise as EGR rates increase. In contrast, an EGR of 10% reduced NO_X emissions by a maximum of 16,34% with only a minor drop in performance.
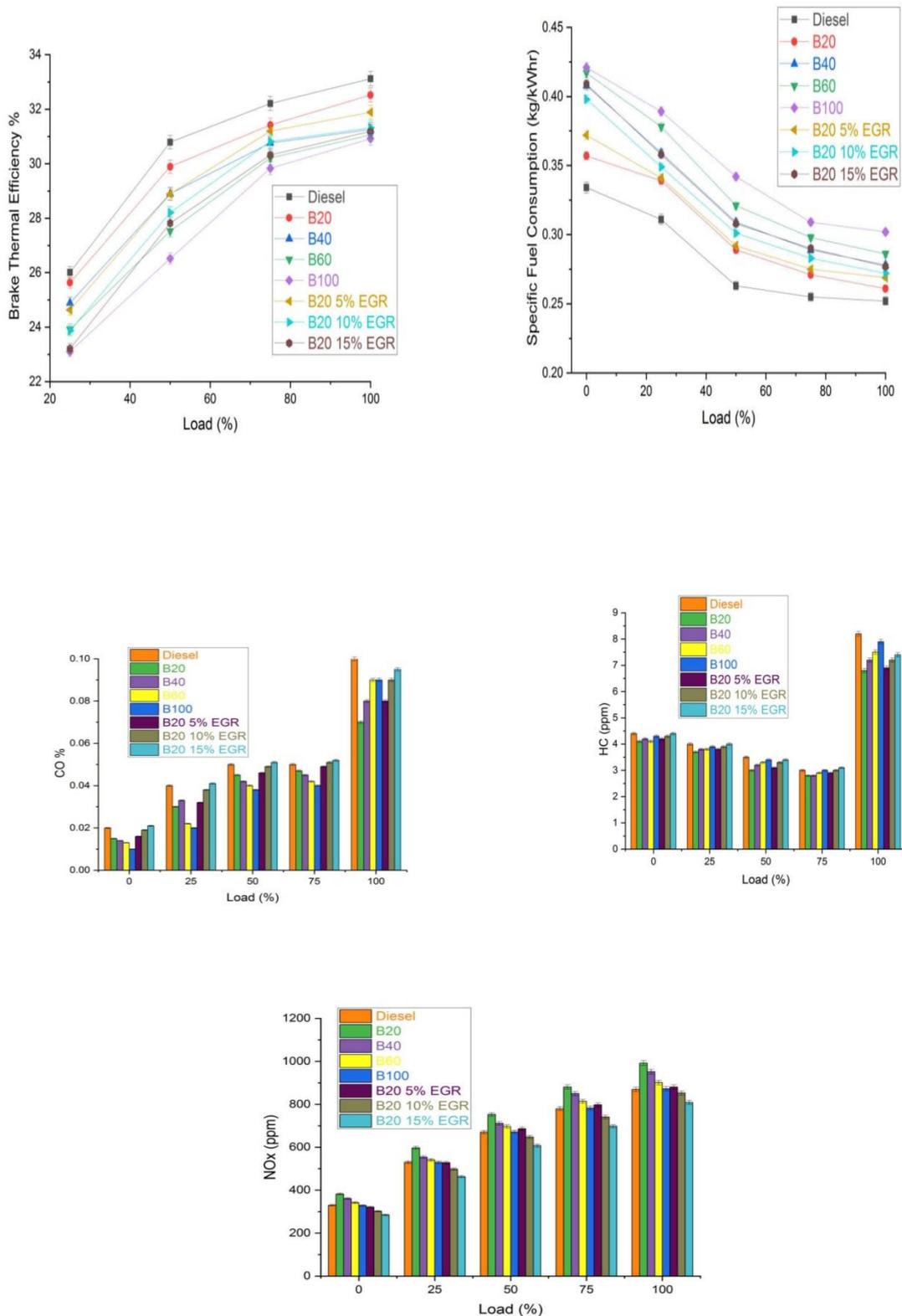
Figure (2.1) The variation of Engine performance and emissions with load at different EGR

A.Viornery, et al. (2020) [49] concluded after running the engine with a mixture of WCO biodiesel and pure diesel with a ratio of B25. Due to the high viscosity of biodiesel and its high density, causes poor pyrolysis and thus incomplete combustion and this leads to an increase in carbon dioxide emission by 52% and nitrogen oxides and an increase in fuel consumption. According to the emission results, the researcher found that it is necessary to link the technical specifications of the CI engine with the physical and chemical properties of the fuel in order to choose the appropriate proportion of biodiesel in the mixture.

Maki and Haroun (2020) [50] ran the diesel engine with a mixture of ethanol, diesel and 10% biodiesel produced from WCO. Thermal tests showed a reasonable improvement in BTE by 4%. Nitrogen oxides are recorded for the ethanol-diesel mixture at lower values than for the diesel by about 3.3%. A mixture of 70% diesel and 10% biodiesel with 20% ethanol is the optimal rate if thermal efficiency and emitted pollutant rates are taken into account when compared with other pollutants.

M Obed, Ali (2019) [23] Run a diesel engine on a biodiesel blend of diesel and used cooking oil at a high mixing ratio of (B30) . when conditions are fixed and engine speed is raised from 900 rpm to 2400 rpm in continuous steps of 300 rpm. The use of diesel fuel at maximum engine speed followed by B30 blended fuel resulted in the greatest amount of braking power and thermal efficiency. The findings revealed a significant difference in fuel characteristics after blending .When using blended fuel B30, the viscosity difference between pure biodiesel and diesel decreased from 34% to roughly 9% at a density comparable to that of B30 and diesel blended fuels. The heating value obtained with B30 blended fuel converges from approximately 18% to about 4% in a direction similar to that. With the same engine speed and minimal fuel usage, slight

variances in BSFC between B30 and diesel fuel were obtained. the highest BTE was seen at full engine speed using mixed fuel B30.

Abed, K. A., et al. (2018) [51] used a blend of biodiesel made from waste cooking oil and diesel to power a single-cylinder DI. It was determined that blends' thermal efficiencies were minor than that of pure diesel and that their individual fuel consumptions were higher. Waste cooking oil biodiesel mixtures reported higher exhaust gas temperatures than diesel fuel at the same engine load. Diesel fuel had lower air-fuel ratios than B10, B20, and B30 diesel-biodiesel blends. CO, HC, and other emissions from waste cooking oil biodiesel mixtures were lower compared to diesel fuel. With an increase in the amount of biodiesel fuel in the blends, NO_X and CO_2 emissions rise. The figure (2.2) shows the effect of mixing biodiesel with diesel on engine characteristics
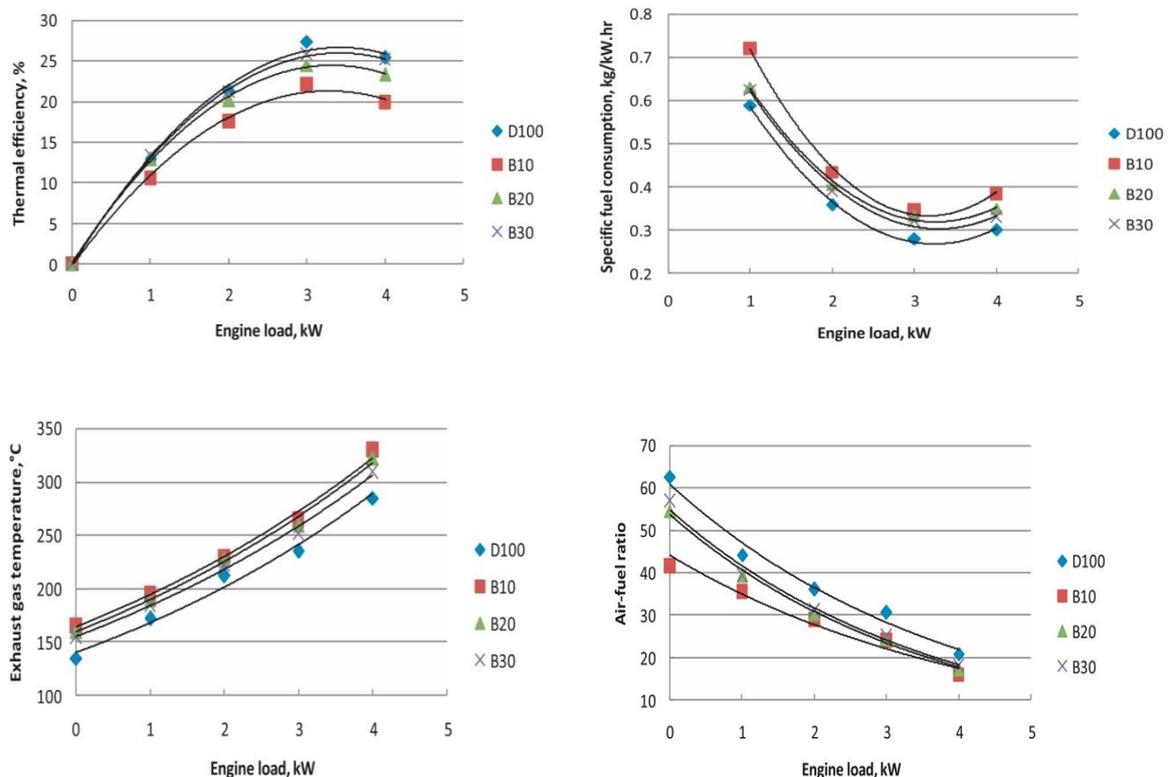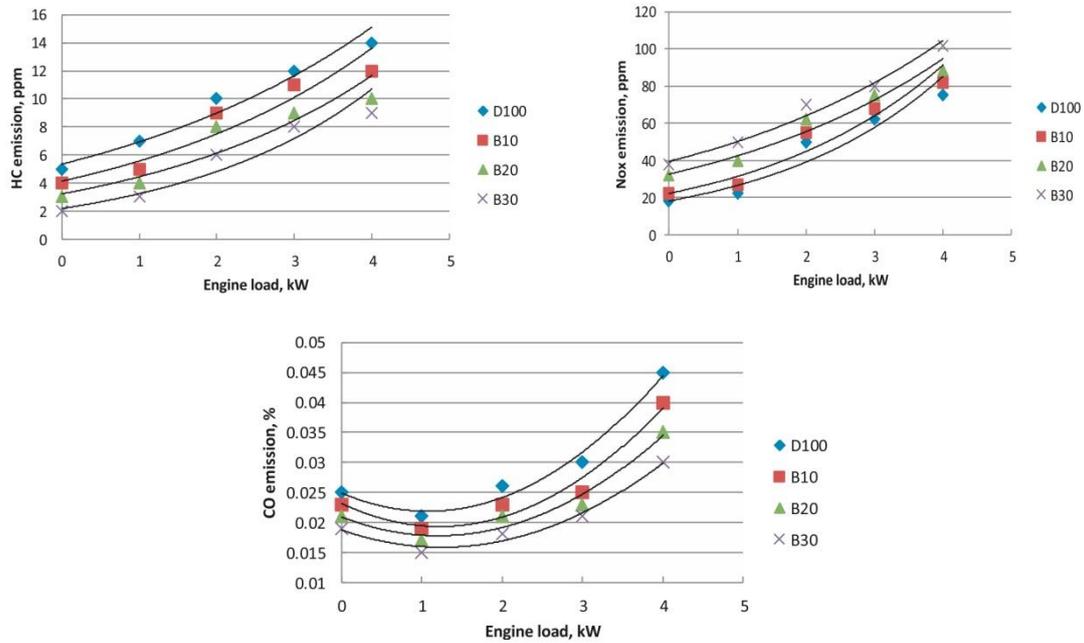
Figure (2.2) The variation of Engine performance and emissions with addition biodiesel

Borugada, et al. (2018) [52] examined how regular diesel, biodiesel made from the used cooking oil, and their blends performed and emitted pollutants (B10, B15). Engine testing was carried out at a steady 1500 rpm. According to the experimental findings, the fuel mixtures' higher density and kinematic viscosity, which decreased the rate of fuel atomization, caused a loss in the brake thermal efficiency of 1.7–4.14% and an increase in specific fuel consumption of 2.18–5.57%. Moreover, the majority of the exhaust gas constituents decreased, including CO_2 (13.67-16.89%), HC (4.35-11.84%), and CO (8.34-17.39%), were present in all combinations. The considerable amount of cetane in the fuel mixes, which shortens the ignition delay, is the main cause of the rise in NO_X emissions (0.3–4.2)% .

Patel , et al. (2015) [53] assessed the efficiency of a diesel engine using a biodiesel/diesel blend. The study came to the conclusion that the brakes thermal efficiency reduces as the amount of biodiesel fuel in the combination rises. B10 compounds' braking thermal efficiency is inferior to ordinary diesel

fuel in all blends and is closest to that of diesel fuel. Compared to diesel, specific fuel consumption rises with blends. The consumption of B30 mixture is most similar to that of diesel. The fuel consumption increased along with the biodiesel content. As the load increased, the brakes used less energy. In comparison to regular diesel fuel, B20 blend has a high mechanical efficiency.

2.4 Change in Compression Ratio's Impact on Diesel/biodiesel Engine Emissions Performance

Sharma , et al. (2022) [54] treated the emission of NO_X as a result of the use of biodiesel saturated with oxygen by changing CR with the addition of EGR. Without EGR the BTE has a minimum of 0.15% compared to diesel. With NO_X reduced by almost 50% for all EGR values but increased when CR increased, smoke and hydrocarbon emissions also increased with exhaust gases. According to the results ,the biodiesel produced by WCO can be a long-term alternative to pure diesel.

Rao , et al. (2022) [55] discussed the effect of EGR and compression ratio on the performance, combustion and emission characteristics of a diesel engine fueled by 20% Palmyra oil methyl ester (POME). It was discovered that the brake thermal efficiency of the POME 20 mixture operating in CR 20 was 24.59%, 6.91% higher than that of POME 20. Under full load, the usage of EGR led to a small drop in BTE. 10.25% less BSFC is seen when POME20 is operated at 20 CR as opposed to 16 CR. With a 20 compression ratio of POME 20 biodiesel blend, the current study indicates substantial reductions in HC, CO, and smoke emissions. At peak load, diesel hydrocarbon, carbon dioxide, and smoke emissions reduced by 8.82 percent, 13.33 percent, and 8.2 percent, respectively. Yet, it was determined that NO_X emissions for the POME 20 mixture rose as the compression ratio increased for all loads. Applying 10% EGR to POME 20 in the diesel engine operating at a compression ratio of 20:1

reduces NO_X emissions by 14.30% and 23.0%, respectively, compared to the diesel and POME 20 blend operating at a compression ratio of 18:1 without EGR.

Sahu , et al. (2021) [56] conducted an experiment to operate an engine powered by biodiesel fuel produced from WCO and diesel at a speed of 1500 revolutions per minute. An increase in BTE of 32% was inferred for biodiesel when CR was increased from 18 to 20 at full load, with a decrease in BSFC of 6% for the same operating conditions**.**

More , et al. (2021) [58] concluded that increasing the CR from 14 to 18 leads to a decrease in nitrogen oxides emissions at all loads, but an increase in carbon dioxide emissions. When CR=16 minimum exhaust emissions (CO, HC, CO_2, and NO_X) successfully occur for the tested mixtures. As CR=16 works effectively and provides good emission results for all exhaust gases with improved performance using a biodiesel / diethyl ether / diesel fuel blend. It also improved BTE by 80% and BSFC reduction of 32%.

Mahmood , et al. (2021) [57] ran the diesel engine with a mixture of diesel and biodiesel. When compression ratios are raised, the BTE and BSFC for all utilized fuels are reduced. Due to the higher viscosity and density of biodiesel, it was discovered that the BTE content of biodiesel blends reduced marginally, while the BSFC content increased, compared to diesel fuel alone. With a rise in compression ratio and biodiesel blend ratio, Carbon dioxide and hydrocarbon emissions and smoke opacities have been reduced, and at the same time increased NO_X emissions. Up to 20% biodiesel blends can be used and blended with diesel fuel in CI engines without any modifications. Because the B20 biodiesel blend demonstrated the greatest reduction in carbon dioxide, hydrocarbon, and smoke emissions, and the greatest increase in NO_X emissions.

Hariram, et al. (2020) [59] tried to experiment using palm stearin wax as a value-added raw material for the production of biodiesel fuel through the transesterification process. The results showed that adding 20% of this substance to diesel increased BTE by 40.3% and decreased BSFC by 10.72% for CR = 18. While diesel showed a BTE increase of 41.8% at partial load conditions of CR=17.5. HC emissions decreased significantly with an rise in compression ratios. Smoke and CO emissions tended to decrease as compression ratios increased. NO_X emissions were also observed to be higher in all CR18 fuel tests. At a compression ratio of 18, it demonstrates enhanced performance characteristics and lower exhaust emissions.

Rosha, et al. (2019) [60]observed an increase in BTE with an increase in CR from 16:1 to 18:1 for an engine running on B20 palm oil. An average decrease in hydrocarbon and carbon monoxide emissions and smoke opacity was also observed by 47.8, 41.0 and 35.7%, respectively, while NO_X emissions increased by 41.1%. Thus, it is concluded that B20 fuel performed well at a high engine compression ratio.

Suresh, **et al. (2018) [61]** clarified the necessity of switching to a variable compression ratio engine over a fixed compression ratio because it provides improved fuel economy, a 30% reduction in fuel consumption, improved management of peak cylinder pressure, the possibility to use diverse fuels, and decreased exhaust pollutants.

Bharadwaz, et al (2016) [62] concluded that the best performance of a diesel engine with variable compression ratios with the lowest emissions at CR = 18 and a payload of 9.03 kg, when engine operated with a blend of methanol and biodiesel at a rate of 5%.

S., Nagaraja, et al (2015) [63] investigated the performance and characteristics of an engine with different compression ratios when running on diesel fuel mixed with palm oil at different rates and at 1500 rpm. They found

that thermal efficiency reaches its maximum at the highest compression ratio at a mixing ratio (20% preheated palm oil). They note that the exhaust temperature decreases in all combinations along with a reduction in CO_2 and HC emission. Finally, they showed that the engine performed best at 20% and a 20 compression ratio at full load.

EL_Kassaby, et al. (2013) [64]found that the BSFC decreased for all mixtures with increasing CR and for all CRs, but it stayed higher for higher blends with increasing biodiesel ratio. Changing the compression ratio from 14 to 18 resulted in an increase in the brakes thermal efficiency. Carbon dioxide emissions also increased by 14.28%, hydrocarbons emissions decreased by 52%, carbon monoxide emissions by 37.5% and nitrogen oxides emissions increased by 36.84% when the compression ratio increased from 14 to 18.

Sayin, et al. (2011) [65] investigated the effect of compression ratio (CR) using three different ratios (17, 18, and 19) on the performance and emissions of A diesel engine using biodiesel (5%, 20%, 50% and 100%) blended diesel fuel. The results showed that BSFC and BTE improved significantly with increasing CR. NO_X emissions increased, while brake thermal efficiency, smoke opacity, carbon monoxide (CO) and hydrocarbon (HC) decreased with increasing amount of biodiesel in the fuel mixture. Sufficient air in the fuel mist contributes to complete combustion. HC and CO emissions with a biodiesel blend are lower than diesel for all CR values due to the higher in-cylinder combustion temperature. But this leads to increase emissions of nitrogen oxides.

Muraleedharan, et al. (2011) [66] conducted a test in which diesel and biodiesel were injected into a diesel engine with a variable compression ratio at various ratios.It was concluded that the B40 ratio when compared to conventional DIs, the thermal efficiency was slightly higher. using higher compression ratios. Compared to other mixtures and all kinds of diesel engines,

the special fuel consumption is lower. At higher compression ratio, the exhaust gas temperature drops. The minor calorific value of combined fuel related to pure diesel is a reason. The amount of hydrocarbons released increase with increasing compression ratio .

2.5 Effect of EGR on the Performance and Emissions of a Diesel/biodiesel Engine

Prakash, et al. (2022) [67]concluded that 20% of the EGR caused a decrease in the BTE of an engine running on Bongamia biodiesel mixture by B20, in addition to a slight increase in CO_2 and HC emissions due to the availability of insufficient air for combustion. NO_X emissions were reduced at the same conditions by 31% compared to the no EGR. Smoke emissions have also been increased.

Manyyan, et al. (2021) [68] used an EGR system using carbon nanotubes to reduce pollution from the use of a diesel-biodiesel mixture of B20 in a diesel engine. EGR percentages (5%, 10%, 15% and 20%). The maximum brake thermal efficiency was at 5% EGR and lower SFC. SFC reduced when EGR was raised by 5% in comparison to the other EGR. With 20% EGR, the emission factor for NO_X is reduced by 21.06%, but other carbon dioxide emissions were lowered by 5.2%, HC emissions were reduced by 6.2%, and smoke intensity was reduced by 4.34%.

Ma , et al. (2021) [69] concluded that adding 10% of pentanol alcohol to the diesel and biodiesel mixture at low EGR rates, lower HC emissions are obtained compared to not being add it, but all mixed fuels have little effect on CO_2emissions. Furthermore, higher EGRs can lead to better performance on NO_X and soot emissions, but have a negative impact on HC and CO emissions.

Chandravanshi, A., et al. (2021) [70] concluded that 20% of biodiesel gives a slight decrease in BTE and an increase in BSFC and emission of less CO_2, HC, and smoke. Due to the higher oxygen concentration and higher exhaust gas temperature associated with biodiesel, NO_X emission increases, which restricts the usage of biodiesel at low level. The researcher added high-oxygen dimethyl carbonate to biodiesel to increase combustion quality, thus reducing emissions and improving thermal efficiency. With 10% (EGR), results showed higher brake thermal efficiency. There are modest CO_2 increase at all loads, but they are below the safe limit. With EGR, the emission of nitrogen oxides (NO_X) reduces further. A higher EGR content has a negative impact on performance and emission characteristics, excluding NO_X and smoke emissions.

Appavo, et al. (2021) [26] discussed the addition of EGR technology to reduce NO_X emissions with the use of biodiesel mixed with diesel due to the presence of oxygen in biodiesel, which, as a result of an increase in BSFC, results in a drop in the BTE, and they also note that carbon dioxide, hydrocarbons and smoke decrease slightly. In most cases, studies have revealed that adding antioxidants used in biodiesel reduces NO_X emission by up to 43% but adding EGR is a technique widely accepted by many researchers because of its economy. More studies are needed to discover the optimal value of out-of-range EGR without affecting engine performance. The researchers state the need for further studies to explore corrosion and sulfur oxides emissions from fuel additives used in biodiesel.

Lobo, et al. (2021) [71] ran a diesel engine using biodiesel fuel derived from waste cooking oil with a very small portion of (ZnO) added as an enhancer. The engine is equipped with EGR technology which when useful to the blend increases BSFC by 9% due to lack of oxygen and lower combustion rate, making it difficult to reach a stable combustion condition. NO_X emissions decreased by about 20% due to less oxygen and lower flame temperature.

Emissions of carbon dioxide, hydrocarbons and soot are reduced by 20% due to more fuel being burned in the chamber.

Nanthagopal, et al. (2019) [72] revealed that 30% of EGR reduced the brakes thermal efficiency by 8% to 18% for conventional diesel and waste cooking oil methyl ester as fuel. NO_X emissions were also significantly reduced by 47.5% for diesel fuel and 58.9% for biodiesel in full download status. This rate led to a significant increase in CO and HC emissions and the rate of heat release.

Punitharani, K., and V. Parameshwaran (2017) [27]concluded, after running a diesel engine fueled by a mixture of diesel and biodiesel derived from waste plastic oils at a mixing ratio of 20% with the addition of 30% of EGR at maximum load, that the value of BTE and BSFC is almost equal to diesel and higher than the other mixture values when compared. It was found that NO_X emissions are 14% lower than diesel emissions. Thus, the mixing ratio of 20% is the best ratio between 10% and 30%.

De Serio, et al. (2017) [73] analyzed the performance and emissions of a diesel engine after applying the EGR system. The engine runs on 7% biodiesel fuel, and the use of EGR by 7.5% causes an increase in CO, HC and CO_2 emissions , and reduce nitrogen oxides (NO_X) emissions.

Jeevahan, et al. (2017)[25] talked about how to fix it. The researcher said that there are many ways to reduce NO_X, including combustion and exhaust post-treatments like adding EGR and lean nitrogen traps, but they cost more and take up more space in the exhaust pipe. Strategic fuel treatments like low-temperature combustion, the blending of fuel additives, and reformulation of fuel composition also appear promise for future biodiesel since they lower NO_X emissions without compromising other emissions or performance characteristics.

K. Rao, et al. (2015) [74] indicated the use of the EGR system to decrease the emission of NO_X. It concluded that the best achieved EGR is 15% of the air intake in terms of performance and engine emissions for all mixtures compared to 0% for diesel. When this percentage increased, oxygen decreased, BTE decreased, BSFC increased, and EXT decreased. As for emissions, an increased in carbon dioxide and hydrocarbon emissions observed when the EGR increased.

Elshaib, et al. (2014) [75] observed after running the engine with different proportions of a mixture of diesel and diesel derived from the WCO. When using 100% biodiesel, combustion efficiency increased by 1.8% at full load, while CO and HC emissions decreased at all loads and speeds. The researcher observed a reduction in CO_2, HC and NO_X emissions when using the EGR technology by 17%.

Kumar , et al . (2013) [76] conducted an experimental study on a single-cylinder diesel engine with different compression ratios, EGR percentages, and changing loads in order to determine the engine's performance, combustion, and emission characteristics. Brake thermal conductivity is increased and specific fuel consumption is reduced with an increase in compression ratio. However, as the EGR increases, NO_X emissions gradually decrease from 11% to 85% at different compression ratios as a result of lower flame temperatures, lower combustion chamber oxygen, higher brake temperatures, and lower oxygen content.

Mohebbi, et al (2012) [24] reduced NO_X emissions using a 13% EGR method. Due to the higher viscosity and poorer compressibility of WCO compared to diesel fuel, the injection start moved up. Compared to diesel fuel, a higher cetane number lead to a more rapid burning. WCO in the fuel mixture decreases engine torque and power and raises BSFC as a result of reduced engine temperature. Yet, due to the accelerated combustion and higher biodiesel

lubrication, torque and power were partially recovered. With the same EGR, diesel achieves a greater brakes thermal efficiency than gasoline. Hence, the researcher concluded that the usage of EGR with biodiesel has a lesser detrimental effect than with diesel since the drop in engine torque and an increase in BSFC are less pronounced with biodiesel.

Agarwal, et al (2011) [77] studied the result of problems with EGR technology on engine , as shown in figure (2.3) such as elevated carbon deposits, lubricant deterioration and engine degrading , as EGR replaces oxygen in the intake air by recirculating the exhaust gas into combustion. Exhaust gases lower the oxygen concentration in the combustion chamber and increase the specific temperature of the chamber. Leading to lower flame temperatures. As a result, the thermal efficiency is slightly increased and the BSFC is reduced at low loads. At greater loads, however, thermal efficiency and BSFC are nearly same with or without EGR. EGR decreases EXT, increases HC, CO, and smoke opacity, but drastically reduces nitrogen oxide emissions. It has been determined that 15% EGR effectively reduces NO_X emissions without impairing engine performance in terms of thermal efficiency, BSFC, or emissions.
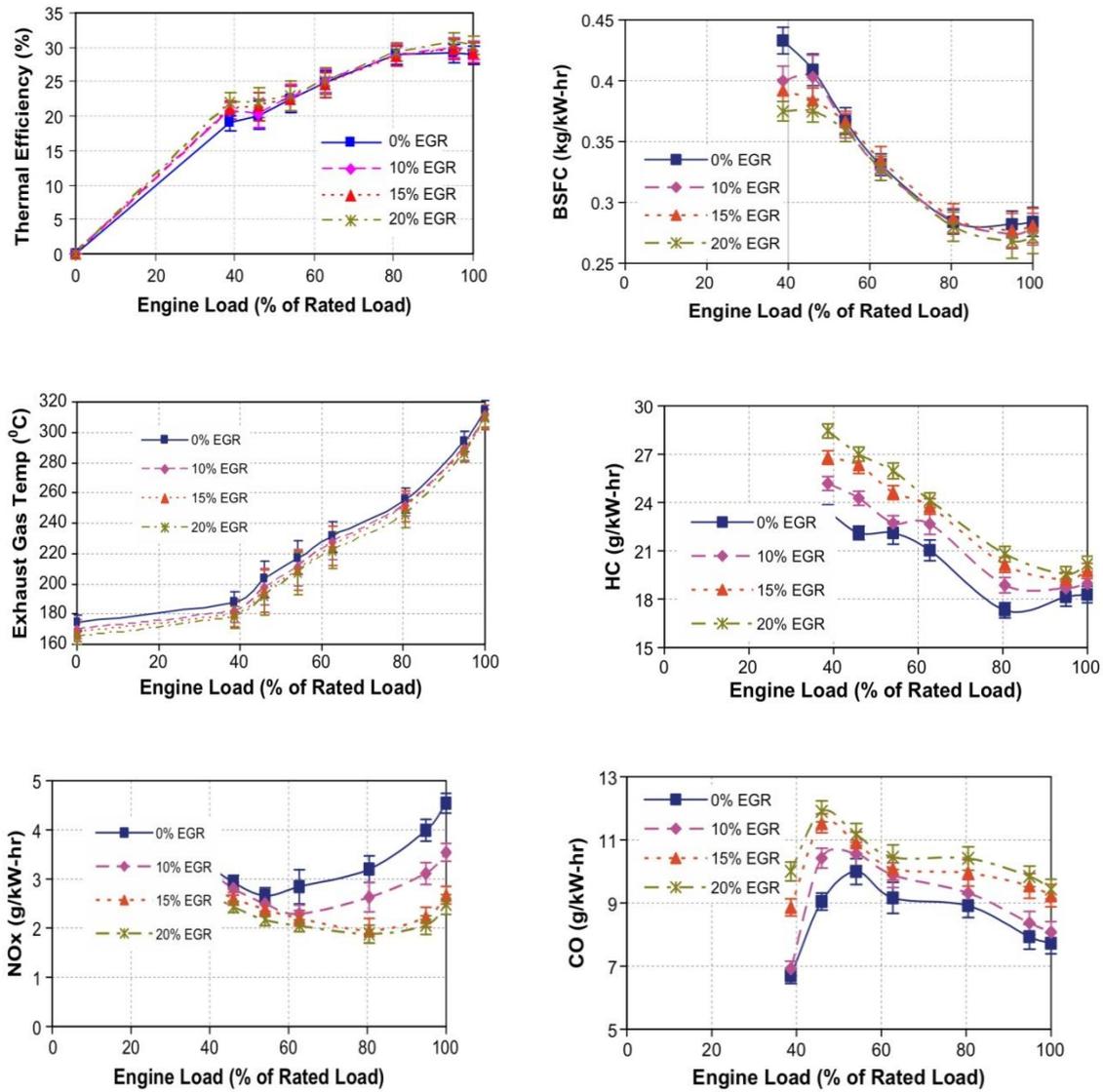
Figure (2.3) The variation of Engine performance and emissions with EGR

Table 2.1 summarizes the methodological comparison and conclusions of

the current study with other studies

year	Country	Researcher's name	Title	Influencing factors	Results
[30] (2022)	Turkey	Yildiz, et al.	Assessment of biodiesels from waste cooking oils for diesel engines in terms of waste-to-energy perspectives	Biodiesel Fuel properties CI engine Performance combustion emission	1) The kinematic viscosity of biodiesel produced found to be 6.270 mm^2/s. kinematic viscosity of pure diesel was 3,743 mm^2/sec. 2) Usage of biodiesels was anticipated to result in greater fuel consumption than diesel fuel. 3) High fuel density affects emissions and engine performance negatively, and biodiesel has a higher density value than diesel fuel. The density of biodiesel produced was 882 kg/m3, while that of diesel fuel was 831 kg/m3.
[32] (2021)	India	Pauline et al.	Transesterification kinetics of waste cooking oil and its diesel engine performance	Activation energy Biodiesel Engine testing Emission	1) 90% biodiesel was obtained at 60 °C. 2) Increase in power output with a decrease in SFC , decrease in (CO_2, CO, and HC) emissions, and an increase in the emission of NO_X. 3) B20 was found to have the best mixing ratio.
[37] (2019)	United States	Park, et al .	Biodiesel Production from Locally Sourced Restaurant	Biodiesel Fuel properties	1) The biodiesel was produced with properties whose values are within the optimum ranges optional by (ASTM). 2) The overall results showed that the

			Waste Cooking Oil and Grease: Synthesis, Characterization, and Performance Evaluation		blend of biodiesel and pure diesel can be a sustainable alternate fuel from local sources.
[40] (2017)	India	Sharma, et al	PERFORMANCE EVALUATION OF DIESEL ENGINE USING BIODIESEL FUEL DERIVED FROM WASTE COOKING REFINED SOYABEAN OIL	Biodiesel, Performance, Diesel Engine	1) 100% biodiesel should not be used, due to the fact that biodiesel has a higher viscosity than diesel. 2) By using biodiesel, we can solve the waste oil disposal problem and it can improve the economic aspect and its environmentally friendly nature may have good results in terms of emission standards. 3) The B20 biodiesel blendwas the most suitable of all biodiesel and petroleum diesel fuels.
[45] (2008)	China	Meng, et al .	Biodiesel production from waste cooking oil via alkali catalyst and its engine test	Biodiesel Transesterification Diesel engine test	1) The best yield of biodiesel with a value of 89.8% was obtained at a methanol/oil ratio of 6:1, with 1.0 wt% NaOH, at a temperature of 50°C and 90 minutes. 2) B20 fuel mixture reduced carbon dioxide, hydrocarbons and particulate matter by 18.6%, 26.7% and 20.58%, respectively.
[47] (2022)	Thailand	Dangsun thoncha, et al.	Nanoparticle Components and Number−Size	WCO Engine emission Engine	1)Increase in the percentage of WCO in the mixture caused an increase in the specific fuel consumption and a slight

|					
			Distribution of Waste Cooking Oil-Based Biodiesel Exhaust Gas from a Diesel Particulate Filter-Equipped Engine	performance	decrease in the brakes thermal efficiency . 2) The engine showed a decrease in unburned hydrocarbon but an increase in nitric oxide emission when WCO mixtures were used. 3) Carbon reduction was carried out using diesel particulate filters on a laboratory scale.
[48] (2021)	India.	Balasubr amania, et al.	NUMERICAL AND EXPERIMENT AL EVALUATION ON THE POOLED EFFECT OF WASTE COOKING OIL BIODIESEL/DI ESEL BLENDS AND EXHAUST GAS RECIRCULATI ON IN A TWIN-CYLINDER DIESEL	Biodiesel EGR Engine emission Engine performance	1) The best mixing ratio was B20 because of it showed a BTE decrease of a maximum of 1.85% at the highest load, an increase of SFC of a maximum of 6.89% in all loading conditions. 2) B20 at 10% EGR was chosen as the most suitable fuel because of its low NO_X emissions well without affecting the emissions of hydrocarbons, CO, smoke and carbon dioxide. 3) The addition of EGR decreased BTE and increased SFC under all loading conditions.
[51] (2018)	Egypt	Abed, et al.	Effect of waste cooking-oil biodiesel on performance and exhaust emissions of a diesel engine	Biodiesel Transesterificati on Performance Emissions	1) The addition of biodiesel generated from WCO to diesel decreased BTE while increasing fuel consumption. 2) Rising EXT as the percentage of biodiesel increases. Using biodiesel, CO, HC, and other emissions were reduced.

