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# STUDY THE PERFORMANCE AND EMISSIONS FOR ENGINE WITH RENEWABLE FULE

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MSc.TECH

IN MECHANICAL ENGINEERING TECHNIQUSE OF POWER

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AL-FURAT AL-AWSAT TECHNICAL UNIVERSITY - IRAQ

# STUDY THE PERFORMANCE AND EMISSIONS FOR ENGINE WITH RENEWABLE FULE

**THESIS**

**SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING TECHNIQUES OF POWER IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER THERMAL TECHNOLOGIES IN MECHANICAL ENGINEERING TECHNIQUES OF POWER (M.TECH.)**

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**1445** **2023**

# بِسْمِ اللَّـهِ الرَّحْمَـٰنِ الرَّحِيمِ

الَّذِي جَعَلَ لَكُم مِّنَ الشَّجَرِ الْأَخْضَرِ نَارًا فَإِذَا أَنتُم مِّنْهُ تُوقِدُونَ

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# DISCLAIMER

I confirm that the work in this thesis " **Study the performance and emissions for engine with renewable fuel**" is entirely mine and has not been submitted to another organization or to obtain any other degree, except perhaps properly cited quotations and summaries.

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**Name: Ali Sadoon Mohammed**

**Date: / / 2023**

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Finally, I would really want to give gratefulness to my family for their standing with me and their lovingness.

**Ali Sadoon Mohammed**

**2023**

# SUPERVISORS CERTIFICATION

We certify that this thesis titled " **Study the performance and emissions for engine with renewable fuel**" which is being submitted by **Ali Sadoon Mohammed** was prepared under our supervision at the Power Mechanical Engineering Techniques Department, Engineering Technical College/Najaf, AL-Furat Al-Awsat Technical University, as a partial fulfillment of the requirements for the degree of Master in thermal mechanical engineering.

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This is to certify that this thesis "Study the performance and emissions for engine with renewable fuel" was reviewed linguistically. Its language was amended to meet the style of the English language.

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# ABSTRACT

For many years, petroleum-based fuels have been a popular choice for energy needs. Yet, the growing focus on preserving our environment and finding new energy sources has spurred a desire for renewable and clean options. Alternative fuels for diesel engines are becoming increasingly popular, specifically those that are renewable. These studies have introduced us to environment-friendly and economically feasible fuel options. Biodiesel and alcohol have emerged as potential alternatives to diesel engines. One of the key advantages of these fuels is that they are renewable and domestically produced. Using an air-cooled, single-cylinder, compression-ignition diesel engine, our study utilized pure Iraqi diesel (D) as a point of reference before preparing several fuel blends. The purpose of this work is to conduct experimental studies and to substantiate the possibilities of using biofuel mixtures, composed of (alcohol) and biodiesel (waste cooking oil), in a diesel engine, evaluating the engine performance and emissions. Our work is entailed creating various blends: [D100, D80B20, D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15]. Diesel fuels and fuel mixtures were tested by changing the load on the engine (4, 5.5, 7, 8.5 and 10 Nm). And constant engine speed (1750, 2000, 2250, and 2500 rpm). To obtain Exhaust gas emissions are measured from Engine by an exhaust gas analyzer (carbon monoxide CO, carbon dioxide CO2, unburned UHC hydrocarbons, and nitrogen oxides [NOx]). The engine's performance parameters were brake power Bp, brake specific fuel combustion BSFC, exhaust gas temperature EGT and brake thermal efficiency ƞbth are measured from Engine. For constant engine speed with variable load, the results of the experimental work showed that when adding blends biodiesel and higher alcohols to diesel, the brake specific fuel consumption increases

[D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20] by values of 5.19%, 10.99%, 7.63%, 21.68%, 12.01%, 15.93%, and 3.82%, respectively, compared to diesel fuel. While for the same blends there was a decreased to the break thermal efficiency (ηbth)of by values of 5.19%, 10.99%, 7.63%, 21.68%, 12.01%, 15.93%, and 3.82%, respectively, compared to diesel fuel. An increase of higher alcohols concentration had an effect on exhaust gas temperature (EGT) when compared to diesel fuel, and ternary blends were found to decrease brake thermal efficiency (ηbth)while increasing brake specific fuel consumption (BSFC). The EGT of diesel fuel was found to be higher than that of other fuels. The reduction in the EGT (exhaust gas temperature) by (6.7%, 11.7%, 18.9%, 10.9%, 7.95%, 17.8% and 22.6%). For the same blends respectively, compared to diesel fuel. In terms of exhaust gas emissions, the CO and UHC emissions decreased in biodiesel and higher alcohol blends except CO2, increased while the NOx increased by using biodiesel (D80B20) blends with a contrary behavior decreased with higher alcohol blends.

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## Nomenclature

| Symbol | Definition | SI Unit |
|---|---|---|
| Bp | Brake Power | kW |
| D | Diameter | m |
| H | Height | m |
| rpm | Revolutions per minute | r/min |
| L | Length | m |
| m | Mass | kg |
| $m\dot{f}$ | Fuel consumption rate | kg/sec |
| $m\dot{a}$ | Air consumption rate | kg/sec |
| P | Pressure | bar, N/m2 |
| Tb | Brake Torque | N.m |

| | | |
|---|---|---|
| T | Temperature | C° |
| EGT | Exhaust Gas Temperature | C° |
| ρ | Density | kg/$m_3$ |
| t | Time | sec |
| W | Width | m |
| B | Bore | mm |
| S | Stroke | mm |

## Abbreviations

| **Symbol** | **Description** | **SI Units** |
|---|---|---|
| ASTM | American Standard Test Method | --- |
| FFA | Free fatty acid | --- |
| bsfc | Brake Specific Fuel Consumption | kg/kW.hr |
| Ƞbth | Brake Thermal Efficiency | % |
| CR | Compression Ratio | --- |
| C.I. E | Compression Ignition Engine | --- |
| S.I. E | Spark Ignition Engine | --- |
| DI | Direct Injection | --- |
| TDC | Top Dead Center (Degree) | --- |
| BDC | Bottom Dead Center (Degree) | --- |
| LHV | Lower Heating Value | kJ/kg |
| Ppm | Part Per Million | --- |
| B | Biodiesel fuel | --- |
| CN | Cetane Number | --- |
| ID | Ignition Delay | --- |
| WCO | Waste Cooking Oil | --- |
| H/C | Hydrogen to Carbon ratio | --- |
| FAME | Fatty Acid Methyl Ester | --- |
| NOx | Nitrogen oxides | --- |
| HC | Hydrocarbon | --- |
| CO | Carbon Monoxide | --- |
| $CO_2$ | Carbon Dioxide | --- |

## Chemical Abbreviations

| Symbol | Description | Chemical Formula |
|---|---|---|
| PEN | Pentanol | ($C5H12O$) |
| HEX | Hexanol | ($C_6H_{14}O$) |
| BU | Butanol | ($C_4H_{10}O$) |
| --- | Methanol | $CH4O$ |
| --- | Ethanol | $C2H6O$ |
| --- | Sodium hydroxide | $NaOH$ |
| --- | Potassium hydroxide | $KOH$ |

## Subscripts

| Symbol | Description |
|---|---|
| A | Air |
| atm | Atmosphere |
| F | Fuel |
| I | Initial State |
| act | Actual |

# CHAPTER ONE

# INTRODUCTION

# CHAPTER ONE

# INTRODUCTION

## 1.1 Introduction:

The degradation of air quality in urban environments has become a growing concern due to the rapid expansion of the vehicle industry and their exhaust emissions [1]. The two main contributing factors to this issue are petrol engines and diesel engines, both of which have a significant impact on human health. Diesel engines are frequently selected for utilization in several industries, including agriculture, transportation, and electricity production, owing to their inherent stability and notable thermal performance [2]. The use of diesel fuel has been predominant in these sectors. However, the environmental consequences of burning diesel fuel cannot be ignored, including negative impacts such as climate change, acid rain, and global warming. As natural resources diminish and production costs rise, alternative sources need to be sought out [3]. Efforts to replace diesel fuel and preserve the environment have become an urgent cause. In order to achieve this goal, researchers have been focusing on finding alternative fuel sources that are cost-effective while decreasing dependence on diesel fuel [4]. Academic researchers exhibit a keen interest in producing environmentally sustainable fuels on a worldwide scale, primarily due to their potential to mitigate adverse environmental emissions and foster industrial growth and wealth. Substituting conventional petroleum-based products with alternative fuels represents a viable approach towards attaining this objective. These studies have introduced us to environment-friendly and economically feasible fuel options. Biodiesel and alcohol have emerged as potential alternatives to diesel engines.

One of the key advantages of these fuels is that they are renewable and domestically produced [5].

## 1.2 Diesel fuel:

Diesel fuel holds significant importance as a fuel source for compression ignition (CI) engines. Typically, it comprises a blend of petroleum-derived constituents, encompassing paraffins, naphthenes, olefins, and aromatics. Diesel fuel can be obtained with a wide range of molecular weights and physical properties [6]. Since diesel fuel has a complex chemical composition, intermolecular interactions may occur due to the different polarities of hydrocarbons, influencing attributes and performance characteristics [7]. Diesel fuel can be made by fractionally distilling crude oil, which separates both fuels- gasoline and white oil. Diesel fuel evaporates at a temperature of 180°C to 360°C and has an energy density of about 8%, which is higher than that of gasoline fuels. Moreover, diesel fuel, which is commonly utilized in heavy vehicles, has lower flammability compared to gasoline fuel. This is evident from the fact that diesel fuel has an ignition point temperature of 52°C, whilst gasoline fuels have an ignition point temperature of -40°C.

Diesel fuel can be categorized into two unique classifications based on its molecular composition. The first classification is heavy diesel fuel, denoted as $C_{14}H_{24}$, with an approximate molecular weight of 200 MW. The second classification is light diesel fuel, denoted as $C_{12}H_{22}$, with a molecular weight of around 170 MW. Light diesel fuel is manufactured in numerous nations, including those in Europe, where it is produced in accordance with established regulations that mandate a maximum sulfur concentration of 50%. This adherence to standardized specifications ensures that light diesel fuel has minimal impact on the environment in terms of pollution.

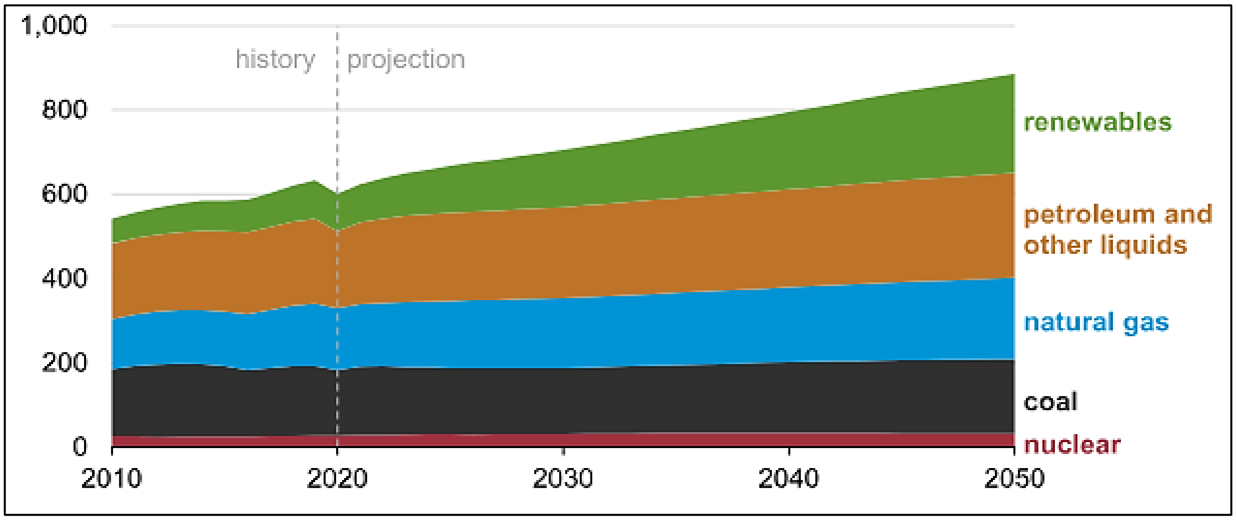

Figure (1-1): Global primary energy consumption by energy source (2010 – 2050) [8].

## 1.3 The Utilization of Biodiesel as an Alternative Fuel Source

In recent times, there has been a growing focus among academics on Biodiesel due to its potential as an environmentally sustainable fuel source. Biodiesel is derived through a chemical reaction involving the combination of vegetable oil or animal fat with alcohol in the presence of a catalyst. The conversion of fatty acids found in oil into a liquid known as Biodiesel is a method used to generate monoalkyl compounds [9]. Biodiesel has the potential to serve as a viable alternative fuel for diesel engines, either by direct utilization or by blending with conventional fossil diesel in different proportions [10]. Biodiesel possesses several characteristics that render it highly suggested for utilization as an alternative fuel in an internal combustion engine [11]. Biodiesel possesses both benefits and drawbacks. The advantages of Biodiesel encompass its reduced sulfur level, elevated flash point, lubricating properties, high cetane number, non-toxic nature, and around 10% to 11% oxygen content. The utilization of Biodiesel in place of diesel fuel offers several notable benefits, including biodegradation and the capacity to decrease smoke emissions [12]. Nevertheless, biodiesel fuels present certain drawbacks, including increased viscosity, elevated pour points, reduced heating value, and decreased volatility [13].

Biodiesel is a fuel variant including monoalkyl compounds obtained from the triglycerides of long fatty acid chain, with the glyceride component removed. The alkyl ester, specifically the methyl ester or FAME, is a prevalent type as depicted in Figure (1-2) [14].

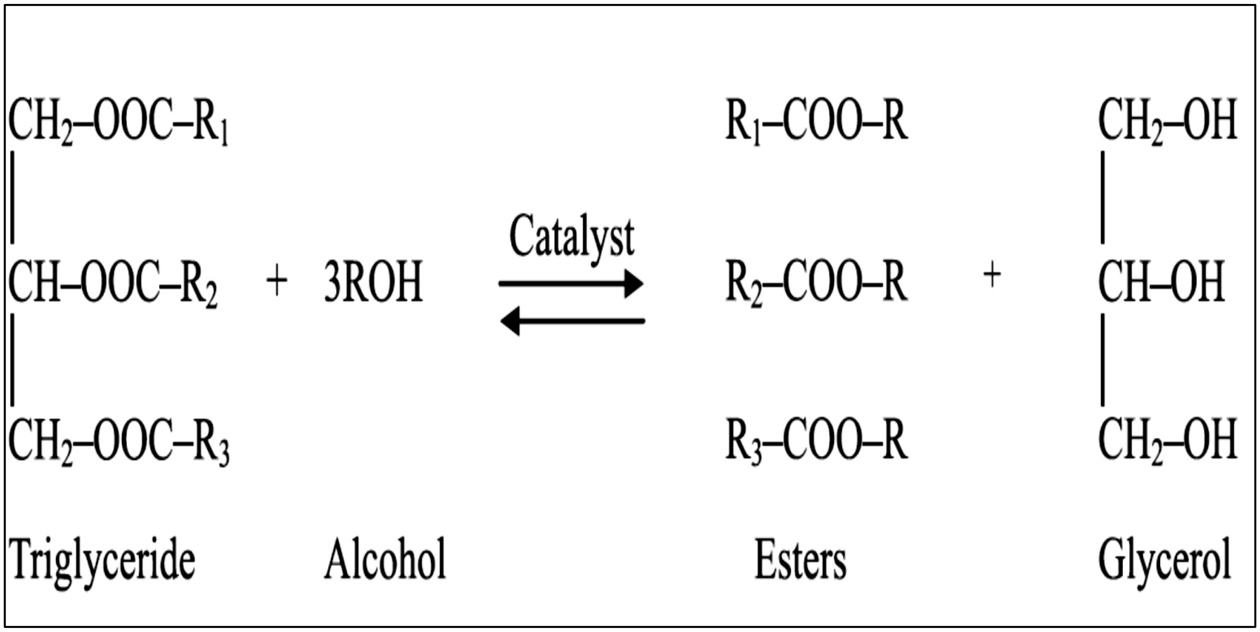

Figure (1-2): Illustrates the process of transesterification, wherein triacylglycerol is converted into fatty acid and glycerol utilizing Methanol.

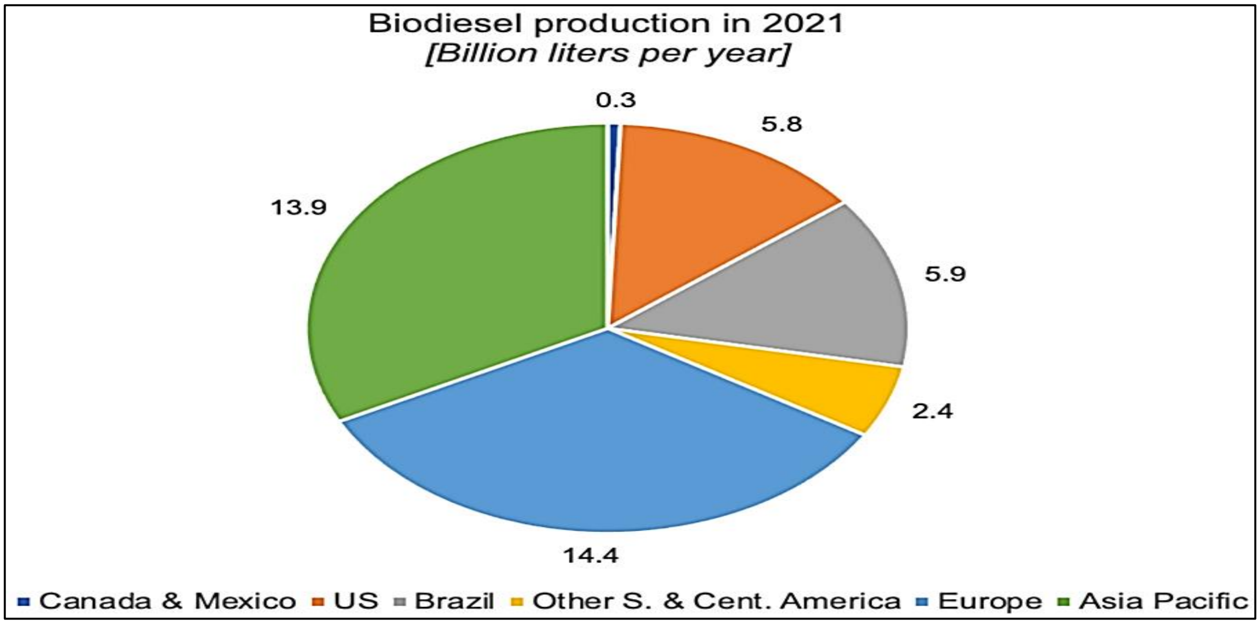

Figure (1-3): biodiesel production in 2021[15].

## 1.4 The historical development of Biodiesel:

The diesel engine, also known as the compression ignition engine, was developed by Rudolf Diesel with the intention of utilizing a variety of fuel sources. These fuel sources encompassed coal dust suspended in water, heavy mineral oils, and vegetable oils [16]. In 1911, Diesel stated: "The diesel engine can be fed with vegetable oils and will greatly help in the development of agriculture in the countries that use it. The engine underwent subsequent modifications to enable its operation using the environmentally detrimental petroleum fuel commonly referred to as "diesel". However, vegetable oils have been used as alternatives to Diesel today [17]. Many nations are increasingly adopting biofuels as a result of its renewable nature and lower environmental impact. The exploration of fats and oils as alternative fuels gained significant momentum due to concerns about elevated petroleum costs [18]. Biodiesel, alternatively referred to as monoalkyl ester, witnessed widespread use throughout the early 1990s, and its production has subsequently exhibited a consistent upward trend. Biodiesel was advocated in the 1980s inside the European Union as a means to mitigate rural degradation and address the escalating energy requirements. However, it was not until the second half of the 1990s that its large-scale development began [19]. Biodiesel production is a current and technological field of research due to the increased demand for petroleum and environmental benefits. The transesterification of vegetable oils and animal fats is widely recognized as the prevailing and efficacious approach for biodiesel synthesis. The process is not new. The introduction of the aforementioned concept occurred in 1853, as documented by Duffy and Patrick. Since then, numerous research has been undertaken utilising various types of oils [20].

## 1.5 Biodiesel source:

Biodiesel can be derived from various sources, such as vegetable oils, cooking oil residues, animal fats, algae, microalgae, and fungi [21]. However, the majority of research has focused on oil-bearing plants. The initial step in biodiesel production involves selecting suitable raw materials. Globally, over 350 oil crops are identified as potential sources for biodiesel production [22]. The primary consideration for biodiesel production is the availability of diverse feedstocks [23]. These raw materials must fulfill two key criteria: cost-effectiveness and suitability for large-scale production. The accessibility and manufacturing of biodiesel are contingent upon various elements, including geographical location, climate conditions, local soil texture and conditions, and agricultural practices. As indicated by previous research, Biodiesel feedstocks can be classified into four distinct classes [24] :

1. Edible vegetable oils, including rapeseed, soybean, peanut, sunflower, palm, and coconut oil, are commonly consumed in many culinary practices.
2. Vegetable non-edible oils, like Karanja, jatropha, sea mango, algae, and halophytes, are examples of plant-derived oils unsuitable for human consumption.
3. The utilization of waste or recycled oils.
4. Animal fats, including beef tallow, yellow fat, chicken fat, and fish oil derivatives, are commonly used in many applications.

## 1.6 Waste Cooking Oil (WCO):

Waste oil production increases due to the rise in food consumption. In Spain, approximately 400,000 tons of waste cooking oil (WCO) are produced each year, whereas Canada and the European Union (EU) produce approximately 135,000 and 700,000-1,000,000 tons of WCO yearly, respectively [25]. Re-using WCO harms the environment and is disposed of by dumping in rivers, which will cause pollution [26]. Fatty acids can be found in used cooking oil (WCO), and by the process of transesterification utilizing catalysts that consists of acidic, alkaline, or enzyme-based substances. The conversion of fatty acids into biodiesel can be accomplished. The process of heating oil leads to the production of FFAs, glycerides, diacids, and polyacids, which in turn impacts the efficiency and yield of transesterification [27]. Therefore, it is imperative to assess the WCO acid index. In the event that the WCO acid index exceeds 2.5%, it may be necessary to perform pre-esterification prior to exposing the WCO to transesterification. Waste oil that is wasted otherwise is an economically viable opportunity for biodiesel production. Because it is two to three times cheaper than virgin ones [28], in comparison, waste cooking oil could be seen as the most practical source for producing Biodiesel because it saves money and reduces garbage disposal issues. Manufacturers concentrate their efforts on exploiting inexpensive feedstock, like used cooking oil. Every country produces a significant amount of waste oil. Waste oils can come from the restaurant and home industries as well as non-food industries. Palm, soybean, rapeseed, sunflower, peanut, cottonseed, coconut, olive oil, etc., are the main sources of cooking oil.

## 1.7 Alcohol Fuels:

Alcohols Over the past several decades, the use of alcohol to replace conventional fuels in engine applications has been investigated in order to reduce air pollution. Short-chain alcohol and long-chain alcohol are the two types available. Higher alcohols are those that contain more than two carbon atoms. The basic fuel properties of alcohols improve as the number of carbons in their chemical structures increases.[29] As a result, it has a higher heating value, higher naphthalene, lower volatility, lower ignition difficulties, solubility, higher viscosity and lubrication, lower corrosion risk, and lower heat of vaporization than lower carbon alcohol. Therefore, high-carbon alcohols have been proposed as a viable alternative for diesel engines [30]. Alcohol is excellent as an alternative fuel because it can be produced from different naturals and many manufactured origins. High alcohol, namely pentanol, hexanol, and butanol, comprises a linear arrangement of alcohol molecules that possesses remarkable efficacy as an additive in diesel fuel blends due to its superior energy density and elevated cetane number, as well as its mixture stability, which is high, and hygroscopic kind, which is low if it is compared to ethanol and Methanol [31]. The properties of pentanol and hexanol are expected to have a greater similarity to Diesel fuel compared to other alcohols with respect to the latent heat of vaporization, density, and viscosity. Long-chain alcohols can improve the combustion process by allowing proper mixing of air and fuel.

## 1.8 Characterization of Biodiesel:

### 1.8.1 viscosity

It refers to the characterization of fuel's flowability. The aforementioned attribute holds significant significance in the functioning of the fuel injection apparatus and atomizer, as it exerts an influence on the fuel injection process [32]. The viscosity of the fuel exhibits an upward trend as the ambient temperature decreases. The viscosity of Biodiesel is significantly greater, ranging from 10 to 15 times higher, compared to Diesel fuel obtained from fossil fuel sources. The reason for this phenomenon can be attributed to the substantial molecular mass and extensive chemical structure [33]. At reduced temperatures, Biodiesel has a high viscosity or may undergo solidification. The elevated viscosity of Biodiesel has the potential to impact the engine's volume flow and injecting spray characteristics. This is due to the consequent rise in fuel viscosity, which leads to a decrease in fuel atomization and evaporation, an increase in droplet size, and a greater penetration of fuel mist into the cylinder. One potential consequence of high viscosity is the potential reduction in fuel flow rates, which can lead to inadequate fuel supply. Another consideration is the potential impact on the mechanical integrity of injection pump drive systems, particularly in low-temperature conditions. The ASTM D445 standard specifies that the allowable range for viscosity is between 1.9 and 6.0 mm2/sec, while the EN ISO 3104 standard specifies a range of 3.5 to 5.0 mm/sec [34].

### 1.8.2 Fuel and Relative density

The density of the fuel is determined by the weight per unit volume. Oils exhibit higher density and possess a greater amount of energy. The determination of Biodiesel density can be conducted using the methods outlined in EN ISO 3675/12185 and ASTM D1298. The reference standard measures the density at a specified reference temperature of either 15 or 20 °C [35]. The density of fuel is influenced by temperature, with a decrease in temperature leading to an increase in density. Consequently, when the cold process commences at lower ambient temperatures, the heightened density results in a greater mass of fuel being injected for a given volume of fuel. This, in turn, impacts the air-to-fuel ratio, fuel composition, and energy within the cylinder. The concept of relative density Related to the comparison between the density of a given fuel and the density of water. The determination of biodiesel relative density is essential for conducting mass-to-volume conversions, evaluating flow and viscosity properties, and assessing the uniformity of biodiesel storage containers [36].

### 1.8.3 flash point

The flash point refers to the specific temperature at which a fuel substance can undergo ignition. It is the flammability of the fuel when exposed to flame. It reflects the level of safety associated with the handling, storage, and transportation of fuel. When subjected to standardized testing conditions, the lower limit of temperature at which the fuel releases adequate vapors to generate a flammable combination of fuel vapor and air above the fuel's surface [37]. Fuel volatility varies inversely with flash points. The flash point of Biodiesel is higher than that specified for petroleum diesel, Biodiesel exhibits a flash temperature above 150 °C, whereas traditional Diesel possesses a flash point ranging between 55-66 °C.

The flash point values of fatty acid methyl esters are significantly lower compared to those of vegetable oils [38]. The ASTM D93 standard stipulates a flash point limit of 93°C, while the EN ISO 3679 standard sets a flash point limit of 120°C [39].

### 1.8.4 cetane number (CN) and ignition delay (ID)

The parameter that signifies the ignition properties of a fuel, specifically its capacity to ignite rapidly without external ignition sources following injection, is referred to as the fuel's cetane number (CN). This parameter serves as a primary indicator of the fuel's self-ignition characteristics and combustion quality when utilised in a compression ignition (CI) engine [40]. The cold starting capability of the engine is influenced by its ability to lower engine cranking time, which refers to the duration before the engine reaches the "start" phase. In order to achieve a shorter cranking time, a higher cetane number (CN) is necessary [41]. A greater value of cetane number (CN) is consistently correlated with improved ignition quality. A greater cetane number confers significant advantages in terms of engine performance and emissions, enabling the engine to operate with enhanced smoothness and reduced noise levels while utilising biodiesel-derived fuels [42]. Biodiesel exhibits a greater cetane content in comparison to conventional diesel fuel. A greater cetane number signifies a reduced ignition delay, resulting in a prompt engine start and seamless operation, particularly in the context of Biodiesel Ignition Delay (ID) can be considered as a very significant parameter in fuel combustion and highly effect on both engine design and performance, the ID is outlined on the curve as shown in Figure (1-4), [43]. In the process of selecting methyl esters, naphthalene holds significant importance. The concentration of naphthalene has a positive correlation with both the length of the fatty acid chain and the degree of saturation. Higher compression ratios correspond to reduced time intervals between the ignition event and the initiation of fuel injection into the combustion chamber of the engine. Biodiesel exhibits a comparatively elevated naphthalene content in comparison to traditional petroleum diesel, hence suggesting a heightened level of combustion efficiency. The cetane number (CN) of Diesel, as established by the ASTM D613 standard, is 47 minutes, but the EN ISO 5165 standard specifies it to be 51.0 minutes.

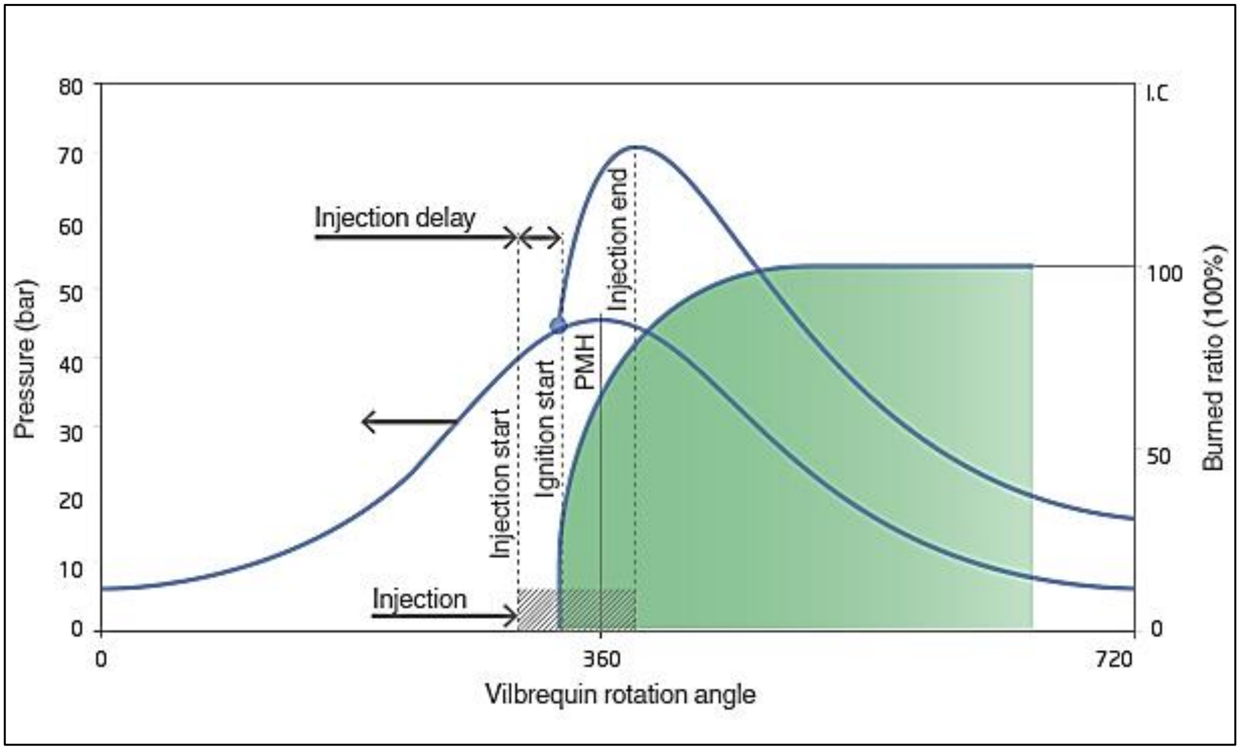

Figure (1-4): Effects of Cetane Improver on Ignition Delay [43].

### 1.8.5 Calorific Heating Value

The calorific value of a fuel refers to the amount of thermal energy that is generated when a certain quantity of fuel is entirely burned and the resulting combustion products are cooled to the beginning temperature of the combustible mixture. The measurement related to the energy content present inside a certain fuel source. The aforementioned characteristic is a fundamental attribute of Biodiesel, which plays a crucial role in assessing its viability as a substitute for conventional diesel fuels. The calorific value of vegetable oils and their methyl esters was determined using a bomb calorimeter in accordance with the ASTMD240 standard method. The calorific value is a crucial characteristic of fuels intended for combustion in engines, as it significantly influences the power output. Various types of biodiesel fuels have varying calorific values. The higher calorific value of a fuel leads to the generation of greater heat energy, resulting in enhanced engine performance during the combustion process [44].

## 1.9 Air Pollution:

In recent times, the severity of environmental concerns has been amplified due to the detrimental discharge of exhaust pollutants and the escalating levels of Carbon monoxide (CO) from fossil fuel combustion. Renewable fuels have emerged as a promising substitute for finite fossil fuel reserves due to their capacity to alleviate reliance on fossil fuels and curb the release of greenhouse gases. Consequently, using biofuels presents an opportunity to confront environmental preservation and sustainable development concerns. The utilization of alternative fuels in internal combustion (IC) engines has garnered attention in recent years due to its potential for mitigating emissions, particularly in terms of reducing particulate matter (PM) emissions. The elevated temperature of compressed air within diesel engines facilitates the attainment of the self-ignition temperature of the air/fuel mixture, leading to the liberation of stored chemical energy through the combustion process. The byproducts of an ideal combustion process consist of water vapor ($H_2O$) and carbon dioxide ($CO_2$). However, in practice, a minor fraction of the fuel and lubricating oil may stay unburned.

Emissions generated by insufficient combustion in diesel engines include carbon monoxide (CO), hydrocarbons (UHC), nitrogen oxides (NOx), and particulate matter (PM), all of which are subject to regulation. The potential health implications of these byproducts resulting from incomplete combustion include the exacerbation of respiratory conditions such as asthma, chronic obstructive pulmonary disease (COPD), diminished lung function, and the development of lung cancers. The primary pollutants discharged from internal combustion engines (IC engines) include:

1. Carbon monoxide (CO)
2. Unburned hydrocarbons (UHC)
3. Oxides of Nitrogen (NOx)
4. Carbon dioxide ($CO_2$).

### 1.9.1 Carbon monoxide (CO Emission):

Carbon monoxide is widely recognized for its lack of color, odor, and taste. The density of the substance is marginally greater than that of ambient air. Furthermore, carbon monoxide (CO) possesses a highly poisonous characteristic that harms human health within natural environments. Additionally, a little carbon monoxide (CO) concentration might result in symptoms such as shortness of breath and headaches. Carbon monoxide emissions result from incomplete combustion of hydrocarbons available in the fuel [45]. Carbon monoxide (CO), which expresses the chemical energy lost, is an important parameter through exhaust gases. Also, the exhaust's Carbon monoxide (CO) can determine incomplete combustion due to insufficient oxygen in the combustion chamber [46]. With the increase in speed, the amount of oxygen reduces hence, CO emission increases with the load. However, blending with Biodiesel provides an adequate amount of oxygen for burning hence CO emission is reduced considerably. Consequently, elevating the proportion of Biodiesel in a blend leads to a decrease in carbon monoxide (CO) emissions due to improved fuel/air mixing, prevention of fuel-rich areas, and the mitigation of hot stoichiometric zones, all of which contribute to lower CO levels. Hence, the presence of sufficient oxygen in the medium is crucial in preventing the formation of Carbon monoxide (CO) [47].

### 1.9.2 Carbon Dioxide ($CO_2$ Emission):

Carbon dioxide is not classified as air pollution when present in moderate concentrations. Nevertheless, carbon dioxide is widely recognized as a significant greenhouse gas and, when present at elevated levels, has a substantial role in exacerbating the phenomenon of global warming. Carbon dioxide ($CO_2$) constitutes a significant proportion of the emissions produced during the burning process of hydrocarbon fuels. The amount of carbon dioxide in the atmosphere continues to grow because of the growing number of motor vehicles, along with more factories and other sources [48]. At higher elevations within the atmosphere, an increased concentration of carbon dioxide and other greenhouse gases forms a thermal radiation shield. This shield functions to limit the dissipation of thermal radiation energy from the Earth, resulting in a marginal increase in the average global temperature. Biodiesel, as an oxygenated fuel, exhibits a higher carbon dioxide ($CO_2$) emission profile compared to conventional diesel fuel. In essence, the occurrence of elevated temperature and pressure within the combustion chamber due to the utilization of a biodiesel blend results in the achievement of thorough combustion, hence resulting in reduced carbon monoxide (CO) emissions and increased carbon dioxide ($CO_2$) emissions.

### 1.9.3 Oxides of Nitrogen (NOx):

NOx refers to a gaseous blend of many compounds, namely nitric oxide (NO), dinitrogen dioxide ($N_2O_2$), nitrous oxide ($N_2O$), dinitrogen trioxide ($N_2O_3$), nitrogen dioxide ($NO_2$), dinitrogen tetroxide ($N_2O_4$), and dinitrogen pentoxide ($N_2O$). The generation of nitric oxide (NO) accounts for the predominant portion (about 95%) of nitrogen oxides (NOx) in the majority of combustion processes characterized by elevated temperatures. Once released into the atmosphere, NOx emissions undergo chemical reactions that result in ozone formation. This phenomenon is widely recognized as a significant contributor to the occurrence of photochemical smog [49]. NOx is primarily generated through the oxidation of atmospheric nitrogen, which can also be present in fuel mixtures. The production of NOX is a consequence of elevated temperatures during the process of combustion. When Biodiesel is used as a blend, the heat within the combustion chamber is further intensified, resulting in an increased release of NOx emissions [50]. Thus, the emission of NOx increases linearly with the load. Increasing the percentage of additives in the mixture can reduce the temperature inside the combustion chamber, controlling NOx emission.

### 1.9.4 Unburned Hydrocarbons (UHC):

The presence of exhaust smoke is typically attributed to suboptimal combustion resulting from insufficient oxygen supply during the combustion process and inadequate temperature near the cylinder wall. During this phase, the temperature of the air/fuel mixture is lower compared to the center of the cylinder [51]. The presence of unburned hydrocarbons (UHC) in exhaust gases can be attributed to inadequate fuel atomization, leading to insufficient vaporisation of fuel droplets and requiring a longer residence time for proper mixing with oxygen. The UHC, or unburned hydrocarbon, exists in the exhaust as droplets and vapor. Additionally, it is possible for the UHC to include a hydrocarbon species with a lower molecular weight [52]. The nonstoichiometric air/fuel ratio is a significant contributing factor to the generation of carbon monoxide (CO) and unburned hydrocarbons (UHC). When the air/fuel mixture is rich, meaning there is an inadequate amount of oxygen available to react with all the carbon present, it results in elevated levels of UHC and CO in the resulting components. The reduction of diesel exhaust smoke can be achieved by using oxygenated fuel, such as Biodiesel.[53][54] Table (1.1) presents a comprehensive overview of the mechanisms involved in the emission of gases within internal combustion engines (I.C. engines) and their corresponding effects.

Table (1.1): IC The emission of gases from engines.

| Pollutant | Effect | Mechanism |
|---|---|---|
| CO | Toxic | Incomplete combustion, dissociation of $CO_2$, (low temperature, weak or rich A/F ratio, poor mixing). |
| $CO_2$ | the critical public health problem (Green-house gas) emissions | more oxygen molecule<br>CO will convert to $CO_2$. |
| UHC | Toxic | Incomplete combustion, (insufficient flame speed, poor atomization). |
| NO*x* | Toxic, smog<br>Ozone depletion | Thermal NO ($N_2 + O \rightarrow NO + N$, $N + OH \rightarrow NO + H$). |

| | | |
|---|---|---|
| | | Prompt NO ($CH + N_2 \rightarrow HCN + N$, $CN + O\_2 \rightarrow NO + CO$).<br>Fuel NO (Oxidation of fuel bound $N_2$ mainly heavy distillate fuel). |

## 1.10 Research Objectives:

The main objective of this study is to undertake experimental investigations in order to validate the potential application of biofuel blends, namely those consisting of alcohol and Biodiesel derived from waste cooking oil, in a diesel engine. The performance and emissions of the engine will be assessed as part of this evaluation. The primary aims of the current investigation can be succinctly outlined as follows:

1. Using waste cooking oil (WCO) to produce alternative fuel (disposing of waste to preserve the environment)
2. Mixing several types of fuel to find the best type of fuel in terms of capacity or efficiency and reducing emissions
3. investigate the impact of incorporating higher alcohols, including pentanol, hexanol, and butanol, into biodiesel-diesel blends at varying proportions.
4. The performance evaluation examines specific fuel consumption (BSFC) and brake thermal efficiency (BTE).
5. The examination of exhaust gas emissions, encompassing NOX, CO, UHC, and $CO_2$, is being conducted.

# CHAPTER TWO

# Literature Review

# CHAPTER TWO

# Literature Review

## 2.1 Introduction:

The rise for industrialization and societal expansion has resulted in a greater reliance on fossil fuels, leading to heightened emissions of pollutants from petroleum-based fuels. These environmental consequences have prompted extensive research into alternative fuel sources. Many researchers have carried out several of studies on diesel fuel of C.I engine and reported that the use of diesel, biodiesel and different types of alcohol as well as other enhanced additives, have a significant effect on exhaust emissions control and engine performance. This chapter provides an overview of previous research efforts on the C.I engine, using different percentages of adding alcohol and biodiesel to the fuel.

## 2.2 Effect of Biodiesel/Diesel blend on Engine Performance and Exhaust Emission

Amidst the continuous rise in the demand for energy on a global scale, the downside of depletable fossil fuels, carbon emissions, and the alarming issue of global warming, a quest for alternate energy sources had been underway. One of the prime candidates for alternative fuels in compression ignition engines is biodiesel. This renewable and eco-friendly fuel is readily available, low in sulfur, non-toxic, and can be used by blending it with diesel fuels in CIE. However, direct use in diesel engines is not possible due to some of its properties that can negatively impact engine operation. The environmental benefits of biodiesel are reflected by its low emission rate of carbon monoxide and superior lubricating qualities compared to petroleum diesel fuels.

**Rupesh Kanwar et al. (2016)** [55] An experimental investigated the Kirilskar water-cooled four-stroke diesel engine. Single-cylinder compression ignition. The experiment was conducted under controlled conditions, maintaining a consistent rotational speed of 3000 revolutions per minute (rpm). Different weights were applied during the test while varying the proportions of biodiesel (B100) and conventional diesel used in its pure form (100%). Biodiesel mixtures (5, 10, 15, 20%) with diesel (95, 90, 85, 80%). The transesterification procedure was employed to synthesize castor oil and ethyl ester. The results were that the brakes' thermal efficiency and the brakes' specific fuel consumption were decreased and increased, respectively on biodiesel with different compositions compared to metallic diesel. The average $CO_2$ reduction for B05,B10,B15,and B20 were 11.75,22.02,24.23,and 28.79%, respectively, in contrast to the metallic diesel. The findings demonstrate a noteworthy decline in emission levels of carbon monoxide (CO) as the fraction of biodiesel increases. The comparative test findings revealed that the utilization of B05, B10, B15, and B20 fuels in the engine resulted in reduced emissions of carbon dioxide, oxygen ($O_2$), and smoke density in comparison to metallic diesel. Additionally, the emissions of nitrogen oxide (NOx) and carbon dioxide ($CO_2$) were also seen to be lower. It is found with a slight increase in B05, B10, B15 and B20.