					4) As the percentage of biodiesel fuel in blends rises, NO_X and CO_2 emissions rise as well.
[60] (2019)	India	Rosha, et al.	Effect of compression ratio on combustion, performance, and emission characteristics of compression ignition engine fueled with palm (B20) biodiesel blend	Biodiesel CR performance Emissions	1) BTE improved with CR increase (16:1 to 18:1) by 14.9% in BTE, the increase in BSFC values was observed with B20 fuel in comparison to diesel due to lower heating value of B20 fuel and due to improved combustion properties when CR higher compared to CR was low. 2) Significantly reduce emissions of hydrocarbons, carbon monoxide and smoke with B20 fuel When compared to the pure diesel. It was found that the formation of nitrogen oxideswas higher in the case of B20 fuel compared to diesel. due to the high combustion temperature. It increased further with increasing CR
[70] (2021)	India	Chandra vanshi, et al.	Effect of di-methyl carbonate as additive and exhaust gas recirculation on the performance and emission parameters of diesel engine using diesel-biodiesel blends as fuel	Biodiesel Dimethyl carbonate EGR Performance Emissions	1) 20% biodiesel results in a modest reduction in BTE while BSFC climbs somewhat. 2) Lowers carbon dioxide, hydrocarbons, and smoke. Due to biodiesel's increased oxygen content and higher exhaust gas temperature, NO_X emissions increase. 3) The use of EGR increases BTE somewhat in comparison to diesel and reduces NOx and smoke emissions. In addition to the greater HC and CO emissions, the use of an EGR was also

					limited by their presence.
					4) Dimethyl carbonate has a great deal of oxygen. It improves the combustion quality of biodiesel, hence reducing emissions and enhancing thermal efficiency.
					5) 75% diesel and 5% additive to 20% biodiesel at 10% EGR shows the optimum level of output.

2.6 Remarks

This chapter presents a summary of the most important results of experimental studies presented in the previous literature for the preparation of biodiesel, its production sources, methods of synthesis, and the factors on which biodiesel production depends. Moreover, the effect of biodiesel on the performance and emissions of diesel engine with a variable or constant compression ratio And techniques to reduce NO_X emissions resulting from the use of biodiesel.

While this thesis included all that the researchers discussed, starting with the preparation of biodiesel from WCO through the transesterification process and the effect of temperature on the amount of production , the present study will consider biodiesel's effect on the performance and emissions of a variable compression ratio engine, and the usage of EGR technology to reduce NO_X emissions.
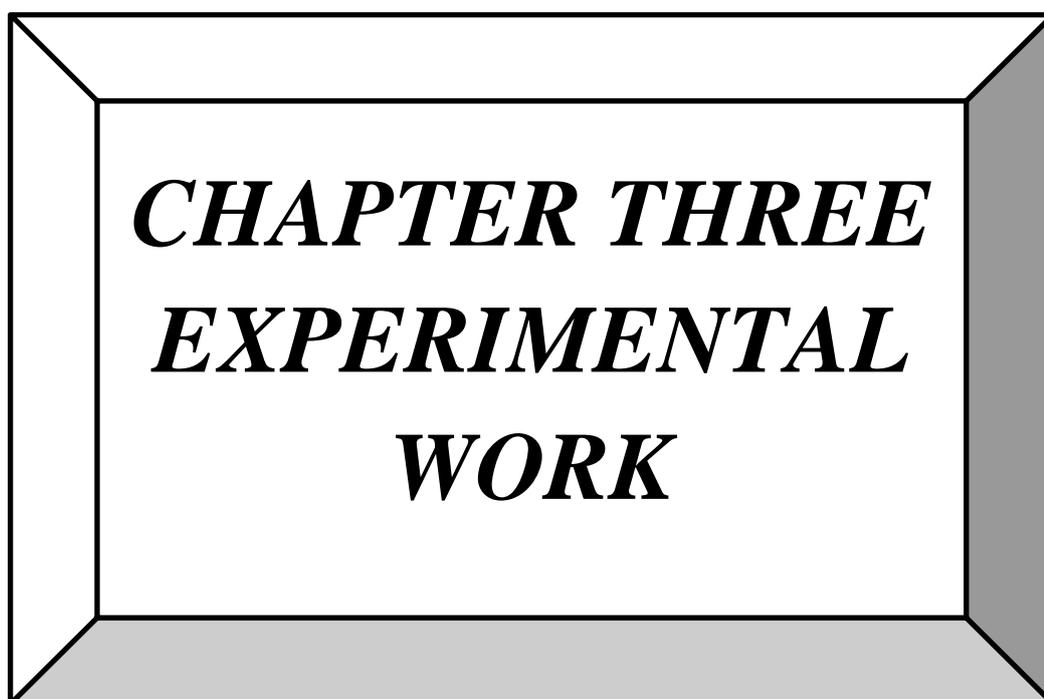
CHAPTER THREE
EXPERIMENTAL
WORK

3.1 Introduction

This chapter highlights the use of the apparatus and materials that has been used in this experimental work for this thesis with an explanation of the experiments and tests, which include:

- Synthesis of biodiesel derived from WCO, physical and chemical properties testing

- Testing Biodiesel waste cooking oil in diesel engine to investigate performance and exhaust emissions.

- Recycled the exhaust gaseous to control NOx emissions.

All electronic apparatus have been calibrated to a steady level. The tests are repeated three times to minimize errors.

3. 2 Design of Experiment

Design of experiments (DOE) is a technique that permits scientists and engineers to study the relationship between several input variables (factors) and significant output variables in a systematic and efficient manner (responses). It is an organized approach to data collection and discovery [78]. DOE is utilized when it is necessary to determine whether a factor or group of factors affects the response : -

- To examine whether factors influence the response jointly.

- To simulate the response's behavior as a function of the components.

- To improve the reaction.

In 1926, Ronald Fisher presented four fundamental DOE principles: the factorial principle, randomization, replication, and blocking. Historically, these designs were developed and analyzed by hand; only recently practitioners have begun adopting computer-generated designs for a more effective and efficient DOE.In thepresent work, three major sets of test are achived. Namely, tests for

sunthesize the biodiesel, tests of theDEperformance and exhaust emissions when its fuelled by diesel – WCO biodiesel blends, and the tests of utilized EGR to control the NO_X emissions.

3.2.1 DOE of synthesize biodiesel from WCO

According to the chemical equation of transisetrification, the WCO, NaoH, and methanol are the input parameters. The biodiesel and glycerin are the out put. To complete the design of experiment, the environment parameters are studied tofind outthat theyhave no effect on experiments of biodiesel synthesize.
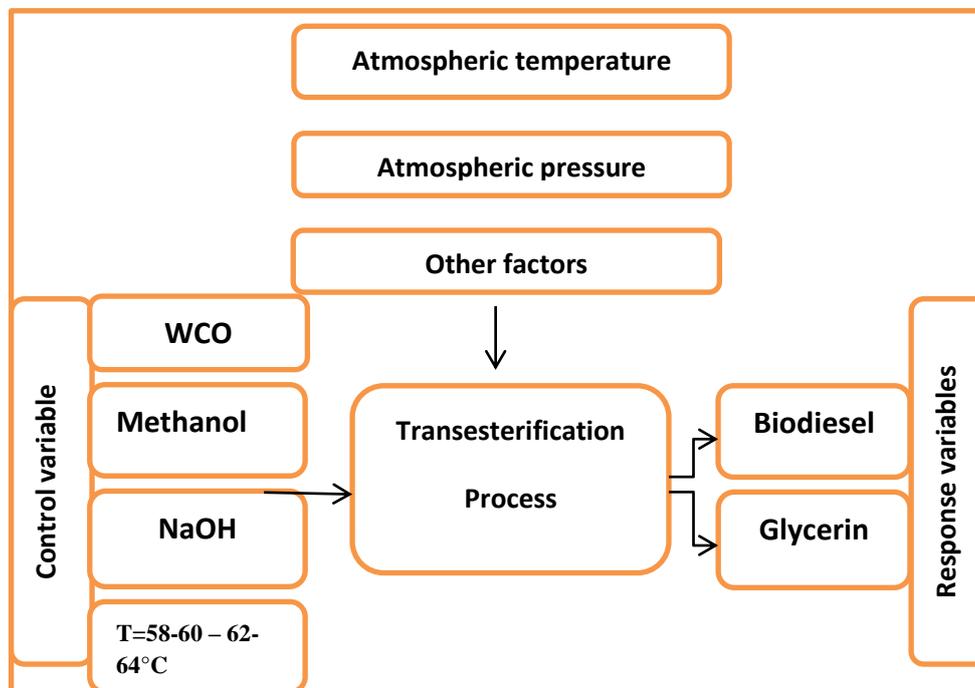

Figure (3.1) DOE for Transesterification process

The design of experiment gives the researcher details about the Input prameters, how measure it, how vary it, what is the sensbility of measuring device, uncertainity and errors. In response side, the researcher can define the measuring output parametres, calculated parameters. Also, DOE helps to specify the measuring instruments , its precise and accurecy.

3.2.2 DOE of diesel engine performance and exhaust emissions testing when its fuelled by diesel – WCO biodiesel blends

Figure (3.2) shows the DOE for the testing of biodiesel –diesel blends fulled compression ignition engine. Compression ratio varied from 14.5 to 16.5, the engine load is varied from no load, 1/4 load up to full load. The blend of biodiesel ratio is changed from 0 to 30 percent with 10% increament on base of biodiesel volume to diesel volume. The response parameters are measured and calculated to study the effect of input on outputs. Spesifically, The "experimental test" is affected by three different types of variables (input, output, and enviroment) as shown in figure (3.2). Engine load, compression ratio, biodiesel ratio and EGR are paper input variables. Brake thermal efficiency, volumetric efficiency, specific fuel consumption, air-fuel ratio, and exhaust temperature are the output variables or responses. In addition, we can think of measuring CO, HC, O2, and NOx as output variables or response to exhaust emissions. Environmental variables include ambient temperature and pressure, diesel and biodiesel requirements. All devices and instruments are selected according to readings range with good precise and accuracy for input and out put.
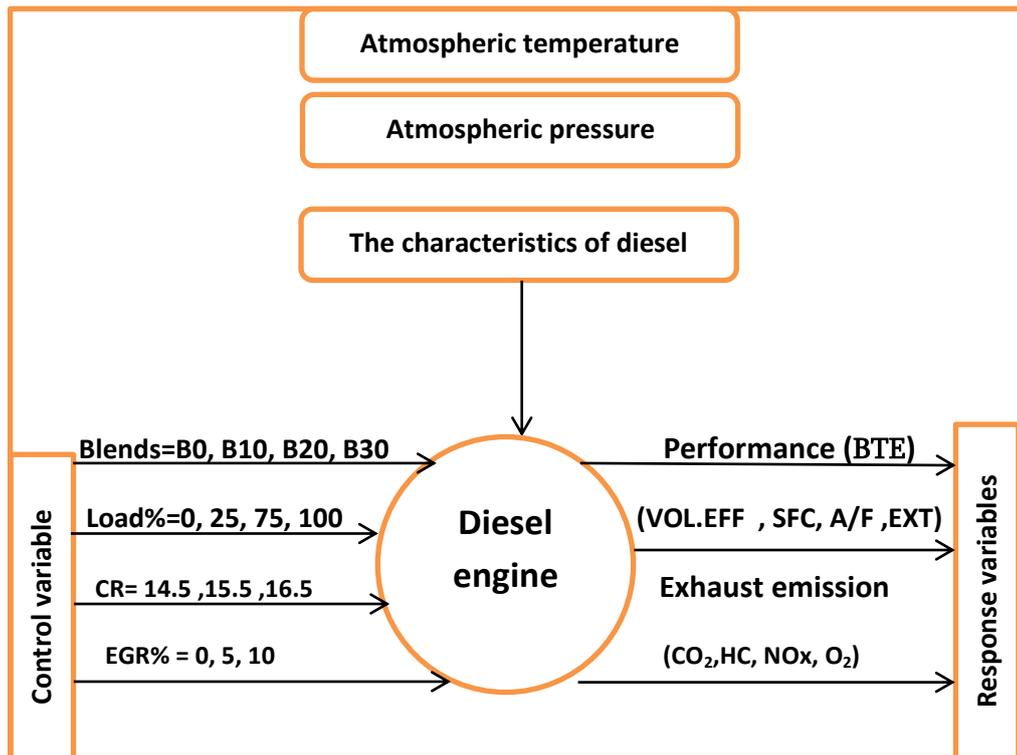
Figure (3.2) DOE for testing biodiesel in diesel engine

3.2.3 DOE of recyclation of exhaust gas to control the NO_X emissions

To control the NO_X emission, The DOE conducted a research to determine the impact of EGR on engine performance and NO_X emissions . the EGR variation is studied with optimum fuel blend ratio. Figure(3.3) below gives the DOE for those tests .
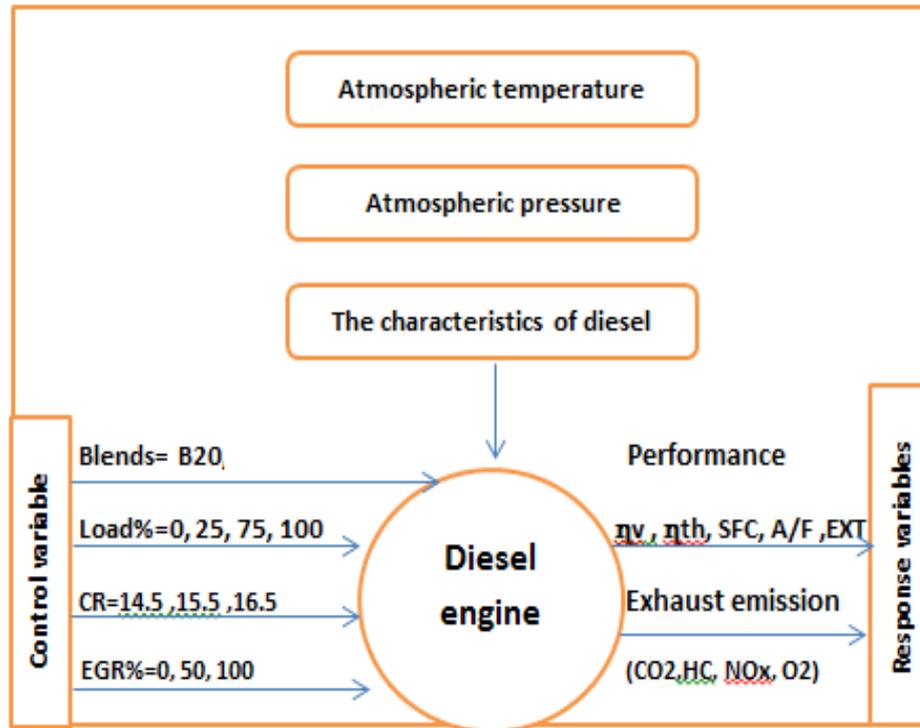
Figure (3.3) DOE for testing biodiesel in diesel engine with EGR system

3.3 Apparatus and Materials for the Preparation of Biodiesel

Conventional transesterification is used to synthesize biodiesel from WCO. To achieve the successful transfer of oil into biodiesel. The process needs the main materials , Figures (3.4),(3.5),(3.6) :

- Waste cooking oil, which is leftover sunflower oil mainly and other type of cooking oil and fats, after being filtered from the impurities.

- Suitable catalyst such as sodium hydroxide NaOH .

 -A suitable solvent such as methanol alcohol

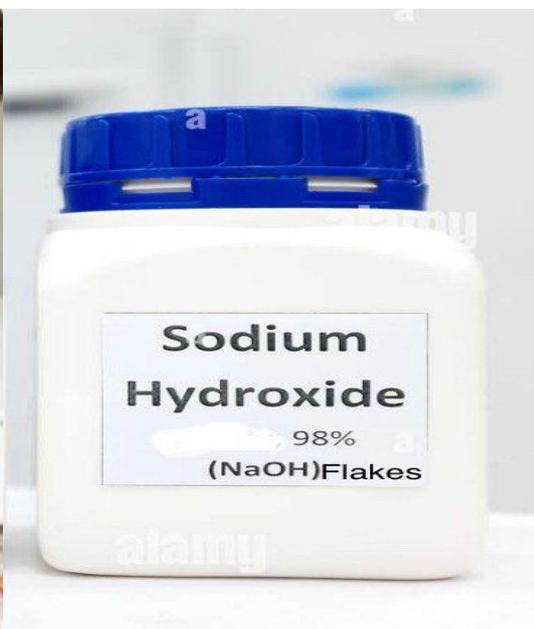Figure (3.4) photo of waste cooking oil   Figure (3.5) photo of NaOH
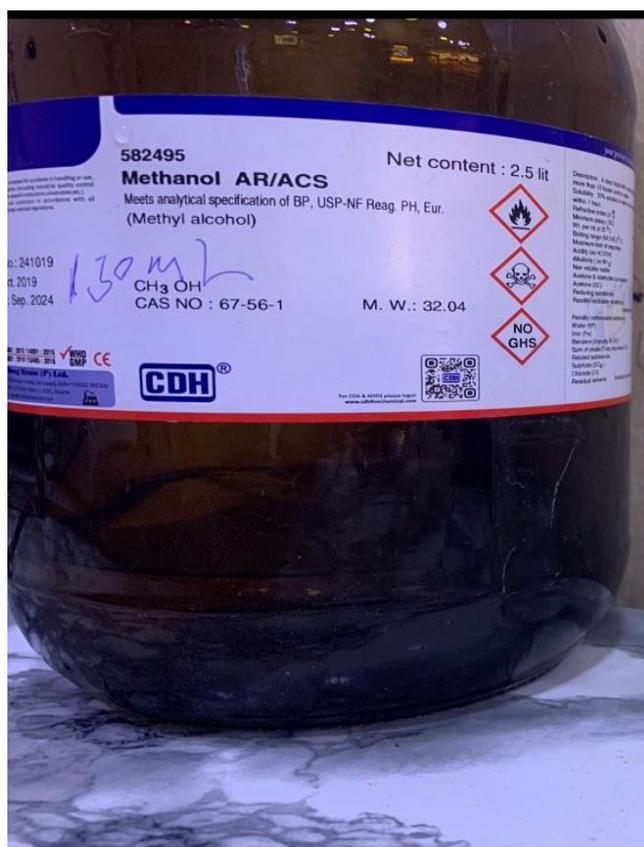

Figure (3.6) photo of methanol

Devices that are used in the transesterification process:

- Decanters of different sizes, commensurate with the amount of WCO and alcohol.

- Digital sensitive scale to measure the amount of catalyst.

- A water bath to heat the WCO to 62 °C. A water bath is used to obtain a gradual increase in temperature and to ensure that the heat is distributed to all oil molecules evenly.

- Electric mixer (stirrer)to mix materials (NaOH, methanol, hot WCO).

These materials (alcohol and catalyst) are chosen due to their availability and to reduce their cost compared to the rest. The amount of alcohol and catalyst is relied upon by referring to other literature [1][43][19][32], in addition to conduct several experiments to reach the production of the largest possible amount of biodiesel compared to the amount of glycerin.

The water bath apparatus is calibrated using a mercury thermometer and calibrate the digital scale with more than one other scale.

3.4 Biodiesel Synthesis

The transesterification process has been resorted to because it is the most widely used and depends on the presence of solvents (methanol or ethanol) and catalysts NaOH that are available, due to its low cost and high yield of biodiesel at atmospheric pressure and low temperature ranging (58-65) °C.

Transesterificationis carried out in chemical engineering laboratories affiliated to the University of Babylon, College of Engineering, in December 2021. It is the reaction of triglycerides in oil with alcohols to produce alkyl esters and glycerol. Triglycerides consist of three long-chain fatty acids bonded to a glycerol molecule, as shown by equation in figure (3.7).

CH$_2$-COO-R   R-COO-CH$_3$ CH$_2$-OH

CH-COO-R   + 3CH$_3$OH   NaOH   →   R-COO-CH$_3$ + CH$_2$-OH

CH$_2$-COO-R   R-COO-CH$_3$ CH$_2$-OH

(Triglycerride) + (3Methanol)   NaOH   →   (3Biodiesel)   +(Glycerol)
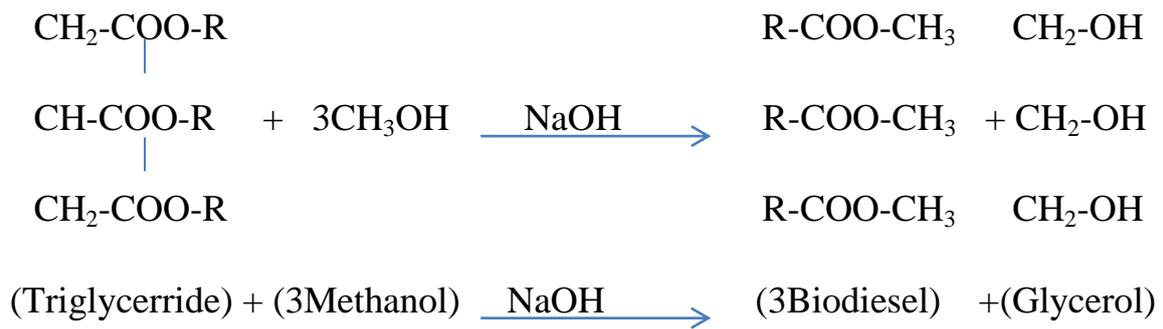
Figure (3.7) Transesterification Equation[1]

3.5 Experiment description

The experiment is conducted at a temperature of (58 ,60, 62 , 64) °C with variable amounts of methanol alcohol and NaOH for 1 liter of WCO. It is noted that the highest percentage of biodiesel production could be obtained compared to glycerin, which occurs at the subsequent amounts and steps.

- Insert 1 liter of WCO into a suitable beaker. Figure (3.8) shows the flask with oil is placed in a water bath , then the heat is transferred to the oil gradually until the desired temperature.

Figure (3.8) photo of water bath

- As a reference, figure (3.9) shows mix 130 ml of methanol (7.7:1, WCO /methanol) with 4 grams of catalyst (NaOH) to every one liter in powder form at room temperature (0,43% according to the eqution:).

WCO weight(g) = WCO volume(ml) * WCO density(g/ml)

WCO density = 0.9155 g/ml [35]

The percentage of the catalyst weight in relation to the weight of the oil

$$= \frac{NaOH \ \text{weight}}{WCO \ \text{weight}}$$

 The catalyst and the methanol are sufficiently mixed for 15 minutes (until all catalyst dissolves) to produce the approved methoxide.
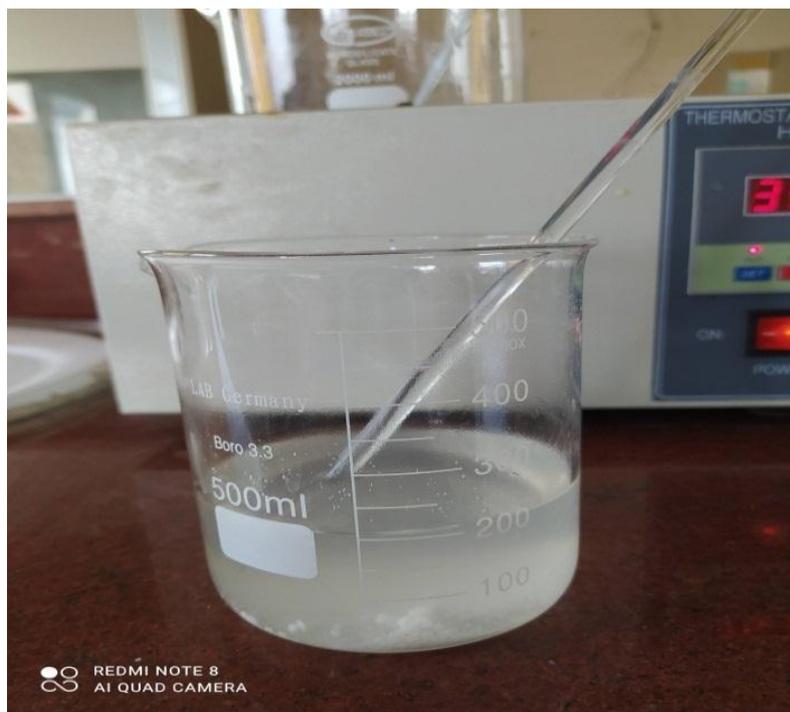
Figure (3.9) photo of methoxide

- Methoxide is added to the WCO at (58,60,62,64)°C . After mixing, they are removed from water bath and stirred for 20 minutes as shown in figure (3.10), to ensure the completion of the reaction by the electric mixer, where the methoxide enters into the reaction with the oil and begins to change the R radicals to manufacture biodiesel.

Figure (3.10) photo of electric mixer.

- Keep the mixture in the beaker to separate 1060 ml of FAME (top layer) with 70 ml of glycerol (lower layer) after about 24 hours to be separated manually, figure (3.11).Which gives 94% biodiesel and 6% glycerol of total WCO,the aforementioned production percentages were obtained at 62°C .

Figure (3.11) photo of Biodiesel and Glycerin

3.6 Physical Properties for Diesel and Biodiesel

After biodiesel production from WCO , the physical properties of biodiesel is specifically measured at the Dora refinery in Baghdad/Iraq. Table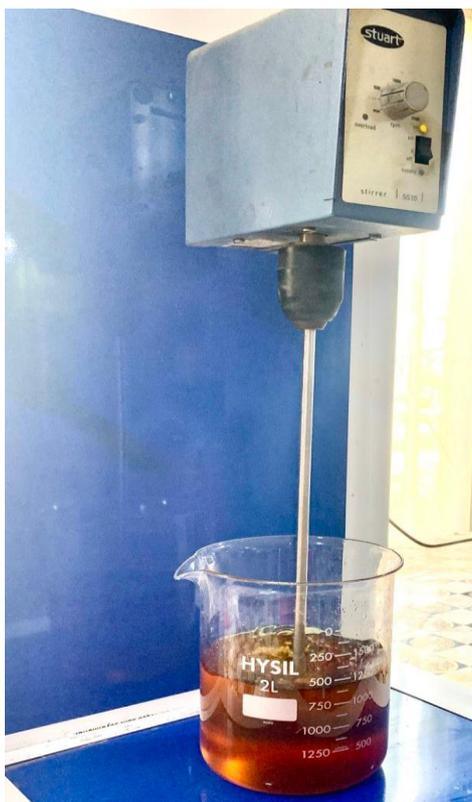 (3.2) shows the characteristics of diesel fuel [79] and their comparison with those of biodiesel along with ASTM standards that are frequently reported in the literature. Tests are occurred to ensure that the product is biodiesel.

Table 3.2: Diesel and Biodiesel characteristics

Fuel Properties	Unit	Diesel[79]	Biodiesel	Standard Method
Density @15°C	Kg/m^3	830	902.4	ASTMD4052
Flash point		68	49	ASTMD 93(A)
Pour point	°C	(-)16	(-)3	ASTMD 97
Cetane Index	_	53.4	51.1	ASTMD 4739
Calorific Value	MJ/kg	45.836	42.123	Calculated
Viscosity @40°C	Pa.s	0.002241	0.007872	ASTMD 445
Ash content		0.01	0.1679	ASTMD 482
Total sulfur	%wt	0.2759	0.01	ASTMD 4294

3.7 The Iraqi Economic Scenario for Biodiesel Synthesizing

Since long time Iraqi rivers and water supply sources are facing pollutants issues from different pollutant sources [89]. Recently, with increase Iraqi population for more than 40 million and increase rate of cooking oil consumption around 20 kg / person annually due to demand of life as mentioned in figure 1.1.

The United Nations, together with a group of international and local environmental organizations, sounded the alarm due to the exposure of river water and water sources to high levels of pollution, amounting to more than 73% [90],[92] . Therefore, it became necessary to treat the sources of water and soil pollution, including waste cooking oil. The process of collecting and treating waste cooking oil is considered as economically costly treatment due to expensive chemical material and process. Hence, the transferring of waste cooking oil to biodiesel is considered as a double solution method in dealing with pollution and providing a vital sustainable source of energy.