**Jayashri N. Nair et al. (2016)** [56] Studied the performance and emission characteristics of a single-cylinder, four-stroke, constant-speed, water-cooled diesel engine. The engine ran at a constant speed of 1500 rpm, with a constant compression ratio of 18. The engine underwent testing using pure diesel fuel and a distinct combination of biodiesel. The use of neem-based biofuels, specifically B10, B20, and B30 blends, is being considered. Biodiesel is derived from neem oil by the method of cross-conversion. The findings indicate that B10 exhibits reduced emissions and enhanced performance compared to other blends and conventional diesel fuel. Additionally, the neem biodiesel mix demonstrates superior thermal efficiency of the brakes when compared to diesel fuel, and emissions of $CO_2$, CO, and NOx are 23%, 8.5%, and 22% lower than those of diesel.

**J. Jayaprabakar and A. Karthikeyan (2016)** [57] used experimental investigation involved testing a vertical, constant speed, four-stroke air-cooled direct injection diesel engine. Two fuel mixtures were utilized, namely AME (comprising 20% algae oil methyl esters and 80% pure diesel by volume) and RME (comprising 20% rice bran oil methyl esters and 80% pure diesel by volume). To conduct an analysis of performance and emissions for two types of biodiesels, five distinct load conditions were considered: 0%, 25%, 50%, 75%, and 100%. The findings indicate a rise in the particular fuel consumption associated with the use of biodiesel. The thermal efficiency values associated with biodiesel exhibit a higher degree of similarity to those observed in diesel fuel. Biodiesel mixes have been found to result in reduced levels of unburned hydrocarbons, carbon monoxide, and smoke emissions. The levels of NOx emissions exhibited a modest increase in the biodiesel mixes. When the injection timing was advanced, both performance and emission parameters exhibited positive outcomes. Based on the experimental findings, it can be inferred that the utilization of a blend of rice bran oil and algal oil derived from biodiesel (specifically B20) is employed as a fuel source within a compression ignition engine with marginally enhanced injection timing.

**N. Karthik et al (2017)** [58] Used experimental study was conducted on an air-cooled, direct-injected, CI engine at constant speed (1500 rpm). The use of rubber seed oil with diesel 20% by volume (RSO20) on performance and emission characteristics at different injection times (24°, 27 degrees, 30 degrees, 33 degrees Celsius). The test series was carried out under different load conditions for the motor with a rated power of 5.9 kW. The injection pressure remains consistent at a value of 200 bar. The brake thermal efficiency of RSO20 at 30°C is observed to be higher during investigations and experiments conducted under full load conditions. This increase in efficiency is particularly notable when compared to other injection times. The utilisation of rubber biodiesel in a conventional diesel engine has been found to enhance the thermal efficiency of the brakes, especially when injection timing is introduced during the loaded state. The introduction of injection time in BSEC brakes also affects the overall fuel usage. There is a significant reduction in emissions of unburned hydrocarbon (UHC) and carbon monoxide (CO). CO and UHC emissions decrease due to higher cylinder temperatures. Delaying injection helps reduce NOx emissions due to low flame temperature and poor combustion. The increase in advanced injection time leads to elevated levels of NOx emissions as a result of the corresponding rise in flame temperature and the maintenance of a stoichiometric fuel-air ratio.

**M.S. Gad et al (2017)** [59]: research experimental examination of running a single cylinder diesel engine using palm oil and biodiesel from palm oil by transesterification process. A mixture of diesel, biodiesel and palm oil was prepared in 20 and 100% volume proportions as B20, B100 and PO20. The measurement of exhaust emissions was conducted at various engine loads, specifically at 1, 2, 3, and 4 kilowatts. and a constant engine speed of 1,500 rpm. The Bsfc specific fuel consumption for biodiesel and oil blend was higher than that of diesel oil. The Bth thermal efficiency of biodiesel and oil blends with diesel fuel was lower compared to diesel fuel. The emissions of unburned hydrocarbons and carbon monoxide were found to be lower for biodiesel blends, while higher for oil blends, in comparison to diesel fuels. The study found that NOx emissions exhibited a small rise when biodiesel and oil mixes were used in comparison to conventional diesel fuels. The nitrogen oxide (NOx) emissions from the B20, B100, and PO20 diesel engines were recorded at 174, 190, 285, and 301 parts per million (ppm), respectively. The study findings demonstrate that the utilization of palm oil methyl ester in a diesel engine, when blended with diesel fuel at a maximum concentration of 20%, yields satisfactory outcomes in terms of engine performance and exhaust emissions.

**K.A. Abed et al (2018)** [60] the experimental procedure involved the utilisation of a Kirloskar diesel engine, namely a single-cylinder, four-stroke, direct-injection model, which exhibited a power output of 5.775 kW at an engine speed of 1500 rpm. A comprehensive investigation was conducted to examine the impact of utilising a cooking oil blend in conjunction with diesel fuel on the performance and exhaust emissions of diesel engines. The conversion technique was employed to make biodiesel from leftover cooking oil. A solution including a blend of waste cooking oil, biodiesel, and diesel oil was formulated with varying mixing proportions of 10%,20%,and 30%, denoted as B10,B20,and B30, respectively.. At different engine loads (1, 2, 3 and 4 kW) and a constant engine speed of 1500 rpm. The thermal efficiency of biodiesel blends was lower than that of diesel oil. The specific fuel consumption of biodiesel blends was higher than that of diesel fuel. The exhaust gases had higher temperatures for biodiesel fuel mixtures than for diesel oil. The $CO_2$ emissions of the biodiesel waste mixture were higher than those of diesel oil. NOx emissions from biodiesel blends were higher than those from diesel fuels. The carbon dioxide, smoke opacity and hydrocarbon emissions of biodiesel blends were lower than that of diesel fuels.

**Ahmet Uyumaz (2018)** [61] In this study, a four-stroke direct injection diesel engine with a single cylinder was employed to investigate the impact of different biodiesel blends derived from mustard oil (M10, M20, and M30) and standard diesel fuel (D100) on combustion characteristics, performance, and emissions. The experiments were conducted at a constant engine speed of 2200 revolutions per minute (rpm) and under various engine loads ranging from 3.75 Nm to 15 Nm, as well as at full load conditions. A reduction in thermal efficiency of 6.8% was recorded while utilising M10, while the brake specific fuel consumption (BSFC) increased by 4.8% when converting M10 to D100 under full load conditions. A significant reduction in carbon dioxide and smoke emissions was observed using biodiesel and mustard oil blends compared to diesel. However, NOx emissions increase if a bio mustard oil blend is used. NOx emissions were determined as 582ppm with D100 while they increased by about 22.1% and 711ppm were obtained using M30 test fuel. Biodiesel and bio mustard oil blends have demonstrated efficient utilization in compression ignition (CI) engines without necessitating any modifications. The experimental findings also indicate that reduced concentrations of a blend consisting of biodiesel and biodiesel derived from mustard oil exhibit favorable characteristics as a fuel source during operation of the engine under partial load conditions.

**N. Nirmala a et al (2020)** [62]: worked in this study the performance and emissions of biodiesel derived from Chlorella variabilis MK039712.1 and cooking oil were evaluated by conducting tests on an IC Kirloskar TV1 5.20 kW four-stroke diesel engine. The engine operated at a constant speed of 1500 rpm, had a single cylinder, and was water-cooled. The obtained results were then compared to those of petroleum diesel. The experiment was conducted under various engine load conditions (0%,25%,50%,75% and 100%) to test the fuel and its mixtures.

AOBD, WCOBD, AOBD10: WCOBD90, AOBD20: WCOBD80, AOBD50: WCOBD50, AOBD70: Compared with conventional pure diesel. The engine performance of WCOBD is superior to that of AOBD, as indicated by its lower Brake Specific Fuel Consumption (BSFC) and higher Brake Power (BP), resulting in a higher Brake Thermal Efficiency (BTE) compared to AOBD. Nevertheless, it has been demonstrated that AOBD has superior performance in terms of emissions. The emissions of nitrogen oxides (NOx) were found to be higher for both fuels in comparison to conventional diesel (CD). The emissions reports demonstrate both reduced levels of carbon dioxide ($CO_2$) and elevated levels of carbon monoxide (CO) compared to the World Carbon Observatory Database (WCOBD) and the Control Dataset (CD). The test mixtures exhibited performance characteristics that were determined to be comparable to the standards set by ASTM, which are considered adequate benchmarks for fuel requirements. The results indicate a reduced level of smoke opacity (SO) in the case of waste cooking oil biodiesel (WCOBD). Overall, the incorporation of pure AOBD (Advanced Oxidation Catalyst) with WCOBD (Wall-Coated Oxidation Catalyst) resulted in enhanced engine performance and improved emission characteristics.

**Suleyman Simsek and Samet Uslu (2020)** [63] experimental study on a 3000 rpm constant speed air-cooled four-stroke naturally aspirated direct-injection four-stroke diesel engine. The primary objective of this study was to examine the effects of the combination of animal fat biodiesel (AFBD) and vegetable biodiesel (VEBD) obtained from canola and safflower oils through a series of trials. The research involved the utilization of five separate fuel types, namely D100, AFBD100, VEBD100, VEBD50, and AFBD50. The test engine was subjected to several power loads, specifically 500, 1000, 1500, 2000, 2500, and 3000 watts. Throughout each load cycle, data on the engine's efficiency and exhaust emission values were meticulously recorded and subsequently subjected to thorough analysis. The trials yielded findings indicating that the use of AFBD100 and VEBD100 fuels resulted in an elevation in the specific brake fuel consumption (BSFC). The analysis of exhaust emissions revealed a decrease in brake thermal efficiency (BTHE) value. However, the utilization of AFBD100 and VEBD100 fuels resulted in a reduction in carbon monoxide (CO), hydrocarbon (HC), and smoke emissions compared to the D100 fuel. In contrast, there was a notable rise in emissions of carbon dioxide ($CO_2$) and nitrogen oxide (NOx). It is evident that gasoline compositions with VEBD provide superior outcomes in relation to both performance and emissions. If compared to fuels with VEBD in them, the VEBD50 performed better, while the VEBD100 gave better results in terms of emissions.

**Suleyman Simsek (2020)** [64] This study employed a single-cylinder, air-cooled diesel engine with a four-stroke configuration. The system operates at a constant rotational speed of 3000 revolutions per minute (rpm). The study investigates the impact of utilising a blend of canola, safflower, and waste oil generated by transesterification as biodiesel on both engine performance and exhaust emissions. The experimental findings demonstrate that the specific fuel consumption and thermal efficiency of the brakes exhibit a 1.95% increase and decrease, respectively, with the progressive inclusion of biodiesel fuel in the mixture relative to diesel fuel. Additionally, the emission analysis results indicate the stability of the mixture. In comparison to diesel fuel, the hydrocarbon content exhibited a reduction of 17.49%, the average concentration of carbon monoxide experienced a fall of 34.28%, and the emission of smoke decreased by 50.95% at a specified engine load. Conversely, carbon dioxide ($CO_2$) levels increased by 42.62% at the same engine load conditions. The concentration of nitric oxide (NOx) had a significant increase of 80.50%.

**Manzoore and Mahmood Khan (2021)** [65]. In this investigation, a single-cylinder, four-stroke, direct-injection diesel engine with an eddy-current dynamometer were used. The engine was subjected to full load circumstances, encompassing a range of engine speeds from 1000 rpm to 2400 rpm. Biodiesel was derived from the oil of Moringa oleifera. The performance and emissions characteristics of B10 and B20 biodiesel blends were evaluated and compared to those of high-speed diesel in a compression ignition engine. The data pertaining to performance and exhaust contaminants were gathered and subjected to analysis. The results of the study indicated that the use of MOB10 resulted in a decrease in blood pressure (7.44%), brake-specific fuel consumption (7.51%), and carbon dioxide emissions (7.7%). The application of MOB10 resulted in a decrease in smoke opacity by 24% and a reduction in hydrocarbon (HC) emissions by 10.27%. In contrast to diesel, the use of MOB10 resulted in elevated levels of carbon dioxide emissions by 2.5% and nitrogen oxides emissions by 9%.

**M.S. Gad et al (2021)** [66] .The researchers studied the effect of cooking oil on engine performance, emissions and combustion characteristics. The experimental investigation involved the testing of several oil mixtures in a diesel engine operating under a varied load condition and a rated rotational speed of 1500 revolutions per minute (rpm). The pyrolysis oil was blended with diesel oil and cooking oil in varying volume ratios of 0%, 20%, 40%, 60%, 80%, and 100%. Increasing the oil mixture ratio resulted in a decrease in both thermal efficiency and emissions of NOx and $CO_2$ in the vicinity of diesel oil. The B100 oil blend achieved maximum thermal efficiency and emissions of CO and NOx by 29, 45 and 65%, respectively, compared to pure diesel. The increase in the proportion of oil in the mixtures increased the specific consumption of hydrocarbons, fuel and smoke emissions compared to diesel oil. The utilization of pyrolysis oil B100 as a cooking oil resulted in the most significant rise in specific fuel consumption, hydrocarbon emissions, and smoke emissions, with increases of 28.3%, 33%, and 11% correspondingly, as compared to diesel oil. The utilisation of waste cooking oil (WCO) pyrolysis as a potential substitute fuel in diesel engines has been explored.

**K S Karthi Vinith et al (2021)** [67] study focused on doing experimental research on a single cylinder diesel engine. The study was conducted to examine the features, emissions, and performance attributes of the compression ignition (CI) method. The trans-esterification method facilitates the conversion of oil into biodiesel. In this pilot project, a blend of rice bran oil and jatropha oil was utilised as a co-feedstock for biodiesel production. The findings indicate that there is a drop in the calorific value of dual biodiesel blends as the concentration of biodiesel increases in the mixture of biodiesel and diesel. The specific fuel consumption of biodiesel is greater than that of diesel fuel the thermal efficiency of the brakes has been found to be lower for biodiesel blends. Diesel has lower carbon dioxide emissions than biodiesel blends. In the case of higher energy, biodiesel blends produce emissions of hydrocarbons and nitrogen oxides.

## 2.3 Effect of Alcohol/Biodiesel in Diesel blend on Engine Performance and Exhaust Emission

Efforts to replace diesel fuel and preserve the environment have become an urgent cause. In pursuit of this objective, researchers have concentrated on cost-effective alternative fuel sources while decreasing dependence on diesel fuel. Renewable alcohols have been extensively studied due to their potential as biofuels. These sustainable bio-fuels are oxygenated fuels that are good for the environment and may be made from a wide variety of non-food biomass sources, including tree bark, seaweed, and scraps from the farm. Due to their low cetane number and high latent heat of evaporation, the utilization of short chain alcohols in compression ignition engines presents a challenge. In contrast to short-chain alcohols, long-chain alcohols work better in CI engines. This is due to their greater CN and LHV values and lower hygroscopicity in comparison to short-chain alcohols.

**R. Sridhar et al (2018)** [68] :The researchers conducted an investigation of the impact of 1-pentanol on engine performance and emission characteristics, specifically focusing on its interaction with a blend of 1-pentanol/diesel and 1-pentanol/biodiesel. The experiment involved studying a single-cylinder piezo ignition diesel engine under six different load circumstances (0, 4, 8, 12, 16, and 20 kgf) while maintaining a constant speed of 1200 rpm. The study involved the testing of two reference fuels, namely diesel and biodiesel, as well as two test fuels consisting of mixes. The present study aimed to investigate and analyse the engine performance and emission characteristics of a fuel blend consisting of 20% 1-pentanol and 80% diesel or biodiesel. The experimental findings revealed that the combination of 1-pentanol and diesel fuel resulted in a simultaneous decrease in the emissions of nitrogen oxides (NOx), hydrocarbons (HC), and carbon monoxide (CO) when compared to the use of diesel fuel alone. However, it was also noted that the 1-pentanol/diesel mixture led to a loss in brake thermal efficiency (BTE). The utilisation of 1-pentanol/biodiesel blends shown reduced emissions of NOx, HC, and CO in comparison to pure biodiesel. The inclusion of 1-pentanol may be regarded as a highly promising fuel additive for utilisation in conjunction with both diesel and biodiesel fuels. The experiment was conducted solely on a 20% addition of 1-pentanol.

**A. Osman Emiroglu and Mehmet Şen (2018)** [69]: This study aimed to assess the impact of biodiesel and other alcohol additives on petroleum-based diesel fuel (DF) in terms of combustion, performance, and emissions of a single-cylinder diesel engine under varied engine load conditions. The initial step involved the combination of a 20% concentration of biodiesel with diesel fuel, resulting in a mixture referred to as B20. The composition of the combination was established as follows: 20% biodiesel, along with 10% butanol, 10% ethanol, or 10% methanol, which were denoted as B20Bu10, B20E10, and B20M10, respectively. The findings indicated that the ignition delay (ID) of the blend of biodiesel and alcohol was comparatively greater than that of diesel fuel (DF) due to the lower cetane numbers associated with the former. The heating values of biodiesel and alcohol were found to be comparatively lower than those of DF. The experiment revealed that the combination of B20 and alcohol exhibited elevated levels of specific brake fuel consumption (BSFC). The brake thermal efficiency (BTE) values for all fuels utilised in the conducted studies exhibited a high degree of similarity, with a maximum attainment of 0.27 MPa. The combination of B20 and alcohol resulted in a marginal elevation in nitrogen oxide (NOx) and hydrocarbon (HC) emissions, accompanied by a decrease in smoke and carbon monoxide (CO) emissions. The introduction of alcohol into the fuel mixture resulted in a notable decrease in smoke emissions across all engine loads. This can be attributed to the increased oxygen content and reduced carbon-to-hydrogen ratio present in alcohol.

**Jeya Jeevahan et al (2018)** [70]: This study investigated the impact of incorporating a substantial proportion of alcohol on both engine efficiency and emission parameters. The study involved conducting experiments on a single-cylinder piezo ignition diesel engine with a four-stroke cycle. The engine was subjected to four different load circumstances, specifically 5 kg, 10 kg, 15 kg, and 20 kg. During the duration of the experiments, the rotational velocity of the engine was continually maintained at a fixed value of 1500 revolutions per minute (rpm). Conventional diesel and biodiesel are commonly employed as benchmark fuels in various research and industrial applications. Various quantities of butanol (10%, 20%, 30%, 40%, 50%) were incorporated into diesel fuel dregs during the blending process of the experimental fuels. The researchers measured and analyzed the thermal efficiency of the brakes, as well as the emissions of carbon dioxide, nitrogen oxides, and hydrocarbons, and afterwards engaged in a discussion regarding these findings. The experimental findings indicate that the inclusion of 1-butanol resulted in a marginal decrease in the thermal efficiency of the brakes when compared to the use of pure biodiesel. Nevertheless, this development resulted in a decrease in specific fuel consumption, exhaust gas temperature, as well as the emissions of several pollutants such as nitrogen oxides, carbon dioxide, and hydrocarbons. Therefore, it can be inferred that the incorporation of butanol into biodiesel exhibits potential as a viable substitute for traditional diesel fuel in conventional combustion engines.

**Hazrulzurina Suhaimi et al (2018) [**71]: The study was conducted on a YANMAR TF120M single-cylinder diesel engine with a constant engine speed of

1800 rpm under various loads (0%, 25%, 50%, 75%, and 100%). In order to create a diesel-alcohol fuel blend with enhanced properties, varying concentrations of 2-ethyl 1-hexanol (2-EH) at 5%, 10%, and 20% were introduced into diesel fuel (DF). Fuel mixes were created with a Hielscher UP400S ultrasonic emulsifier operating at a stirring speed of 20% Hz. The analysis of performance indicated a significant gain of 91.72% in Brake Thermal Efficiency (BTE), accompanied by a notable decrease of 45.22% in Brake Specific Fuel Consumption (BSFC) while utilising a 5% concentration of 2-Ethylhexanol (HE5). The findings indicated that HE5 exhibits unique characteristics compared to other fuel combinations in relation to its calorific value (45.87 MJ / kg), density (806.1 kg / m3), and viscosity (3.02 MPa / s). The combination of 2-EH and DF leads to a notable decrease in NOx emissions across all load ranges. In addition, HE5 exhibits the capability to decrease the release of carbon dioxide (CO2), carbon monoxide (CO), and hydrocarbons within the medium and high load ranges. Evidently, the incorporation of long-chain alcohol, 2-EH, in conjunction with DF, exhibits favorable outcomes in terms of performance and combustion, resulting in a reduction in the engine's operational temperature and perhaps enhancing its longevity.

**Murat Kadir Yesilyurt et al (2018)** [72]: This study aimed to investigate and compare the performance and exhaust emissions of four-stroke, single-cylinder, direct-injection diesel engine operating on biodiesel/diesel/1-butanol and biodiesel/diesel/pentanol fuel blends, in comparison to conventional diesel fuels. The analysis was conducted under various engine speeds and full load operating situations. The test fuel was prepared through the addition of 5% and 10% by the amount of 1-butanol and n-pentanol, respectively. Motor test results showed that BSFC increased between 0.77% and 8.07%. As the quantity of alcohol increased, there was a corresponding decrease in brake force and torque. Nevertheless, the utilization of alcohol-blended fuel led to a notable elevation in both the temperature of exhaust gases (EGT) and carbon dioxide ($CO_2$) emissions. Additionally, the higher oxygen content in alcohol compared to diesel fuel led to a higher emission of oxygen ($O_2$). The addition of alcohol mixtures resulted in a decrease of nitrogen oxides ranging from 0.56% to 2.65%, carbon dioxide ranging from 6.90% to 32.40%, and smoke ranging from 10.47% to 44.43%. Furthermore, the fuel blend including n-pentanol exhibited superior performance and emission outcomes compared to the blend containing 1-butanol. Empirical investigations have demonstrated that the incorporation of higher alcohols, specifically n-pentanol and 1-butanol, into biodiesel/diesel blends exhibits potential as an alternate strategy for enhancing emissions in diesel engines.

**Geetesh Goga et al (2019)** [73]: A research investigation was carried out in this work on a single-cylinder diesel engine with direct injection and air-cooling, having a power output of 3.73 kW. The experiments were conducted under conditions of a consistent rotational speed of 1,550 revolutions per minute (rpm). The utilization of biodiesel derived from rice bran, as well as the incorporation of mixes including n-butanol at various concentrations (B10, B20, B10 nb10, and B20nb20), is being investigated. These combinations were tested, and performance and emissions characteristics were observed at different engine loads and BSFC, BTE, CO, HC, NOx and smoke were compared to pure diesel fuel. Biodiesel was prepared by transesterification process. The findings indicated that the utilisation of particular BSFC brake fuel exhibited an upward trend as the proportion of biodiesel and n-butanol in the blends surpassed that of conventional diesel fuel. The thermal efficiency of the brakes was lower than that of diesel for mixtures containing n-butanol. Carbon dioxide emissions have been found to decrease with biodiesel and decrease with n-butanol. Hydrocarbon emissions were reduced with rice bran biodiesel blends but with addition of n-butanol, NOx emissions are greater when biodiesel is added to fuel mixtures, while a decline was observed in the presence of n-butanol in biodiesel blends, as indicated by the findings of an experimental study. Rice bran and n-butanol have the potential to be utilized as a fuel source in diesel engines without necessitating any modifications to the engine.

**Umit Agbulut et al (2019)** [74]: This study aimed to conduct an empirical examination of the impact of a mixture comprising diesel, biodiesel, and alcohol on combustion characteristics, engine performance, and emissions. The analysis was carried out on a direct-injection, air-cooled, naturally aspirated, and single-cylinder diesel engine. The experiments were carried out at various engine speeds, specifically 1750,2250,2750, and 3250 rpm, while operating under load conditions. Multiple fuel types were utilised in the study, including a reference diesel fuel (referred to as D100), a blend consisting of 20% cottonseed methyl ester (referred to as D80C20), a blend containing 10% ethanol (referred to as D90E10), and a blend including a triple combination of these derivatives (referred to as D70C20E10). The findings indicated that the decreases in NOx and CO2 emissions were not substantial and exhibited a range of 2-7%. In conjunction with the decrease in exhaust emissions, notable percentages of CO2 emissions were recorded for the D90E10, D70C20E10, and D80C20 fuels, amounting to 42%, 30%, and 8% correspondingly. The reductions in hydrocarbon emissions, amounting to 40%, 31%, and 23%, were successfully attained in the D90E10, D70C20E10, and D80C20, correspondingly. The biodiesel blends exhibited a prolonged ignition delay in comparison to the D100 fuel, which can be attributed to their lower cetane values. The duration of combustion was seen to decrease concomitantly with an increase in engine speed, owing to the heightened turbulence within the combustion chamber at higher engine speeds. Furthermore, this circumstance resulted in enhanced uniformity of the test fuel and a heightened level of combustion process efficiency.

**Nagarajan Jeyakumar and N Bose (2019)** [75]: This study aimed to investigate the impact of varying amounts of pentanol when added to Karanja oil biodiesel on the performance and emission characteristics of diesel engines. The experimental investigation involved analysing the performance and emission characteristics of various fuel samples, including diesel, K100, K90Pn10, and K80Pn20. These analyses were conducted under varying loading situations while maintaining a constant speed of 1500 rpm. The studies were conducted on a water-cooled direct injection diesel engine with a single cylinder. The engine was fueled with a blend of Karanja biodiesel and pentanol, with a volume ratio of 10% and 20% respectively. The use of Pentanol into Karanja biodiesel resulted in an elevation in Brake Thermal Efficiency (BTE) and a reduction in Brake Specific Fuel Consumption (BSFC). In addition, the utilization of an oxygenated fuel blend in diesel engine fuel has been observed to result in a reduction of hydrocarbon (HC), carbon dioxide ($CO_2$), and smoke emissions. This reduction can be attributed to the higher latent heat of vaporization exhibited by pentanol, as well as the subsequent increase in carbon dioxide emissions. Additionally, the aforementioned oxygenated fuel blend has also been found to contribute to a decrease in nitrogen oxide (NOx) and exhaust gas temperatu Based on the findings, it can be inferred that both K90Pn10 and K80Pn20 exhibit characteristics that render them viable substitutes for conventional fuels in diesel engines, without necessitating any modifications.

**Mingzhang Pan et al (2019)** [76]: The researchers conducted experiments on a four-cylinder diesel engine. The study included visualisation techniques and engine pilot testing methodologies to investigate the spraying, combustion, and emission characteristics of diesel/n-pentanol blends. The findings of the study indicate that when engine load increases, the dissolving properties of the diesel/n-pentanol mixture exhibit superior characteristics compared to diesel alone. Additionally, the maximum pressure within the cylinder and the rate of heat release also experiences an increase. The findings of the engine performance study demonstrated a decrease in brake-specific fuel consumption (BSFC), nitrogen oxides (NOX), hydrocarbon (HC), and carbon monoxide (CO) emissions. However, it was observed that there was an increase in soot emissions. The addition of n-pentanol to pure diesel fuel led to a decrease in soot emissions when compared to diesel fuel alone, but with an increase in hydrocarbon (HC) and nitrogen oxide (NOX) emissions. The addition of a 50% concentration of n-pentanol to pure diesel fuel (referred to as P50) resulted in a reduction of soot emissions by as much as 77.15% and a a reduction seen in the thermal efficiency of brakes (BTE) amounting to a loss of 1.86%. Therefore, the P50 fuel can be combusted directly in the diesel engine without necessitating any alterations. This combustion method leads to a noteworthy reduction in soot emissions. However, it is important to note that the brake thermal efficiency (BTE) experienced only a minor decline in this scenario.

**Mohamed Nour et al (2019)** [77]: In this study, the effect of a butanol/diesel, heptanol/diesel and octanol/diesel mixture on diesel engine combustion, performance and emissions was evaluated using an air-cooled, single-cylinder, four-stroke diesel engine. The study focuses on the use of a natural air intake piezo ignition system in conjunction with direct injection, specifically examining engine speeds of 900 rpm and 1500 rpm. In order to preserve the fuel system without necessitating any alterations, it is necessary to adhere to the mixing ratios of 10% and 20% volume/volume. The detected combinations displayed stable and homogeneous traits throughout a period of 4 months, despite any instances of separate phases. The study involved conducting experiments under various load conditions, specifically at 0%, 25%, 50%, and 75% full load. The findings of the study indicated that the brake specific fuel consumption (bsfc) and brake thermal efficiency (BTE) generally exhibited an increase across the majority of the tested top alcohol/diesel mixes. The combustion process of pre-blended fuels was found to be optimised across all evaluated alcohol/diesel blends. It was observed that the ignition delay time rose as the proportion of alcohol in the mixture increased. Notably, the longest ignition delay time was observed in the But10 and But20 blends. The Hept20 experiment yielded the largest cumulative net heat release. The recorded emissions of carbon dioxide and hydrocarbons exhibited an increase in all examined mixes of greater alcohol and diesel, when compared to the respective values for D100. While NOx emissions and blackout have been reduced.

**Helin Xiao et al (2020)** [78]. The combustion performance and emission characteristics of direct injection diesel engines running experimentally with an iso-butanol/biodiesel blend under different loading conditions were studied. The experiment was conducted at five different engine load circumstances, specifically 0.13, 0.38, 0.63, 0.88, and 1.13 MPa BMEP, while maintaining a constant engine speed of 1800 rpm. The study revealed that the incorporation of iso-butanol in biodiesel enhances both the evaporation and spray performance, while also altering the combustion characteristics of the mixed fuels. The ignition delay is shown to be prolonged in fuels that have been subjected to higher concentrations of isobutanol during testing. However, the combustion time will decrease as the iso-butanol level rises when engine loads exceed 0.38 MPa. It was found that the iso-butanol/biodiesel mixture increases BTE and decreases BSFC at a 1.13 MPa BMEP engine load compared to pure biodiesel. For pollutants, the isobutanol/biodiesel mixture reduces $CO_2$ emissions except for 0.13 MPa. A substantial augmentation in nitrogen oxide (NOx) emissions is found when isobutanol is blended with medium and high engine loads. In relation to particulate emissions (PM), it was observed that the concentration of particles measuring less than 10 nm saw an increase, while the concentration of larger particles exhibited a progressive drop as the iso-butanol level increased.

**A. Devaraj et al (2020)** [79] The study involved the utilisation of cashew nut biodiesel (CNBD) in the experimental procedure. Specifically, two blends were created by including 10% and 20% pentanol with cashew nut biodiesel, resulting in the concentrations CNBD90P10 and CNBD80P20, respectively. The emission characteristics of biodiesel have also been extensively studied and analysed. The experiment involving fuel testing was conducted using a single-cylinder four-stroke diesel engine. The experimental procedures were conducted without making any alterations to the engine. Furthermore, the engine operates with optimal efficiency and no signs of damage were detected during the meticulous examination of the Clean and Neatly Balanced Diagnostic (CNBD). The addition of pentanol mixtures at concentrations of 10% and 20% to CNBD results in a notable decrease in the emissions of carbon monoxide (CO), hydrocarbons, and smoke when compared to both diesel fuel and CNBD without any pentanol additives. Moreover, it serves as a potentially viable solution for enhancing energy security.

**Rickwinder Singh et al (2020)** [80] The impact of biodiesel (B) butanol on the performance of a diesel engine was investigated by the researchers. In order to investigate the effects of various fuel samples on the performance of a Kirloskar TV1 engine, which is a single cylinder, four-stroke, naturally aspirated, liquid-cooled engine operating at a speed of 1500 rpm, biodiesel (B) is produced using eucalyptus oil. The produced biodiesel is then blended with conventional diesel fuel at a mixing ratio of B20, which corresponds to a 20% biodiesel content. The study involved the use of different fuel samples, namely B100 (a type of biodiesel known for its aesthetic appeal), B20-5Bu (a blend consisting of 20% biodiesel, 75% diesel, and 5% butanol), B20-10Bu (a blend consisting of 20% biodiesel, 70% diesel, and 10% butanol), and B20-15Bu (a blend consisting of 20% biodiesel, 65% diesel, and 15% butanol). These fuel samples were subjected to varying engine loads for testing purposes. The findings indicated a marginal rise in braking force (BP) and an elevated brake fuel consumption (BSFC) attainable with the utilisation of butanol, biodiesel, and diesel fuel. However, the brake thermal efficiency (BTE) experienced a decrease at full load conditions. The findings demonstrated a mean decrease of 10% and 20% in carbon dioxide (CO2) levels. The unburned hydrocarbon emissions for B20 and B100 are found to be 36.7% and 46%, respectively. Additionally, it is worth noting that: the experimental results indicate that B20-5Bu, B20-10Bu, and B20-15Bu exhibited an average decrease in NOx emissions of 23.55%, 21.9%, and 25.16% respectively, owing to the cooling impact of butanol. Ultimately, it has been declared that butanol diesel, specifically biodiesel, exhibits considerable potential as a viable fuel alternative to traditional diesel.

**Kartikkumar Thakkar et al (2020)** [81] The objective of this research, conducted on a four-stroke single-cylinder diesel engine, is to examine the impact of a triple mixture comprising n-butanol, castor oil methyl ester (COME), and diesel on various aspects of engine performance, emissions, and combustion characteristics. The primary goal is to identify the optimal blending ratio that can effectively reduce emissions of unburned hydrocarbons (UHC), carbon monoxide (CO), and nitrogen oxides (NOx), while maintaining engine performance. The study involved utilising elegant diesel as the reference fuel in order to conduct a comparative analysis of its combustion characteristics, performance, and emissions in relation to fuel blends consisting of dual and tertiary components (namely, B30, B20Bu10, B10Bu20, and B15Bu15). The ignition delay period remained unaffected for the B30 combination; however, an increase ranging from 2.89 to 3.35 degrees Celsius was detected for the gasoline combined with n-butanol. The experimental findings demonstrated that the utilisation of a tri-fuel blend, specifically B15Bu15, resulted in enhanced engine performance attributes. Additionally, this fuel mixture exhibited a notable reduction in NOx emissions, ranging from 20% to 60% when compared to the utilisation of B30 fuel. The findings of the study indicate that the utilisation of the B30 fuel blend resulted in a reduction of 1-3% in brake thermal efficiency (BTE), accompanied by an elevation in greenhouse gas emissions. The utilisation of B10Bu20 has been found to have a negative impact on engine performance, emission characteristics, and combustion behaviour. Hence, the gasoline mix known as B15Bu15 was seen as an optimal choice.

**Murat Kadir Yesilyurt et al (2020)** [82] Tests were conducted on a single-cylinder, four-stroke, naturally aspirated, four-load direct injection diesel engine at a constant engine speed of 3000 rpm. The objective of this research is to examine the impact of a combination of safflower oil biodiesel and a triple blend of diesel, biodiesel, and pentanol on the operational efficiency, emissions, and combustion characteristics of a diesel power generator. The test fuel samples were formulated using a volumetric approach, resulting in the following compositions: B20, B20P5, B20P10, B20P15, and B20P20. Based on the findings, it was observed that the utilization of triple mixes resulted in a decrease in brake thermal efficiency (BTE), while brake specific fuel consumption (BSFC) exhibited an increase of up to 13.90% in comparison to the use of diesel fuel. Adding pentanol to the diesel and biodiesel mixture reduced emissions (carbon dioxide, hydrocarbons and smoke).In addition, increasing the concentration of pentanol has a significant impact on the decrease in NOx emissions. The rise in carbon dioxide emissions can be attributed to the phenomenon of complete combustion, which occurs as a result of an excess of oxygen content. Upon reviewing the findings of the combustion analysis, it was observed that the inclusion of pentanol resulted in a decrease in the rate of heat release and a reduction in ignition delay by approximately 15% when compared to diesel fuel. The current study suggests that pentanol exhibits potential as a viable higher alcohol option for utilization in pressure ignition engines in the foreseeable future.

**Krishna Shrivastava et al (2021)** [83] Experiments were conducted on a single-cylinder four-stroke diesel engine with a constant speed of 1500 rpm and an injection pressure of 210 bar. This study examines the Karanja biofuel blend, consisting of ethanol and diesel, and investigates the effects of different payloads (ranging from 0 kg to 12 kg) on three fuel samples, namely K20, K25, and K30. The test samples consist of three different compositions: K20, K25, and K30. K20 is composed of 15% Karanja biodiesel, 5% ethanol, and 80% diesel. K25 contains 20% Karanja biodiesel, 5% ethanol, and 75% diesel. Lastly, K30 is composed of 20% Karanja biodiesel, 10% ethanol, and 70% diesel. The experiment involved altering four input parameters: compression ratio, blending ratio percentage, loads, and injection angle. These modifications were made in order to observe the resulting engine responses, namely brake thermal efficiency, brake specific fuel consumption, $CO_2$ emissions, CO emissions, NOx emissions, hydrocarbon emissions, and exhaust gas temperature, and experiments have shown that the specific fuel consumption of the brakes is 3% higher. and a marginal reduction in brake thermal efficiency of about 2%, an increase in exhaust gas temperature of 3%, an increase in carbon dioxide by 0.86%, a decrease in carbon monoxide, a decrease in hydrocarbons by 12 ppm. There is a rise in nitrogen oxide levels of 0.029% and 8% when comparing to diesel at full load.

**B. S. Ajith et al (2021)** [84] The practical efficacy of Garcinia gummi-gutta (GGG) oil-based methyl esters blended with 20% ethanol and diesel fuel was investigated by the researchers. This investigation involved conducting experiments on six fuel samples (D100, B20E20, B30E20, B40E20, B100E20, and B100) under various engine loads (0%, 20%, 40%, 80%, and 100%) while maintaining a constant engine speed of 1500 rpm. Biodiesel, diesel, and ethanol blends demonstrated fuel characteristics that closely resembled those of conventional diesel fuels. The findings indicate that the brake fuel consumption of all biodiesel fuels exhibited a modest increase compared to diesel fuels, but dropped as the engine load increased. When the engine operated under maximum loads, the researchers determined that the brake thermal efficiency (BTE) of the diesel fuel was measured at 26.25%. In contrast, the biodiesel blend exhibited a range of brake thermal efficiencies, spanning from 22.5% to 25.2%. Biodiesel (B100E20) exhibits a 35.71% decrease in hydrocarbon (HC) emissions in comparison to diesel fuel. The results indicate a significant decrease of 32.56% in carbon monoxide (CO) emissions across all engine loads for biodiesel blended fuels. However, it should be noted that the levels of nitrogen oxides (NOx) emissions in these fuels are slightly elevated compared to those of conventional diesel fuels. When operating at maximum capacity, the B100E20 fuel blend, consisting of 100% diesel and 20% ethanol, exhibits a reduction in $CO_2$ emissions by 6.45% and hydrocarbon emissions by 6.64%, while simultaneously increasing brake thermal efficiency (BTE) by 0.8% in comparison to pure biodiesel (B100). The incorporation of GGG-derived biodiesel in conjunction with ethanol has demonstrated enhancements in the fuel characteristics, operational efficiency, and exhaust emissions of conventional diesel fuel.

## 2.4 Summary for (Diesel+ Biodiesel) Engines

Table (2.1): Summary for (Diesel+ Biodiesel) Engines.

| No.S | Author Ref. | Engine description | Experimental Fuels | Engine performance results | Exhaust emission results |
|---|---|---|---|---|---|
| **1** | **Roopesh Kanwar et al. [55]** | Kirloskar single cylinder water-cooled, four-stroke diesel engine | castor oil (Ethyl ester) | 1-Brake thermal efficiency and brake specific fuel consumption decrease and increase respectively | 1-decrease in (CO)<br>2- (CO2) and (NOx) increase |
| **2** | **Jayashri N. Nair et al. [56]** | a single cylinder four stroke water cooled engine. | Neem oil as biodiesel | 1-higher brake thermal efficiency than diesel. | 1-CO and HC, CO2, and NOX emissions decreasing than diesel |
| **3** | **J. Jayaprabakar [57]** | four stroke, vertical, and air cooled Diesel engine | Algae oil methyl esters<br>Rice bran oil methyl esters | 1-increased specific fuel consumptin<br>2-Brake thermal efficiency values of biodiesel are closer to Diesel. | 1-lesser unburnt hydrocarbons, Carbon monoxide<br>2-higher NOx emissions |

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| **4** | **N. Karthik et al. [58]** | A single cylinder, four-stroke CI engine | rubber seed oil (RSO) | 1-BSEC increases | 1-decrease in (UHC) and (CO)<br>2-Increase in NOx |
| **5** | **M.S. Gad et al. [59]** | diesel engine a single cylinder, four stroke, air cooled, | palm oil/palm oil methyl | 1-Thermal efficiency lower<br>2- Specific fuel consumptions higher. | 1-NOX emissions increased<br>2-CO and HC were reduced |
| **6** | **K.A. Abed et al. [60]** | diesel engine Kirloskar make, single cylinder, four strokes | Waste cooking-oil (wco) | 1-Thermal efficiencies of lower<br>2- BSEC higher. | 1-CO, HC and other emissions lower for (wco)<br>2-NOX and CO2 emissions are increased with the increase of (wco) |
| **7** | **Ahmet Uyumaz [61]** | single cylinder, four stroke, DI diesel engine | mustard oil (M) | 1-BTE decreased with M10<br>2- BSFC increased with M10 | 1-Reduce carbon dioxide and smoke emissions<br>2-Increase in NOx with (M) |
| **8** | **N. Nirmala [62]** | A four stroke Kirloskar TV1 vertical model IC diesel engine | Waste cooking oil WCOBD algal oil AOBD | 1-WCOBD has better lower BSFC, higher BTE and BP than AOBD | 1-AOBD has better lesser CO%, higher CO2% than WCOBD<br>2-NOx emissions for both the fuels were higher |
| **9** | **Suleyman Simsek [63]** | air cooled, naturally aspirated, four-stroke, single cylinder and direct injection diesel engine | Vegetable Biodiesel (VEBD)<br>Animal Biodiesel (AFBD) | 1-BTHE values decreased<br>2-BSFC values increased | 1-NOx emissions increased<br>2-decreased CO and 3-HC emissions risen CO2 emissions |
| **10** | **Suleyman Simsek [64]** | A naturally aspirated, air-cooled, single-cylinder, four-stroke, | consisting of canola, safflower | 1-specific fuel consumption increased<br>2-Brake thermal efficiency was | 1-Use of biodiesel reduced HC, CO emissions and increased NOx emissions. |

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| | | direct injection diesel engine | | observed decreased | |
| **11** | **Manzoore Elahi M. Soudagar [65]** | A naturally aspirated, single-cylinder, four-stroke, direct injection diesel engine | Moringa oleifera oil (MOB) | 1-BTE for MOB10 lower<br>2- BSFC for MOB10 higher | 1- HC emission lower than diesel<br>2- NOx emission higher than diesel |
| **12** | M.S. Gad **[66]** | diesel engine DEUTZ FI L511 | waste cooking oil | 1-reduced the thermal efficiency<br>2-increased the specific fuel consumption | 1-decrease in CO emission<br>2- increase of HC emissions |
| **13** | **K S Karthi Vinith et al [67]** | stroke Single-Cylinder Diesel Engines | rice bran and Jatropha oil blend mixture | 1- BTE of biodiesel is lower.<br>2- BSFC of biodiesel is larger than the diesel | 1- The biodiesel has lower HC<br>2- reduces NOx emissions |