Table (3.1) shows the cost of producing one liter of biodiesel in Iraqi dinars which includes the price of the row material, bio alcohol, catalyst, and equipment cost (water bath, digital scale, and electric mixer, and flasks) divided by its useful life.

The researcher [87] produced methanol alcohol from Al-Zuhdi dates. The production of one liter of alcohol amounted to 1021 ID.The cost of one liter of biodiesel is approximately 191 ID .

The cost of producing methanol alcohol and biodiesel for the purpose of academic work is higher than the actual cost in the case of mass production. It is possible to provide more than 70% of energy needs. It can be observed from table 3.1, the roughly price of 1 liter WCO biodiesel around 191 ID which

locally less than price of diesel (200 ID/liter). Again, the WCO is cheapest than any type of biodiesel because it achieved to goals in one process by eliminating chemical pollutants and finding a sustainable alternative fuel to replace partially or totally the expensive fossil fuel, which are considered as one of high global pollution source.

Table 3.1 cost estimation of 1 liter synthesized biodiesel from WCO

Material	Needing quantity to synthesized one liter of biodiesel	Iraqi Dinars/ liter of biodiesel
Methanol	130 ml	133
Waste cooking oil*	1liter	0
NaOH	4 g	40
Laboratory equipment**	-	18

*The price of used cooking oil is free. Moreover, the use of WCO to produce biodiesel saves the cost of complex chemical treating this type of waste that harms the environment, which obliges the state to spend expenses for workers, equipment and materials for water treatment.

** Laboratory equipment indicates all apparatus and devices that utilize to transfer one liter of WCO to biodiesel. Whereas, calculate its cost and divided on number of transferring process roughly.

3.8 Testing of WCO Biodiesel Blends in Diesel Engine

The biodiesel test is carried out in the internal combustion laboratory in college of Mechanical Engineering / University of Babylon / Hilla, IraqStarting from April 2021 at an ambient temperature of 26.3 °C. Figures (3.12) and (3.13)

show a computerized diesel engine test system with sensors ,instruments and eddy current booster to test the performance and emissions of a biodiesel/diesel

blend and compare them with diesel.The uncertainty analysis has been achieved adopted Moffat error formula [94]. Table (3.3) describes the uncertainties.

Table 3.3 The Uncertainties Of Measured And Calculated Experimental Factors.

No.	Factor	Uncertainty %
1.	Engine speed	0.1
2.	Brake power	1
3.	Air flow rate	3
4.	Fuel flow rate	2
5.	Exhaust temperature	0.2
6.	Gas analyzer	0.02

Valve

Fuel tank

Fuel pump

Screw to change
the compression
ratio

Valve

Exhaust

Muffler

EGR Manometer

0.00

Electronic balances

Fuel injector

Gas analyzer

Computer

Combustion analyzer

Pressure sensor

Nozzle

Cylinder head

Intake air

Camshaft
position sensor

Engine block

Water tank

Air surge tank

Data logger

Temperature
measurements

Water manometer

Valve

Dynamometer

Voltage
regulator

Dynamometer controller

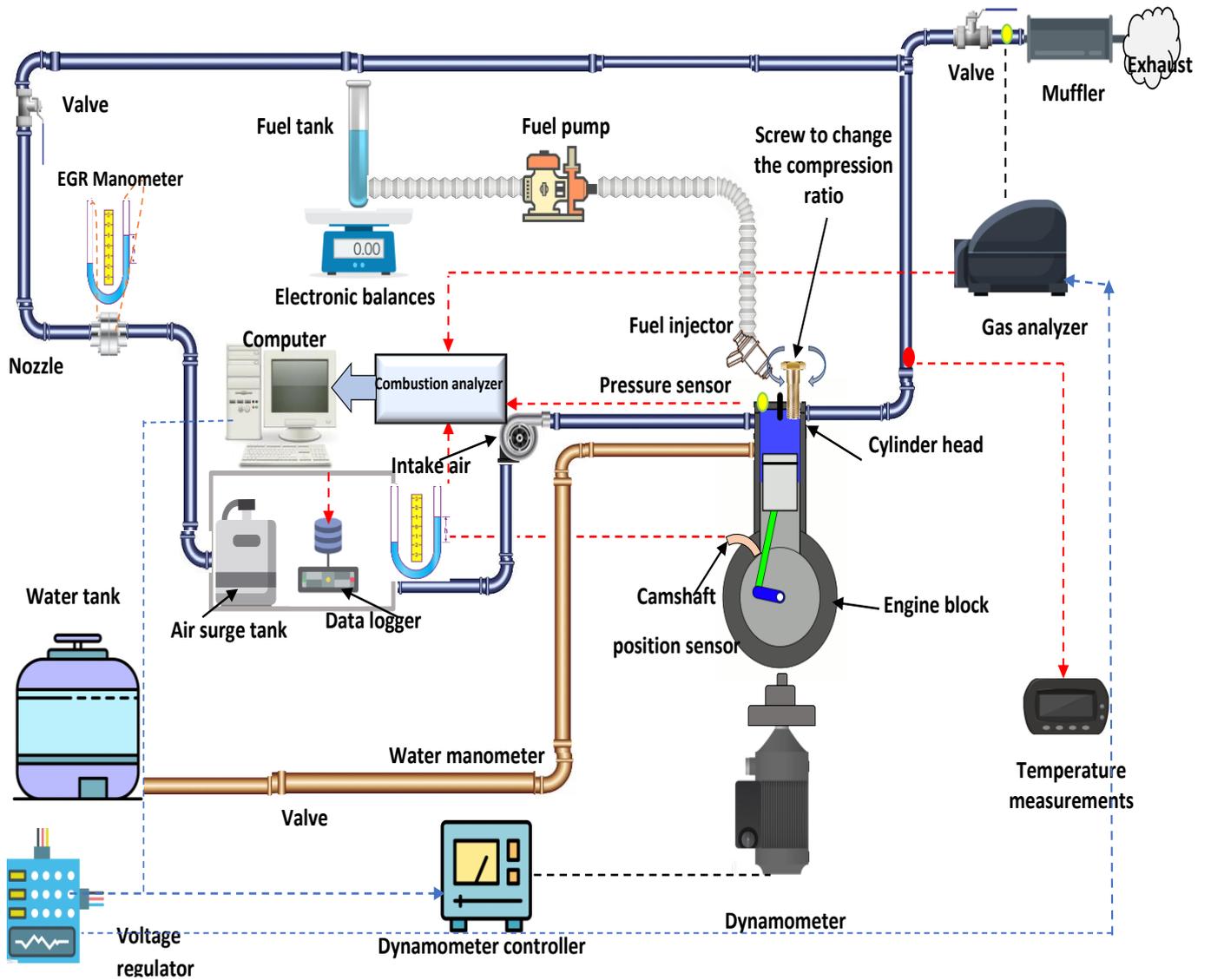Figure (3.12) diagram of experimental rig

Figure (3.13) Main components of the investigational system

The description of system is mentioned below :

A- Diesel Engine

The single-cylinder compression ignition engine is retained during the chase for
the purpose of testing. Engine details, make and specifications are given in table

(3.4). A suitable water cooling, lubrication and water supply systems are attached. Figure (3.14) gives a picture of the engine.

Figure (3.14) The diesel engine.

Table 3.4 the engine made and technical measurement[50]

Make And Model	Kirloskar
General Details	Single Cylinder, Four Stroke, Compression Ignition, Vertical, Direct Injection, Water Cooled
Bore	80 mm
Stroke	110 mm
Rating Speed	1500 rpm
Swept Volume	553 cm^3
Clearance Volume	0.03687 m^3

Compression Ratio	12.5-17.5
Rated Power	3.7 KW
Static Injection Timing	-30 BTDC
Injection Pressure	160 Bar
Start Of Injection	150 °CA
End Of Injection	190 °CA
Nozzle Diameter	0.02 mm

B- Eddy current dynamometer:

The eddy current dynamometer is a device for measuring torque and engine braking force, shown in Figure (3.15). It is based on the principle of converting kinetic energy into electrical energy . The dynamo is connected to the engine through coupling . The dynamo takes its movement directly from the engine at the same speed . The rotation process causes the generation of an anti-magnetic field that pushes electrons inside the copper wire to generate an electric current and voltage to form electric energy operates the engine parts.

Figure (3.15) Eddy current

The generated current and voltage can be read through the voltage and current reader that appears in figure (3.16), in this thesis a fixed voltage of (220-223) volts is relied upon.

Figure(3.16) Voltage and current reader

To control engine load , an electric variable loads are used where the full engine load is divided on 4 steps namely ,0 load ,1/4 load ,1/2 load ,full load.The full load of engine is taken from engine specificatione . for example ¼ load means $\frac{3.7 \text{ KW}}{4} = 925W$.

Figure 3.17 Loading system

C- Exhaust temperature sensor

It is a digital device connected to the engine by a sensor, that measures the temperature of the engine exhaust gas. It consists of a k-type thermocouple which is connected to a digital screen to show the reading directly after measurement. As shown in the figure (3.18).

Figure (3.18) Exhaust temperature measurment system

D- Air flow meter

To measure the air flow, a water pressure gauge is used in the intake tank according to the equation in(Appendix B ,equation (4)) as shown in Figure (3.19), where the air volume changes based on the change of engine speed and load, it is connected to the air flow tank with a 15 mm opening.

Figure (3.19) Air flow meter

E- Speed tachometer

To measure the engine speed, the tachometer is connected to the dynamometer to transmit the engine speed to the computer screen. The engine speed is controlled by the engine data control system .Figure (3.20) shows speed tachometer.The speed in this work is fixed at 1500 rpm .

Figure (3.20) Speed tachometer

F- Measurement of fuel consumption

Through a graduated fuel tank equipped with a cantilever load cell as shown in figure (3.21) , the fuel consumption is measured. The gauge has a load range of 0 to 1000ml. Whereas, the fuel consumption rate is the difference between the final (m_{f2}) and initial (m_{f1}) weights of the fuel in the tank over time (t) ,whichis represented by the equation in (Appendix B,equation (2)) . Biodiesel fuel is mixed with regular diesel according to four biodiesel blends by volume (B0, B10, B20 and B30) in the same fuel tank. In thepresent work, the fuel consumption time is fixed, within 2 minutes.

Figure (3.21) Unit of fuel consumption measurement

G- Measurement of engine exhaust emissions

Exhaust Gas Analyzer from TEXA -Italy is used to measure CO_2, HC, NO_X and O_2. A tube connected to the gas analyzer is placed near the engine exhaust, then the gas analyzer sends all readings via Bluetooth to the computer after the driver is installed appearance (3.22) .

Figure (3.22) Gas analyzer

H- Engine data control system

Using the microprocessor control unit and the specially designed software shown in figure (3.23) to measure variable engine data such as speed and the exhaust temperature.

Figure (3.23) Data Acquisition System

I- CR variability

The engine compression ratio is changed mechanically by means of a mechanical screw at the top of the cylinder in the range of 12.5 to 18.5 by step one. Figure (3.24) shows the screw arrangment where rotation clockwise a full turn (increase in CR) and counterclockwise a full turn (decrease in CR) from the reference value of 15.5 CR .

Figure (3.24) Screw to change the compression ratio

3.9 Exhaust Gaseous Recirculation to Control NO$_X$

To reduce the NO$_X$ emissions that increases after the use of biodiesel, EGR technology is used to return the engine exhaust gas. This technology is present in modern cars to preserve the environment from NO$_X$ emissions. The EGR system consists of the following equipment :

- A manually operated valve installed on the engine exhaust gas path to control the amount of gas returning from the engine to the orifice by pipe in diameter (1 inch) and length (2m) as shown in figure (3.25) , which is designed to resist the exhaust temperatures that usually range (60 -300)°C. through the tube.

Figure (3.25) manual control valve

- U-tube water manometer to measure EGR. The manometer is connected to the orifice meter, which consists of a plate with a circular sharp-edged orifice fixed inside the tube. A water pressure gauge is attached across the orifice to measure the pressure difference in order to determine the return exhaust gas flow through the pipe. Figures (3.26),(3.27) show the orifice made according to the British Standard [80].

The first pressure tap on the high pressure side has a distance (D) from the centerline of the orifice gauge, while the second tap on the low pressure side has a distance (D/2) from the centerline of the orifice gauge.

A flow meter is not used to measure the return exhaust gas flow rate because manometers are more sensitive to small flow rate values, although manometers are imprecise compared to flow meters.
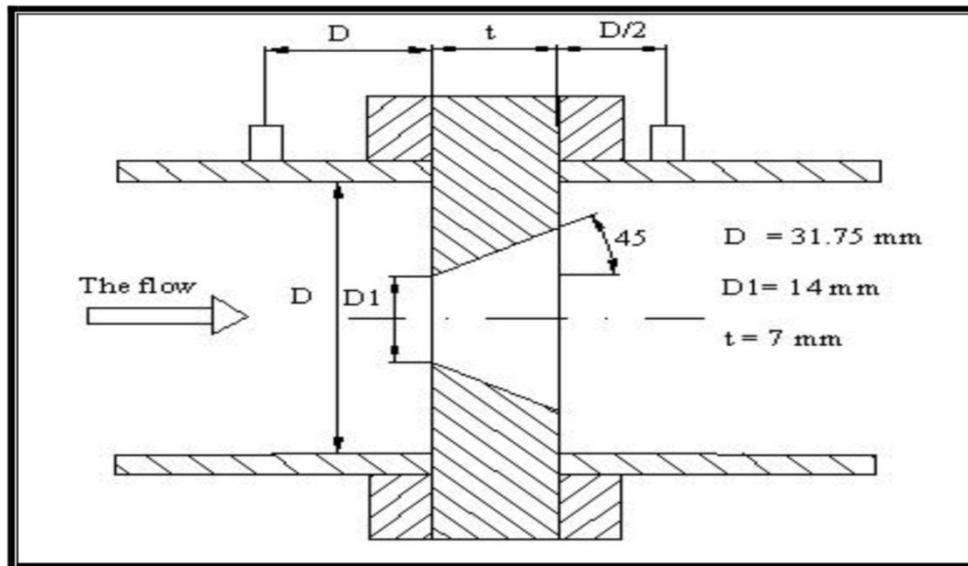

Figure (3.26) orifice meter [80]

Figure (3.27) photo of the orifice meter

To apply the EGR system, the following steps are applied:

- Connect the orifice to the air inlet box to mix the return exhaust gas with the air entering the engine

-Run the engine at 1500 rpm, a compression ratio of 16.5, and a full load.

-Calculate the amount of return exhaust gas flow at the previous conditions using the manometer equation (Appendix B,equation (7)).To get the maximum amount of exhaust gas out of the engine.

-Install the manual valve when the general gas flow value reaches 5% and 10% of the maximum value.

- Calculate engine parameters (BTE, SFC, EXT, VOL.EFF, A/F), read engine emissions (CO_2, HC, O_2, NO_X).

- Repeat the previous step with all biodiesel mixtures and at the three compression ratios. To find out the most appropriate conditions in which NO_Xemission decreases.Figure (3.28) shows the EGR sensor system.
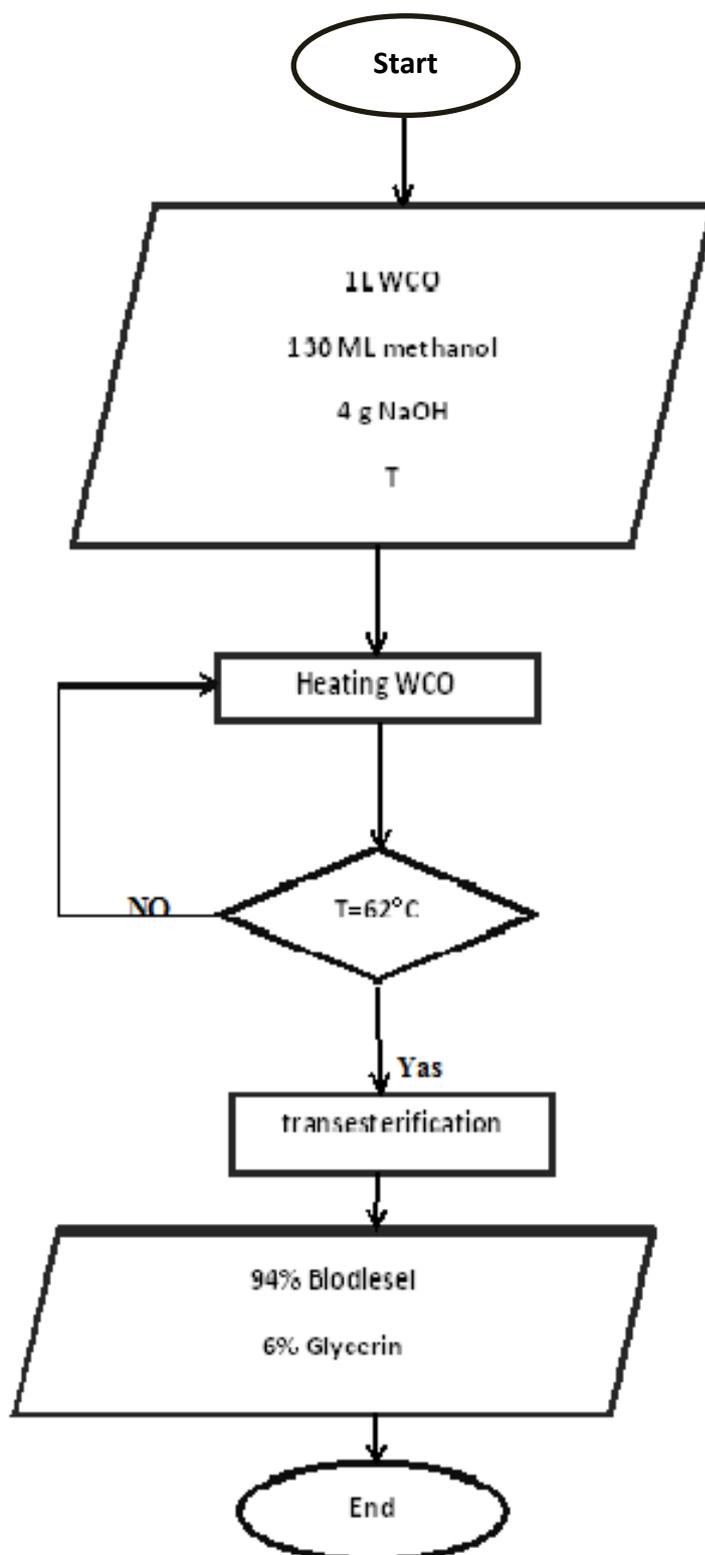

Figure (3.28) System of EGR
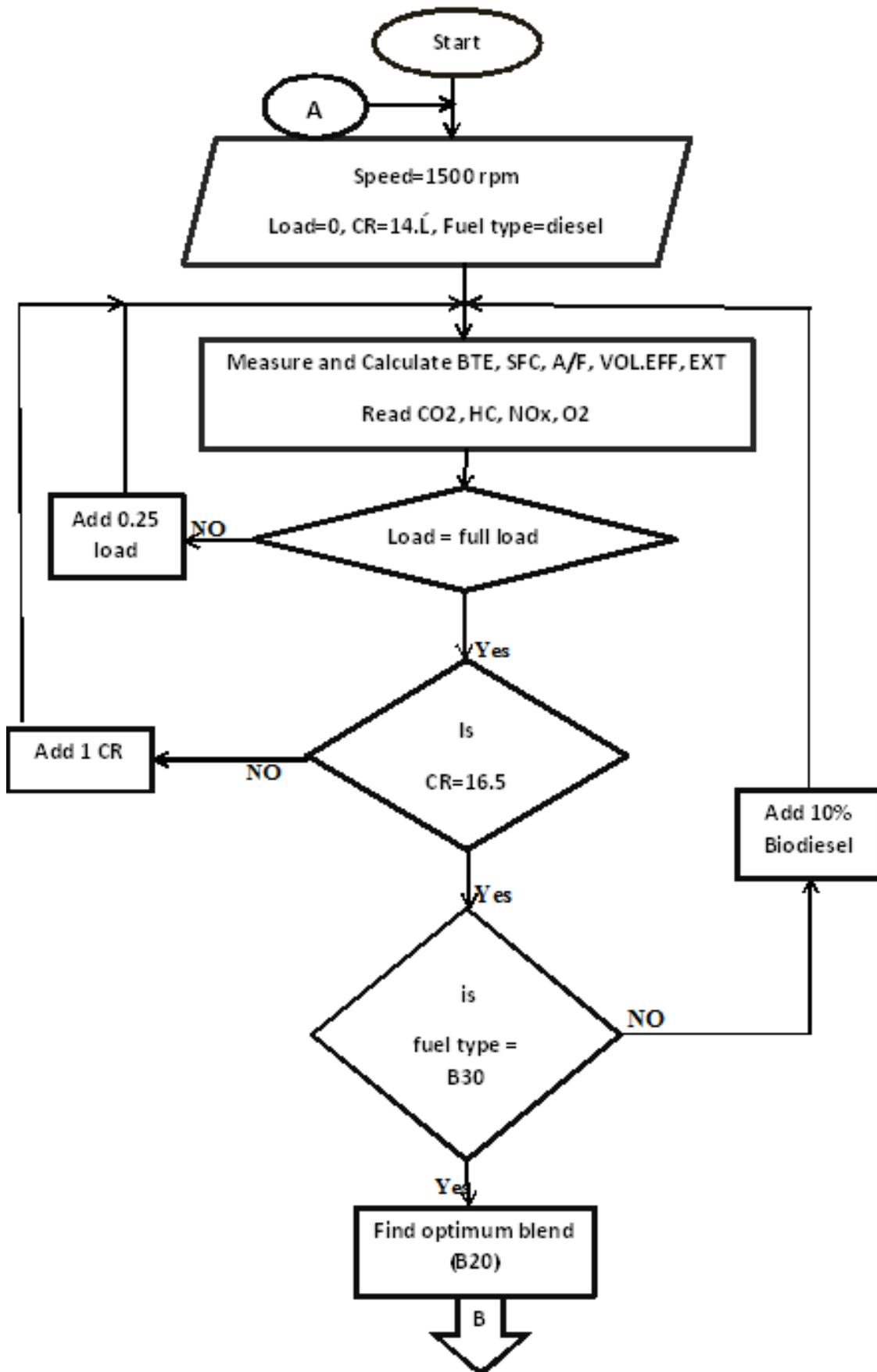
3.10 Experimental Steps

After preparing the diesel/biodiesel blends, the below sequential steps ara followed on diesel engine to obtain the results being discussed in the coming chapter.
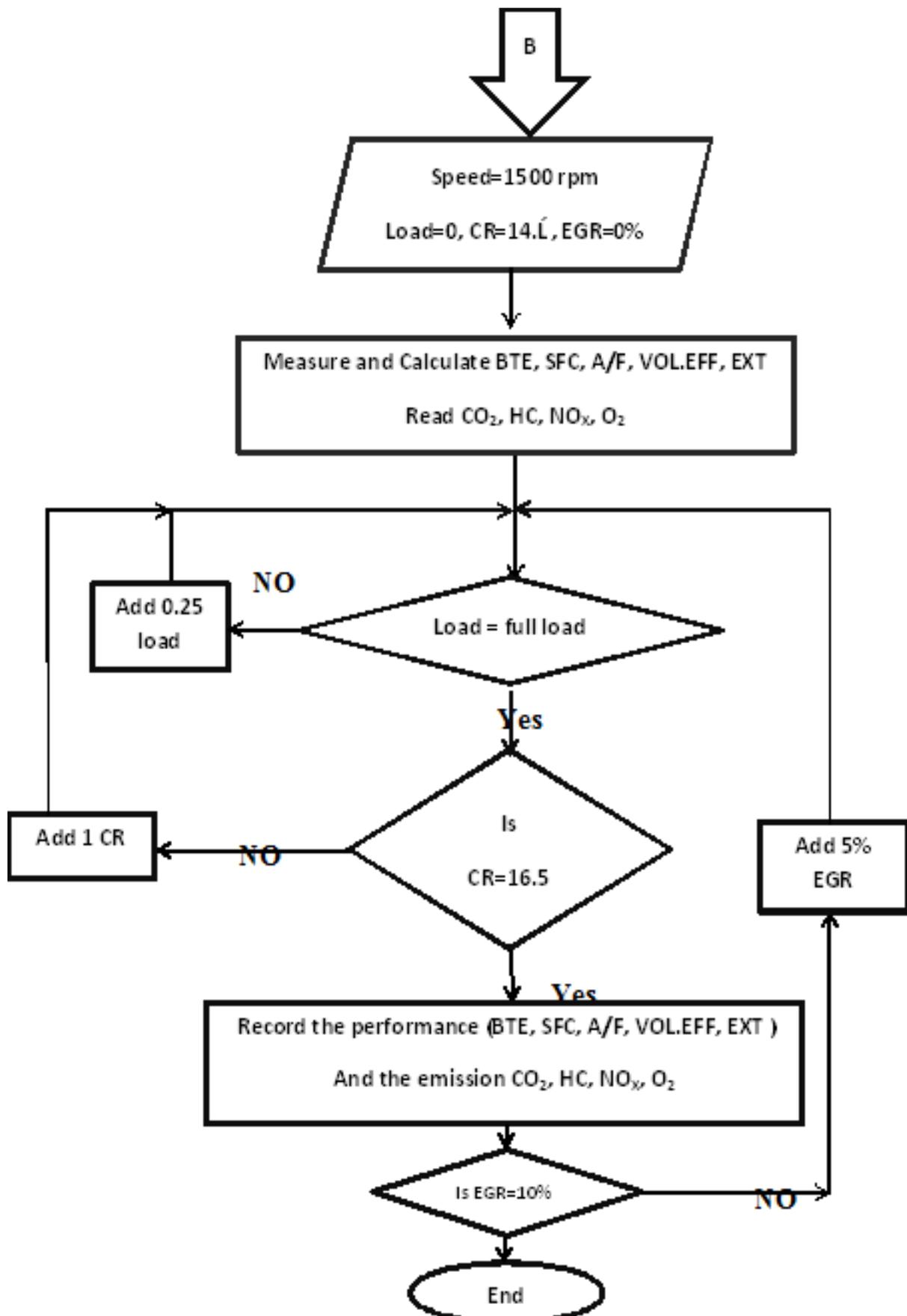
1. To ensure proper operation, check all equipment and diesel pipelines for leaks, engine cooling water lines and the lubrication system.

2. All digital and electrical instruments are tested for operation.

3 . Turn the crank to start the engine after confirming the required compression ratio .

4. Run the engine for a few minutes to heat up to reach thermal balance, then set the required speed (1500 rpm).

5. Start the engine with pure diesel (B0) only and record the data with the load change (0% , 25% ,50%, 75% , 100%) for the three compression ratios (14.5 , 15.5 , 16.5). These steps are repeated with the other mixtures (B10 - B20 - B30).

6. Use the EGR technique twice (5% and 10%) for the same previous conditions, so that the total number of readings becomes 120.

7. Use the various systems that are integrated with the engine, record all input control variables.

8. Turn off the motor after reaching the no-load state.

3.11 Flow charts for different experimental works:

Start

1L WCO

130 ML methanol

4 g NaOH

T

Heating WCO

T=62°C

NO

Yas

transesterification

94% Biodiesel

6% Glycerin

End

Scheme (A) Biodiesel Synthesis

B

Speed=1500 rpm

Load=0, CR=14.Ĺ, EGR=0%

Measure and Calculate BTE, SFC, A/F, VOL.EFF, EXT

Read CO_2, HC, NO_x, O_2

NO

Add 0.25 load

Load = full load

Yes

Add 1 CR

NO

Is

CR=16.5

Add 5% EGR

Yes

Record the performance (BTE, SFC, A/F, VOL.EFF, EXT)

And the emission CO_2, HC, NO_x, O_2

Is EGR=10%

NO

End

Scheme (B) gives the flow charts of experimental tests

81
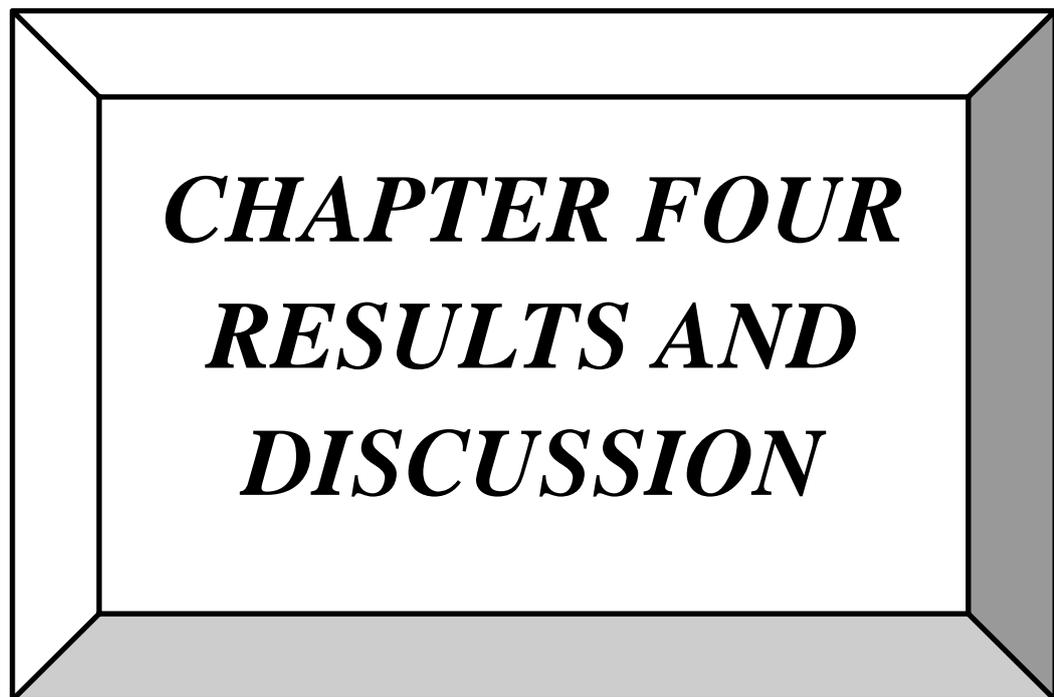
CHAPTER FOUR RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the experimental results are discussed where the results are gathered from experimental of:

1-Synthesis of biodiesel.

2-Testing of biodiesel mixtures in the engine

3-Control of NO_X by EGR technique

4.2 Synthesis of Biodiesel

It is noticed that the percentage of biodiesel production from WCO is changed. According to the amount of temperature of heating the WCO in the water bath, the ratio of biodiesel to the percentage of glycerol production is changed. The experiment of biodiesel synthesize from Iraqi local waste oil is conducted at variable waste oil temperatures. The results are summarized in table 4.1below.

Table (4.1) Biodiesel production according to WCO heating

Test Num.	WCO heating temperature °C	Biodiesel production %
Test 1	58	86
Test 2	60	90
Test 3	62	94
Test 4	64	92

From table 4.1 can be observed that, the preheated temperature of waste oil is important to initiate the reaction between oil and mixture of NaOH + methanol.

This temperature is a response of the chemical roots transferring from oil to biodiesel. From experimental achieved in laboratory, the temperature of maximum biodiesel synthesized is assessed between 58 ^{o}C and 64 ^{o}C. The amounts of reaction productions are calculated. Reaction production is presented by biodiesel volume and glycerin volume. For each type of oil there is optimum temperature from range of temperatures that oil transferred to biodiesel [81,82] this range of temperatures means the transterfection process start at 58 ^{o}C in this type of oil.

Table(4.1) shows the percentage of the volume of biodiesel produced, which is calculated from the equation of the percentage of the volume of biodiesel produced :

$$\text{The biodiesel \%} = \frac{\text{volume of biodiesel produced}}{\text{Total product volume}} * 100\%$$

The rest of the volume of the product represents glycerin.

4.3 Testing of Biodiesel Mixtures in the Engine

4.3.1 Performance and emissions of diesel engine run by diesel at VCR

The engine first runs with pure diesel at a constant speed (1500) rpm with variable compression ratio VCR to study the performance and emissions of the engine. The compression ratio is changed from 14.5, then 15.5, and finally 16.5 by changing the angle of the control column in the piston arm by moving a screw mechanically, previously referred to. The larger the cylinder size , the smaller the combustion chamber, the higher the CR according to the mathematical equation

$$\text{CR} = \frac{\text{combustion chamber volume(V1)} + \text{cylinder volume(V2)}}{\text{combustion chamber volume(V1)}} =$$

$$\frac{\text{The volume of the air/fuel mixture at bottom dead center (BDC)}}{\text{The volume of the air/fuel mixture at top dead center (TDC)}}$$

- Performance Characteristics

Figures (4.1), (4.) represent a comparison between brake thermal efficiency BTE and specific fuel consumption SFC in sequence for diesel fuel with overload at CR values. Whereas, BTE and SFC increase with increasing load. The total energy release increases with the increase in the engine load, and therefore the output power ratio increases, and this leads to more fuel consumption as the fuel pump increases with the increase in the load. Volumetric sufficiency decreases with increasing load. Because the engine speed decreases with increasing load [75].

 The graph shows that there is an increase in BTE and an increase in SFC with a rise in CR.

SFC is the percentage of average fuel consumption at a specific time (Appendix B, equation (5)), an important parameter that reflects how well an engine performs at converting fuel into energy.

A rise in the CR means a rise in the volume of the cylinder, and thus the entry of the air-fuel mixture increases. This causes an increase in fuel consumption and an increase in the combustion process inside the combustion chamber. Increasing CR improves the pyrolysis process and air-fuel mixing, which leads to improved combustion

The brakes thermal efficiency is calculated (Appendix B,equation (1)) by the ratio of measured brake force to the product of fuel flow rate and calorific value. The heat generated from the combustion process of the mixture increases to give mechanical energy to move the pistons, and thus the brakes thermal efficiency increases with the increase in the compression ratio.

All researchers agreed that the motor reaches its highest efficiency at 75% load. At high load, the thermal efficiency decreases, which may be due to friction losses. At

low loads, the engine needs to produce power to overcome friction losses .The highest efficiency a diesel engine can reach (55-60%).
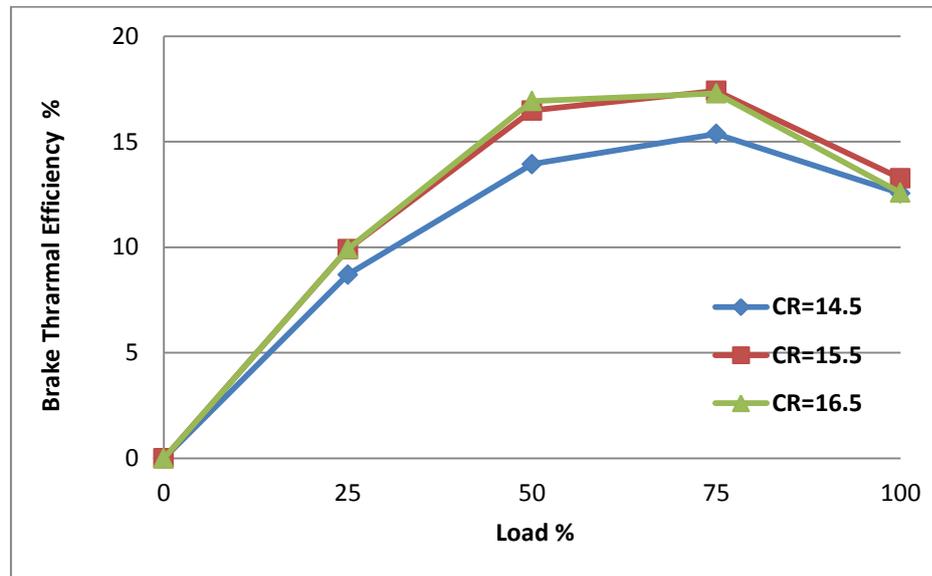

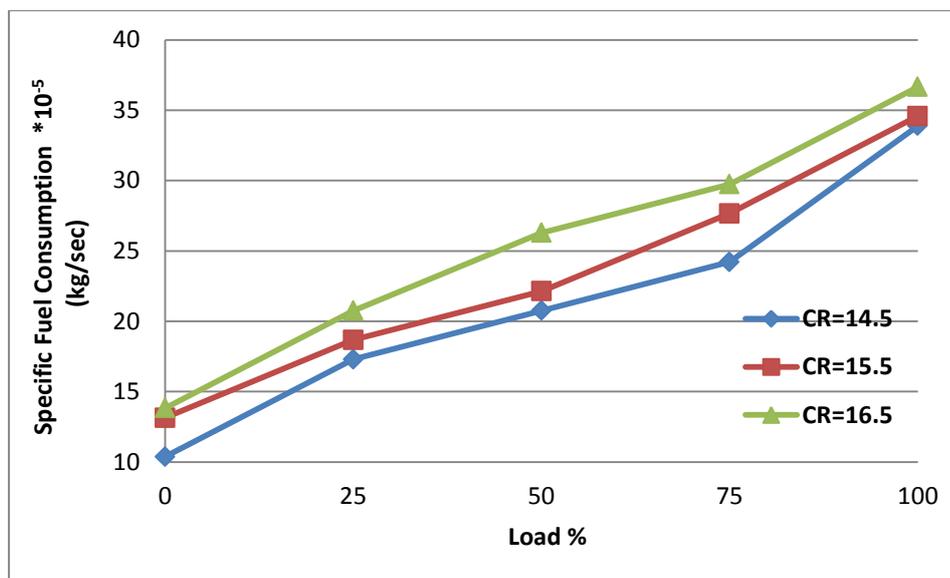Figure 4.1: Variation of brake thermal efficiency with compression ratio

Figure 4.2: Variation of specific fuel consumption with compression ratio

Figure (4.3), (4.4) shows comparison of exhaust gas temperature EXT and volumetric efficiency VOL.EFF in series for diesel at CR values with increased load.

Exhaust gas temperature is the form of heat losses resulting from the burning of the fuel-air blend in the combustion chamber. EXT is an important parameter in the thermodynamic analysis of an engine used with different fuels. Volumetric efficiency is the ratio of the actual air intake in the cylinder to the maximum amount of air that can be drawn during the intake stroke(Appendix B,equation (3)), represented by the displacement of the piston.

EXT increases and volumetric efficiency decreases with increasing loading conditions. Due to the increase in fuel consumption with the increase in CR, that is, the increase in the combustion process, as shown in the diagram. In addition, the rise in reaction rate and flame velocity that occurs with increasing load is believed to cause an increase in EXT, as well as an increase in the rate of heat emission relative to the rate of heat loss. The fluctuation in the manometer reading and the optical errors are reflected at the expense of the volumetric efficiency, and irregular readings appeared. Increasing the CR means increasing the volume of the cylinder, that is, increasing the actual compressed air volume, and this leads to an increase in CR by a small percentage, as shown in the diagram.
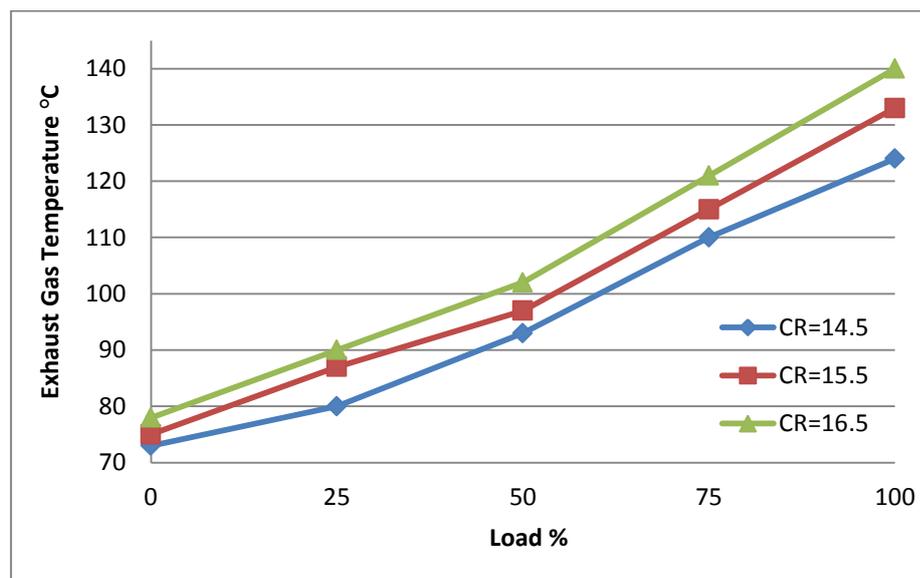
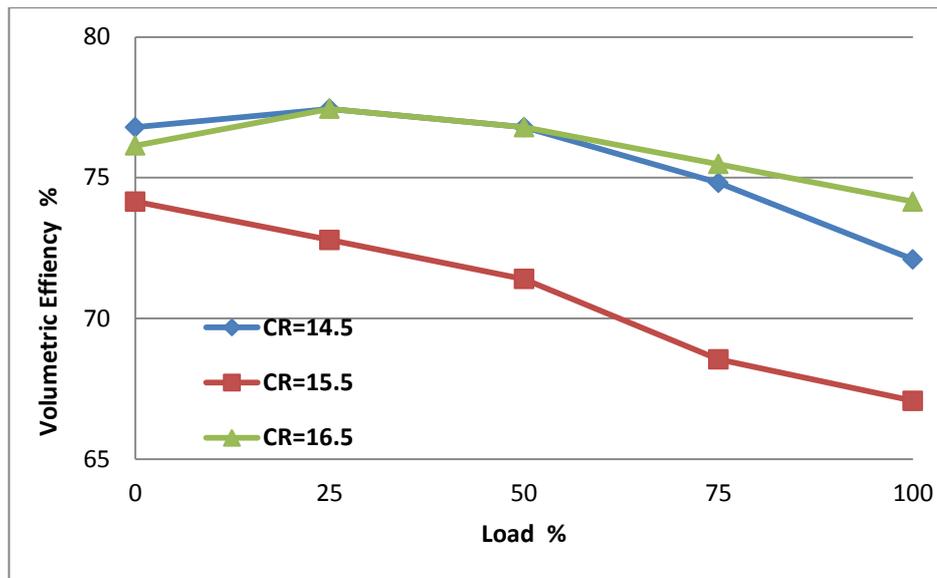Figure 4.3: Variation of Exhaust Gas Temperature with compression ratio

Figure 4.4: Variation of volumetric efficiency with compression ratio

Figure (4.5) shows the air to fuel A/F comparison of diesel at CR values with overload.

A /F is the proportion of air weight to the weight of fuel inside the combustion room. It is a measure if the mixture is flammable. On the amount of energy and pollutants that are launched from the combustion of fuel.Since the actual air entering the engine decreases with increasing load, this means a decrease in the air-to-fuel ratio.

The air-to-fuel ratio decreases with increasing loading conditions. due to the increase in fuel consumption. As CR increases, sucking air increases and thus A/F increases[46].
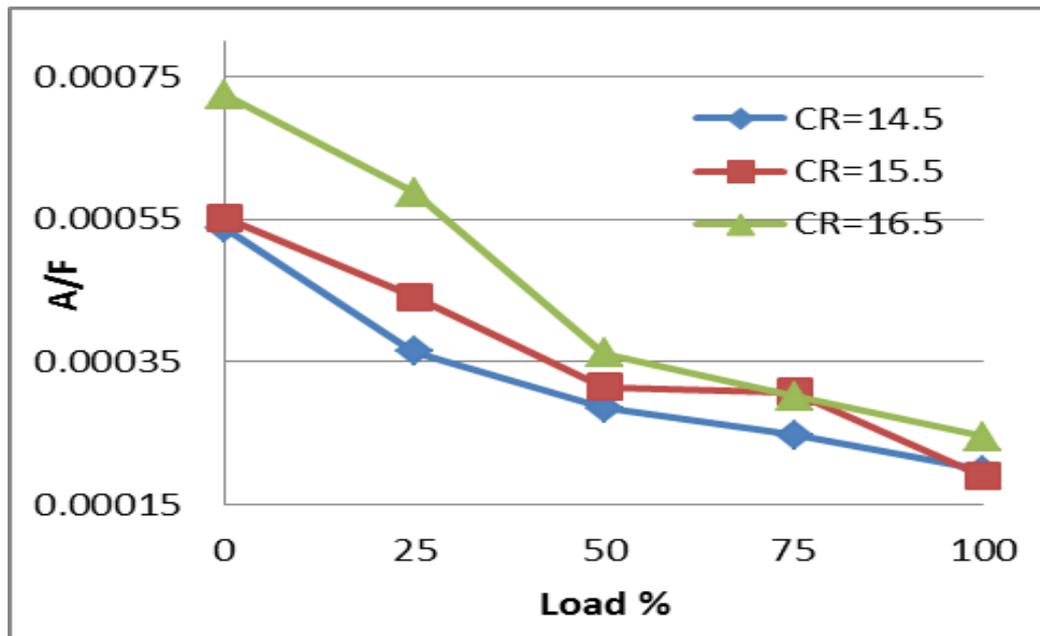
Figure 4.5: Variation of air to fuel ratio with compression ratio

-Emission characteristics

Figures (4.6) , (4.7) show the comparison of carbon dioxides CO_2 and hydrocarbon values in series for diesel at CR values with increasing load. Due to the increase in fuel injection in the combustion chamber with the increase in engine load, diesel emissions rise exponentially, including CO_2 and HC.

A rise in CR leads to a rise in the burning of fuel in the combustion chamber, and thus an increase in the emission of CO_2 and HC. Cracks, oil films and deposits, liquid fuels, flame suppression, and exhaust valve leaks are six main theories put out as causes of hydrocarbon emissions. Hydrocarbon is generated in the exhaust when liquid fuels do not find enough oxygen to burn before combustion ends [83].As for CO_2, it is formed the more diesel burns, because it is rich in carbon.
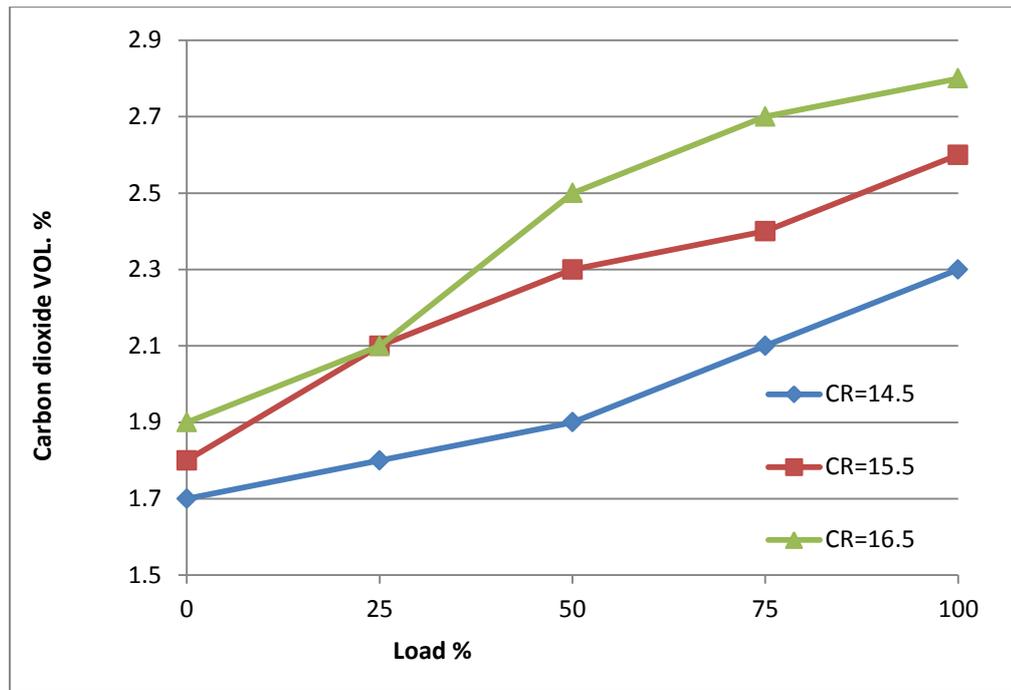
Figure 4.6: Variation of carbon dioxide with compression ratio
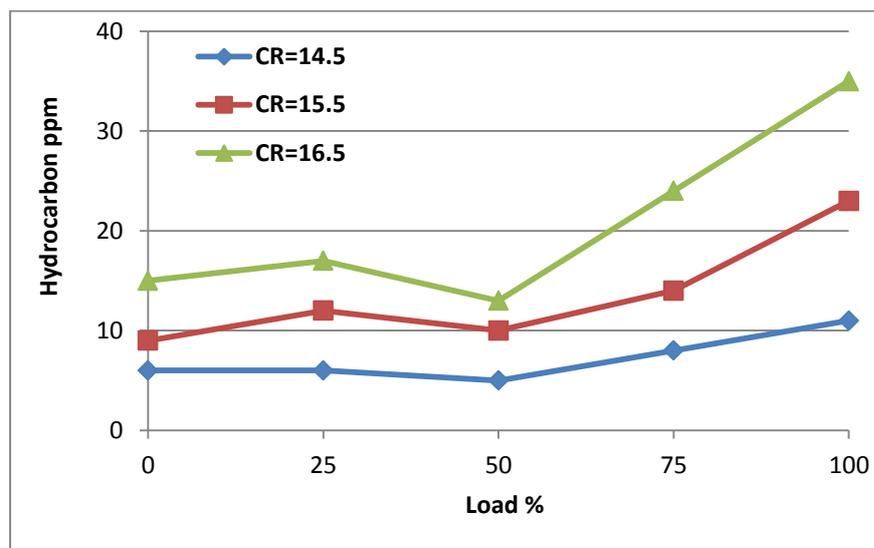
Figure 4.7: Variation of hydrocarbon with compression ratio

Figures (4.8) , (4.9) show a comparison of the nitrates oxides NO_X and O_2 values for diesel at CR values with increased load.

There is an increase in NO_X emission and a decrease in O_2 with respect to the height of the load.

Oxygen increases with the increase of CR because the entry of air is more. The same factor also contributes to an increase in NO_X emissions with an increase in CR, as well as a rise in combustion temperature with an increase in the compression ratio. Where nitrogen oxides are formed as follows:

$O + N2 \leftrightarrow NO + N$

$N + O2 \leftrightarrow NO + O$

$N + OH \leftrightarrow NO + H$
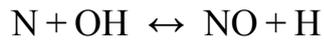
During the combustion process, higher post-flame temperatures and oxygen concentrations result in an increase of NO production .The NO_X concentration triples when the oxygen concentration in the air reaches27%[83]
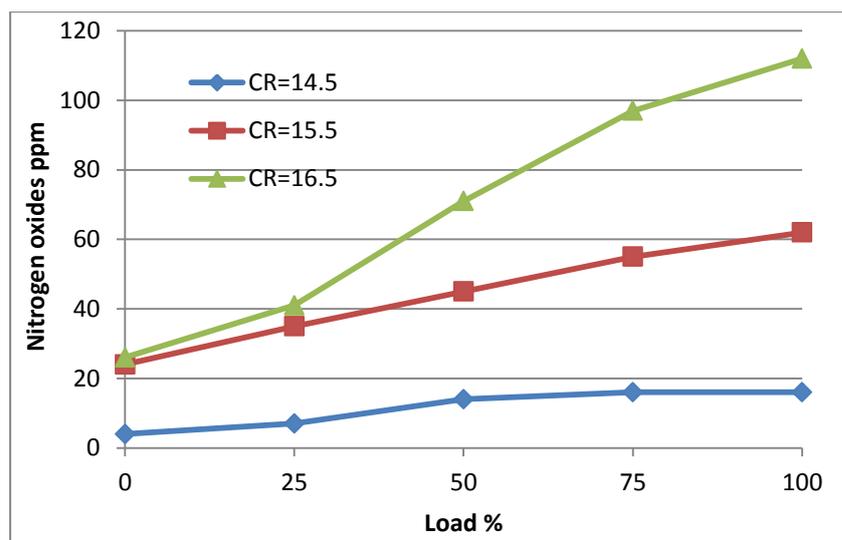
Figure 4.8: Variation of Nitrogen oxides with compression ratio
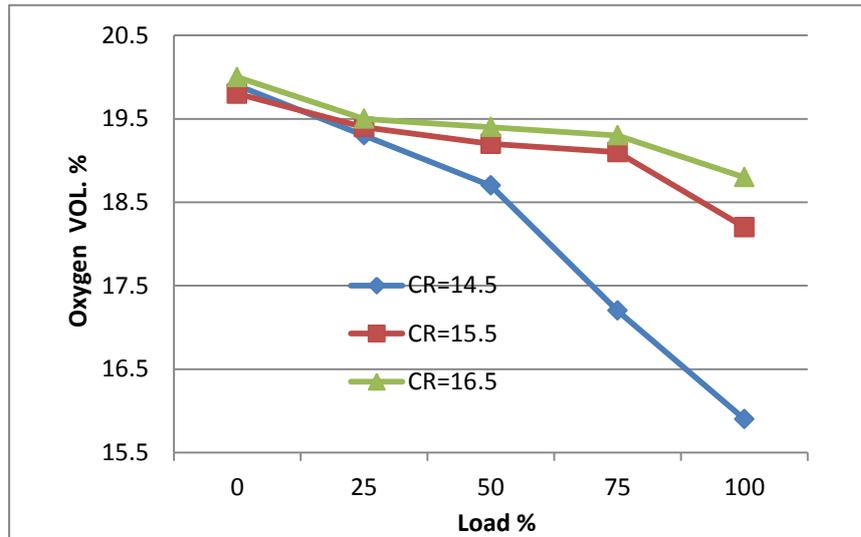
Figure 4.9: Variation of Oxygen with compression ratio

Table (4.2) shows approximate percentage values that represent an increase↑ or decrease↓ in performance and emissions of the diesel engine according to the change in the compression ratios and the varying engine loads.

Table (4.2) Engine characteristics behavior with changing loads and CR

Properties	Trend with increasing load at CR=15.5	Trend with increased CR at full load
BTE%	↑ 25%	↑ 17%
SFC	↑ 18%	↑ 5%
EXT	↑ 16%	↑ 4%
VOL.EFF	↓ 6%	↑ 10%
A/F	↓ 30%	↑ 5%
CO_2	↑ 8%	↑ 7%
HC	↑ 2.5%	↑ 37%
NO_X	↑ 25%	↑ 40%

O_2	↓ 3%	↑ 3%

4.3.2 Performance and emissions of diesel engine run by diesel / biodiesel at VCR

Biodiesel is added with diesel in three proportions to study performance and emissions of diesel engine to prove the suitability of biodiesel as a substitute for diesel.

- Performance Characteristics

Figures (4.10), (4.11) represent comparison of BTE and SFC for diesel and WCO biodiesel at CR values with increasing load.

The graph shows a decrease in BTE and an increase in SFC with an increase in the proportion of the WCO-biodiesel blend in diesel. Biodiesel has a higher viscosity and density than diesel, so the engine needs to consume more fuel to get the same power output as the proportion of biodiesel in the mixture increases. Properties tests show that the calorific value of bio-diesel is lower than that of diesel, so the brake thermal efficiency decreases.
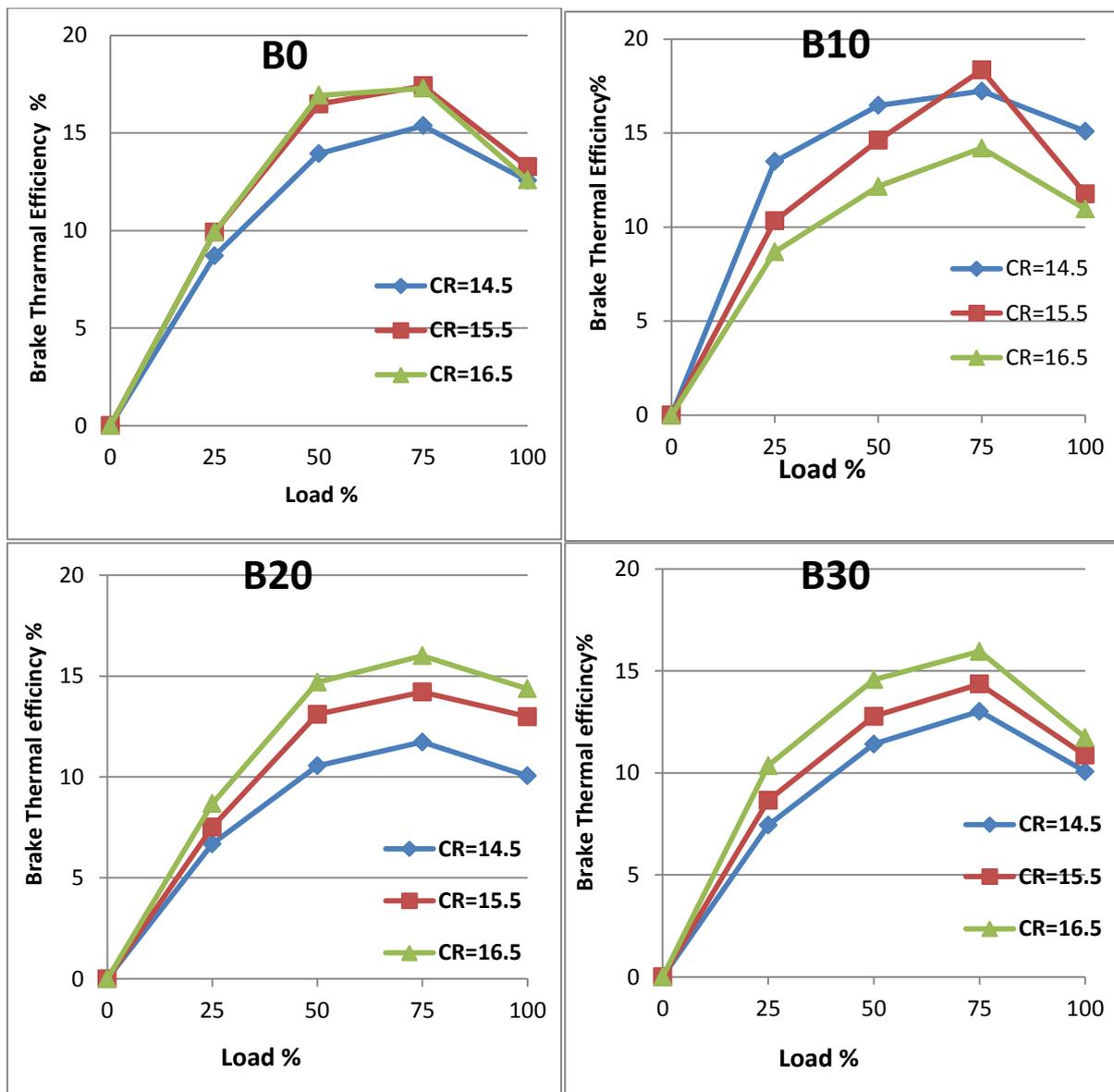
Figure 4.10: Variation of brake thermal efficiency with compression ratio for diesel/biodiesel
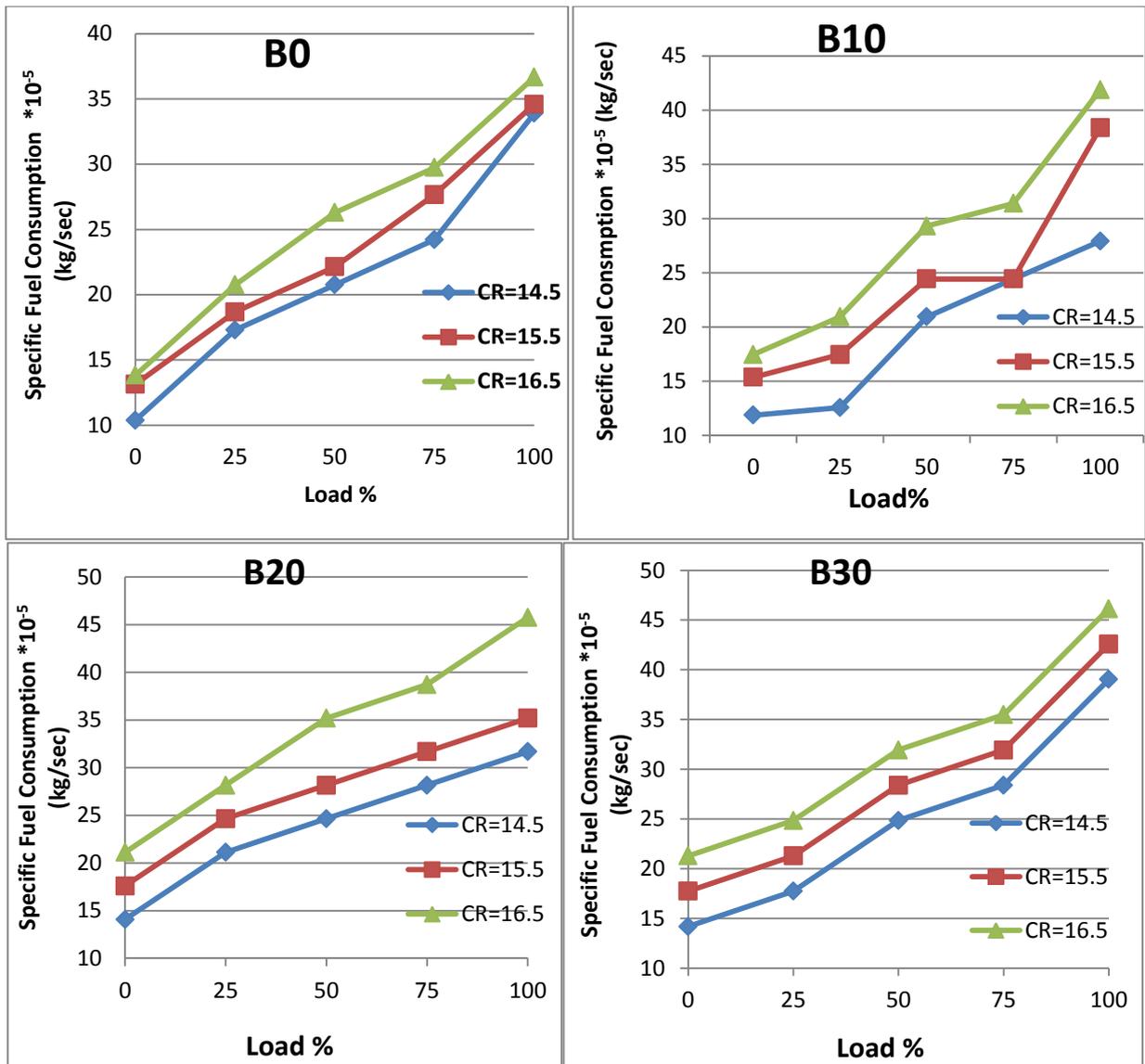
Figure. 4.11: Variation of specific fuel consumption with compression ratio for diesel/biodiesel