## 2.5 Summary for (Diesel+ Alcohol/Biodiesel) Engines

Table (2.2): Summary for (Diesel+ Alcohol/Biodiesel) Engines

| No.S | Author Ref. | Engine description | Experimental Fuels | Engine performance results | Exhaust emission results |
|---|---|---|---|---|---|
| **1** | **R. Sridhar et al. [68]** | A single cylinder and four stroke diesel engines | waste cooking oil<br>pentanol | 1-efficiency of diesel fuel is higher than that of biodiesel and the fuel blends<br>2-Diesel showed the least specific fuel consumption | 1-Pentanol, biodiese blends lowered the emissions of NOx, HC and CO |

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| **2** | **A. Osman B. [69]** | single-cylinder diesel engine a Kistler | cottonseed biodiesel butanol, ethanol, and methanol | 1-B20 and alcohol blends had higher BSFC<br>2-The BTE values of all the fuels less than diesel | 1-(NOx) increased with B20<br>2-reducing smoke and (CO) with alcohols |
| **3** | **Jeya Jeevahan et al. [70]** | A single cylinder and four stroke diesel engines | waste cooking oil<br>Butanol | 1-addition of butanol reduced the brake thermal efficiency<br>2-reduced specific fuel consumption and exhaust gas temperature | 1-addition of butanol reduced emissions of all tested gases (NOx, CO and HC) |
| **4** | **Hazrulzurina Suhaimi et al. [71]** | The engine works on four-stroke cycle | 2-ethyl -hexanol | 1-HE5 has the BTE is higher and BSFC is lower than other fuel blends | 1-HEX show decreased of CO, HC, and NOx |
| **5** | **Murat Kadir et al. [72]** | a single-cylinder, four-stroke, direct injection diesel engine | yellow mustard seed oil<br>butanol<br>pentanol | 1-BSFC of butanol and n-pentanol higher than diesel fuel<br>2-BTE of most ternary blends was lower than diesel | 1-The addition of pentanol and butanol fuel reduced CO and NOx |
| **6** | **Geetesh Goga et al. [73]** | air-cooled engine manufactured by Kirloskar Oil India | rice bran biodiesel<br>butanol | 1-Brake specific fuel consumption increased with biodiesel and n-butanol<br>2-Brake thermal efficiency lesser than diesel for blends | 1-CO and HC decreased with the inclusion of rice bran and n-butanol in the blends<br>2-NOx more by adding biodiesel and decreases by adding butanol |
| **7** | **Ümit Ağbulut et al. [74]** | direct injection, air-cooled, | cottonseed methyl ester<br>ethanol | 1-blends resulted in the highest torque values | 1-reduce in CO emissions and HC |

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| | | naturally aspirated and single-cylinder diesel engine. | | 2-increasing engine speed, the power increased approximately | 2-biodiesel and ethanol reduce of NOx |
| **8** | **Nagarajan Jeyakumar [75]** | Single cylinder, water-cooled, direct injection diesel engine | Karanja oil biodiesel (K)<br>Pentanol | 1-BTE increased than that of K100<br>2-BSFC decreased<br>3-EGT values lower than that of K100 | 1-The CO2 value higher than that of K100<br>2-CO emission and HC lower than that of K100 |
| **9** | **Mingzhang Pan et al. [76]** | a four-cylinder diesel engine | Diesel-pentanol | 1-BSFC increased<br>2-BTE decreased | 1-CO and HC emissions decreased<br>2-NOX emissions decreased |
| **10** | **Mohamed Nour [77]** | a single cylinder, air cooled, four stroke, and direct injection CI | butanol/diesel,<br>heptanol/diesel<br>octanol/diesel | 1-decrease in BTE<br>2-bsfc lower than of D100 | 1-NOx and opacity were reduced<br>2-CO and HC emissions were increased |
| **11** | **Helin Xiao et al. [78]** | direct injection diesel engine | soybean biodiesel<br>butanol | 1-butanol/biodiesel blends could increase the BTE and reduce the BSFC compared with pure biodiesel | 1-CO and HC emissions increase<br>2-NOx emissions decrease |
| **12** | **A.Devaraj et al. [79]** | four-stroke, singlecylinder diesel engine | cashew nut biodiesel (CNBD)<br>pentanol | | 1-lowered CO, HC and smoke emissions |
| **13** | **Rickwinder Singh et al. [80]** | Kirloskar TV1, single-cylinder, four-stroke, naturally aspirated, liquid-cooled diesel engine. | eucalyptus oil<br>butanol | 1-increase in brake power (BP)<br>2-higher brake specific fuel consumption (BSFC) | 1-CO and HC are decreased<br>2-CO2 has higher value than diesel |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 3-brake thermal efficiency (BTE) is decreased | 3-NOx emission is increased (B100) and blend (B20) |
| **14** | **Kartikkumar et al. [81]** | Zero-dimensional engine modeling studies using multi-Wiebe burn | castor oil methyl ester (COME)<br>butanol | 1-B30 fuel blend showed reduction in BTE and increased in BSF compared to butanol blended fuels | 1-NOx and CO formation reduced compared to B30 and diesel. |
| **15** | **Murat Kadir Yesilyurt et al. [82]** | a single-cylinder, four-stroke, air-cooled DI diesel engine generator | diesel–safflower oil biodiesel<br>diesel–biodiesel–pentanol | 1-ternary blends reduced BTE while increased BSFC compared to diesel and B20 | 1-The addition of pentanol increases the decrease in nitrogen oxides and reduce emissions (carbon dioxide, hydrocarbons, smoke), while carbon dioxide emissions increased |
| **16** | **Krishna Shrivastava [83]** | four stroke single cylinder diesel engine | Karanja biodiesel<br>ethanol | 1-reduction of brake thermal efficiency<br>2-Brake specific fuel consumption higher | 1-Carbon dioxide increases hydrocarbon decreases<br>2-Carbon monoxide and Nitrogen oxide reduced |
| **17** | **B. S. Ajith et al. [84]** | Four stroke, direct injection, variable compression ratio diesel engine | Garcinia gummi-gutta seed<br>ethanol | 1-BSFC for all biodiesel blends is slightly higher<br>2-Thermal efficiency (BTE) is lower | 1-reduction (CO) emission and of hydrocarbon (HC) |

# CHAPTER THREE

# EXPERIMENTAL WORK

# CHAPTER THREE
# EXPERIMENTAL WORK

## 3.1 Introduction:

This chapter provides a detailed description of the experimental equipment, measuring tools used, and the procedural steps undertaken to conduct the study. Provides a description of the fuel used and procedures for measuring operational parameters, biodiesel production, and exhaust gas emissions measurement to assess the impact of incorporating various forms of renewable fuels into a compression ignition engine in terms of both performance and pollutant concentrations, compared to conventional diesel. Experiments with the engine use mixed proportions of biodiesel, diesel, and alcohol. In order to investigate the efficiency and environmental impact of C.I. Light Iraqi diesel, the TD202 engine was chosen as the experimental platform. The TD202 engine is specifically designed for testing tiny single-cylinder engines commonly used in various applications such as lawnmowers, cultivators, pumps, and generators. The engine load test package includes a powerful hydraulic dynamometer with simple operation. The efficiency of this dynamometer is notable, since it eliminates the requirement for substantial electrical supply or load resistors due to the dissipation of the motor's power in water flowing through the dynamometer.

## 3.2 Biodiesel:

Biofuels, such as biodiesel and ethanol, pentanol, heptanol, and methanol, derived from renewable sources such present promising alternatives for fulfilling energy demands and mitigating emissions. The renewable nature, biodegradability, and superior fuel properties compared to diesel make it a favorable choice [85],[86]. Currently, biodiesel is widely considered as a potential alternative to conventional diesel fuel. Biodiesel is a potential alternative fuel that can be used to address the environmental issues arising from the combustion of diesel fuel.

### 3.2.1 Biodiesel Preparation:

Biodiesel was synthesized using the process of transesterification using waste cooking oil (WCO) as feedstock. The process of transesterification involves the conversion of a triglyceride, commonly present in vegetable oil or animal fat, with alcohol. This chemical reaction results in the formation of glycerol and esters derived from the three initial fatty acids, which collectively constitute biodiesel. The addition of excess alcohol is employed in order to promote the synthesis of esters, as transesterification is known to be a reversible reaction. Furthermore, using a catalyst serves the purpose of minimizing the reaction time and maximizing the yield. The aforementioned preparation was conducted at the laboratory specializing in fuels. Figure (3-1) illustrates the flow chart representing the process of biodiesel generation.

### 3.2.2 Characteristics of Alcohols and Catalysts Used in Biodiesel Production:

Alcohols that are suitable for biodiesel generation are characterised by short carbon chains. These alcohols include amylic alcohol, ethanol, and methanol [87]. Ethanol ($C_2H_5OH$) and methanol ($CH_3OH$) are extensively employed alcohols in various applications owing to their favorable characteristics and cost-effectiveness. Methanol is frequently favored over ethanol, despite its elevated toxicity, due to its compatibility with less complex technological requirements in the context of biodiesel synthesis. It is crucial to consider that the generation of biodiesel as an environmentally friendly fuel requires obtaining it from oils made from vegetables and fats from animals, in combination with alcohol obtained from biomass, such as bioethanol, instead of relying on petrochemical compounds. In the current study, methanol was employed as the reagent alcohol. Both catalysts (KOH) or (NaOH) are commonly utilized to produce high-quality biodiesel. As a result, using (KOH) as a catalyst for biodiesel production from any (WCO) is preferable than using (NaOH). When it comes to biodiesel productivity, the usage of (KOH) results in a better output than (NaOH)

## 3.3 Biodiesel Preparation system:

The experimental setup comprises a glass flask affixed to an electric heater and a magnetic stirrer equipped with a temperature sensor for monitoring and regulating the temperature. As seen in Figures(3-1a) and (3-1b), and Figure (3-2), the flow chart illustrates the biodiesel production process. Waste cooking oil was brought in from a local restaurant. The other chemicals, including alcohol and catalyst, were procured from a local vendor in Najaf Governorate for the purpose of producing biodiesel from Waste cooking oil. Heavy pollutants were first taken out of the oil using a medium-permeability sieve, and then any leftover impurities were taken out using filter paper. To dilute the waste cooking oil and remove the humidity, it was heated to (150°C).

The stages of the biodiesel production process are as follows:

1. The process of alcohol-catalyst blending.
2. The chemical reaction.
3. The process of segregating the reaction products
4. The purification process of the reaction products is undertaken.

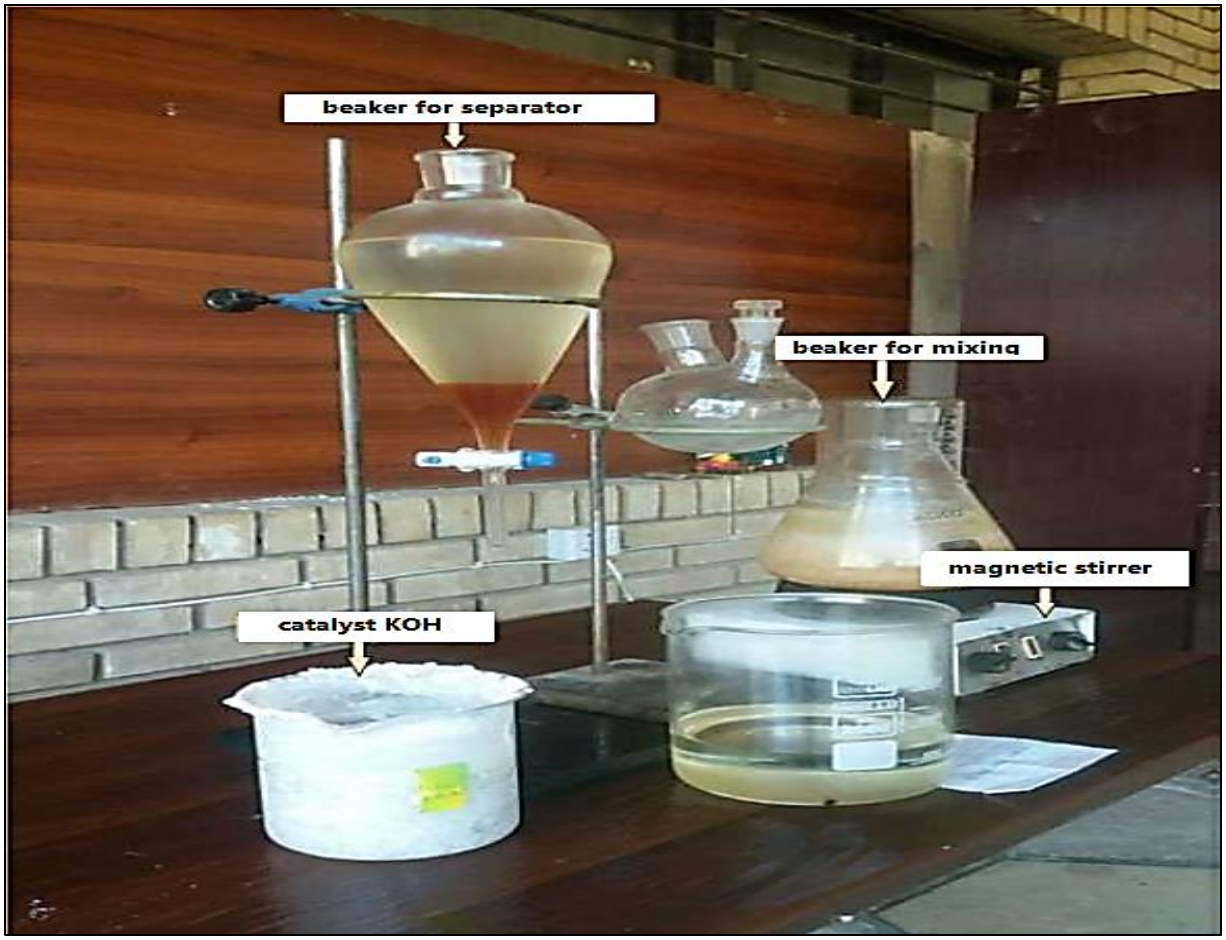


Figure (3-1a): Biodiesel preparation system.

### 3.3.1 Blending of alcohol- catalyst:

It Methanol was employed in the synthesis of biodiesel in conjunction with the catalyst potassium hydroxide (KOH) and waste cooking oil (WCO). In the process of biodiesel production, it is recommended to combine alcohol (specifically methanol) with the catalyst (potassium hydroxide, KOH) before introducing the waste cooking oil. The mixture was agitated for a duration of 20 minutes until complete dissolution of the catalyst in the alcohol was achieved [88][89]. A mixture consisting of one litre of waste cooking oil (WCO)(25% v/v oil) of methanol (6:1 mol ratio) and (1% m/m oil) of potassium hydroxide (KOH) dissolved in methanol. Potassium hydroxide (KOH) and methanol are inherently dangerous substances, particularly methoxide. It is imperative to ensure that these compounds do not come into touch with the skin, and that inhalation of their vapors is strictly avoided.

### 3.3.2 The chemical reaction:

The initial step involves heating the oil to a temperature below the boiling point of alcohol. Subsequently, the alcohol catalyst mixture is cautiously added to the heated oil, followed by stirring the combination at a rotational speed ranging from 300 to 400 rpm. The admixture is heated and maintained between (50 to 65°C), which is quite near the alcohol's boiling point but not exceeding it in the mixing machine, and approximately for ninety minutes it is continually stirred. It is imperative to maintain a state of strong and continuous stirring throughout the whole reaction duration in order to facilitate the interaction between the reaction components, particularly when employing short-chain alcohols. Following the completion of the reaction, it is advisable to remove any residual methanol by subjecting the resulting product to ambient air, therefore facilitating its evaporation. The mixture was then allowed to undergo sedimentation inside a separating funnel, where it was left undisturbed for 8 to 12 hours, facilitating the separation of its constituents into two distinct liquid phases. Glycerol makes up the lower layer, whereas biodiesel or (FAME) makes up the upper layer.

### 3.3.3 Separation of reaction products:

The beaker was employed for the purpose of segregating the mixture of reaction products comprising fatty acid methyl esters (FAME) and glycerin. The separation of reaction products is achieved through the process of decantation.

Specifically, a biphasic system is formed when a mixture of fatty acid methyl esters (FAME) and glycerol is allowed to settle. This separation occurs due to the distinct densities of the two phases. Notably, the formation of the two phases commences once the stirring of the mixture has halted. The majority of the catalyst and surplus alcohol will accumulate in the bottom phase, which consists of glycerol. Simultaneously, a layer composed of methyl or ethyl ester, known as biodiesel, will form at the upper phase. Following the separation of glycerol, the resulting mixture, known as FAME, is found to contain contaminants like alcohol and residual catalysts. The presence of impurities in FAME can lead to the manifestation of unfavorable characteristics, such as a decrease in flash point, an increase in spill point, and an alteration in draw point, among others. Consequently, the purification process becomes significant in ensuring that the ultimate product adheres to the prescribed requirements. The matter at hand warrants further examination in the subsequent section.

### 3.3.4 Purification of the Reaction Products:

In order to adhere to the prescribed quality criteria for biodiesel, it is imperative to purify the mixture of fatty acids methyl esters (FAME) derived from the transesterification procedure. Consequently, it is necessary to cleanse FAME using distilled water and thereafter subject it to a drying process. The elimination of methanol, catalyst, and glycerin residues can be achieved through a series of sequential washing procedures utilising hot water at a temperature of 70°C. This is due to the water solubility of these pollutants. The washing procedure involves the combination of biodiesel with distilled water, followed by vigorous agitation of the liquid for approximately one minute. This procedure is employed to remove any unwanted residues of methanol, potassium hydroxide (KOH), and glycerin.

Subsequently, it is necessary to subject the substance to a temperature of 120°C in order to effectively eliminate any remaining water residue. Following this procedure, the biodiesel is prepared for utilisation in the engine. The comprehensive process of biodiesel preparation is illustrated in Figure (3-1b).

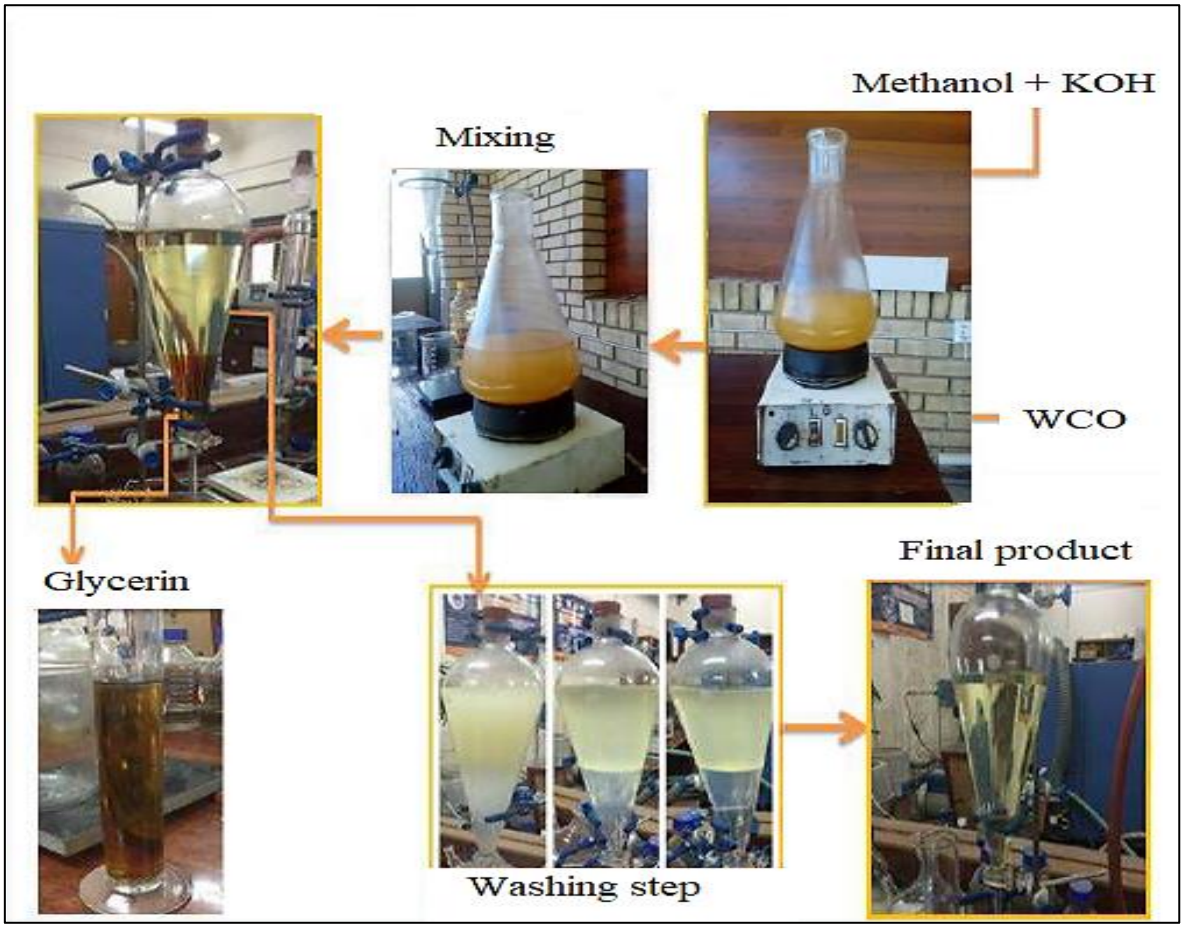


Figure (3-1b): Biodiesel preparation steps

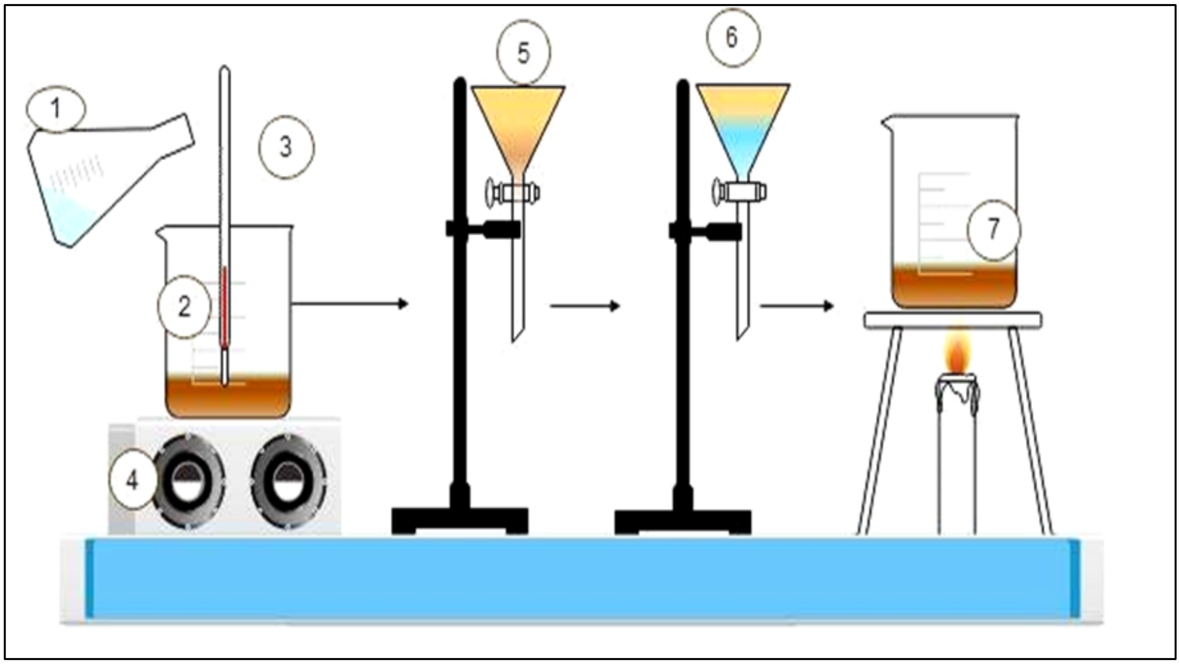


Figure (3-2): Transesterification process 1- methoxide 2-wco oil 3-thermometer 4-magnetic stirrer 5-separation process 6-washing process 7-drying process

### 3.3.5 Fuel Characterizations

The biodiesel density was measured at a temperature of 25 ºC using a hydrometer. Additionally, the flash point of the biodiesel was tested using the Pensky Marten's flash point tester, following the ASTM D93 standard.