Figures (4.12), (4.13)show comparison of EXT and VOL.EFF for diesel and WCO biodiesel at CR values with overload, when compared blends,it note that the volumetric efficiency is not affected between fuel mixtures, because the volumetric efficiency does not depend on the type of fuel. Increases EXT values for all combinations. This is because the increase in fuel consumption increases the combustion process, and thus the heat is released in the form of thermal losses, which

causes a rise in the exhaust temperature. This is also an indication of the reason for the low brakes thermal efficiency .
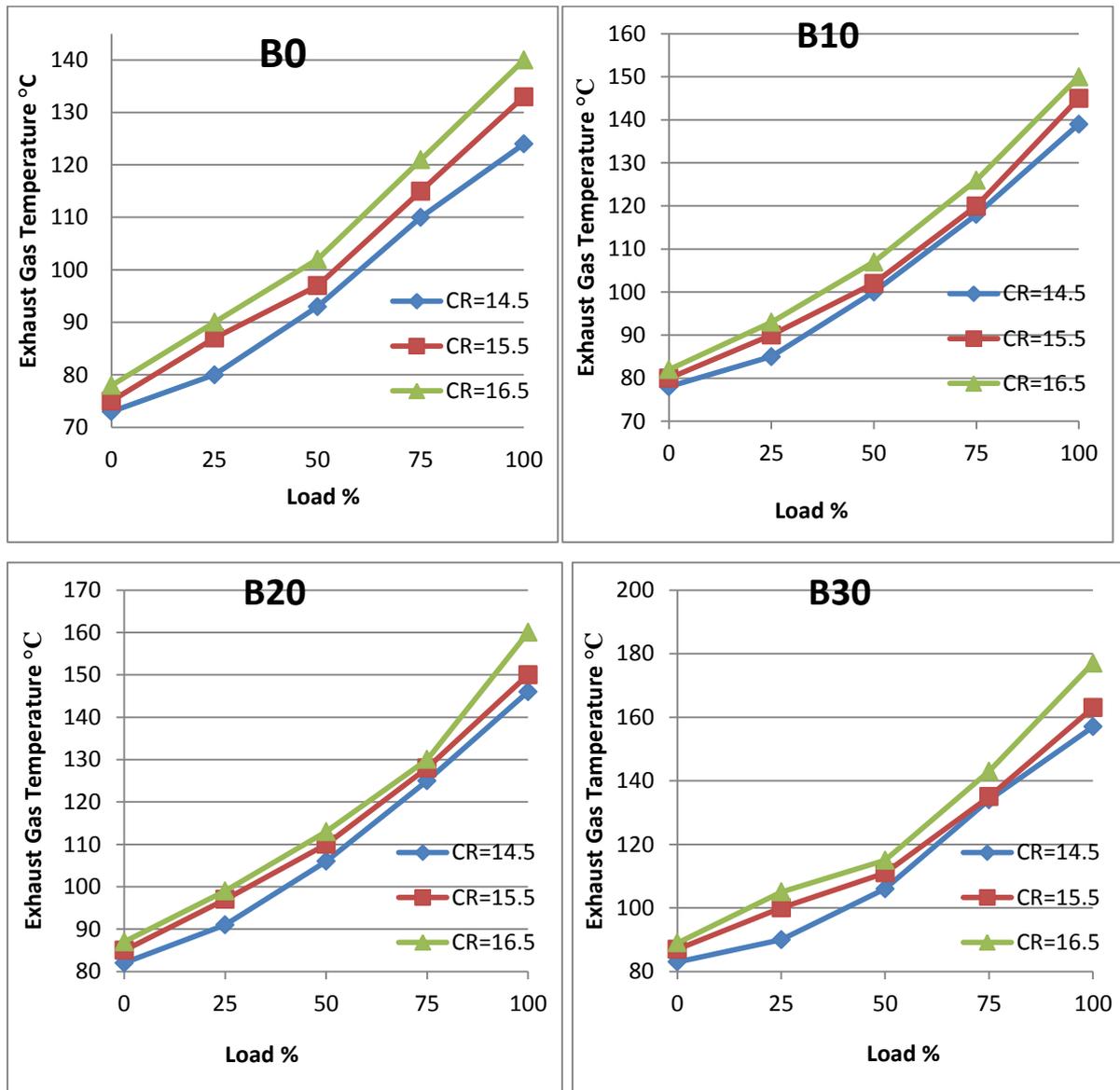
Figure. 4.12: Variation of Exhaust Gas Temperature with compression ratio for diesel/biodiesel
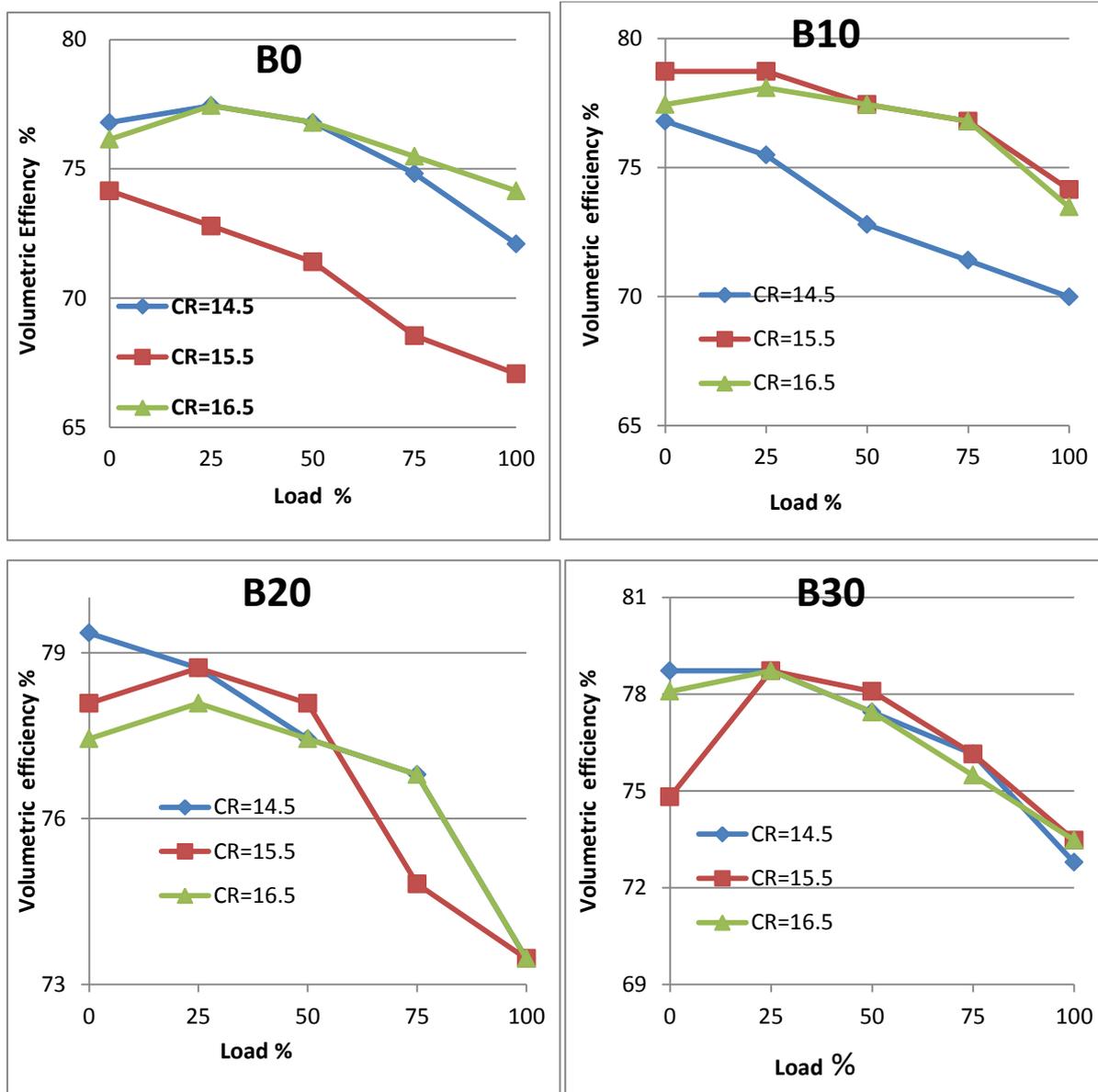
Figure. 4.13: Variation of volumetric efficiency with compression ratio
for diesel/biodiesel

Figure (4.14) shows an A/F comparison of diesel and WCO biodiesel at CR values with overload. When comparing fuel, we note that the ratio of air to fuel decreases with the rise in the part of biodiesel in the mixture.

Increasing the percentage of biodiesel means more fuel consumption, and this means drawing more fuel into the combustion chamber, and thus the A / F value decreases.
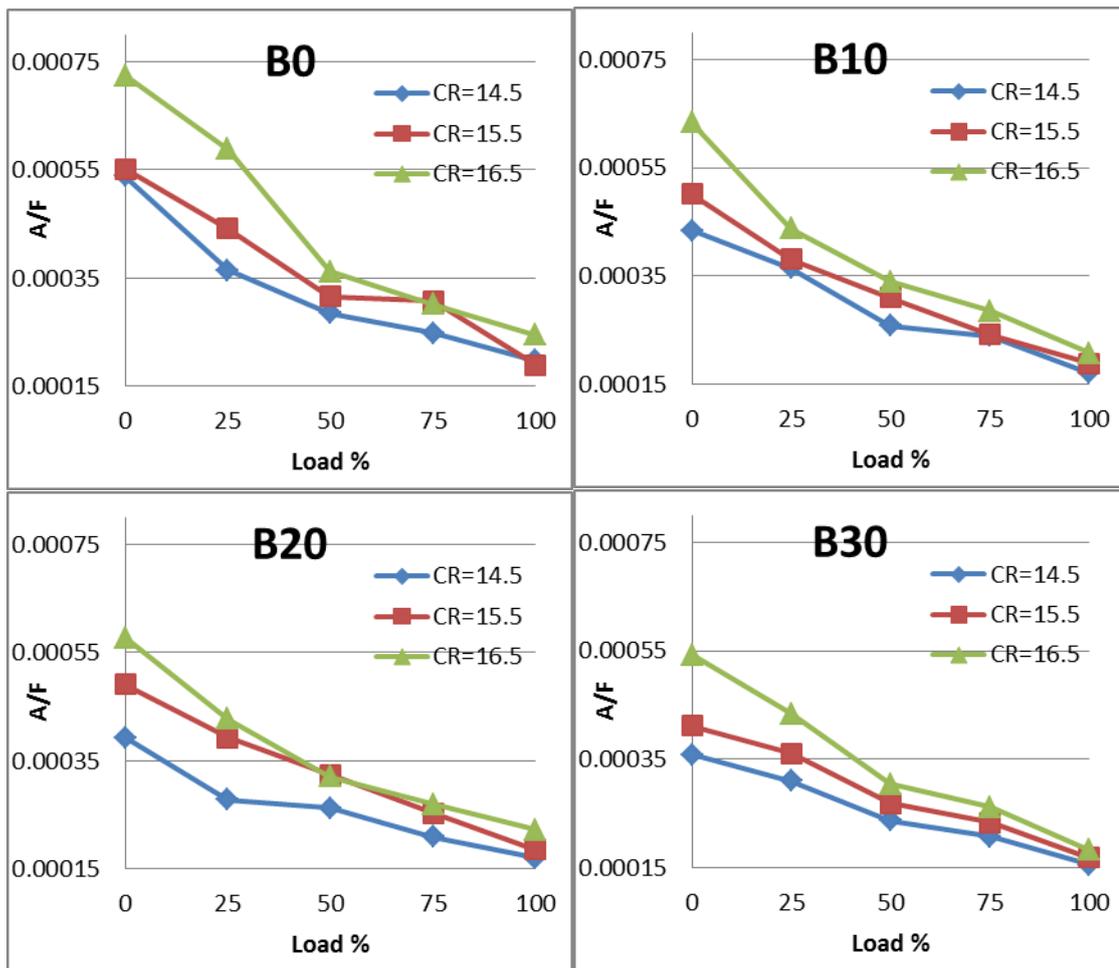
Figure. 4.14: Variation of air to fuel ratio with compression ratio for diesel/biodiesel

- Emission characteristics

Figures (4.15), (4.16) show a comparison of CO_2 and hydrocarbon values for diesel and biodiesel WCO at CR values with increasing load. The amount of CO_2 and HC decreases as the mixing ratio rises in the WCO. This is one of the most important advantages of using biodiesel as an alternative fuel.

Biodiesel is an oxygenated fuel that improves combustion efficiency and reduces CO_2 and hydrocarbon (HC) emissions.
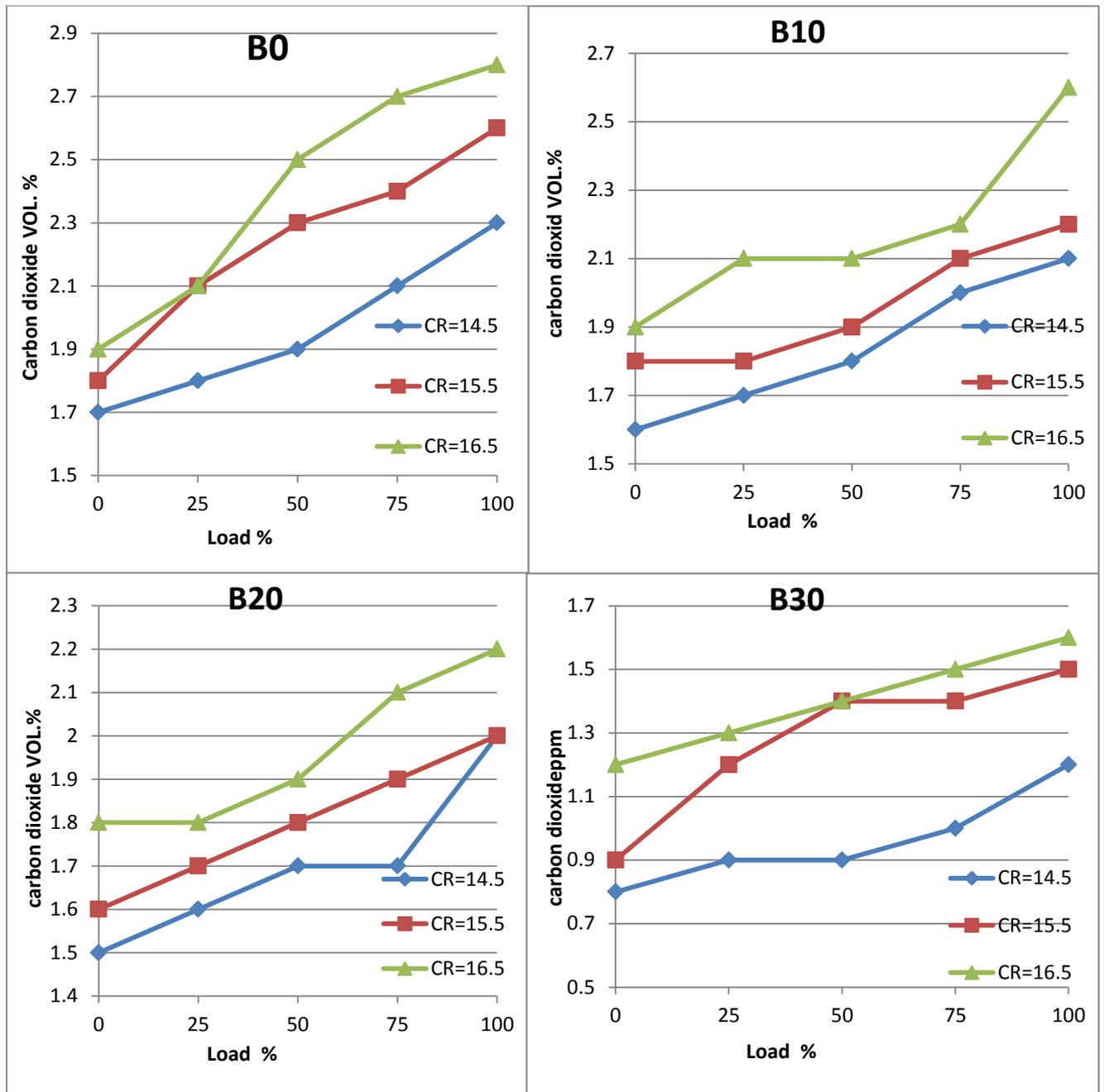
Figure. 4.15: Variation of carbon dioxide with compression ratio for diesel/biodiesel
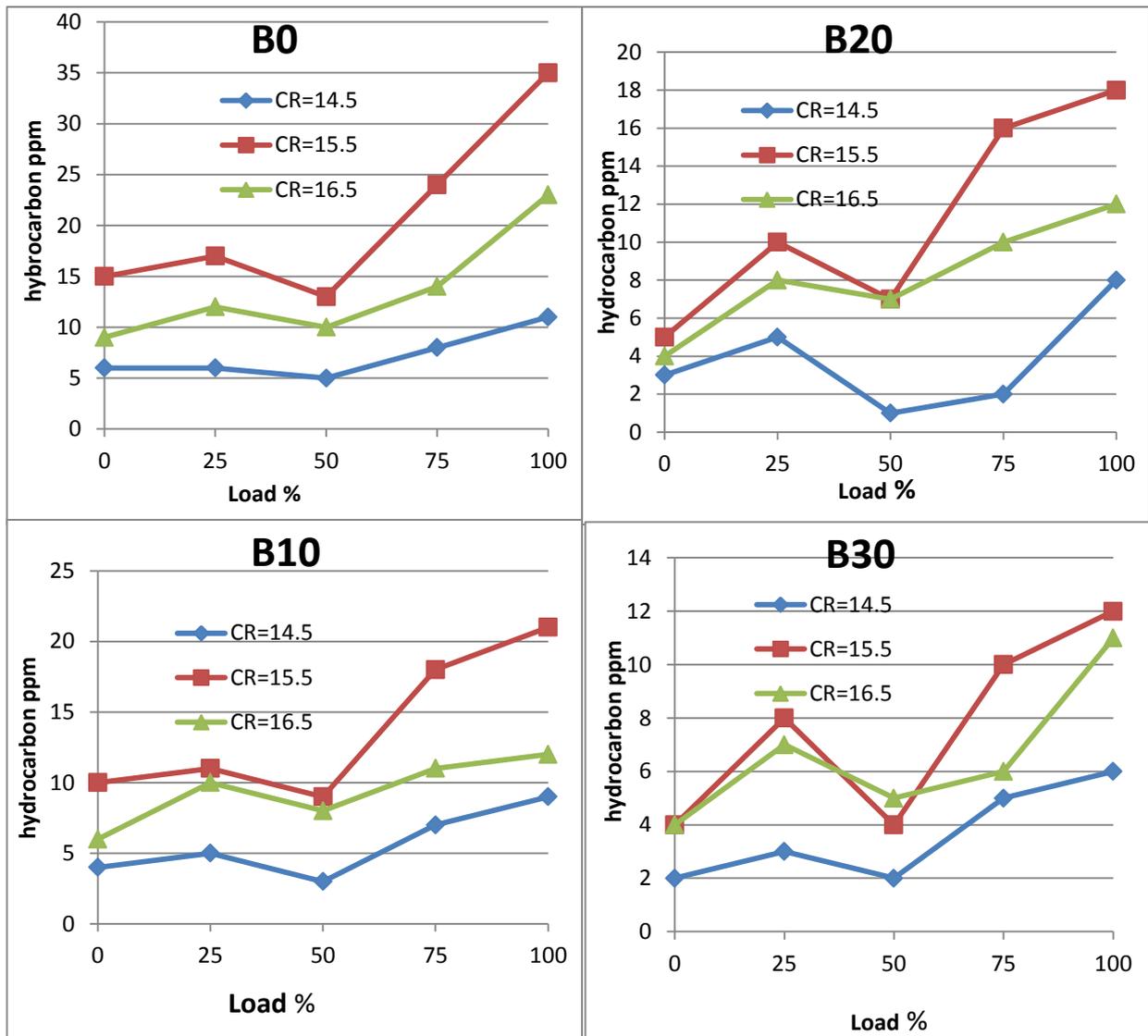
Figure. 4.16: Variation of hydrocarbon with compression ratio for diesel/biodiesel

Figure (4.17), (4.18) show a comparison between the values of nitrogen oxides and oxygen for diesel and WCO biodiesel at CR values with increasing load. As shown in the graph, the oxygen level increases with biodiesel due to the chemical composition of biodiesel produced from the WCO, which leads to complete combustion and thus an increase in temperature inside the cylinder. High flame temperature as a result of the rapid reaction with the increase in load and also due to the high rate of heat

release, which increases the emission of nitrogen oxides. Therefore, biodiesel mixtures contain higher nitrogen oxides than diesel.
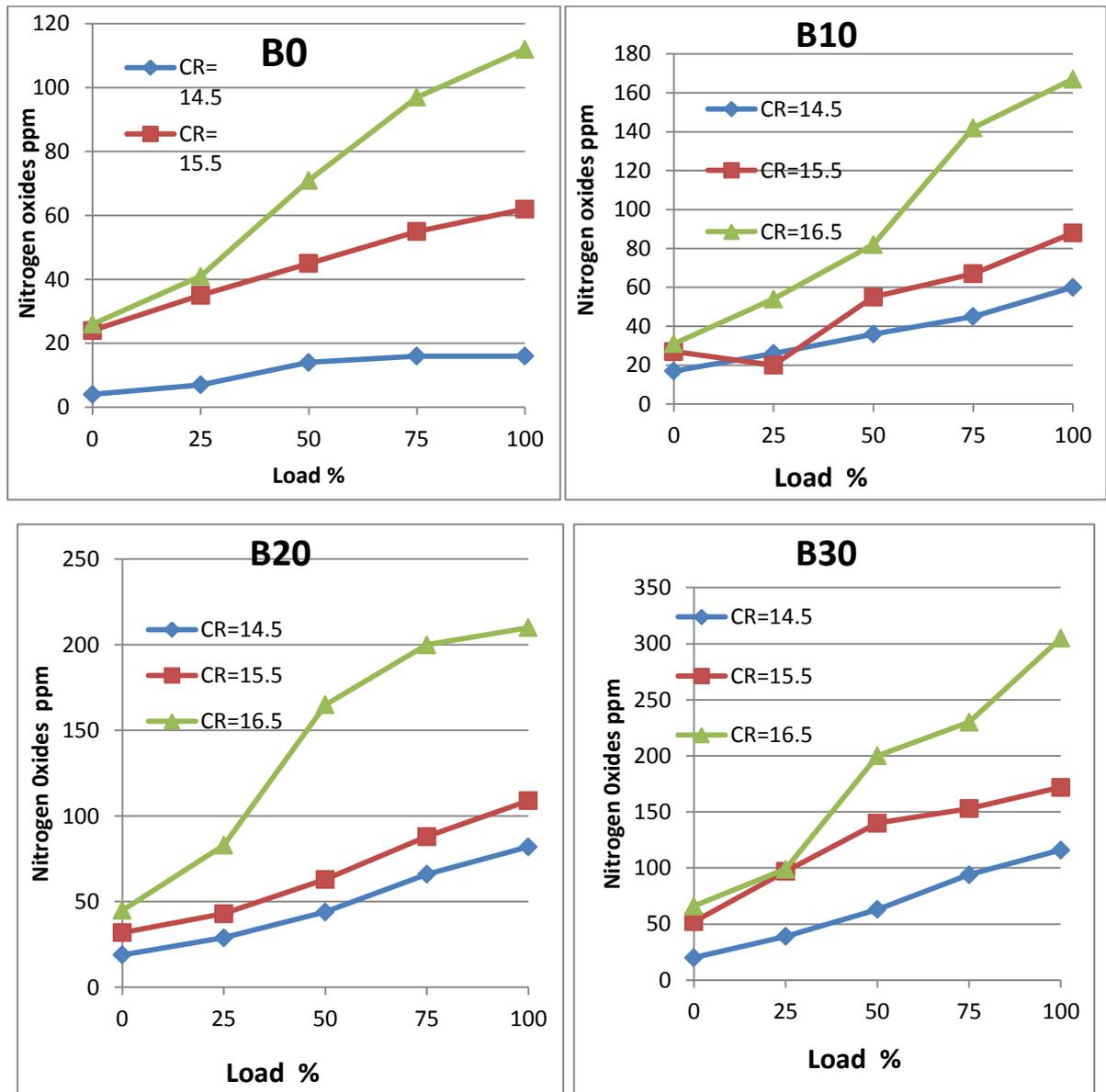
Figure. 4.17: Variation of Nitrogen oxides with compression ratio for diesel/biodiesel
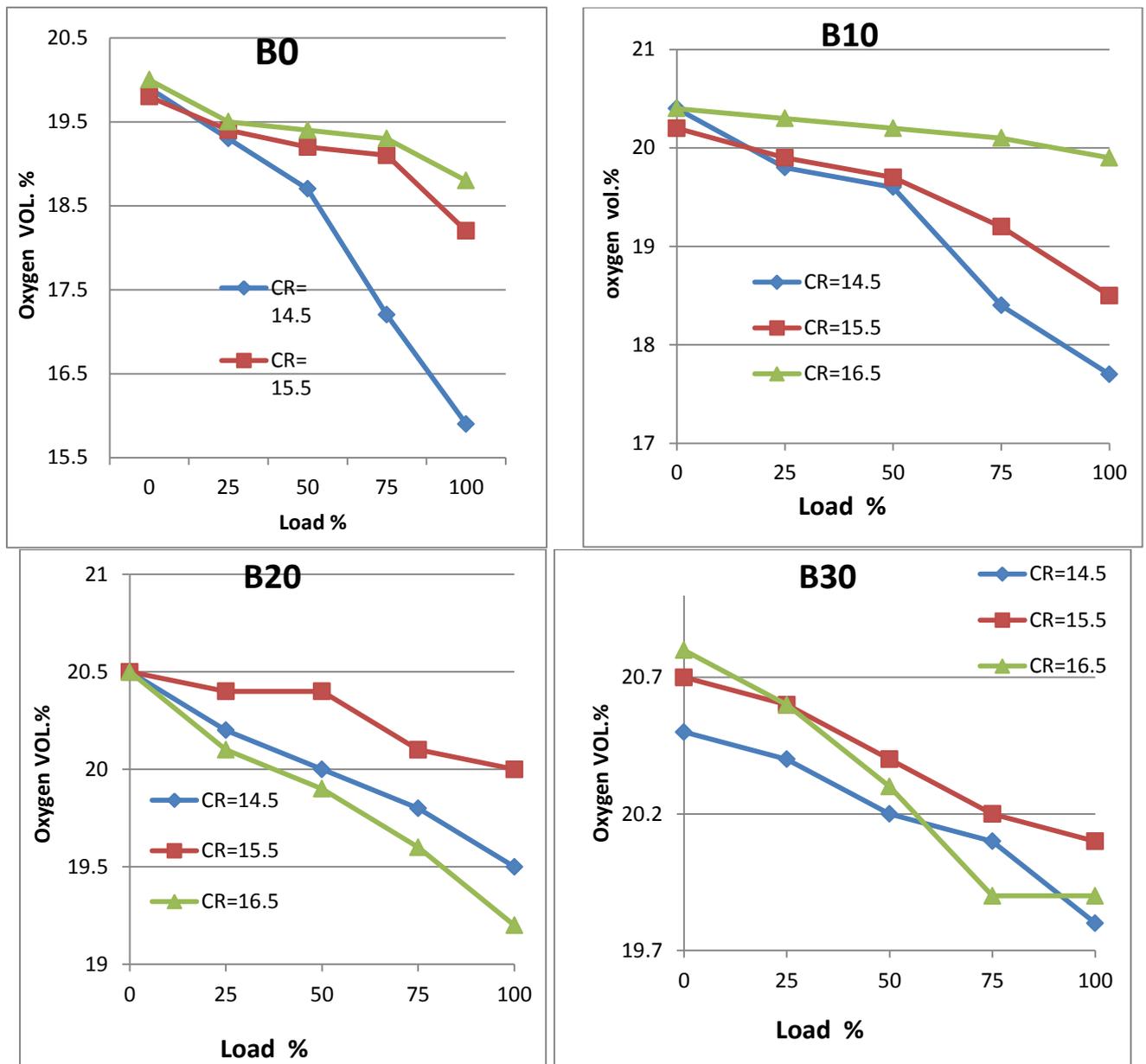
Figure. 4.18: Variation of Oxygen with compression ratio for diesel/biodiesel

To clarify the characteristics of the engine after adding biodiesel, table (4.3) shows the direction of the behavior of these characteristics at the mixing ratio B20 by considering it the middle value between the rest of the mixing ratios and comparing it with diesel at full load, CR = 15.5

Table (4.3) engine characteristics with the addition of biodiesel

Properties	Behavioral trend with the addition of biodiesel
BTE%	↓ 15.5%
SFC	↑ 15%
EXT	↑ 12.5%
VOL.EFF	-
A/F	↓ 20%
CO_2	↓ 23%
HC	↓ 48%
NO_X	↑ 40%
O_2	↑ 6%

4.4 Performance and Emissions of Diesel Engine Run by B20 at VCR and EGR

4.4.1 Selection of B20 as optimum blend

The test of different fuel mixtures shows that the increasing biodiesel percentage in biodiesel/diesel mixture indicates a reduction in brake thermal efficiency with noticeable increase in fuel consumption. On the pollutants side, obviously increasing of biodiesel rate in fuel mixture leads to decrease in CO_2 and HC emission and an increase in NO_X. As far as, the reducing of adding biodiesel rate to the mix does not meet the purpose of using biodiesel as a substitute for pure diesel (reducing carbon and sulfur emissions of the diesel engine,Which has a negative impact on human health and the environment [88]). B10 could not consider as best blend biodiesel ratio due to limit substitute of fossil fuel by renewable bio fuel. To show the best mixing ratio between the blends B10, B20, and B30 that are selected according to literatures [51], [53], and [74]. B20 is concluded as the most suitable ratio for mixing biodiesel with pure diesel to obtain the best brake thermal efficiency and fuel consumption side by side with sensible reduction in hydrocarbons emissions

compared with the other blends as shown in table(4.4) which gives the engine performance and its emissions at full load and CR=15.5. The trend appeared in the engine parameters for compression ratio15.5 is similar to the variations in the engine performance and emissions at variable blends and compression ratios 14.5 and 16.5.

Table (4.4) Engine performance and emissions at all blends for full load and 15.5 compression ratio

Engine characteristics	B0	B10	B20	B30
BTE %	13.261	11.766	12.986	10.870
SFC (kg/sec) $*10^{-5}$	34.583	38.373	35.186	42.586
CO_2	2.6	2.2	2	1.5
HC	35	21	18	12
NO_X	62	88	109	172

The critical literatures approved that blend of 20% biodiesel with 80% diesel is the best or the optimist ratio according to the experimental results. The researcher [48] found that the B20 fuel blend is the most suitable for the test engine with a maximum reduction of 17% for HC, 30% in CO and 16.46% increase in NO_X emissions. The B20 blend shows a decrease in BTE of 1.85% at full load compared to diesel, and an increase in SFC of 6.89%. Also, researcher relied [46] on the B20 mixture, which shows a decrease in the brakes thermal efficiency of the by 32.7% at maximum load. Meanwhile, the researcher [71] added ZnO to the B20 fuel mixture to improve engine performance, as nitrogen oxides emissions decrease by about 15%. Carbon dioxide and hydrocarbon emissions decrease by 20%.

B20 blend is found to be the most suitable fuel blend in terms of performance characteristics   and engine emissions. Allowing to the effects of the experimental investigation, the mixing ratio B20 gives the lowest emissions according to diesel for the best performance of the engine compared to the remaining mixing ratios.

Therefore, EGR technology is applied at varying rates of 5% and 10% to reduce NOx emissions with B20 mixing ratio.

- Performance Characteristics

Figures (4.19), (4.20) represent the effect of the EGR technique on the BTE and SFC of the mixing ratio B20 compared to diesel and WCO biodiesel at CR values with increasing load, where the graph shows a rise in EGR that slightly increase BTE and decreases SFC.

The exhaust gas takes the place of part of the air inside the combustion chamber, which leads to a decrease in the flame temperature, and the combustion process is improved by burning the return exhaust gases, and this is what happens at high EGR rates. BTE may rise due to an increase in the combustion rate when the combustion of HC increases with the exhaust gas. Therefore, the behavior of BTE varies with the addition of EGR.

The reason for the decrease in fuel consumption may be due to the high temperature of the combustion chamber as the exhaust gas returns.
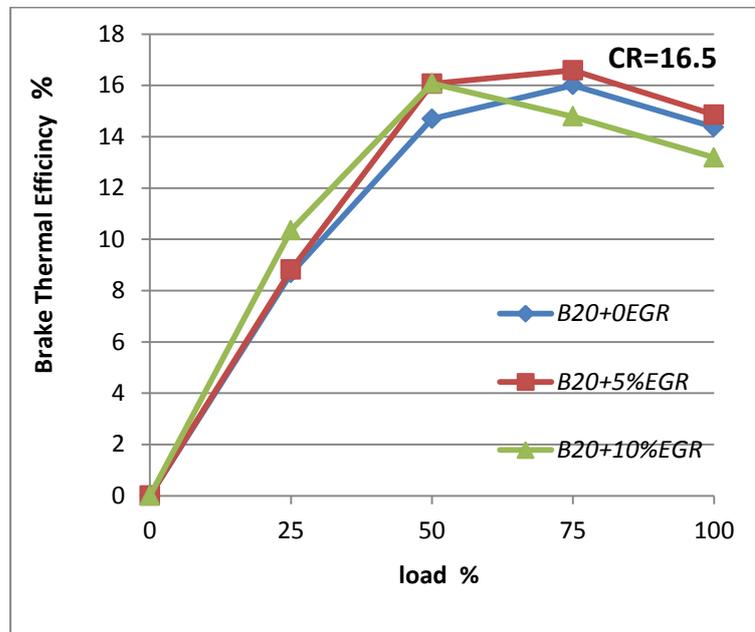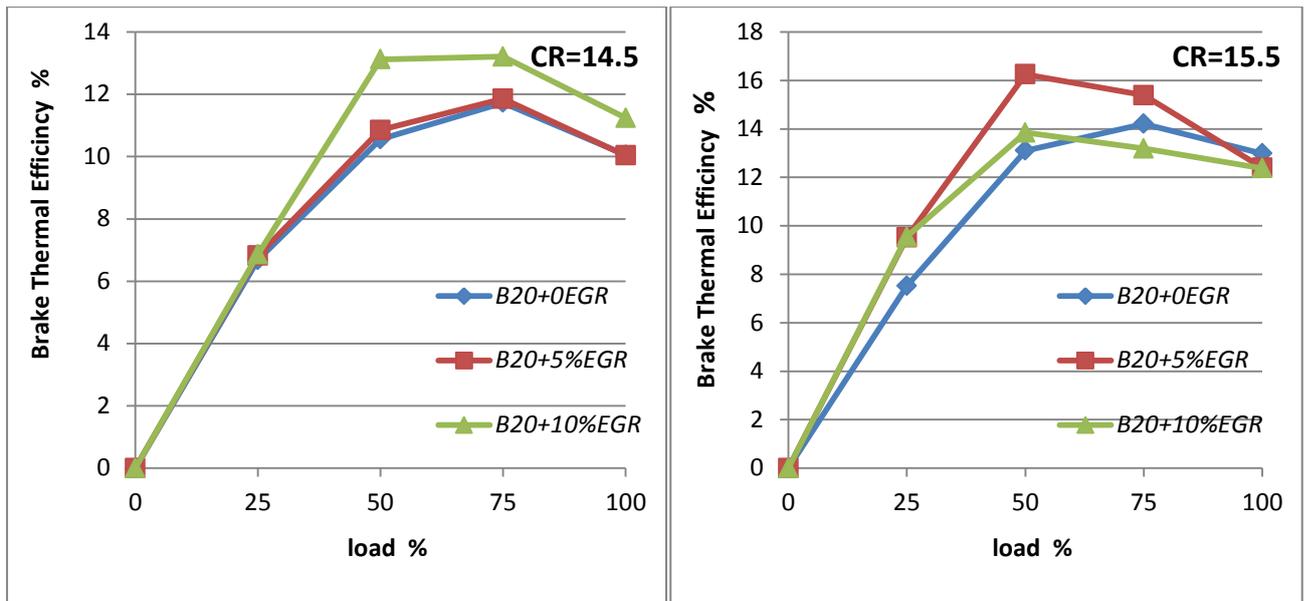
Figure. 4.19: Effect of Exhaust Gas Recirculation on Brake Thermal
Efficiency of B20
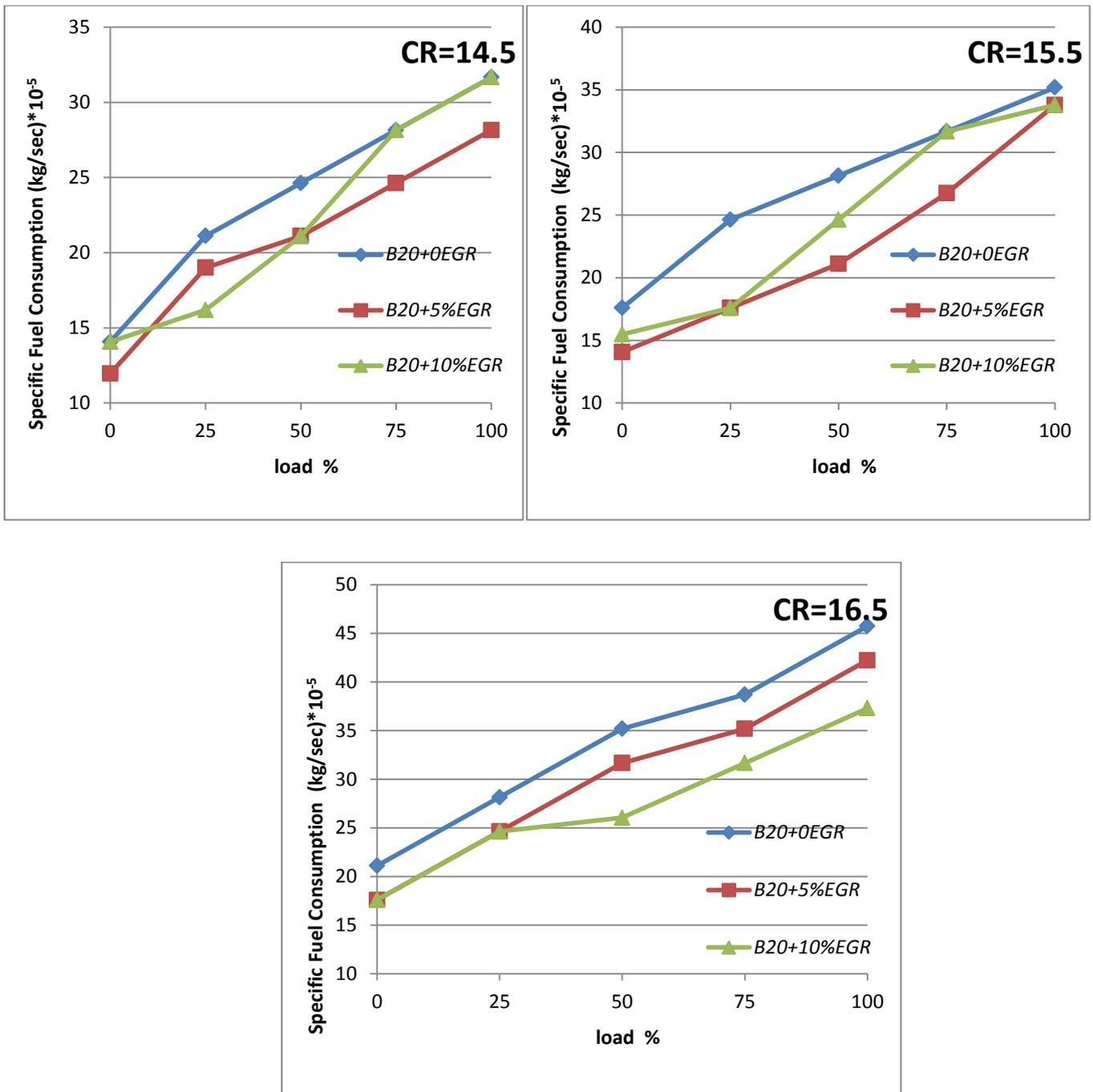
Figure. 4.20: Effect of Exhaust Gas Recirculation on Specific Fuel
Consumption of B20

Figures (4.21),(4.22) show the effect of EGR on EXT and VOL.EFF of a B20
blend compared to diesel and WCO biodiesel at CR values with increasing load. Note
from the graph a decrease of EXT and the volumetric efficiency of the B20 mixture
by using EGR .

The oxygen level decreases with the rise in EGR rate, and thus the ignition decreases with the continuation of combustion, so the exhaust gas temperatures decrease. Since the volumetric efficiency depends on the actual air entering the combustion chamber, therefore, VOL.EFF decreases with the increase in the EGR rate.
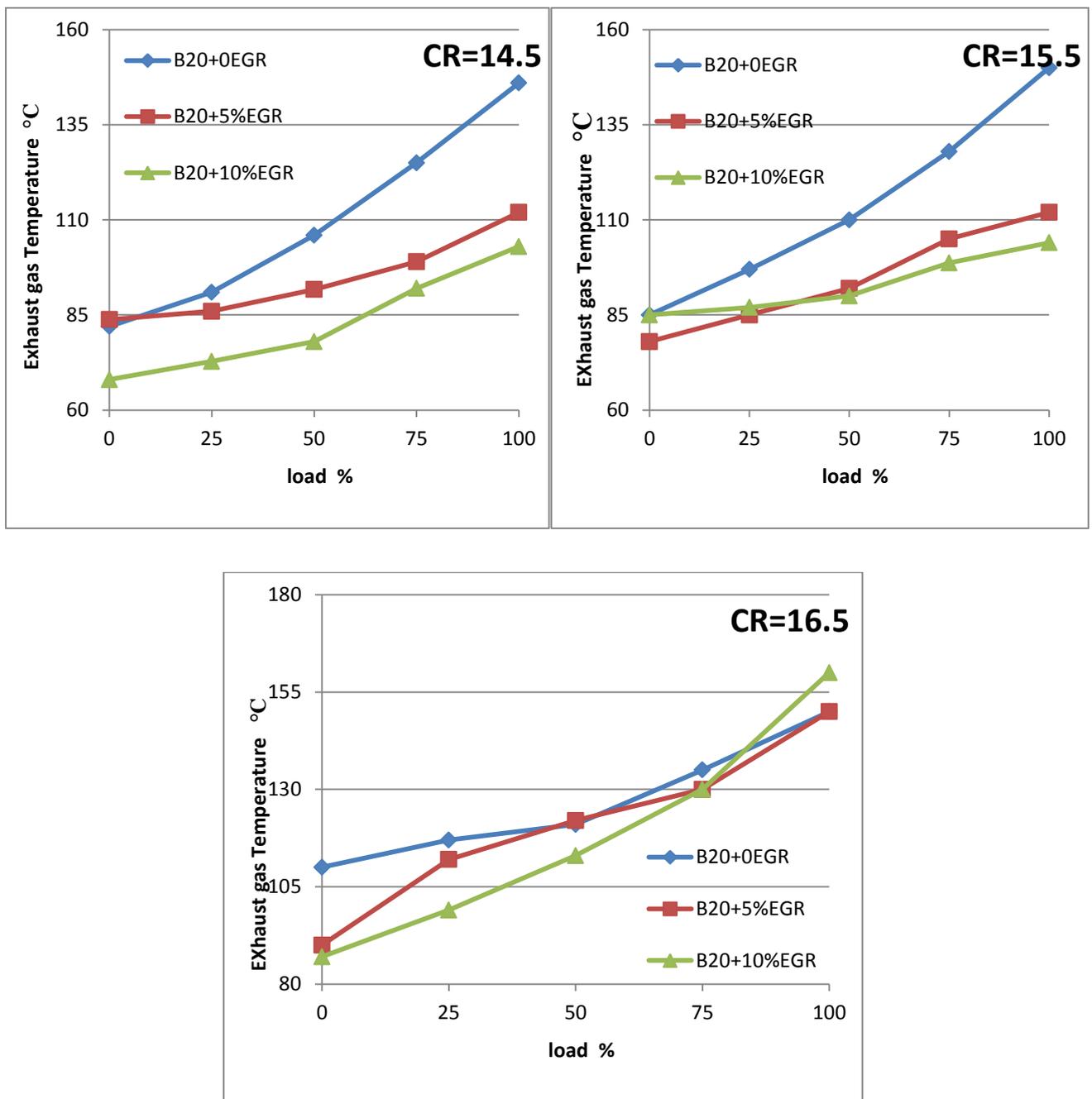
Figure. 4.21: Effect of Exhaust gas recirculation on Exhaust Gas Temperature of B20
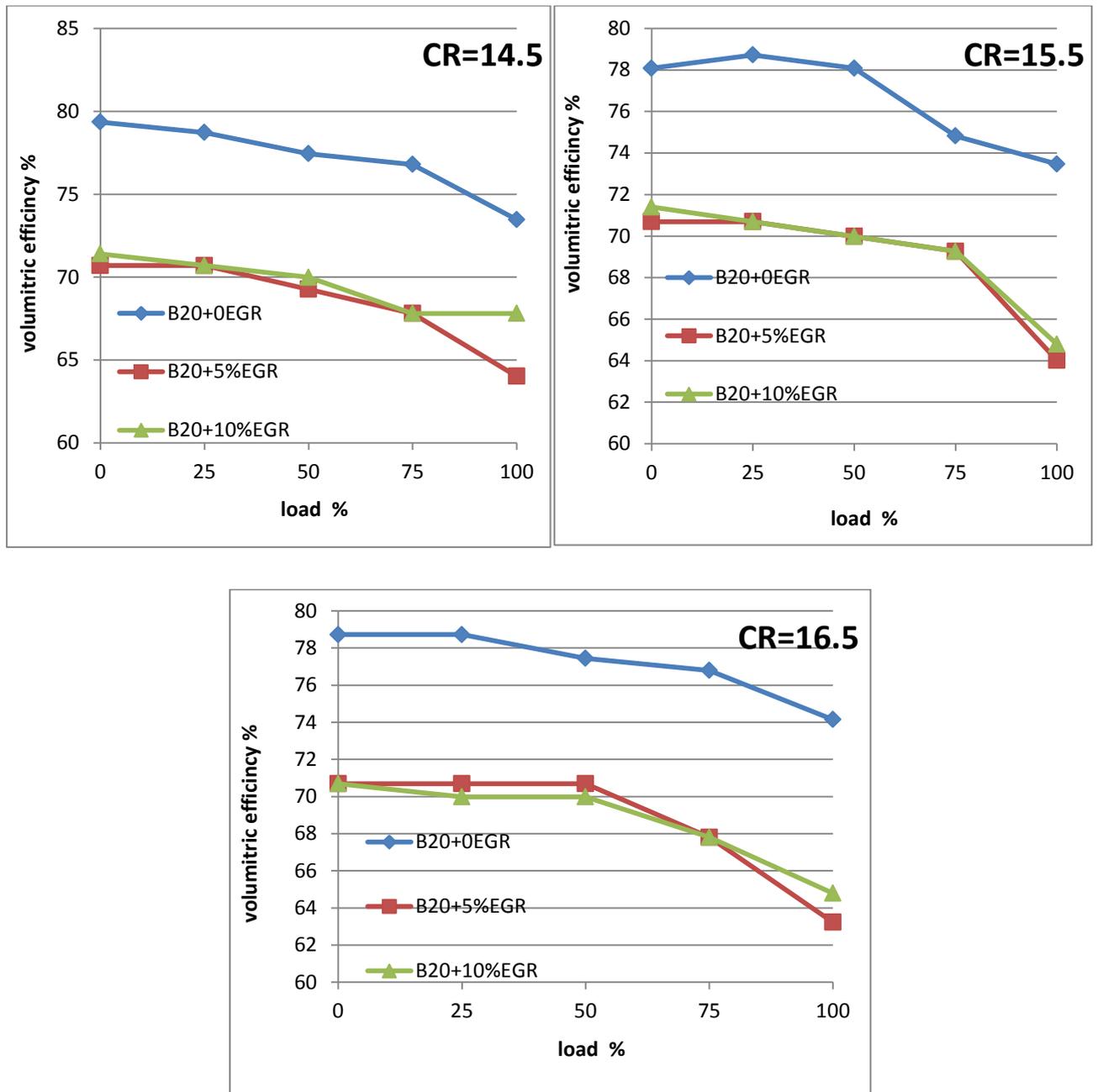
Figure. 4.22: Effect of Exhaust gas recirculation on volumetric efficiency of B20

Figure (4.23) represents the effect of EGR technology on the A/F of mixing ratio B20 compared to diesel and WCO biodiesel at CR values with increasing load. As the graph shows, the higher EGR lower in A/F, because the return exhaust gas replaces part of the air, and this causes the air intake to decrease.
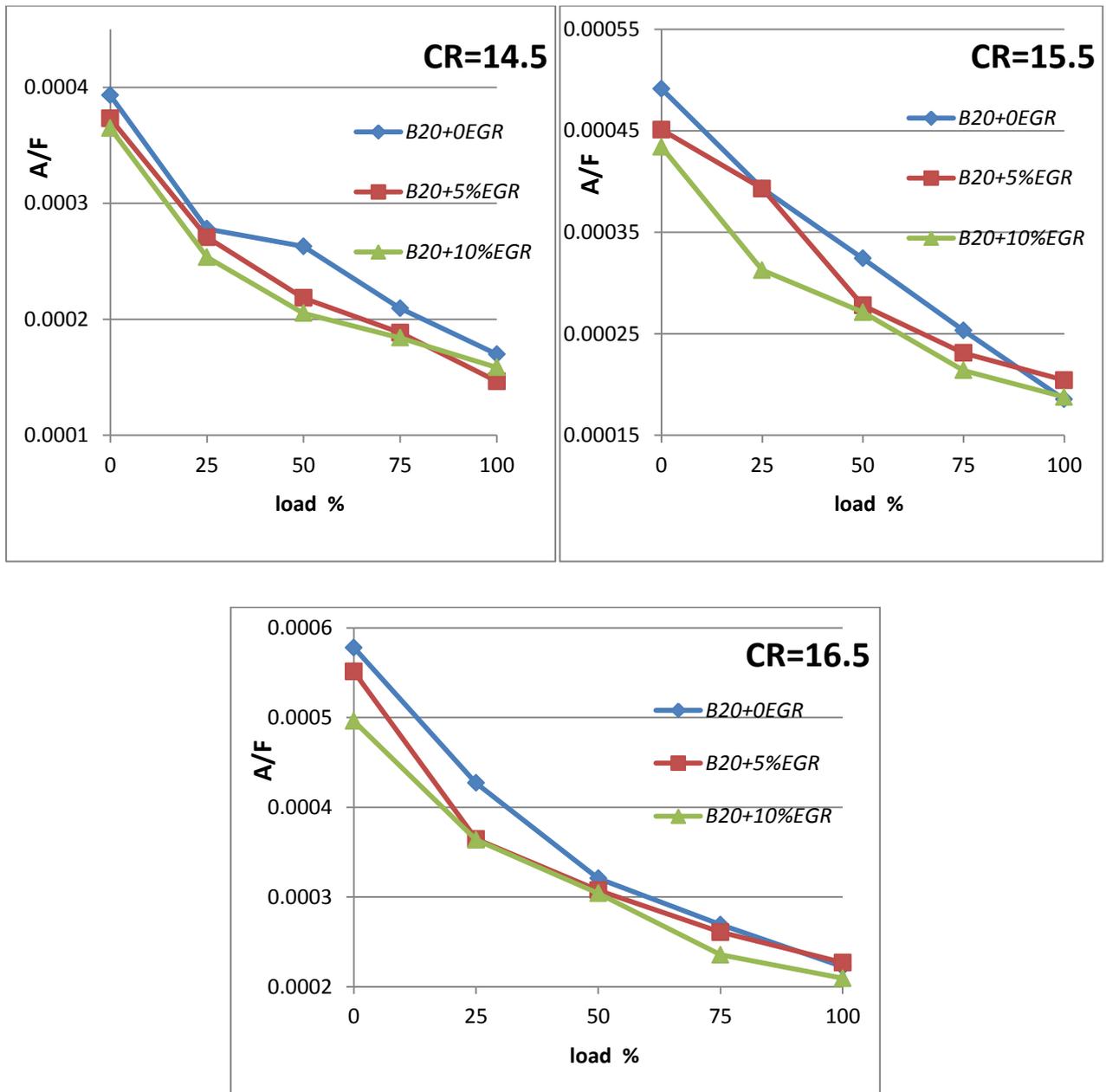
Figure. (4.23): Effect of Exhaust gas recirculation on air to fuel ratio of B20

- Emission characteristics

Figures (4.24), (4.25) show the effect of the EGR technique on the CO_2 and HC of the B20 blend in comparison to diesel and WCO biodiesel at CR values with increasing load. CO_2 and HC emissions increase with the application of EGR in the B20 mixture, as these emissions are returned to the engine along with fresh air and

exhaust gases. Higher EGR results in larger areas of flame suppression in the combustion dispersion stage.
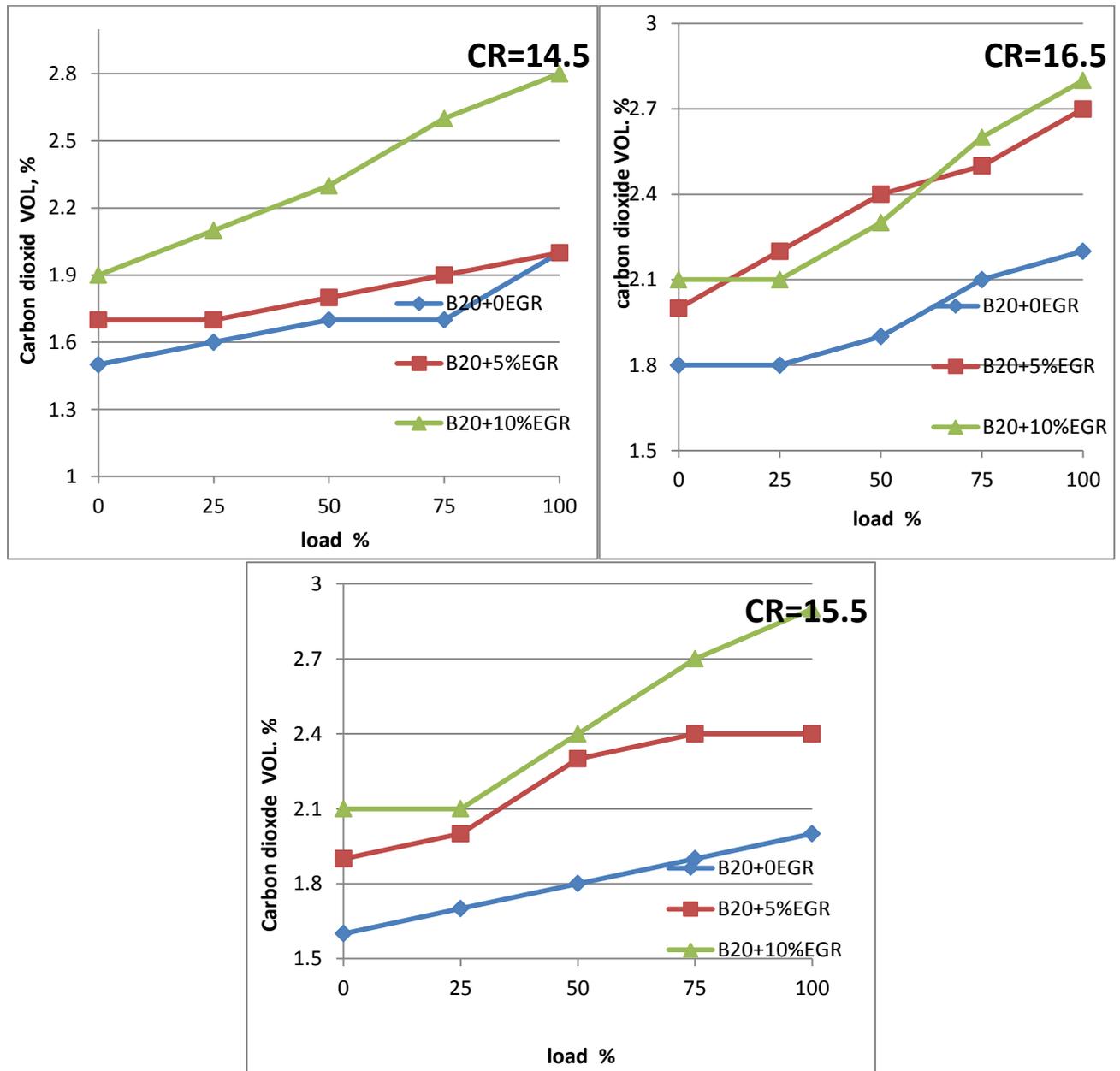
Figure. 4.24: Effect of Exhaust gas recirculation on carbon dioxides of B20
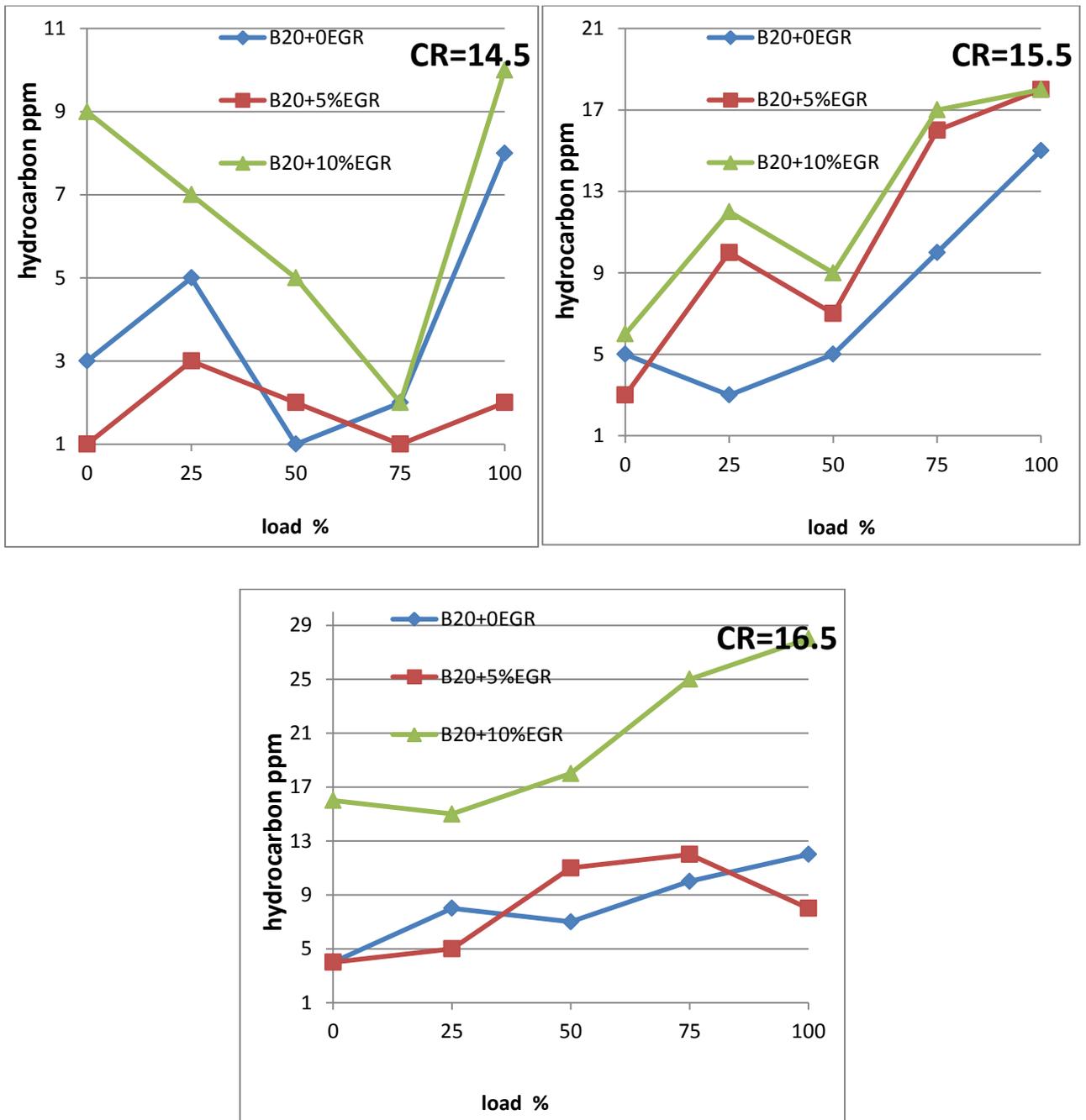
Figure. 4.25: Effect of Exhaust gas recirculation on hydrocarbon of B20