The measurement of viscosity was conducted at a temperature of 40 ºC using a viscometer. The measurement of the fuel's calorific value was also conducted utilising a Bomb calorimeter.

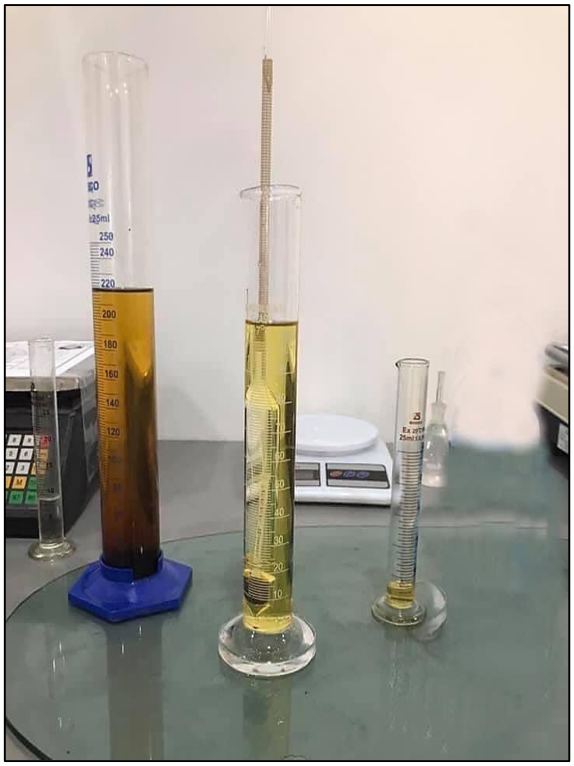


Figure (3-3): Biodiesel density

Figure (3-4): Flash point test

### 3.3.6 Blending of Diesel and Biodiesel:

A total of nine fuel Blend samples were generated in order to conduct subsequent testing. Table (3.1) presents the fuel blending ratio for Iraqi diesel ($C_{12}H_{22}$) - biodiesel (WCO) ($C_{18}H_{32}O_2$), as well as higher alcohols such as Hexanol ($C_6H_{14}O$), Pentanol ($C_5H_{12}O$), and Butanol ($C_4H_{10}O$). Table (3.1) presents the physicochemical parameters of diesel fuel and its mixtures.

Table (3.1): The investigation focuses on the physicochemical characteristics of the fuel sample.

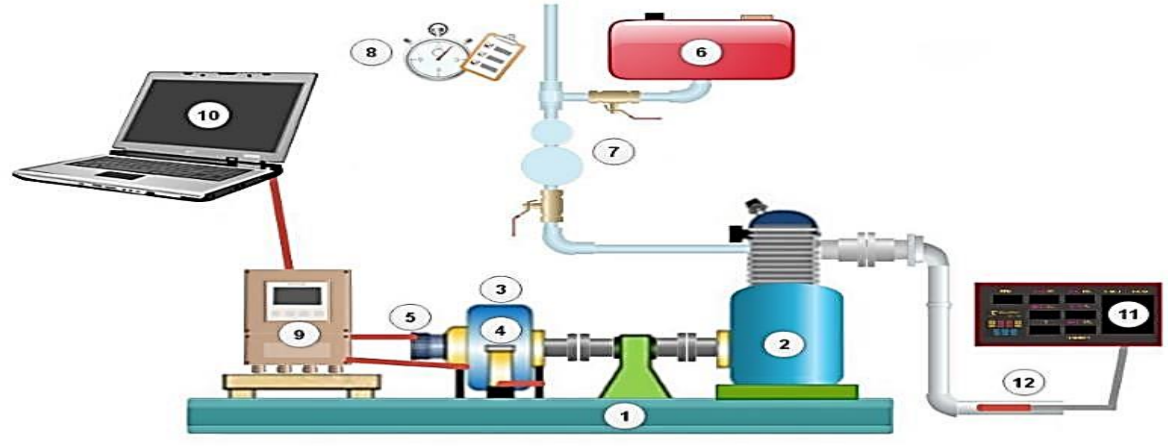
| **Blending ratio** | **Density (kg/m3) at 20°C** | **Flash Point C** | **API** | **Cetane number (CN)** | **LHV (kJ/kg)** |
|---|---|---|---|---|---|
| **Diesel** | 840 | 64 | | 52 | 42500 |
| **Biodiesel** | 892.2 | >120 | 27.1 | 56.5 | 37500 |
| **D80B20** | 845 | 89.2 | 35.3 | 54 | 41450 |
| **D80B10PEN10** | 827 | 57 | 39.6 | 52 | 41165 |
| **D70B15PEN15** | 828.5 | 57.1 | 39.3 | 51.5 | 40500 |
| **D80B10BU10** | 827.5 | 56.8 | 39.5 | 51 | 41000 |
| **D70B15BU15** | 827.9 | 57 | 39.4 | 50.8 | 40250 |
| **D80B10HEX10** | 825.3 | 60 | 41.6 | 53 | 41610 |
| **D70B15HEX15** | 826.1 | 60 | 40.2 | 55.5 | 41189 |

## 3.4 The setup for experimentation

The device exhibits full interoperability using TecQuipment's Versatile Data Acquisition System (VDAS), which can be acquired independently as shown in Figures (3-5) and (3-6). Using the VDAS facilitatesprecise and instantaneous data acquisition, surveillance, and computation of pertinent variables on a computer system (PC supplied separately), hence expediting and ensuring the dependability of testing.

1-Flowmeter 2-CI Engine 3- Dynamometer 4- Fuel tank 5- computer 6-Volumetric fuel gauge 7- Air box 8- Torque sensor (load cell)

Figure (3-5): The actual scheme of the experiment



1. Engine chassis 2. Test engine 3. Dynamometer 4. Load cell 5. Tachometer 6. Fuel tank 7. Fuel burette 8. Stop watch 9. Data acquisition 10. Computer 11. Exhaust gas analyzer 12. Exhaust gas analyzing probe

Figure (3-6): Schematic diagram of the components of experimental rig.

### 3.4.1 Test Engine Description:

The TD202 is comprised of a tiny cooled by air single-cylinder diesel engine, which incorporates the following components as shown in Figures (3-7) and (3-8):

- Overhead valves, consisting of one for intake and one for exhaust.
- Direct system for injecting fuel.
- The mechanism of oil lubrication under pressure.
- Recoil starter for initiating the engine's operation.

The engine is equipped with a governor mechanism that effectively restricts the engine from surpassing its optimal speed. The governor is an integral component located within the engine, which is interconnected with the injecting system of fuel. Once the rotation speed of the engine reaches more than a certain threshold, the regulator activates a mechanism that prompts the injecting system of the fuel to decrease the fuel that injected into the cylinder. This mechanism governs the upper limit of velocity and the power of the engine. The engine’s lubrication is facilitated by using conventional engine oil, which is contained within a compact reservoir located at the lower portion of the engine structure. The oil within the engine is subjected to pressure and subsequently distributed throughout its components, serving the purpose of lubricating the various moving parts and bearings. The oil is subjected to filtration using a finely woven mesh oil filtering system, which functions to enhance the purity of the oil. The engine utilizes a conventional cross-flow arrangement, wherein the fuel/air combination is introduced into the cylinder head from one side, and subsequently exhaust is expelled towards the cylinder’s other head side. The presence of fins that surround the engine flywheel enables the application of air pressure for the cooling process.

As the rotational motion of the flywheel is initiated, the fins have a propulsive effect on the surrounding air, facilitating its circulation around the cylinder using uncomplicated ducting mechanisms.

The engine initiation method entails the utilization of an ignition handle and cable, which are effectively looped around the pulley located on the flywheel. The pulley is equipped with a clutch mechanism that allows for the disengagement of the cable and pulley upon engine activation. This mechanism is commonly referred to as a 'recoil starter'. The engine incorporates a mechanism for controlling the speed called a 'rack'. The primary purpose of the rack is to directly regulate how much fuel can be pumped into the cylinder. When the rack is adjusted to the minimum position, fuel injection into the cylinder ceases, resulting in the cessation of engine operation. In addition, a button for stopping the engine is also included. The function of this button is that the operation of the injection system of the fuel.

Figure (3-7): TD202 small engine

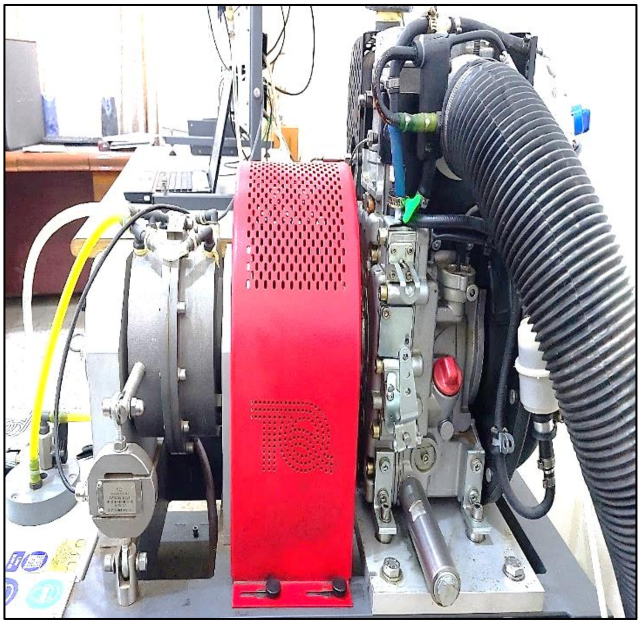


Figure (3-8): TD202 small engine

### 3.4.2 The technical details for testing the engine

Table (3.2): The technical details for testing the engine

| Items | specification |
|---|---|
| **Dimensions** | 400mm width with 450mm height and depth of 350mm |
| **The weight of the net** | 35 kilograms |
| **The Fuel type** | Diesel |
| **Fuel tank** | Steel with a light brown or caramel color containing of filter cap and vent |
| **Absolute maximum power** | 35 kilowatts (4.8hp) at 3600 $\text{rev.min}^{-1}$ |
| **Continuous rated power** | 3.1 kilowatts at 3000 $\text{rev.min}^{-1}$ |
| **Bore** | 69mm |
| **Stroke/crank radius** | 62mm/31min |
| **Connected rod length** | 104mm |
| **The Capacity of the Engine** | $232\text{cm}^3$ |
| **The rate of Compression** | 22:1 |

### 3.4.3 The Hydraulic Dynamometer:

The default hydraulic dynamometer provided for the laboratory is a trunnion-mounted hydraulic dynamometer. The dynamometer generates a load that is contingent upon both the velocity of water flow and the volume of water contained within its casing. A precise needle valve effectively controls the rate of the flow and its level. Utilizing an electronic load cell built into the lateral side of the dynamometer makes it easier to detect torque. The use of a sensor with optics that runs on electricity allows for an assessment of the dynamometer's rotating speed.

The hydraulic dynamometer represents a straightforward yet effective method for applying a load to an engine under test. The structure consists of two shells featuring internal radial ribs. The dynamometer is outfitted with a linked shaft to a rotor containing radiating ribs on both surfaces. To make it easier for the casing to respond to the strain put on it by a load sensor that has a gauge for strain, the position of the dynamometer is located within self-aligning bearings. The dynamometer is designed to facilitate the flow of water, which is introduced into the system via a needle valve located at the upper section, while its discharge is facilitated through a drain situated at the lower section. A vent facilitates the release of excess air and water.

The presence of ribs on the casing and rotor induces turbulent motion in the water, while the engine facilitates the rotation of the shaft. The resistive torque is measured using the load cell. Modulating the flow rate of water induces alterations in the level of resistance, analogous to the impact of the water height within the casing. The dynamometer's continuous water flow helps for dispersing the thermal energy produced by the water's turbulent motion. The dynamometer's continuous water flow helps for dispersing the thermal energy produced by the water's turbulent motion. The valve with a needle is utilized for the indirectly regulation of the dynamometer, functioning within an open-loop configuration. Although the load control operates as an open-loop system, it is capable of maintaining the speed at approximately 100 revolutions per minute.

A flowmeter was incorporated into the system to regulate the engine's load by controlling the water flow to the dynamometer, as depicted in Figure (3-9).

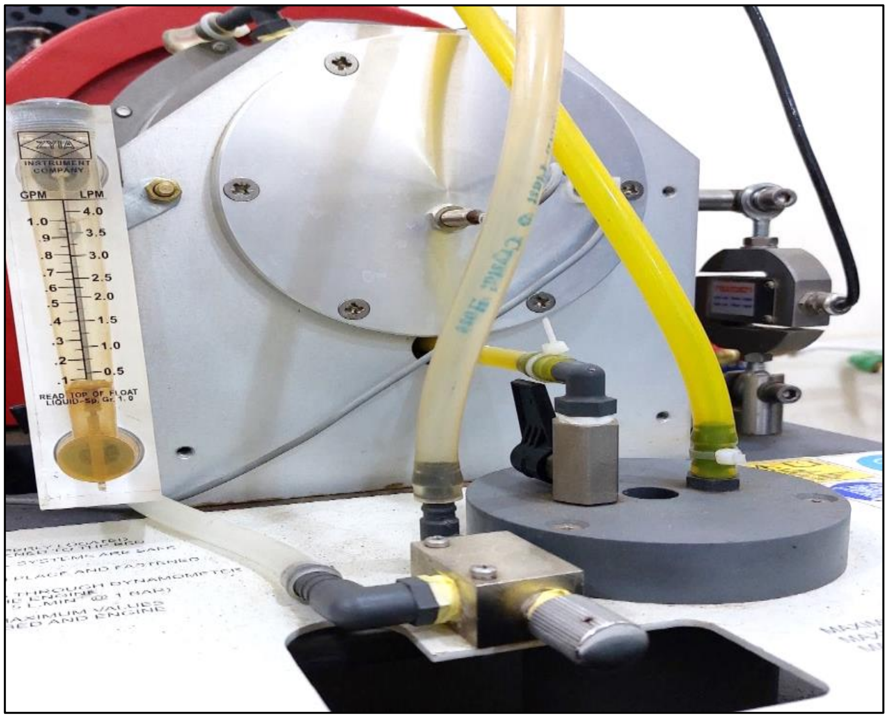


Figure (3-9): flowmeter to the dynameter

### 3.4.4 Instrument Frame:

The TD202 small engine testing modules for the device are attached inside the instrument frame. The frame is equipped with a single IEC type power input and multiple IEC-type outputs to make it easier to supply power to the Sensor Modules. To minimize the transmission of vibrations from the engine to the measurement devices, a distinct separation is upheld between the instrumentation and the test bed.

### 3.4.5 Instrument Modules:

#### 3.4.5.1 Torque and Speed Display - DTS2

This module introduces the visualization of torque data acquired from the dynamometer and the computation of speed based on the pulses detected by the optical sensor. These measurements are recorded and analyzed over a period. The calculation of power involves the multiplication of speed and torque.

#### 3.4.5.2 Air consumption measurement

This module presents a visual representation of the surrounding atmospheric pressure and temperature, along with the pressure inside the airbox. The computation of the engine's input airflow (Ap) incorporates the size of the airbox orifice, as depicted in Figure (3-10a&b), as well as the variation in pressure within the airbox relative to its surrounds (Ap).

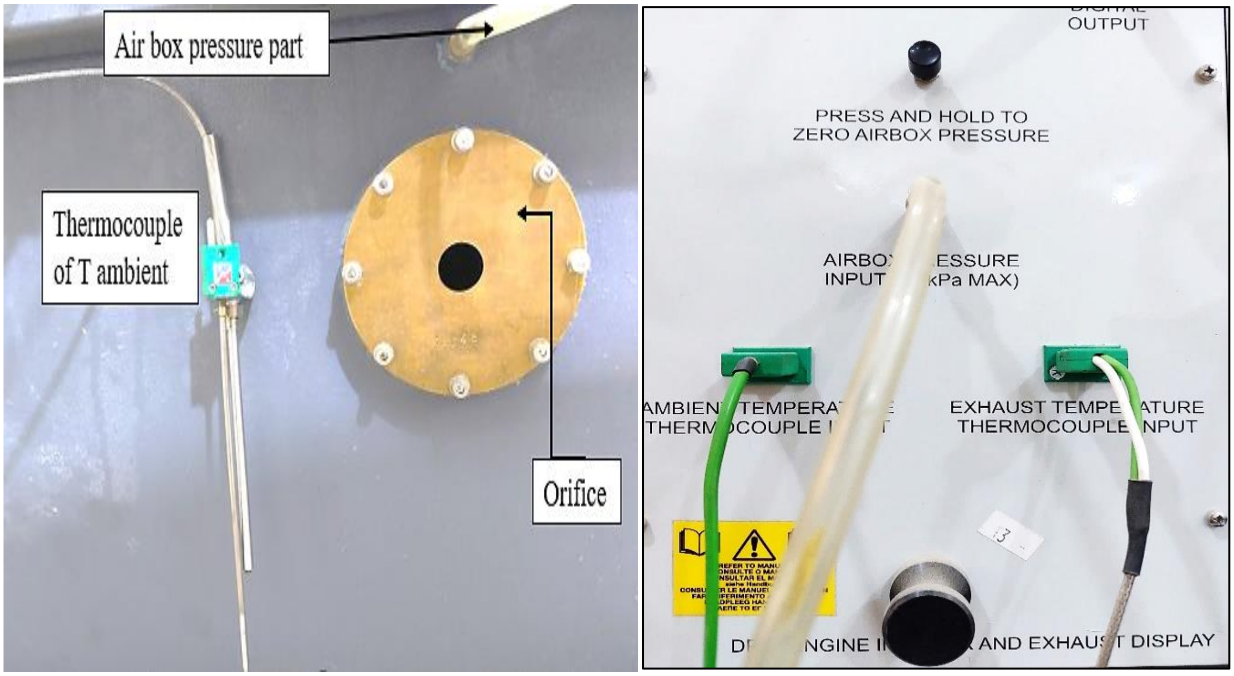
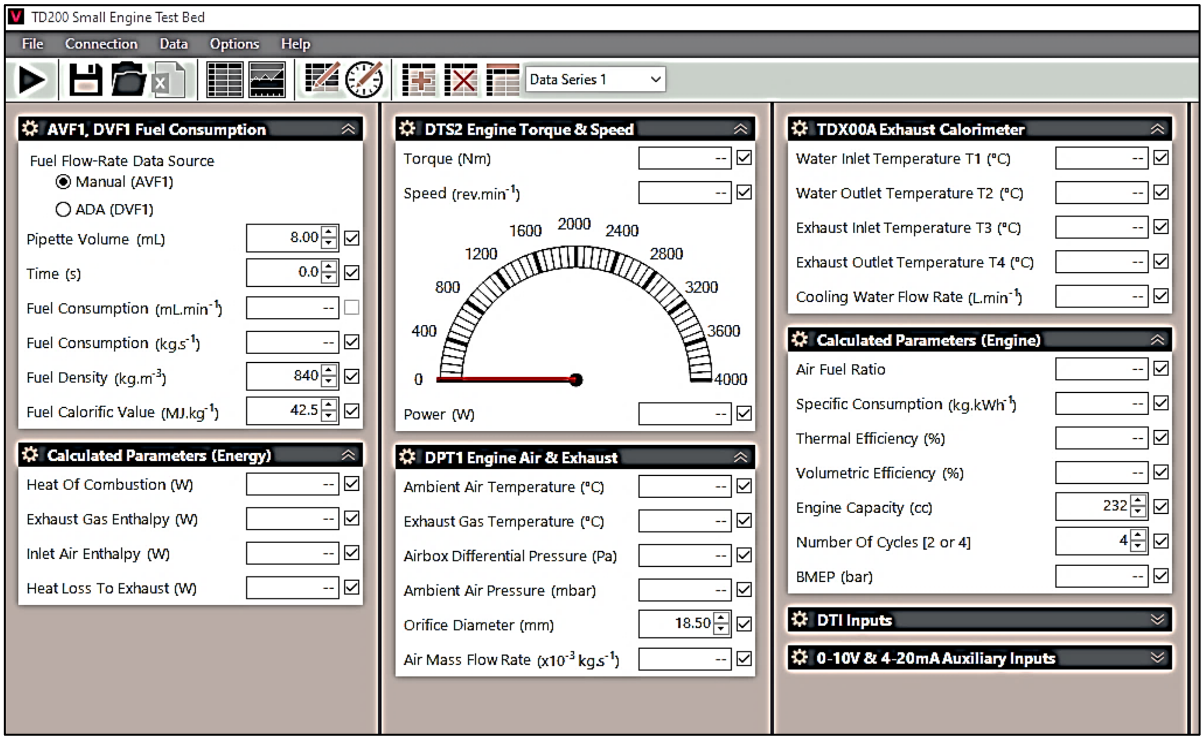


Figure (3-10a&b): Airbox Pressure Port and Orifice.