Figure (4.26), (4.26) show the effect of the EGR technique on the NO_X and O_2 emission of the B20 mixture in comparison between diesel and biodiesel WCO values at CR values with increasing load. EGR causes to lower NO_X by lowering the O_2 content and lowering the firing temperature. Since the exhaust gases replace some of

the oxygen in combustion with carbon dioxide, a higher ratio of EGR leads to a decrease in NO_X. This is the point of using EGR technology.
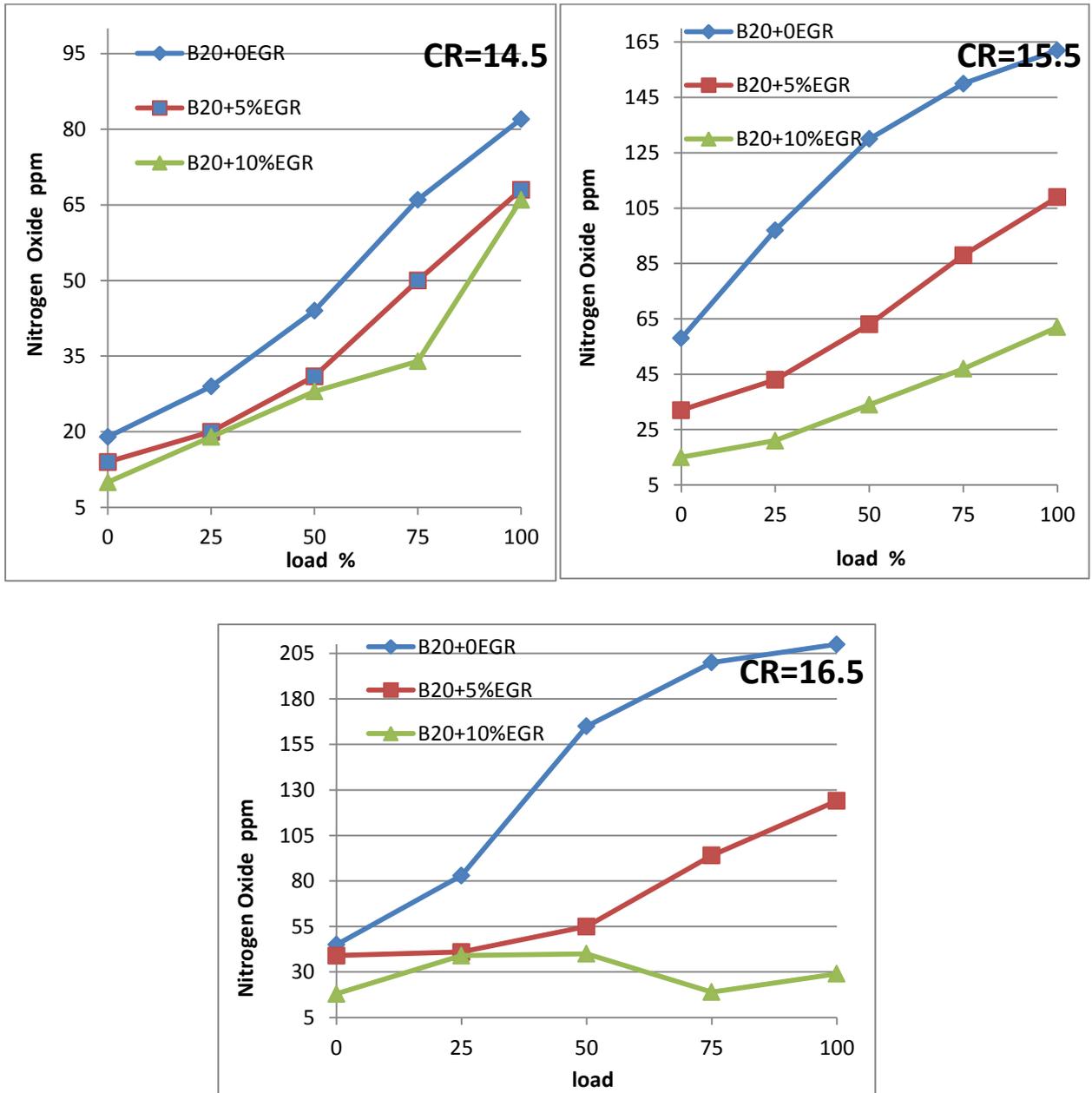
Figure. 4.26: Effect of Exhaust gas recirculation on nitrogen oxides of B20
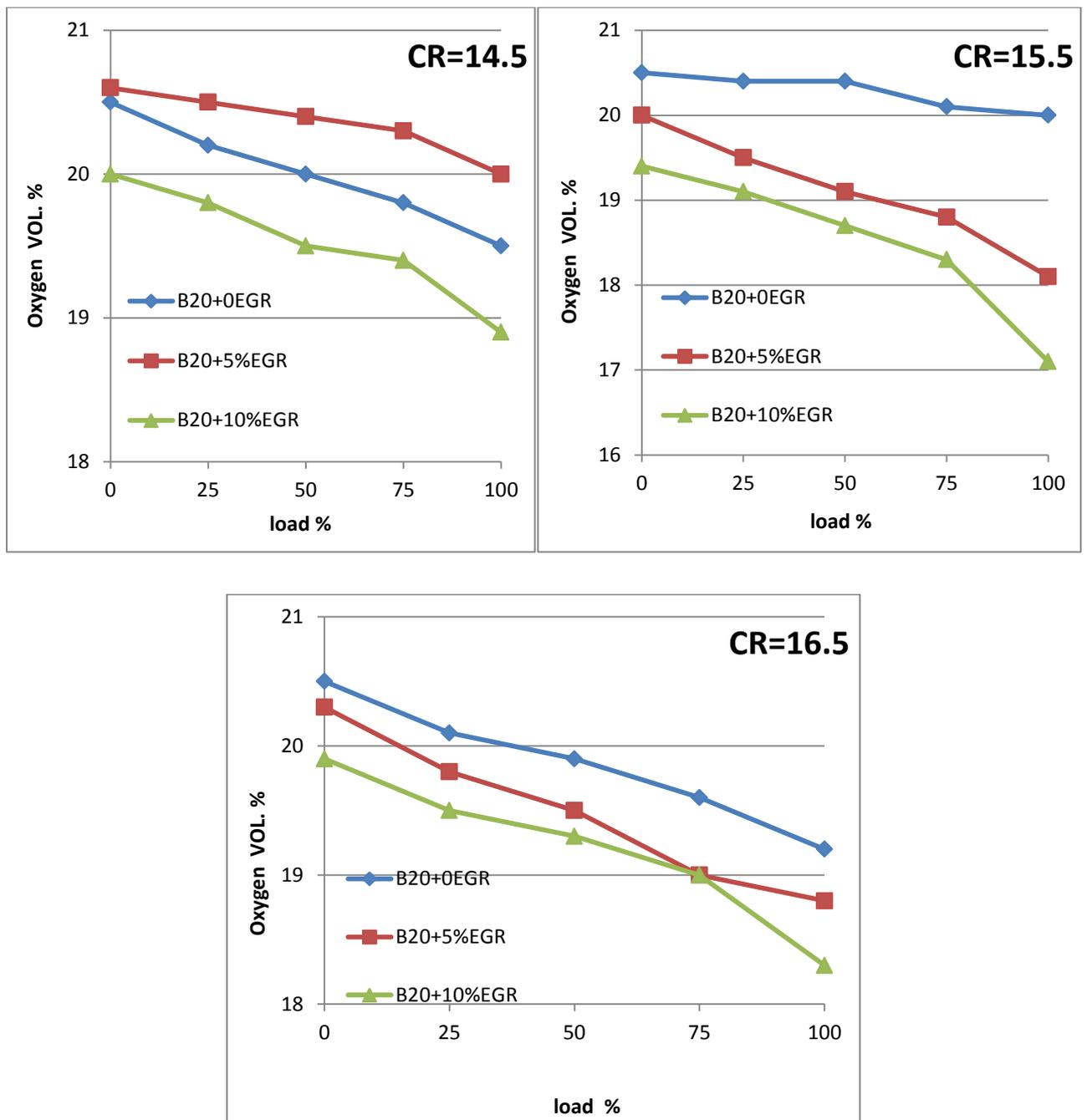
Figure. 4.27: Effect of Exhaust gas recirculation on oxygen of B20

Table (4.5) shows a further explanation of the changes that occur in the characteristics of the engine after adding the EGR at B20 ,full load and CR=15 .

Table (4.5) The behavior of the engine characteristics is injected with B20 with the addition of 10% EGR

Properties	Add EGR
BTE%	-
SFC	↓ 25%
EXT	↓ 27 %
VOL.EFF	↓ 7%
A/F	↓ 12%
CO_2	↑ 11%
HC	↑ 22%
NO_X	↓ 60%
O_2	↓ 15%

4.5 Optimum Exhaust Temperatures:

The exhaust temperature is a measure of the quality of the fuel combustion process inside the combustion chamber. Many factors in engine performance and emissions are related to exhaust temperature such as heat release and NO_X emission. Therefore, it is necessary to note the best exhaust temperature EXT that is achieved improvement in engine performance and emission when the diesel engine is running on B20 fuel with the application of 10% EGR (10% percent from maximum of 15 % of total exhaust flow quantity). The optimum EXT is when you have the highest engine performance and the lowest emissions. Table (4.6) shows the exhaust temperature at different loads and compression ratios for blend of 20% biodiese/ 80% diesel at 10% EGR. From table (4.6), it can be observed that for each compression ratio there is optimum EXT at 3/4 load.

92 ^{o}C as the best EXT when CR =14.5, 98.7 ^{o}C the best EXT when CR =15.5, and130 ^{o}C as the best EXT when CR =16.5 respectively.

Obviously, the best exhaust temperatures are highest than intake air temperatures for each case which leads to enhance the combustion with reasonable NO_X.

Table (4.6) Characteristics of the engine with varying loads and variable compression ratios

Compression Ratio	Load %	EXT °C	BTE %	SFC (kg/sec) $*10^{-5}$	CO_2 VOL.%	HC ppm	NO_X ppm
CR=14.5	0.00	68.0	0.000	14.07	1.9	9	10
	0.25	72.8	6.863	16.19	2.1	7	19
	0.50	78.0	13.120	21.11	2.3	5	28
	0.75	92.0	13.206	28.15	2.6	2	34
	1.00	103.0	11.240	31.67	2.8	10	66
CR=15.5	0.00	85.0	0.000	15.49	2.1	6	15
	0.25	87.0	9.550	17.59	2.1	12	21
	0.50	90.0	13.846	24.63	2.4	9	34
	0.75	98.7	13.190	31.67	2.7	17	47
	1.00	104	12.381	33.78	2.9	18	62
CR=16.5	0.00	87	0.000	17.59	2.1	16	18
	0.25	99	10.348	24.63	2.1	15	39
	0.50	113	16.084	26.04	2.3	18	40
	0.75	130	14.784	31.67	2.6	25	19
	1.00	160	13.190	37.30	2.8	28	29
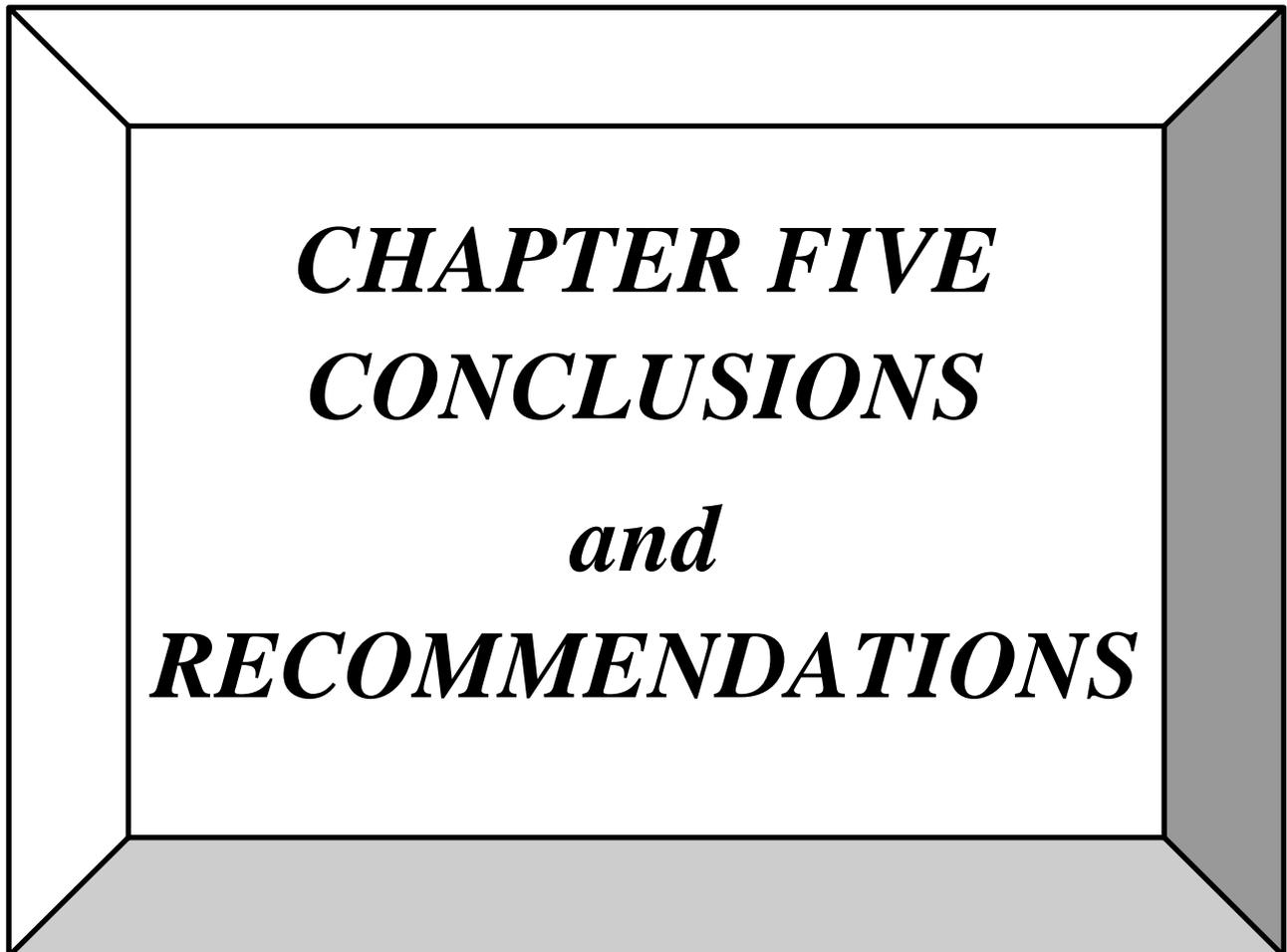
CHAPTER FIVE
CONCLUSIONS
and
RECOMMENDATIONS

5.1 Conclusions

From the results of the current work, the following conclusions can be summarized:

1) Biodiesel produced from WCO can work satisfactorily to operate diesel engine at certain ratios without any modifications to the engine. The researchers confirmed that biodiesel represents a clean and environmentally friendly fuel.

2)Increasing the compression ratio from 14.5 to 16.5 for all blending ratios enhances BTE, volumetric efficiency and the air-to-fuel ratio by 17%, 10% and 22%, respectively. The amount of emissions increase with the increase in the compression ratio.

3) B20 represents the optimum mixture ratio for diesel engine operation, to give the best performance of the engine in return for the lowest emissions compared to the rest ratios.

4)The study shows that the addition of biodiesel reduces the thermal engine efficiency by 15.5% and increases the fuel consumption by 15% at B20 at full load compared to pure diesel. CO_2 and HC emissions decreases by 23% and 48%, respectively, with an increase in NOx emission by 40% .

5) Adding 10% of EGR reduces NOx emissions by 60% at B20 compared to 0% of EGR, due to low oxygen level 15% , in return for an increase in CO_2 and HC emissions by 11% and 22% respectively. The brakes thermal efficiency of the and the volumetric efficiency of the engine changes very little when using EGR technology.10% EGR represents the best percentage for engine characteristics at the B20 mixture ratio.

6) The approximate price of 1 liter of WCO biodiesel is around 190ID which is lower locally than the price of diesel (200 ID/liter). Biodiesel produced from WCO is cheaper than any type of biodiesel because it achieves goals in one

process by eliminating chemical pollutants and creating a sustainable alternative fuel to partially or completely replace expensive fossil fuels.

7) For each compression ratio there is an optimal EXT at 3/4 load. 92 °C as the best EXT when CR = 14.5, 98.7 °C as the best EXT when CR = 15.5, and 130°C as the best EXT when CR = 16.5 respectively.

5.2 Suggestions for Further Studies

1) Studying the behavior of a diesel engine that operates with a biodiesel mixture derived from WCO at high compression ratios up to (20-22).

2)Developing the test engine, for example, making the fuel tank accommodate the largest amount of fuel and placing filters at the way of the exhaust gas returning to the engine.

3) A study of the economic analysis and cost calculation of a plant project for the production of biodiesel derived from WCO in Iraq, to encourage the community to go to work on such projects that have proven successful according to the literature ,such as [34], [41] and [85].

4) A study to address the problems associated with the use of EGR technology in diesel and gasoline engines. Being the most widespread technology currently to reduce NOx.

References

1. Singh, Digambar, et al. "A comprehensive review of biodiesel production from waste cooking oil and its use as fuel in compression ignition engines: 3rd generation cleaner feedstock." Journal of Cleaner Production 307 (2021): 127299.

2. Subramaniam, D., et al. "Bio-diesel production and its engine characteristics—An expatiate view." Renewable and sustainable energy reviews 22 (2013): 361-370.

3. Callegari, Arianna, et al. "Production technologies, current role, and future prospects of biofuels feedstocks: a state-of-the-art review." Critical Reviews in Environmental Science and Technology 50.4 (2020): 384-436.

4. http://dorar.at/t/1203522 .

5. Rolz C, de Leóń R. Ethanol fermentation from sugarcane at different maturities. Ind Crop Prod 2011;33(2):333e7.

6. Jagadale, S. S., L. M. Jugulkar, and M. Intensity. "Review of various reaction parameters and other factors affecting on production of chicken fat based biodiesel." International Journal of Modern Engineering Research 2.2 (2012): 407-411.

7. Gouveia, Luisa, and Luisa Gouveia. Microalgae as a Feedstock for Biofuels. Springer Berlin Heidelberg, 2011.

8. Kalbande SR, More GR, Nadre RG. Biodiesel production from non-edible oils of Jatropha and karanj for utilization in an electrical generator. Bioenergy Res 2008;1(2):170e8.

9. Q. Hu, M. Sommerfeld, E. Jarvis, M. Ghirardi, M. Posewitz, M. Seibert, and A. Darzins, Microalgaltriacylglycerols as feedstocks for biofuel production: Perspectives and advances, Plant J., 54, 621–639 (2008).

10. Kombe, G. G.; Temu, A. K.; Rajabu, H. M.; Mrema, G. D.; Kansedo, J.; Lee, K. T. Pre-Treatment of High Free Fatty Acids Oils by Chemical Re-Esterification for Biodiesel Production-A Review. Adv. Chem. Eng. Sci. 2013, 03, 242−247.

11. Eva-Mari, A. "From first generation biofuels to advanced solar biofuels." Ambio 45.1 (2016): 24-31.

12. K.K. Sharma, H. Schuhmann, and P.M. Schenk, High lipid induction in microalgae for biodiesel production, Energies, 5, 1532–1553 (2012).

13. Pradeep, J. Antony, et al. "Biofuel Production Using Butanol and Used Transformer Oil." Am. J. Eng. Res 5 (2016): 285-293.

14. Nabi, MdNurun, MdShamimAkhter, and MdAtiqurRahman. "Waste transformer oil as an alternative fuel for diesel engine." Procedia Engineering 56 (2013): 401-406.

15. French, Richard, and Stefan Czernik. "Catalytic pyrolysis of biomass for biofuels production." Fuel Processing Technology 91.1 (2010): 25-32.

16. Khalid, K.; Khalid, K.; Othman, M.; Hamid, K. H. K.; Chowdhury, Z. Z. Determination of Some Properties of used cooking oil using AAS, bomb calorimeter and GC-MS techniques. Orient. J.Chem. 2011, 27, 1045−1048.

17. Bart JCJ, Palmeri N, Cavallaro S. 14 e sustainability and use of biodiesel. Biodiesel science and technology. Woodhead Publish- ing; 2010. p. 625e712.

18. Demirbas A. Importance of bio diesel as transportation fuel. Energy Policy 2007;35:4661–70.

19. Kanok, Rodjanokid, Chinda, Charoenphonphanic. Performance of an engine using bio diesel from refined palm oil stearin and bio diesel from crude coconut oil. In: Joint International Conference on Sustainable Energy and Environment, HuaHinTailand; 2004.

20. Mathiyazhagan, M., and A. Ganapathi. "Factors affecting biodiesel production." Research in plant Biology 1.2 (2011).

21. Ogbu, I. M., and V. I. E. Ajiwe. "Biodiesel production via esterification of free fatty acids from Cucurbitapepo L. seed oil: Kinetic studies." International journal of science and technology 2.8 (2013): 616-621.

22. Ganesh p. et al. " Biodiesel as an alternative fuel for compression ignition engines – A review." International Research Journal of Engineering and Technology (2017): 2395-0056.

23. Ali, Obed M. "Evaluation of diesel engine performance with high blended diesel-biodiesel fuel from waste cooking oil." IOP Conference Series: Materials Science and Engineering. Vol. 518. No. 3. IOP Publishing, 2019.

24. Mohebbi, Arash, et al. "Use of waste cooking oil biodiesel in a tractor DI diesel engine." Journal of Food, Agriculture & Environment 10.2 (2012): 1290-1297

25. Jeevahan, Jeya, et al. "Various strategies for reducing No x emissions of biodiesel fuel used in conventional diesel engines: A review." Chemical Engineering Communications 204.10 (2017): 1202-1223.

26. Appavu, Prabhu, et al. "Effect of fuel additives and exhaust gas recirculation in biodiesel fuelled CI engine: A review." International Journal of Ambient Energy 42.15 (2021): 1803-1809.

27. Punitharani, K., and V. Parameshwaran. "Effect of exhaust gas recirculation on performance of a diesel engine fueled with waste plastic oil/diesel blends." Strojníckyčasopis-Journal of Mechanical Engineering 67.2 (2017): 91-100.

28. Murugesan, A., et al. "Bio-diesel as an alternative fuel for diesel engines—a review." Renewable and sustainable energy reviews 13.3 (2009): 653-662.

29. Hosseinzadeh-Bandbafha, Homa, et al. "Managing the hazardous waste cooking oil by conversion into bioenergy through the application of waste-derived green catalysts: A review." Journal of hazardous materials 424 (2022): 127636.

30. Yildiz, Ibrahim, HakanCaliskan, and Kazutoshi Mori. "Assessment of biofuels from waste cooking oils for diesel engines in terms of waste-to-

energy perspectives." Sustainable Energy Technologies and Assessments 50 (2022): 101839.

31. Ahmed, Hanan A., et al. "Effect of Reaction Parameters on Catalytic Pyrolysis of Waste Cooking Oil for Production of Sustainable Biodiesel and Biojet by Functionalized Montmorillonite/Chitosan Nanocomposites." ACS omega 7.5 (2022): 4585-4594.

32. Pauline, J. M. N., Sivaramakrishnan, R., Pugazhendhi, A., Anbarasan, T., &Achary, A. (2021). Transesterification kinetics of waste cooking oil and its diesel engine performance. Fuel, 285, 119108.

33. Liu, Yanbing, X., Adamu, A., & Zhu, Z "Economic evaluation and production process simulation of biodiesel production from waste cooking oil." Current Research in Green and Sustainable Chemistry 4 (2021): 100091.

34. Zhao, Yuanhao, et al. "Converting waste cooking oil to biodiesel in China: Environmental impacts and economic feasibility." Renewable and Sustainable Energy Reviews 140 (2021): 110661.

35. Erchamo, Yeshimebet Simeon, et al. "Improved biodiesel production from waste cooking oil with mixed methanol–ethanol using enhanced eggshell-derived CaOnano-catalyst." Scientific Reports 11.1 (2021): 1-12.

36. Singh, Digambar, et al. "A review on feedstocks, production processes, and yield for different generations of biodiesel." Fuel 262 (2020): 116553.

37. Park, Sang Hyuck, et al. "Biodiesel production from locally sourced restaurant waste cooking oil and grease: synthesis, characterization, and performance evaluation." ACS Omega 4.4 (2019): 7775-7784.

38. Degfie,Tadesse Anbessie, TadiosTesfayeMamo, and Yedilfana Setarge Mekonnen. "Optimized biodiesel production from waste cooking oil (WCO) using calcium oxide (CaO) nano-catalyst." Scientific reports 9.1 (2019): 1-8.

39. Joshi, Sumitkumar, et al. "Techno-economical and experimental analysis of biodiesel production from used cooking oil." BioPhysical Economics and Resource Quality 4.1 (2019): 1-6.

40. Sharma, Shiv Kumar, et al. "Performance evaluation of diesel engine using biodiesel fuel derived from waste cooking refined soyabean oil." Int. J. Mech. Prod. Eng. Res. Dev 7 (2017): 103-110.

41. Hussain, Mohammed Noorul, Tala Al Samad, and IsamJanajreh. "Economic feasibility of biodiesel production from waste cooking oil in the UAE." Sustainable cities and Society 26 (2016): 217-226.

42. Elkady, M. F., Ahmed Zaatout, and Ola Balbaa. "Production of biodiesel from waste vegetable oil via KM micromixer." Journal of Chemistry 2015 (2015).

43. Wang, Yong, et al. "Solid superacid catalyzed glycerol esterification of free fatty acids in waste cooking oil for biodiesel production." European Journal of Lipid Science and Technology 114.3 (2012): 315-324.

44. Singh, S. P., and Dipti Singh. "Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review." Renewable and sustainable energy reviews 14.1 (2010): 200-216.

45. Meng, Xiangmei, Guanyi Chen, and Yonghong Wang. "Biodiesel production from waste cooking oil via alkali catalyst and its engine test." Fuel processing technology 89.9 (2008): 851-857.

46. Sivarethinamohan, Sujatha, et al. "Towards sustainable biodiesel production by solar intensification of waste cooking oil and engine parameter assessment studies." Science of The Total Environment 804 (2022): 150236.

47. Dangsunthonchai, Mongkol, et al. "Nanoparticle Components and Number–Size Distribution of Waste Cooking Oil-Based Biodiesel Exhaust Gas from a Diesel Particulate Filter-Equipped Engine." ACS omega 7.4 (2022): 3384-3394.

48. Balasubramanian, Dhinesh, et al. "Numerical and experimental evaluation on the pooled effect of waste cooking oil biodiesel/diesel blends and exhaust gas recirculation in a twin-cylinder diesel engine." Fuel 287 (2021): 119815.

49. Viornery-Portillo, Emilio A., Brenda Bravo-Díaz, and Violeta Y. Mena-Cervantes. "Life cycle assessment and emission analysis of waste cooking oil biodiesel blend and fossil diesel used in a power generator." Fuel 281 (2020): 118739.

50. Maki, Duraid F., and Haroun AK Shahad. "An Experimental Investigation on Thermal Performance and Exhaust Gas Emission of CI Engine Fueled by Diesel-Ethanol Blended with Waste Oil Biodiesel as Co-Solvent." (2020).

51. Abed, K. A., et al. "Effect of waste cooking-oil biodiesel on performance and exhaust emissions of a diesel engine." Egyptian journal of petroleum 27.4 (2018): 985-989.

52. Borugadda, VenuBabu, et al. "Influence of waste cooking oil methyl ester biodiesel blends on the performance and emissions of a diesel engine." Waste and biomass valorization 9.2 (2018): 283-292.

53. Patel, Mihir J., Tushar M. Patel, and Gaurav R. Rathod. "Performance Analyis of CI Engine Using Diesel and Waste Cooking Oil Blend." IOSR Journal of Mechanical and Civil Engineering 12.2 (2015): 27-33.

54. Sharma, Vikas, et al. "Sustainable biodiesel from flex-mix feedstock and its combustion in a VCR-CRDI engine with variable exhaust gas recirculation and injection pressure." Journal of Physics: Energy 5.1 (2022): 014001.

55. Rao, GeddamPrasada, and LankapalliSathyaVara Prasad. "Combined influence of compression ratio and exhaust gas recirculation on the diverse characteristics of the diesel engine fueled with novel palmyra biodiesel blend." Energy Conversion and Management: X 14 (2022): 100185.

56. Sahu, Tomesh Kumar, SumitSarkar, and Pravesh Chandra Shukla. "Combustion investigation of waste cooking oil (WCO) with varying compression ratio in a single cylinder CI engine." Fuel 283 (2021): 119262.

57. Mahmood, AbdulrahmanShakir, et al. "The effect of compression ratio on the performance and emission characteristics of CI Engine fuelled with corn oil biodiesel blended with diesel fuel." IOP Conference Series: Earth and Environmental Science. Vol. 779. No. 1. IOP Publishing, 2021.

58. More, Ganesh Vijay, et al. "Experimental investigation on the effect of compression ratio over emission and performance characteristics of the diesel engine using ternary blends." International Journal of Green Energy 18.3 (2021): 231-242.

59. Hariram, V., et al. "Effect of variable compression ratios on performance and emission phenomena of DI CI engine fuelled with palm stearin biodiesel-diesel blends." Nature Environment and Pollution Technology 19.4 (2020): 1517-1526.

60. Rosha, Pali, et al. "Effect of compression ratio on combustion, performance, and emission characteristics of compression ignition engine fueled with palm (B20) biodiesel blend." Energy 178 (2019): 676-684.

61. Suresh, M., C. P. Jawahar, and Arun Richard. "A review on biodiesel production, combustion, performance, and emission characteristics of non-edible oils in variable compression ratio diesel engine using biodiesel and its blends." Renewable and Sustainable Energy Reviews 92 (2018): 38-49.

62. Bharadwaz, Y. Datta, et al. "Improvement of biodiesel methanol blends performance in a variable compression ratio engine using response surface methodology." Alexandria Engineering Journal 55.2 (2016): 1201-1209.

63. Nagaraja, S., K. Sooryaprakash, and R. Sudhakaran. "Investigate the effect of compression ratio over the performance and emission

characteristics of variable compression ratio engine fueled with preheated palm oil-diesel blends." Procedia earth and planetary science 11 (2015): 393-401.

64. EL_Kassaby, Mohammed, and Medhat A. Nemit_allah. "Studying the effect of compression ratio on an engine fueled with waste oil produced biodiesel/diesel fuel." Alexandria Engineering Journal 52.1 (2013): 1-11.

65. Sayin, Cenk, and MetinGumus. "Impact of compression ratio and injection parameters on the performance and emissions of a DI diesel engine fueled with biodiesel-blended diesel fuel." Applied thermal engineering 31.16 (2011): 3182-3188.

66. Muralidharan, K., and D. Vasudevan. "Performance, emission and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends." Applied energy 88.11 (2011): 3959-3968.

67. Prakash, S., M. Prabhahar, and M. Saravana Kumar. "Experimental analysis of diesel engine behaviours using biodiesel with different exhaust gas recirculation rates." International Journal of Ambient Energy 43.1 (2022): 1508-1517.

68. Manieniyan, V., et al. "Effect of EGR (exhaust gas recirculation) in diesel engine with multi-walled carbon nanotubes and vegetable oil refinery waste as biodiesel." Fuel 288 (2021): 119689.

69. Ma, Qixin, Quanchang Zhang, and ZunqingZheng. "An experimental assessment on low temperature combustion using diesel/biodiesel/C2, C5 alcohol blends in a diesel engine." Fuel 288 (2021): 119832.

70. Chandravanshi, A., et al. "Effect of di-methyl carbonate as additive and exhaust gas recirculation on the performance and emission parameters of diesel engine using diesel-biodiesel blends as fuel." Journal of Physics: Conference Series. Vol. 2062. No. 1. IOP Publishing, 2021.

71. Lobo, Ashley, D. K. Ramesh, and Dwaipayan Roy Chowdhury. "The effect of zinc oxide on operation of compression ignition engine with

EGR fueled with waste cooking oil biodiesel." IOP Conference Series: Materials Science and Engineering. Vol. 1013. No. 1. IOP Publishing, 2021.

72. Nanthagopal, K., et al. "Influence of exhaust gas recirculation on combustion and emission characteristics of diesel engine fuelled with 100% waste cooking oil methyl ester." Waste and Biomass Valorization 10.7 (2019): 2001-2014.

73. De Serio, Domenico, Alex de Oliveira, and José Ricardo Sodré. "Effects of EGR rate on performance and emissions of a diesel power generator fueled by B7." Journal of the Brazilian Society of Mechanical Sciences and Engineering 39.6 (2017): 1919-1927.

74. Rao, K. Srinivasa, K. BhaskaraMutyalu, and A. Ramakrishna. "Effect of exhaust gas recirculation on performance and emission characteristics of diesel engine fueled with waste cooking oil methyl ester." ARPN Journal of Engineering and Applied Sciences 10.11 (2015): 4799-4804.

75. Elshaib, A. A., M. M. Kamal, and A. A. Elahwany. "Performance of a diesel engine fueled by waste cooking oil biodiesel." Journal of the Energy Institute 87.1 (2014): 11-17.

76. Kumar, N. Ravi, C. Sekhar, and S. Adinarayana. "Effects of compression ratio and EGR on performance, combustion and emissions of DI injection diesel engine." International Journal of Applied Science and Engineering 11.1 (2013): 41-49.

77. Agarwal, Deepak, Shrawan Kumar Singh, and Avinash Kumar Agarwal. "Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits and durability of a constant speed compression ignition engine." Applied energy 88.8 (2011): 2900-2907.

78. Steven A. Weissman and Neal G. Anderson, , Design of Experiments (DoE) and Process Optimization. A Review of Recent Publications,

American chemical society, Org. Process Res. Dev. 2015, 19, 11, 1605–1633

79. Abd-Ali, Ruaa Hassan, and Haroun AK Shahad. "Experimental Investigation of AL2O3 Nano Particles Effect on Soot Release and Morphology Emitted from A Diesel Engine." Design Engineering (2021): 1904-1920.