### 3.4.5.3 Versatile Data Acquisition System – VDAS

The TecQuipment VDAS device is made to work with both the Small Engine Testing Kit and its Instrument Modules that go alongside it. There are two parts to the VDAS apparatus: its software and its hardware. Together, these two components help those who utilize it in:

1. Reducing errors.
2. Minimizing the duration of the experiment
3. Recording the test results on an appropriate computer system.
4. Calculating automatically significant values
5. Possessing the capability to generate graphs and findings of superior quality, as well as making it easier to transmit data to spreadsheet programmes for later graphing and analytic uses. Figures (3-11), (3-12), and (3-13) show the VDAS software and hardware.



**AVF1, DVF1 Fuel Consumption**

Fuel Flow-Rate Data Source
● Manual (AVF1)
○ ADA (DVF1)
Pipette Volume (mL) 8.00 ☑
Time (s) 0.0 ☑
Fuel Consumption (mL.min$^{-1}$) -- ☐
Fuel Consumption (kg.s$^{-1}$) -- ☑
Fuel Density (kg.m$^{-3}$) 840 ☑
Fuel Calorific Value (MJ.kg$^{-1}$) 42.5 ☑

**Calculated Parameters (Energy)**

Heat Of Combustion (W) -- ☑
Exhaust Gas Enthalpy (W) -- ☑
Inlet Air Enthalpy (W) -- ☑
Heat Loss To Exhaust (W) -- ☑

**DTS2 Engine Torque & Speed**

Torque (Nm) -- ☑
Speed (rev.min$^{-1}$) -- ☑
Power (W) -- ☑

**DPT1 Engine Air & Exhaust**

Ambient Air Temperature (°C) -- ☑
Exhaust Gas Temperature (°C) -- ☑
Airbox Differential Pressure (Pa) -- ☑
Ambient Air Pressure (mbar) -- ☑
Orifice Diameter (mm) 18.50 ☑
Air Mass Flow Rate (x10$^{-3}$ kg.s$^{-1}$) -- ☑

**TDX00A Exhaust Calorimeter**

Water Inlet Temperature T1 (°C) -- ☑
Water Outlet Temperature T2 (°C) -- ☑
Exhaust Inlet Temperature T3 (°C) -- ☑
Exhaust Outlet Temperature T4 (°C) -- ☑
Cooling Water Flow Rate (L.min$^{-1}$) -- ☑

**Calculated Parameters (Engine)**

Air Fuel Ratio -- ☑
Specific Consumption (kg.kWh$^{-1}$) -- ☑
Thermal Efficiency (%) -- ☑
Volumetric Efficiency (%) -- ☑
Engine Capacity (cc) 232 ☑
Number Of Cycles [2 or 4] 4 ☑
BMEP (bar) -- ☑

Figure (3-11): The VDAS software.

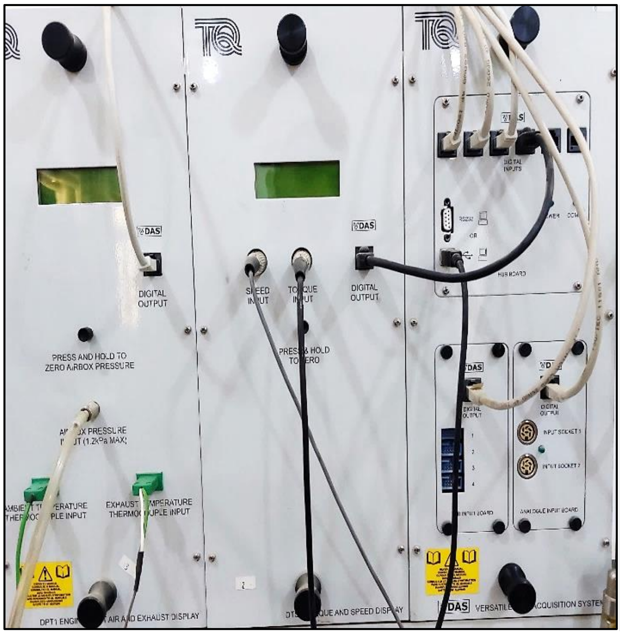


Figure (3-12): The VDAS hardware.

Figure (3-13): Torque sensor (load cell)

### 3.4.6 Fuel Consumption Measurement (FCM)

The volumetric fuel monitor employed in this research is the FCM, as illustrated in Figure (3-14). It is a manual-operated fuel pipettes, therefore precise readings need for the use of a suitable timer or stopwatch.

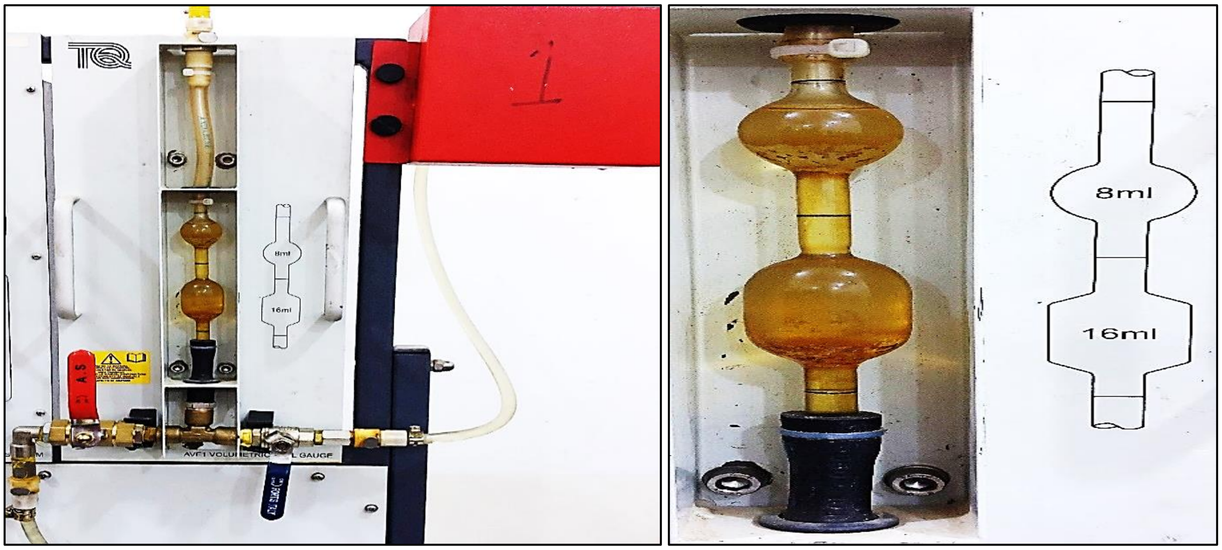


Figure (3-14): The volumetric fuel gauge.

## 3.5 Exhaust Gases Emission Measurement:

The device utilized for measuring the flow of exhaust emissions is the Flux Automotive Emission Analyzer (EGMA) Model (CG-450), as illustrated in Figure (3-15). This device offers the functionality to quantify various gases, including $\mathrm{NOx}, \mathrm{CO_2}, \mathrm{CO}$, and $\mathrm{UHC}$. The gases are extracted from the exhaust pipe of the continuous system through the utilization of a sensor that is installed into the exhaust chimney. Table (3.3) provides information on the measurement range and resolution.

Figure (3-15): Exhaust gas analyzer

Table (3.3): Range of measurement and resolution for exhaust gas analyses.

| Parameter | From | To | Resolution |
|---|---|---|---|
| **CO** | 0 | 9.99% vol. | 0.01% |
| **CO_2** | 0 | 19.9% vol. | 0.1% |
| **HC** | 0 | 9999 ppm | 10 ppm |
| **NOX** | 0 | 2000 ppm | 10 ppm |

## 3.6 Calculations and tabulations of performance characteristics

After the engine reaches thermal equilibrium, the essential statistics, including engine speed, consumption time of fuel, and imposed engine load, are recorded. The emission parameters, which include nitrogen oxides (NOx), monoxide (CO), dioxide ($CO_2$), and hydrocarbons (HC), are then reported. The analysis of engine performance metrics is conducted, including torque, braking power, fuel consumption, brake specific fuel consumption, thermal efficiency.

## 3.7 Measuring Parameters:

The parameters measured for the diesel engine are as follows [90], [91]:

### 1. Fuel mass flow rate (kg/h)

The quantity of fuel used by an engine may be calculated using the following formula, where t is the time in seconds that it takes to burn through one liter of fuel.

$$\dot{m}_f = \frac{\rho f \times v \times 10^{-6}}{t} \times 3600 [\frac{kg}{h}] \qquad \textbf{(3.1)}$$

$\dot{m}_f$: Fuel consumption rate

$\rho f$: fuel density (kg/m$^3$)

$vf$: Volume of fuel consumption (mL)

$t$: Time (sec)

**2. Brake-specific fuel consumption (kg/kW.h)**

The specific fuel consumption at the brakes is another important metric generated from the same data; it reveals how effectively the engine converts fuel into useful effort. Below is the formula used to determine it.

$$\boldsymbol{BSFC} = \frac{\dot{m}_{\boldsymbol{f}}}{\boldsymbol{B.p}} \qquad \textbf{(3.2)}$$

**3. Brake power (kW)**

The equation for determining braking force.

$$\boldsymbol{B.p} = \frac{\boldsymbol{2\pi NTb}}{\boldsymbol{60}} \times \boldsymbol{10^{-3}}\ [\boldsymbol{KW}] \qquad \textbf{(3.3)}$$

B.p: The brake power (kw).

N: The engine speed (rpm).

Tb: The brake torque (N.m).

**4. Brake thermal efficiency** (%)

The thermal efficiency may be calculated after calculating how much fuel consumption and how much power output.

$$\eta\boldsymbol{bth} = \frac{\boldsymbol{B.p}}{\dot{m}_{\boldsymbol{f}} \times \boldsymbol{L_{HV}}} \times \boldsymbol{100}\% \qquad \textbf{(3.4)}$$

LHV: the value of lower heating (kJ/kg).

## 3.8 Experimental Procedure:

The experimental investigation the utilization of various fuel types, including diesel, biodiesel, alcohols (specifically butanol, pentanol, and hexanol), as well as fuel mixtures (namely D100, D80B20, D80B10BU10, D70B15BU15, D80B10PEN10, D70B15PEN15, D80B10HEX10, and D70B15HEX15). The experiment involved assessing the performance of diesel fuels and fuel combinations under varying engine loads, specifically at load levels of 4, 5.5, 7, 8.5, and 10 Nm. The speeds considered in this study are 1750, 2000, 2250, and 2500 rpm. In order to get the values of an exhaust gas analyzer, one must engage in the process of measurement and analysis of the exhaust gases. The levels of carbon dioxide, hydrocarbons, and nitrogen oxides were measured using an exhaust gas analyzer. The steps are:

**1-** Adjusting the engine speed to a value of 1750 (rpm).

**2-** The load experienced a change from 4 to 10 Nm

**3-** The exhaust gas analyzer is subjected to a heating process lasting approximately 15 minutes, following which the concentrations of ($CO$), ($CO_2$), ($HC$), and ($NOx$) are recorded.

**4-** The fuel consumption time inside a specific capacity (8 ml) was recorded using a stopwatch.

**5-** The temperature measurement of exhaust gas was using the VDAS software.

**6-** Using the VDAS programs, the engine characteristics, such as torque, braking power, and fuel consumption, were obtained.

**7-** Performing iterations of steps 2 to 6 at rotational speeds of 2000 rpm, 2250 rpm, and 2500 rpm.

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

## 4.1 Introduction:

Petroleum-derived fuels have consistently maintained their status as a highly sought-after energy source across a wide range of applications and industries. Nevertheless, the substantial emissions resulting from the utilization of petroleum-based fuels have compelled some governments to implement tight laws and raise worries regarding energy security. The utilization of alternative fuels, specifically short-chain alcohols like methanol and ethanol, has been employed as a means to introduce oxygen into diesel fuel (DF) and enhance its oxygen content. Nevertheless, it is worth noting that the use of short chain alcohol-diesel blends does come with certain drawbacks. These include a low cetane number, reduced heating value, an increase in hydrocarbon emissions, and limited miscibility with diesel fuel. In recent times, there has been a growing interest among researchers in long-chain alcohols due to their superior physicochemical features in comparison to short-chain alcohols. In this experiment, 10% and 15% of was added waste cooking oil WCO; methyl ester, and higher alcohols including hexanol (HEX) pentanol (PEN), and butanol (BU) into DF to produce long-chain alcohol-diesel fuel blends.

This chapter provides an overview of the experimental and theoretical findings pertaining to engine performance and exhaust emissions. The study focuses on a single-cylinder compression ignition (CI) engine, which utilizes several liquid fuels including fossil diesel, Biodiesel derived from waste cooking oil (WCO), and higher alcohols such as pentanol, butanol, and hexanol. These fuels are blended in different amounts to investigate their impact on engine performance and exhaust emissions. In the present setting, there is a significant focus on doing extensive research on renewable alternative fuels, including biodiesel and alcohols, with the aim of their application in diesel engines. Nevertheless, its elevated density and viscosity hinder the utilization of pure biodiesel in diesel engines. Hence, incorporating alcohols as a fuel additive is employed to enhance the density and viscosity of the biodiesel blend. Performance (Bp, AFC, EGT, BSFC, and ηbth) and Exhaust gas emissions are measured from the Engine [carbon monoxide CO, carbon dioxide $CO_2$, unburned UHC hydrocarbons, and nitrogen oxides NOx] for all tests are evaluated using engine speed (1750,2000,2250 to 2500 rpm) using a variable load (4,5.5,7,8.5 and 10 Nm).

## 4.2 Repeatability of measurements:

In order to ensure the replicability of experimental findings, every test has been repeated three times. The study utilized the mean value of the repeated tests. Figures (4-1) and (4-2) depict the repeatability of the test. Differences between the tests are reported to exist for the same conditions. The underlying cause for this phenomenon can be attributed to instrumental errors, fluctuations in ambient circumstances, and human errors.

Figure (4-1): Variation of Average fuel consumption (AFC) and Exhaust Gas Temperature (EGT) depending on engine loads at 1750 rpm.

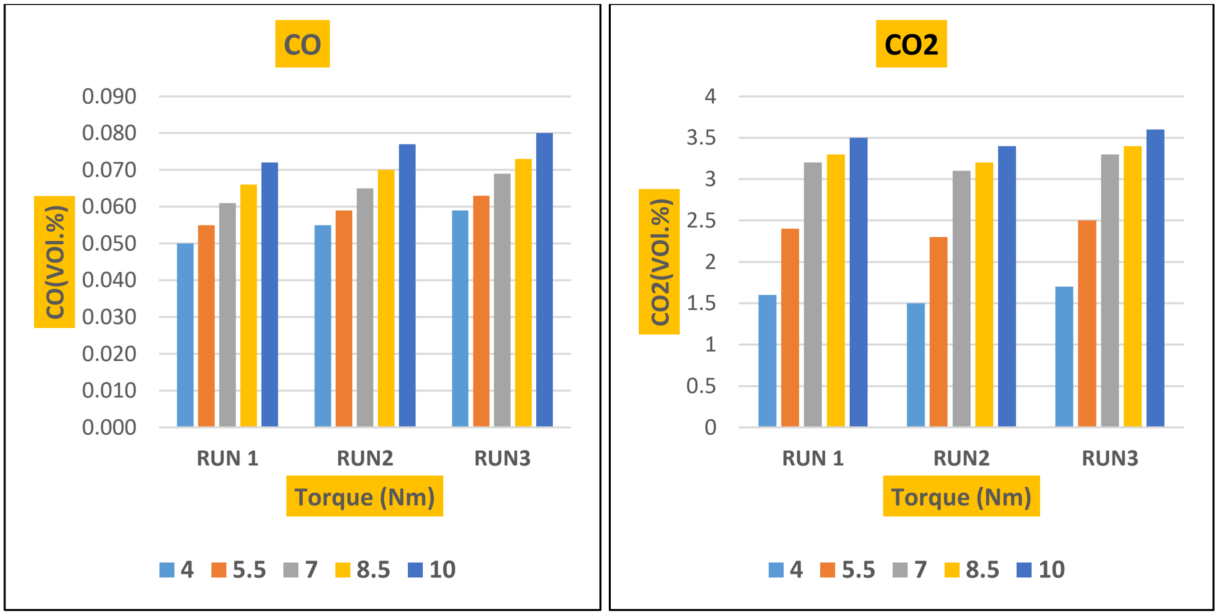


Figure (4-2) Carbon dioxide (CO2) and Carbon monoxide (CO)graphic according to engine load at 1750 rpm

## 4.3 Experimental Results for Blended Fuels:

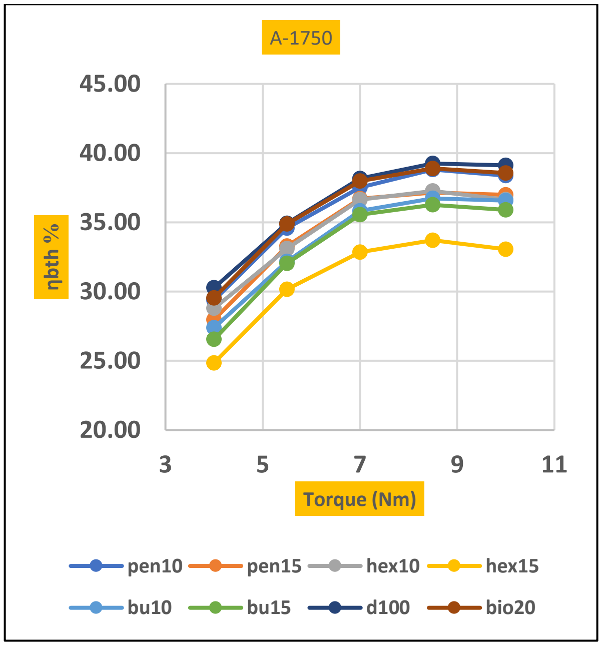
An endeavor was undertaken to enhance engine performance and mitigate emissions by combining biodiesel waste cooking oil (WCO) fuel and alcohol with diesel fuel at varying proportions. The outcomes exhibited discernible variations in both engine performance and exhaust gas emissions for the fuel amalgamation. The aforementioned findings can be categorized under the condition of fluctuating loads and constant engine speed.