80. IVAN MARIC," Flow Engineering-BS-1042 ", http://www.Felip.com, 2002.

81. Istiningrum, Reni Banowati, Toni Aprianto, and FebriaLutfiUdinPamungkas. "Effect of reaction temperature on biodiesel production from waste cooking oil using lipase as biocatalyst." AIP Conference Proceedings. Vol. 1911. No. 1. AIP Publishing LLC, 2017.

82. Guerrero Fajardo, Carlos Alberto, Iván David Osorio León, and Fabio Emiro Sierra Vargas. "Evaluating the effect of temperature on biodiesel production from castor oil." Ingeniería e Investigación 30.2 (2010): 52-61.

83. Baskar, P., and A. Senthilkumar. "Effects of oxygen enriched combustion on pollution and performance characteristics of a diesel engine." Engineering Science and Technology, an International Journal 19.1 (2016): 438-443.

84. Qadeer, Muhammad Umer, et al. "Review of biodiesel synthesis technologies, current trends, yield influencing factors and economicanalysis of supercritical process." Journal of Cleaner Production 309 (2021): 127388.

85. Elgharbawy, AbdallahSayed Ahmed Ali. "Cost analysis for biodiesel production from waste cooking oil plant in Egypt." International Journal of Smart Grid-ijSmartGrid 1.1 (2017): 16-25.

86. Pirola, Carlo, Giulia Bozzano, and FlavioManenti. "Fossil or Renewable Sources for Methanol Production?." Methanol. Elsevier, 2018. 53-93.

87. Ebraheem, A. K. Production and analysis of bioethanol from dates syrup. Diss. M. Sc thesis. College of Engineering. Babylon University. 2013. p 56, 2013.

88. Shihab, Abdulmuhsin S. "Assessment of ambient air quality of Mosul city/Iraq via Air Quality Index." *Journal of Ecological Engineering* 22.10 (2021).

89. Al-Rubaiee, Abdul-Kareem H., and Mohanad RA Al-Owaidi. "Assessment of Heavy Metal Contamination in Urban Soils of selected areas in Hilla City, Babylon, Iraq." *Iraqi Journal of Science* (2022): 1627-1641.

90. Jabar, Mohammed AB, and Jinan AzeezThabit. "Chemical Pollution Risks for Many Drinking Water Sources in Baghdad City, Iraq." Polish Journal of Environmental Studies 30.2 (2021).

91. Awadh, Salih Muhammad. "Atmospheric pollution of Baghdad city, Iraq." *Proceeding of 3 rd Scientific Conference of College of Science, University of Baghdad*. Vol. 1. 2009.

92. Al-Lami, Aqeel M. Ali, ZaidRaad Abbas, and Assal Ghazi Alshammary. "Study of water pollution problem in Basra city of Iraq: a case study." Plant Archives 20.1 (2020): 2274-2276.

93. Kline, S. J., and F. A. McClintock. "Analysis of uncertainty in single-sample experiments." Mechanical Engineering 75.3 (1953).

94. Moffat, Robert J. "Describing the uncertainties in experimental results." Experimental thermal and fluid science 1.1 (1988): 3-17.

Experimental Data

The appendix presents empirical data for a few selected results that were conducted to study the performance and emissions of a diesel engine.

Table (A.1) diesel engine performance and emissions at pure diesel , 1500rpm, No EGR

Compression Ratio	Load %	Brake Thermal Efficiency%			Volumetric Efficiency%					A/F	SFC
		BP(KW)	Input power(KW)	BTE%	cd	area	ha	volume swept	Vol. Eff%		
CR=14.5	0	0	4755.485	0	0.65	0.000314	50.43	553.14	76.79	0.000 724	10.375
	25	786.6	7925.808	9.92454	0.65	0.000314	51.28	553.14	77.44	0.000 438	17.29167
	50	1610	9510.97	16.92782	0.65	0.000314	50.43	553.14	76.79	0.000 362	20.75
	75	1918.2	11096.13	17.28711	0.65	0.000314	47.86	553.14	74.82	0.000 302	24.20833
	100	1955	15534.58	12.58482	0.65	0.000314	44.44	553.14	72.10	0.000	33.89167

	Load	BP(KW)	Input power(KW)	BTE%	cd	area	ha	volume swept	Vol. Eff%	A/F	SFC	
											208	
CR=15.5	0	0	6023.614	0	0.65	0.000314	47.01	553.14	74.15	0.000552	13.14167	
	25	848.7	8559.873	9.914867	0.65	0.000314	45.30	553.14	72.78	0.000381	18.675	
	50	1672.1	10145.03	16.48195	0.65	0.000314	43.59	553.14	71.40	0.000316	22.13333	
	75	2208	12681.29	17.41147	0.65	0.000314	40.17	553.14	68.54	0.000242	27.66667	
	100	2102.2	15851.62	13.26174	0.65	0.000314	40.17	553.14	67.07	0.000194	34.58333	
CR=16.5	0	0	6340.647	0	0.65	0.000314	49.57	553.14	76.14	0.000538	13.83333	
	25	828	9510.97	8.705737	0.65	0.000314	51.28	553.14	77.44	0.000365	20.75	
	50	1679	12047.23	13.93682	0.65	0.000314	50.43	553.14	76.79	0.000286	26.28333	
	75	2095.3	13632.39	15.37001	0.65	0.000314	48.72	553.14	75.48	0.000248	29.74167	
	100	2109.1	16802.71	12.55214	0.65	0.000314	47.01	553.14	74.15	0.000198	36.65833	

Table (A.2) diesel engine performance and emissions at 20% biodiesel and 80% diesel, 1500rpm, No EGR

Load %	Brake Thermal Efficiency%			Volumetric Efficiency%								
	BP(KW)	Input power(KW)	BTE%	cd	area	ha	volume swept	Vol. Eff%	A/F	SFC	EXT	CO_2
0	0	6339.577173	0	0.65	0.000314	53.85	553.14	79.35495	0.000393	14.07467	82	1.5
25	825.1	9509.36576	8.676709	0.65	0.000314	52.99	553.14	78.72263	0.000278	21.112	91	1.6
50	1630.13	11094.26005	14.69345	0.65	0.000314	51.28	553.14	77.4425	0.000263	24.63067	106	1.7
75	2029.3	12679.15435	16.00501	0.65	0.000314	50.43	553.14	76.79444	0.000209	28.14933	125	1.7
100	2049.6	14264.04864	14.36899	0.65	0.000314	46.15	553.14	73.46841	0.00017	31.668	146	2
0	0	7924.471467	0	0.65	0.000314	52.14	553.14	78.08519	0.000491	17.59333	85	1.6
25	834.02	11094.26005	7.517581	0.65	0.000314	52.99	553.14	78.72263	0.000393	24.63067	97	1.7
50	1661.35	12679.15435	13.103	0.65	0.000314	52.14	553.14	78.08519	0.000324	28.14933	110	1.8
75	2027.07	14264.04864	14.21104	0.65	0.000314	47.86	553.14	74.81657	0.000253	31.668	128	1.9
100	2058.29	15848.94293	12.98692	0.65	0.000314	46.15	553.14	73.46841	0.000185	35.18667	150	2
0	0	9509.36576	0	0.65	0.000314	52.99	553.14	78.72263	0.000578	21.112	110	1.8
25	847.4	12679.15435	6.683411	0.65	0.000314	52.99	553.14	78.72263	0.000427	28.14933	117	1.8
50	1672.5	15848.94293	10.55275	0.65	0.000314	51.28	553.14	77.4425	0.000321	35.18667	121	1.9
75	2044.91	17433.83723	11.72955	0.65	0.000314	50.43	553.14	76.79444	0.000269	38.70533	135	2.1
100	2071.67	20603.62581	10.05488	0.65	0.000314	47.01	553.14	74.14555	0.000222	45.74267	150	2.2

Table (A.3) diesel engine performance and emissions at 20% biodiesel and 80% diesel , 1500rpm, 100% EGR

Load %	Brake Thermal Efficiency%			Volumetric Efficiency%								
	BP(KW)	Input power(KW)	BTE%	cd	area	ha	volume swept	Vol. Eff%	A/F	SFC	EXT	CO_2
0	0	6339.577	0	0.65	0.000314	43.59	553.14	71.40	0.000496	14.07467	68	1.9
25	754.4	7290.514	10.34769	0.65	0.000314	42.74	553.14	70.70	0.000427	16.18587	72.8	2.1
50	1529.5	9509.366	16.08414	0.65	0.000314	41.88	553.14	69.98	0.000324	21.112	78	2.3
75	1874.5	12679.15	14.78411	0.65	0.000314	39.32	553.14	67.81	0.000236	28.14933	92	2.6
100	1881.4	14264.05	13.1898	0.65	0.000314	39.32	553.14	67.81	0.000209	31.668	103	2.8
0	0	6973.535	0	0.65	0.000314	43.59	553.14	71.40	0.000451	15.48213	85	2.1
25	756.7	7924.471	9.548902	0.65	0.000314	42.74	553.14	70.70	0.000393	17.59333	87	2.1
50	1536.4	11094.26	13.8486	0.65	0.000314	41.88	553.14	69.98	0.000278	24.63067	90	2.4
75	1881.4	14264.05	13.1898	0.65	0.000314	41.03	553.14	69.27	0.000214	31.668	98.7	2.7
100	1883.7	15214.99	12.38056	0.65	0.000314	35.90	553.14	64.79	0.000188	33.7792	104	2.9
0	0	7924.471	0	0.65	0.000314	42.74	553.14	70.70	0.000393	17.59333	87	2.1
25	761.3	11094.26	6.862107	0.65	0.000314	41.88	553.14	69.98	0.000278	24.63067	99	2.1
50	1538.7	11728.22	13.11964	0.65	0.000314	41.88	553.14	69.98	0.000263	26.03813	113	2.3
75	1883.7	14264.05	13.20593	0.65	0.000314	39.32	553.14	67.81	0.000209	31.668	130	2.6
100	1888.3	16799.88	11.23996	0.65	0.000314	35.90	553.14	64.79	0.00017	37.29787	160	2.8

Appendix B

Sample Calculations

When the engine reaches a state of thermal stability. At each experiment, the engine parameters such as (speed, exhaust temperature, current, voltage......), and engine emissions (CO_2, HC, NOx, O_2) were read. Other data were calculated from the following equations :

1- Brake Thermal Efficiency (BTE)

$$BTE = BP / IP \ldots\ldots\ldots\ldots\ldots (1)$$

$$BP = I*V$$

BP: Brake Power(KW), I: Current electric (A) , V: The voltage (V)

$$IP = (\dot{m}_f * \rho * LCV\ )d + (\dot{m}_f * \rho * LCV\ )bio$$

IP : Input power (KW), LCV : Lower Calorific Value of fuel (MJ/kg)

$LCV)d = 45.836$ $\qquad$ $\rho_d = 830$

$LCV)bio = 42.123$ $\qquad$ $\rho_{bio} = 902.4$

$\dot m_f$: Flow rate of fuel mass (kg/s), ρ : density of fuel

$$\dot m_f = \frac{\dot m_{f1} - \dot m_{f2}}{t} \dots \dots \dots \dots \dots \dots \dots \dots (2)$$

$\dot m_{f1}$: The initial weight of fuel (kg), $\dot m_{f2}$: The final weight of fuel (kg)

t : The fuel consumption time =2 sec

2- Volumetric efficiency (Vol. eff)

Vol. eff $= \frac{\dot Q_a}{\dot Q_s} * 100\%$ ……………(3)

$\dot Q_a$: The flow of air (m^3/s), $\dot Q_s$: swept volume(m^3/s) , V_s= 553cm^3

$$\dot Q_s = V_s * \frac{N}{60 * 2}$$

$$\dot Q_a = C_d * A \ * \sqrt{2 * g * \Delta h_a} \ \dots \dots (4)$$

Cd: coefficient of discharge=0.65,

A = area of orifice =0.000314m^2 (d=20mm), g= 9.81m/s^2

The head pressure of air (ha) is calculated by ideal gas equation :

$P_a = \rho_a R T_a$

Pa: Atmospheric pressure =99.6 kN/m^2 , Ta: Atmospheric temperature

=298.34 K , R: Gas constant =287 J/kg.K , ρ_a :Density of air =1.16

kg/m^3

ha $= \frac{\rho w}{\rho a} * h_w$

ρw : Density of water = 997 (kg/m³) , h_w : The head pressure of water

3- specified fuel consumption (SFC)

SFC $= \dot m_f$ …………… .(5)

4- Air to fuel ratio (A/F)

A/F $= \frac{\dot Q_a}{\dot Q_f}$ ……………(6) $\dot m_f = \dot Q_f * \rho_f$

5- The amount of exhaust gas recirculation

$$\dot{Q}_g = \frac{Cd*A1*A2}{\sqrt{(A2^2-A1^2)}} * \sqrt{2*g*hg} \ldots\ldots\ldots(7) [80]$$

Where :

$\dot{Q}_g$: The flow of EGR (m^3/s)

A_1 : The pipe area (m^2) , D_1 =14mm

A_2 : The orifice area (m^2) , D_2 =31,75mm

hg≈h$_a$

Appendix C

Uncertainty analysis

To estimate errors in the experimental work, some calculations and estimations must be applied to the sensors, devices, and machines that were used to measure the experimental parameters. Also, the experiments conducted because they need to express the uncertainty as

$X^1 = X_i \pm u_x$ (p%)

Where X1, X, u_x and p are true value ,tested value, uncertainty of the measurement and confidence respectively. To do this with confirmation, total uncertainty of each component or part of the experiment or procedure is determined. Total uncertainty is determined by error due to equipment (bias) and due to environment (accuracy). Wherever possible, uncertainty may be minimized. Post-processing uncertainties propagate to quantities that are nonlinear functions of measure or functions of multiple measurements with uncertainties based on the functional relationship. Both bias and accuracy errors are present in the experiment. Accuracy is measured while bias error is usually determined from the equipment vendor's specifications. The total error is the

vector sum of these errors. It should be noted that the errors in estimating each error affect the value of the total error.

$$U_x = (B_X^2 + P_X^2)^{1/2}$$

Where, B_x and P_X are bias and accuracy errors respectively.

In case of several measurement of the same quantity like engine load , is estimated using statistical measures of spread. Several measurement of the same quantity are: $X_1, X_2, X_3, X_4, X_5, \ldots\ldots X_n$. Average load of the dynamometer is calculated as

Average = $(X1, X2, X3, X4, X5, \ldots\ldots, Xn)/n$

Now, there are two ways to describe the scattering in these measurements. The mean deviation and the standard deviation . The mean deviation from the mean is the sum of the absolute values of the differences between each measurement and the mean, divided by the number of measurements:

$$\text{mean deviation} = \frac{\sqrt{\sum_{i=1}^{n}(\text{Xi}-\text{average})^2}}{1-\text{n}}$$

$$\text{standard deviation} = \frac{\sqrt{\sum_{i=1}^{n}(\text{Xi}-\text{average})^2}}{\sqrt{n}}$$

Either the main deviation from the main, or the standard deviation from the main, gives a reasonable description of the scatter of data around its main value.

For parameter that have been evaluated depending on two or more independent parameters, propagation of uncertainty is carried out using

$$\frac{Uy}{y} = \sqrt{\left(\frac{ux1}{x1}\right)^2 + \left(\frac{ux2}{x2}\right)^2 + \cdots \left(\frac{uxn}{xn}\right)^2}$$

Where, Uy and y are uncertainty and the testing value of the evaluated parameter x1, x2,…...xn respectively.

The uncertainty analysis performed in this appendix is based on the lines proposed by Klein and McClintock [93]. It should be noted that the uncertainty analysis presented here considers only the errors that relate to measurements made during testing.

Appendix D

Table (D.1) Gas analyzer technical characteristics

Measurement parameters	Range	Unit of measure	Resolution
CO_2	$0 \div 19.9$	% vol.	0.1
HC	$0 \div 5000$	ppm vol.	1
O_2	$0 \div 21.4$	% vol.	0.1
NOx (optional)	$0 \div 5000$	ppm vol.	5
oil temperature	$5 \div 200$	deg C	0.1
Ambient temperature	$0 \div 45$	deg C	0.1
Ambient pressure	$800 \div 1060$	Mbar	1
RPM	$0 \div 9990$	revol. /min.	10
Lambda*	$0.5 - 1.50$	--	0.01

Table (D.2) the gas analyzer's technical specifications

Technical specifications	Gas box Auto power
Dimensions	460*200*250mm
Weight	6.5kg
External power supply	100-240V,50-60Hz
Temperature range	5ºC-40ºC

Table (D.3) Specifications of the four gas exhaust analyzer

Measurements	Measuring range	Dissolution
CO_2	0-20% vol.	0.10%
HC	0-10.000ppm	1.0ppm
O_2	0-22% vol.	0.010%
NO_x	0-5.000ppm	1.0ppm

Appendix E

Photo (E.1) the properties of biodiesel

No.		Unit	Results	Method
1	Density @ 15 °C	g/cm³	0.9024	ASTM D 4052
2	API Gravity @ 15.6 °C	—	25.2	
3	Flash point		49.0	ASTM D 93(A)
4	Pour Point	°C	(-) 3	ASTM D 97
5	Cetane Index	---	51.1	ASTM D 4739
6	Calorific Value Net Gross	Kcal / Kg	10061 10688	Calculated
7	Viscosity @ 40 °C	c.s.t	7.8725	ASTM D 445
8	Ash content		0.1679	ASTM D 482
9	Total sulfur	% wt	0.01	ASTM D 4294

Shamil

27.01.2022
Labeed Shamil Radhi
Head of the Analyses division

3011

Inaam Mahmood Ali   2022
Manager of Quality Control Laboratories Dept.

وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية الهندسة
شعبة الدراسات العليا

م /أبداء مساعدة

تحية طيبة ...

أشارة الى كتابكم المرقم (٣١٠) في ٢٠٢٢/١/١٠.
تم أجراء الفحوصات المختبرية على عينة البايوديزل و المرسلة صحبة كتابكم أعلاه ونرافق
لكم ربطاً شهادة الفحص المختبري والتي تمت وفقاً للطرق القياسية المؤشرة أزاء كل نتيجة
فحص .

... مع التقدير...

د . عائد جابر عمران
ء . المدير العام
أنعام محمود علي
مدير قسم مختبرات السيطرة النوعية

Appendix F

Effect of Exhaust Gas Recirculation on Diesel Engine Performance Fueled with WCO/Diesel Mixture

Noor Ali[1, a] and Duraid F. Maki[1, b]

[1]*Mechanical Engineering Department, College Of Engineering, University Of Babylon*

[a)]nooratheer98@gmail.com

[b)]eng.duraid.f@uobabylon.edu.iq

Abstract. This study highlighted the influence of exhaust gas recirculation (EGR) on the performance of diesel engine when it's fueled by waste cooking oil (WCO)/diesel mixture. This idea has spread widely for many years to avoid the harm and damage of diesel emission and provided a new energy source whereas, diesel machine is a mechanical power generation in a lot life sectors, including agriculture, business, residential, and transportation, and has emphasized the importance of this concept. However, fuel costs are steadily rising and will continue to do so in the future, as well as the fact that it produces pollution when burned. All researchers agreed that the use of biodiesel leads to encouraging results based on progressive combustion process, shorter ignition delays, less carbon emitted, and increasing rate of heat release. On the other hand, high temperature and availability of oxygen in biodiesel chemical formula lead to an increase in nitrogen oxides. Therefore, this study referred to the use of EGR technology, which is an effective technique to reduce nitrogen oxides emissions when using a mixture of biodiesel fuel with diesel in different proportions. EGR controls NOx production because it reduces the oxygen concentration and the cylinder temperature. The performance parameters such as SFC, BTE and EXT are tested. Also, Emissions such as NO_X, CO_2 and HC are measured. The use of EGR causes marginal decrease in CO_2 emissions depending on the load and the rate of the EGR. It was observed that oxygen decreases with increasing engine load and when EGR is raised. WCO has a lower heating value caused an increase in SFC but the brake thermal efficiency of the engine is not significantly affected. The BTE with WCO biodiesel was obtained less than that of diesel when the same EGR was applied. Also, the SFC increase is less with biodiesel than with diesel fuel. Thus, EGR has less negative impact on engine performance in the case of WCO biodiesel

ID-Code: ICES-125
Authors: Noor Ali and Duraid F. Maki
Date: 30/11/2022

Dear Authors,

On behalf of the scientific and organizing committees of the 6th International Conference on Engineering Sciences (ICES 2022), I am pleased to inform you that your manuscript entitled **"Effect of Exhaust Gas Recirculation on Diesel Engine Performance Fueled with WCO/Diesel Mixture."** has been accepted for publication in the conference proceedings of ICES2022. The accepted paper will be published in the AIP Conference Proceedings which is indexed in the Scopus Journals database. The 6th ICES will be held on 21-22 December 2022 .Thank you for your interest in participating in the 6th ICES.

Best Regards,

L. Sh. Rash

Prof. Dr. Laith Sh. Rasheed
Chair of the Organizing Committee -ICES
Dean of Engineering College at Kerbala University

Appendix G

The Novel of Transforming Waste into Wealth (W2W): Processing Waste Cooking Oil and Converting to Co-Friendly Fuel

[1]Noor Ali and [2]Duraid F. Maki

Mechanical Engineering Department, College Of Engineering ,University Of Babylon

ABSTRACT

The aim of this review is to highlight the use of an alternative fuel to diesel. This idea has been widely circulated for many years. The widespread use of fossil fuels in mechanical power generation in a range of sectors, including agriculture, business, residential, and transportation, has emphasized the importance of this concept, as well as the fact that fuel costs have been rising steadily and will continue into the future. Also, the fact that pure diesel produces pollution gases when burned. All vegetable oils are clean, renewable, and sustainable energy sources. It has the potential to be used as an alternative fuel, particularly in internal combustion engines. The various processes for biodiesel production are described in this review, including transesterification, microemulsification, radio frequency (RF), mixing, and pyrolysis. The process of transesterification is the most widespread due to its low cost and is carried out with simple equipment and materials. The feedstock price determines the price of biodiesel production. Inedible crop oil, waste oil and microalgae oil were investigated. Because it contains a high percentage of free fatty acids. Inedible crop oil and waste cooking oil (WCO) are preferred for biodiesel production.

Keywords: Biodiesel, Production, Review, Methods, Feed stock.

1. Introduction

Diesel fuel prices have risen dramatically in recent years, and it will eventually run out. As a result, finding a different technique to manufacture a diesel substitute is a difficult issue for world. Biodiesel is known as "a diesel fuel alternative or additive generated from the oils and fats of plants and animals." The alcohol molar ratio, the reaction temperature, and the reaction time, the mixing intensity, and the catalyst concentration, among other things, are all factors to consider. All have a significant impact on the transesterification reaction. As a result, In this study, the components that will influence the biodiesel production reaction are briefly discussed [6]. Because it is renewable, nontoxic, and ecologically benign, biodiesel will meet future energy demands. Biodiesel is a long-chain fatty acid monoalkyl ester obtained from biological,

7th Iraq Oil&Gas Conference ٤ آب

إلى أنا

--

السلام عليكم

تحية طيبة .....

نود اعلامكم بقبول خلاصة البحث الموسوم (The Novel of Transforming Waste into Wealth(W2W): Processing Waste Cooking Oil andConverting to Co-Friendly Fuel) في مؤتمر العراق السابع للنفط والغاز

Appendix H

Wiley Online Library

Search

Login / Register

HEAT TRANSFER

ORIGINAL ARTICLE

Combustion characteristics of CI engine fueled with WCO biodiesel/diesel blends at different compression ratios and EGR

Noor Ali, Duraid F. Maki ✉

First published: 07 April 2023 | https://doi.org/10.1002/htj.22859

HEAT TRANSFER

Early View
Online Version of Record before inclusion in an issue

Related   Information

🖹 PDF   🔧 TOOLS   ≺ SHARE

ⓘ **Get access to the full version of this article.** View access options below.

Institutional Login

🏛 **Access through your institution**

Log in to Wiley Online Library

Purchase Instant Access

○ 48-Hour online access $10.00

Details   ⌄

Recommended

Effects of pongamia methyl esters and its blends on a diesel engine performance, combustion, and emission characteristics

M. Sivakumar, N. Shanmugasundaram, R. Rameshkumar, M. Syed Thasthagir

Environmental Progress & Sustainable Energy

Emissions and performance characteristics of a diesel engine operated with fuel blends obtained from

HEAT TRANSFER WILEY

Combustion characteristics of CI engine fueled with WCO biodiesel/diesel blends at different compression ratios and EGR

Noor Ali | Duraid F. Maki

Mechanical Engineering Department, College of Engineering, University Of Babylon, Hilla, Iraq

Correspondence
Duraid F. Maki, Mechanical Engineering Department, College of Engineering, University Of Babylon, Hilla 52003, Iraq.
Email: eng.duraid.f@uobabylon.edu.iq

Abstract

The present study investigated the effect of compression ratio (CR) with the use of exhaust gas recirculation (EGR) technology on the performance of combustion characteristics at different CRs and engine loads; the brake thermal efficiency (BTE), specific fuel consumption (SFC), volumetric efficiency (VOL.EFF), exhaust gas temperature, carbon dioxide emission (CO_2), hydrocarbons (HC), nitrogen oxides (NOx), and oxygen content (O_2). The single-cylinder, four-stroke compression ignition engine was run on a mixture of diesel and biodiesel prepared from Iraqi waste cooking oil at (B0, B10, B20, and B30). A comparison has been achieved for these combustion characteristics at different blends, load, and CRs (14.5, 15.5, and 16.5) at 1500 rpm constant engine speed. The transesterification process is used to produce biodiesel and ASTM standards have been used to determine the physical and chemical properties of biodiesel and compare them to net diesel fuel. The preliminary conducting tests indicated that engine performance and emissions improved with the B20 mixture.

خلاصة

في هذه الدراسة، تم استخدام عملية الأسترة التبادلية لانتاج وقود الديزل الحيوي من زيت الطهي المستخدم . وهي عملية تفاعل الدهون الثلاثية في لتر واحد من زيت الطهي المستخدم مع الميثوكسيد (4 غم من محفز هيدروكسيد الصوديوم المذاب في 140 مل من كحول الميثانول). أجريت التجربة عند درجات حرارة مختلفة (58، 60، 62، 64) درجة مئوية، للحصول على نسب مختلفة لإنتاج الديزل الحيوي (86، 90، 94، 92)% بالتتابع. وبذلك فإن درجة الحرارة المثلى لخلط جميع المواد هي عند درجة حرارة 62 درجة مئوية .تم ترك الخليط لمدة 24 ساعة للحصول على وقود حيوي بنسبة 94% مع 6% جلسرين.

أظهرت النتائج بعد فحص خصائص وقود الديزل الحيوي باستخدام المعايير الأمريكية للاختبارات والمواد أن لزوجة وقود الديزل الحيوي أكبر بثلاث مرات تقريبًا من لزوجة الديزل النقي، وقيمة حرارية أعلى وكثافة أقل تبلغ 0.08 .٪ من وقود الديزل الحيوي وبالنسبة للديزل النقي . ويحتوي وقود الديزل الحيوي الناتج على نسبة كبريت أقل من الديزل النقي بنسبة 96%، مما يجعله صديقًا للبيئة. يعتبر ثاني أكسيد الكبريت الناتج عن احتراق الديزل النقي من الغازات السامة التي تشكل خطراً على صحة الإنسان.

بعد تشغيل محرك ديزل أحادي الأسطوانة بسرعة 1500 دورة في الدقيقة تحت أحمال مختلفة(25,50,75,100,0)٪ وبنسب ضغط متغيرة وخلائط الديزل والديزل الحيوي. تم استخدام خليط من وقود الديزل الحيوي مع الديزل بنسب(0% ديزل حيوي و100% ديزل - 10% ديزل حيوي و90% ديزل - 20% ديزل حيوي و80% ديزل - 30% ديزل حيوي و70% ديزل) . وجد أنه عند 20% من الديزل الحيوي ادى الى انخفاض الكفاءة الحرارية للفرامل بنسبة 15.5% مقارنة بالديزل النقي عند الأحمال العالية ونسبة الضغط 15.5. وفي نفس الظروف، زاد استهلاك الوقود النوعي بنسبة 15% . مع انخفاض انبعاثات (ثاني أكسيد الكربون والهيدروكربونات) بنسبة (23 و48)% مقابل زيادة أكاسيد النيتروجين بنسبة (40%). تعتبر نسبة الخلط 20% أفضل نسبة خلط، لأنها تعطي خصائص المحرك أقرب إلى الديزل النقي مقارنة بـ 10% و 30% .

تعد انبعاثات أكاسيد النيتروجين، التي لها تأثير سلبي على ظاهرة الاحتباس الحراري، إحدى المشكلات التي نواجهها عند استخدام وقود الديزل الحيوي. ولذلك، تمت إضافة تقنية إعادة تدوير غاز العادم . في هذه الدراسة تم اعاده 5% و 10% من غاز العادم .أظهرت النتائج أنه عند نسبة خليط 20% ونسبة ضغط 15.5، زياده في الكفائه الحراريه المكبحيه وانخفاض في استهلاك الوقود بنسبة 25% مع زياده نسبه غازالعادم الراجع .وأظهرت النتائج انخفاض أكاسيد النيتروجين بنسبة (60 إلى 78)% نتيجة انخفاض درجة حرارة غاز العادم بنسبة 30% وانخفاض كمية الأكسجين بنسبة 15% مقابل زيادة ثاني أكسيد الكربون. والانبعاثات الهيدروكربونية بنسبة (12 إلى 20)% و(11 إلى 20)% على التوالي. تكون قيم كفائه الفرامل الحرارية متقاربة عند تغيير نسبة الراجع، مع انخفاض في استهلاك الوقود بنسبة (18)%.

وقد ثبت أن 10% من غاز العادم أفضل من 5% لزيادة انخفاض انبعاث أكاسيد النيتروجين وانخفاض استهلاك الوقود مع اختلاف طفيف في انبعاثات ثاني أكسيد الكربون والهيدروكربونات بين 10% و5% من إعادة تدوير غاز العادم.

في هذا العمل تم تغيير نسبة الانضغاط ثلاث مرات (14.5، 15.5، 16.5)، حيث أظهرت النتائج زيادة في الكفائه الحراريه المكبحيه واستهلاك الوقود بنسبة (14، 25)%، على التوالي. ومع زيادة نسبة الانضغاط من 15.5 إلى 16.5، كانت قيمة الكفاءة الحجمية ونسبة الهواء إلى الوقود متقاربتين بين النسبتين.

تم تحقيق افضل درجة حرارة للمحرك التي تحقق أفضل أداء وانبعاثات للمحرك عند تشغيل محرك الديزل بوقود 20% من الديزل الحيوي مع تطبيق 10% من غاز العادم الراجع. تمت الموافقة أيضًا على أنه لكل نسبة انضغاط، هناك تحويلة مثالية عند حمل 4/3. كانت افضل درجه حراره غاز العادم 92 درجة مئوية عندما نسبه الانضغاط 14.5، 98.7 درجة مئوية عندما نسبه الانضغاط 15.5، و 130 درجة مئوية عندما نسبه الانضغاط 16.5، على التوالي.

دراسة عملية لتأثير اعادة التدوير لغازات العادم على اداء وتلوث لمحرك ديزل يحقن بالديزل الحيوي المستخرج من بقايا زيت الطبخ

أطروحة

مقدمه لكلية الهندسة بجامعة بابل في استيفاء جزئي لمتطلبات درجة ماجستير العلوم في الهندسة الميكانيكية

من قبل

نور علي زياد عبد

(B.Sc. - 2010)

باشراف

أ.م.د دريد فتحي مكي

قسم الهندسة الميكانيكية كلية الهندسة جامعة بابل

2023 A.D.   **1445 A.H**

References