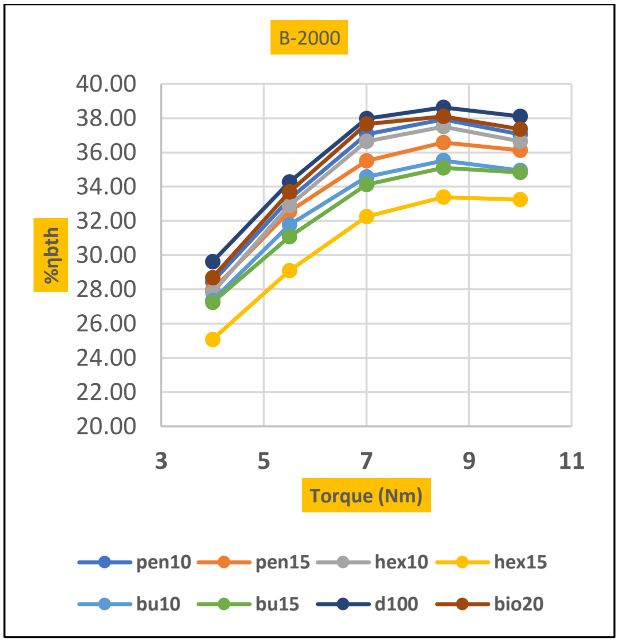
## 4.4 Engine Performance Characteristics at Variable Loads and Constant Engine Speed

### 4.4.1 Effect of Blended Fuel The diesel-biodiesel and Higher alcohol. on Brake Thermal Efficiency (ηbth):

The braking thermal efficiency (ηbth) is defined as the ratio of the output power to the input energy of the fuel quantity in internal combustion engines (CI) [92]. The thermal efficiency of compression ignition (CI) engines is influenced by various factors, such as the air-fuel ratio, fuel qualities (including fuel quality, cetane number, fuel optimization, and fuel evaporation rate), and the combustion process within the engine. Additionally, the design of the combustion chamber, injection timing, compression ratio, and pressure also play significant roles in determining the thermal efficiency of CI engines. By optimizing these variables, the efficiency of combustion can be enhanced, resulting in a decrease in both fuel consumption and the rate of emissions produced by the combustion process [93] (see Figure 4-3). It has been shown that the parameter (ηbth) exhibits a direct correlation with the engine load across all fuel blends. The potential reason for this phenomenon could be attributed to the heightened cylinder temperature experienced at higher engine loads. This elevated temperature facilitates complete combustion, therefore leading to an increase in thermal efficiency (ηbth). Implementing fuel-neutral combustion techniques facilitates enhanced fuel consumption and improved engine performance, leading to increased engine output efficiency (represented by the parameter ηbth). Figure (4-3). This thesis elucidates the brake thermal efficiency (ηbth) map for diesel-biodiesel and higher alcohol fuel mixes, focusing on engine load. Figure (4-3) A The results indicate that the brake thermal efficiency (ηbth) of various fuel blends, namely D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20, experienced reductions in values of 1.68%, 5.29%, 5.11%, 14.91%, 7.17%, 8.50%, and 1.02%, respectively, as compared to the reference fuel D100, which is a fossil diesel fuel. These findings highlight the impact of different fuel compositions on brake thermal efficiency at a rotational speed of 1750 rpm. Figure (4-3) B illustrates the decline in brake thermal efficiency (ηbth) for several fuel blends, namely D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20, at an engine speed of 2000 rpm. These blends experienced reductions in efficiency of 2.7%, 5.53%, 3.97%, 14.30%, 8.08%, 9.08%, and 1.73%, respectively, as compared to the reference fuel D100, which is fossil diesel. In Figure (4-3) C, it can be shown that the braking thermal efficiency (ηbth) of several fuel blends, namely D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20, operating at 2250 rpm, exhibited a drop in efficiency. Specifically, the values of 1.84%, 4.94%, 5.39%, 13.97%, 8.50%, 9.75%, and 1.39% were recorded for each respective blend, as compared to the reference fuel D100, which is a fossil diesel fuel. Figure (4-3) D, specifically panel D, illustrates the decline in brake thermal efficiency (ηbth) for various fuel blends, namely D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20, operating at 2500 rpm. These blends experienced reductions in brake thermal efficiency of 3.36%, 8.42%, 7.10%, 17.71%, 12.20%, 13.82%, and 1.88%, respectively, when compared to the reference fuel D100, which is fossil diesel.

It was also found that(ηbth) was higher for fossil diesel fuels and lower for all blends. The incomplete combustion of fuel within the cylinder leads to a reduction in the thermal efficiency (ηbth) due to the fuel's increased viscosity and reduced calorific value. The value of (ηbth) was shown to be consistently lower in all test fuels containing alcohol compared to the base diesel fuel. The observed decrease in thermal efficiency (ηbth) can be ascribed to the cooling impact generated by the alcohol mixes. The decrease in cylinder temperature resulting from the cooling properties of alcohol leads to the achievement of neutral combustion of the fuel, thus leading to a reduction in thermal efficiency (ηbth) [94].





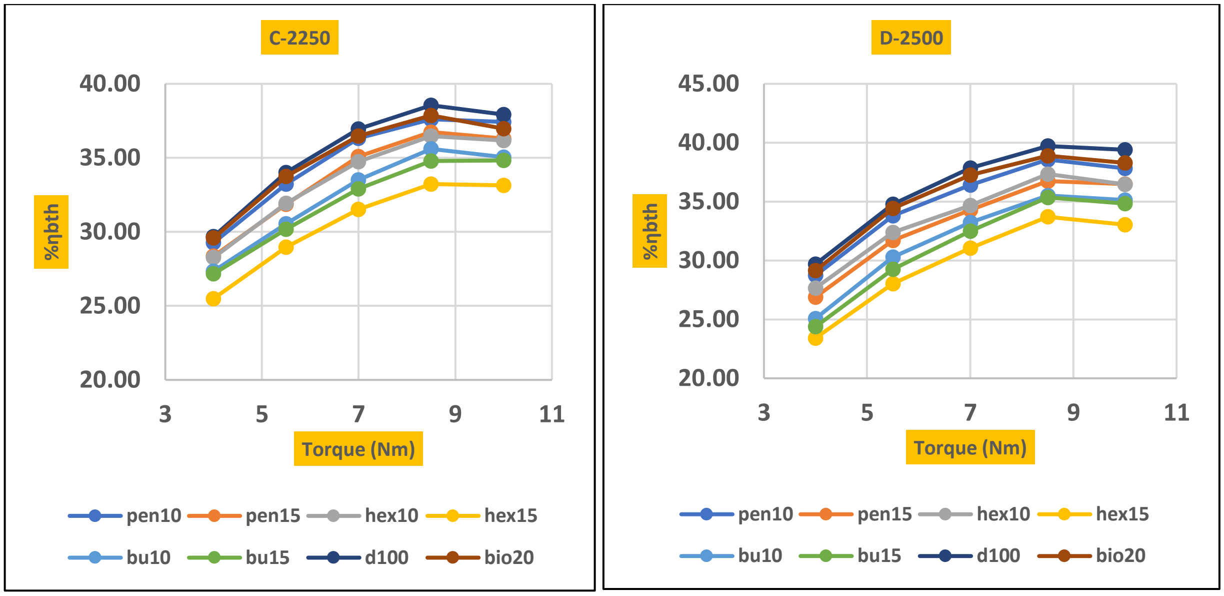


Figure (4-3): Variations of Brake Thermal efficiency (Ƞbth) depending on engine loads

### 4.4.2 Effect of Blended Fuel The diesel-biodiesel and Higher alcohol. on Brake- Specific Fuel Consumption: (bsfc)

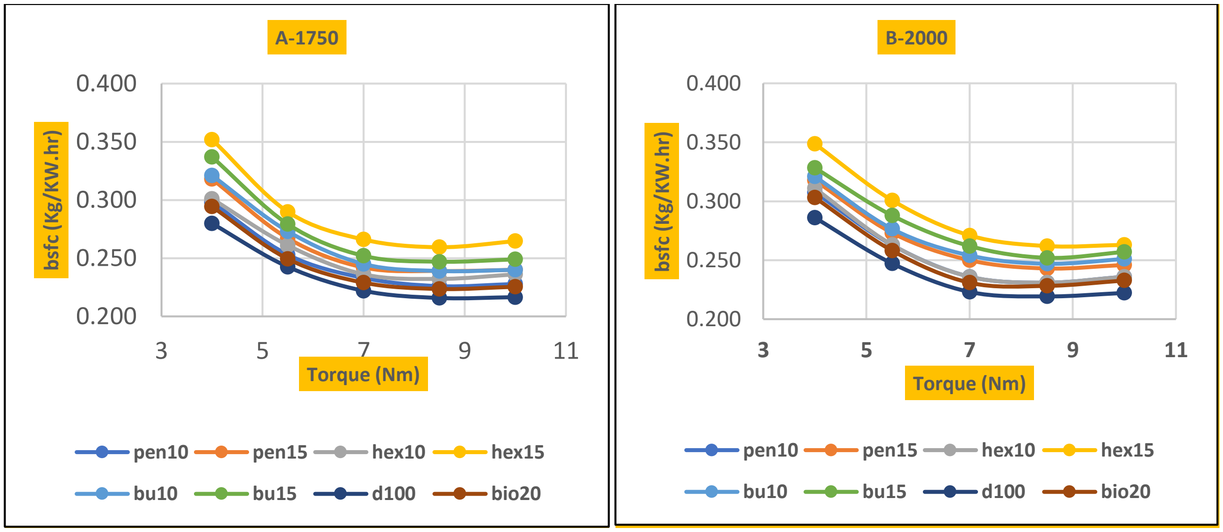
The measurement of brake-specific fuel consumption serves as an indicator of the engine's charge efficiency, making it a crucial metric for analysis; BSFC measures the efficiency of converting fuel to saving useful energy, as it gradually decreases with increasing load and engine speed due to the dissolution of the mixture being better and homogeneous and better thermal efficiency [95]. Figure (4-4) illustrates the fluctuations in brake-specific consumption of fuel (BSFC) in relation to engine loads across various mixes.

Figure (4-4) A illustrates the brake-specific fuel consumption of D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 1750rpm increased by values of 5.19%, 10.99%, 7.63%, 21.68%, 12.01%, 15.93%, and 3.82%, respectively compared to fossil diesel fuelsD100 in accordance with engine loads.

Figure (4-4) B illustrates the brake-specific fuel consumption of D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2000rpm increased by values of 6.30%, 11.02%, 6.60%, 20.66%, 12.65%, 15.80%, and 4.61%, respectively compared to fossil diesel fuelsD100 in accordance with engine loads.

Figure (4-4) C displays the brake-specific fuel consumption of fuel of D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2250rpm increased by values of 5.26%, 10.38%, 7.92%, 20.09%, 13.37%, 16.98%, and 3.98%, respectively compared to fossil diesel fuelsD100 in accordance with engine loads.

Figure (4-4) D indicates the brake-specific fuel consumption of D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2500 rpm increased by values of 6.79%, 14.77%, 9.90%, 26.24%, 18.63%, 23.42%, and 4.58%, respectively compared to fossil diesel fuelsD100 in accordance with engine loads.



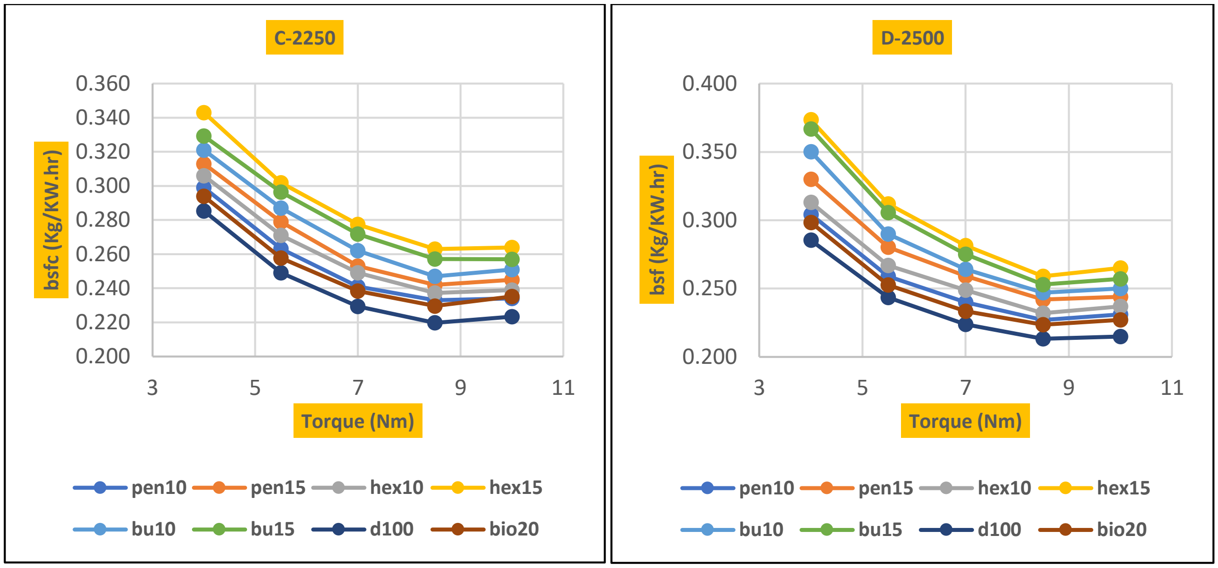


Figure (4-4): Variation of Brake Specific Fuel Consumption (BSFC) depending on engine loads.

The findings indicated that there was a decrease in brake-specific fuel consumption (BSFC) as the engine load increased. As the engine load was augmented, there was a corresponding enhancement in both the efficiency and combustion quality of the engine. The brake-specific fuel consumption (BSFC) of biodiesel and alcohol blends consistently exhibited greater values compared to conventional diesel fuel. This can be attributed to the lower calorific values and heating values of these blends, as well as their higher viscosity. In order to attain equivalent power output as diesel fuel, a greater quantity of fuel is extracted from the fuel pump, hence resulting in an elevation in brake-specific fuel consumption (BSFC) [96].

### 4.4.3 Effect of Blended Fuel The diesel-biodiesel and Higher alcohol on Average fuel consumption (AFC)

Figure (4-5) A presents the chart illustrating the Average Fuel Usage (AFC) for various blends of biodiesel, alcohol, and diesel fuel as a function of load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 1750rpm, Average fuel consumption (AFC) increased by values of 5.00%, 10.81%, 7.75%, 21.36%, 11.55%, 15.31%, and 3.74%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-5) B illustrates the chart depicting the Average Fuel Consumption (AFC) for various blends of biodiesel, alcohol, and diesel fuel, as influenced by the engine load. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2000rpm, Average fuel consumption (AFC) increased by values of 6.08%, 11.05%, 6.30%, 20.27%, 12.81%, 15.91%, and 4.47%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-5), C presents the chart illustrating the Average Fuel Consumption (AFC) for biodiesel, alcohol, and diesel fuel mixes as a function of load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2250rpm, Average fuel consumption (AFC) increased by values of 5.16%, 10.33%, 7.90%, 19.87%, 13.19%, 16.87%, and 4.23%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-5)D exhibits the chart representing the Average Fuel Consumption (AFC) for biodiesel, alcohol, and diesel fuel mixes as a function of load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2500rpm, Average fuel consumption (AFC) increased by values of 6.88%, 14.47%, 9.96%, 25.21%, 17.88%, 22.24%, and 4.71%, respectively, compared to fossil diesel fuelsD100 based on engine loads

It is evident that the air-fuel ratio (AFR) increases proportionally with the increase in load for nearly all examined fuels at a consistent rate. Consequently, the engine requires more fuel to generate an equivalent power output while functioning with fuel mixes. The high density of the fuel leads to a higher fuel flow rate for the same displacement of the plunger in the injection pump thereby increasing AFC.

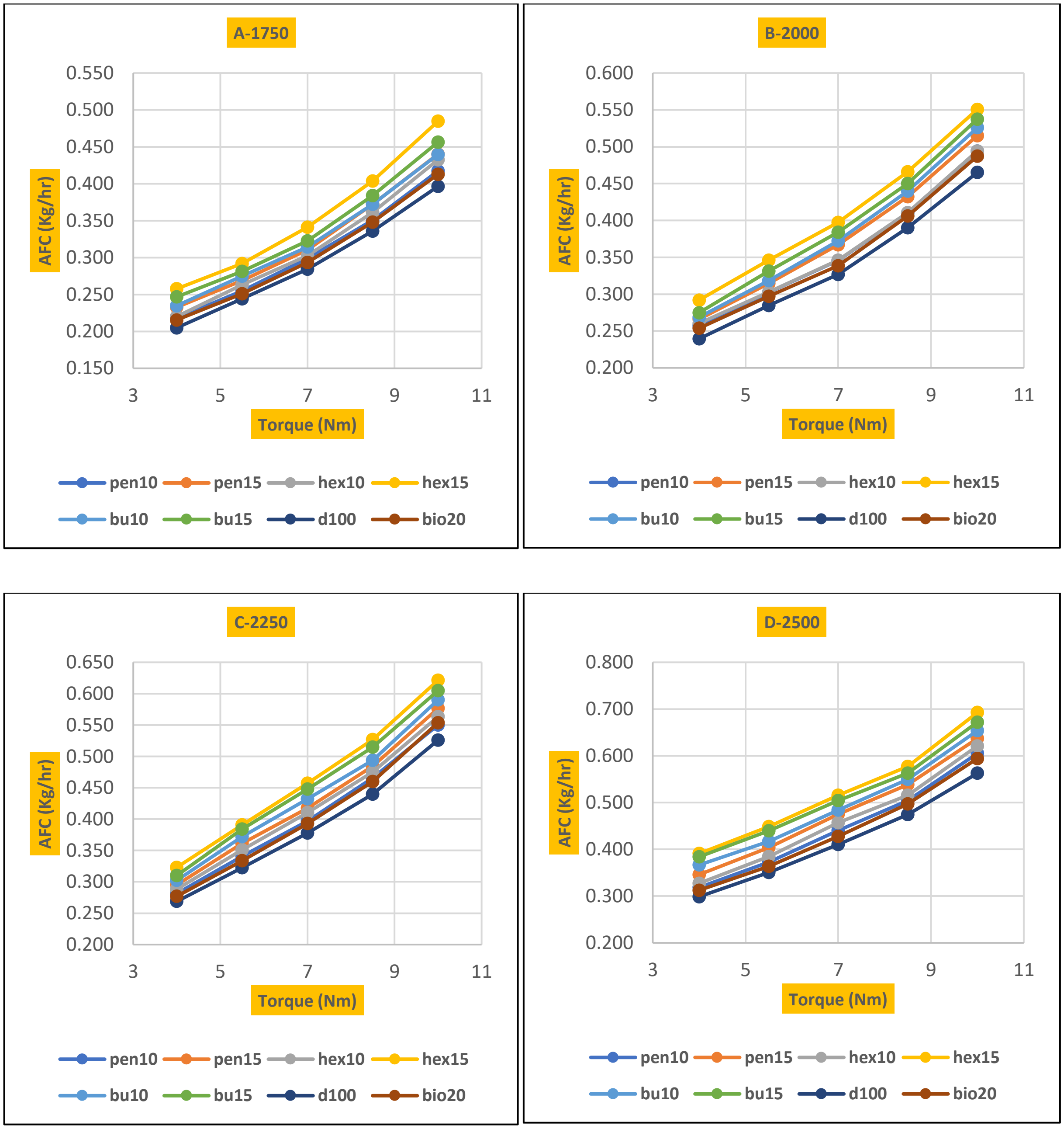


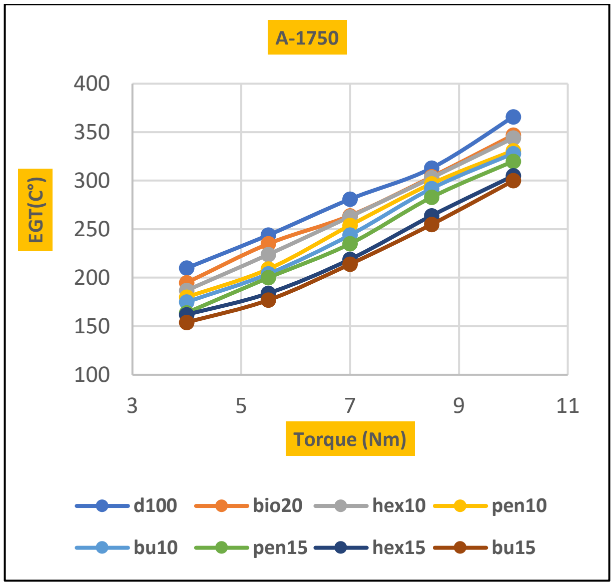
Figure (4-5): Variation of Average fuel consumption (AFC) depending on engine loads.

### 4.4.4 Effect of Blended Fuel The diesel-biodiesel and Higher alcohol on Exhaust Gas Temperature (EGT).

The exhaust gas temperature (EGT) is a significant variable that impacts the exhaust emission properties of a compression ignition (CI) engine. The efficiency of the combustion process can be inferred from the temperature of the exhaust gas [97]. The fuel consumption under different engine load settings is depicted in Figure (4-6). It is evident that the rise in engine load resulted in a proportional increase in the exhaust gas temperature (EGT). One explanation for the increase in the quantity of fuel injected into the combustion chamber is the corresponding rise in engine load. This increase in fuel quantity leads to higher temperatures within the cylinder. In the case of all tested fuels, the exhaust gas temperature (EGT) exhibited an increase as the engine load increased [98]. The experimental gross calorific value (EGT) of diesel fuel was observed to be comparatively higher when compared to other types of fuels. Figure (4-6) A presents the Exhaust Gas Temperature (EGT) chart illustrating the variations seen in biodiesel, alcohol, and diesel fuel mixtures in relation to engine load. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 1750rpm, Exhaust Gas Temperature (EGT) decreased by values of 10.01%, 15.0%, 6.6%, 19.8%, 12.1%, 22.2%, and 4.9%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-6) B illustrates the chart depicting the Exhaust Gas Temperature (EGT) variations in biodiesel, alcohol, and diesel fuel mixtures in relation to the load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2000rpm, Exhaust Gas Temperature (EGT) decreased by values of 11.8%, 18.0%, 8.8%, 21.5%, 14.9%, 24.1%, and 11.8%, respectively, compared to fossil diesel fuelsD100 based on engine loads.

Figure (4-6) C illustrates the Exhaust Gas Temperature (EGT) diagram for biodiesel, alcohol, and diesel fuel mixtures as a function of the load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2250rpm, Exhaust Gas Temperature (EGT) decreased by values of 10.6%, 16.4%, 9.2%, 20.2%, 12.5%, 23.5%, and 2.8%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-6) D presents a graphical representation of the Exhaust Gas Temperature (EGT) chart, illustrating the variations observed in biodiesel, alcohol, and diesel fuel blends as a function of the load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2500rpm, Exhaust Gas Temperature (EGT) decreased by values of 9.6%, 15.3%, 7.8%, 19.3%, 12.2%, 22.1%, and 3.9%, respectively, compared to fossil diesel fuelsD100 based on engine loads.

The exhaust gas temperature (EGT) of diesel fuel was determined to be comparatively higher when compared to other types of fuels. The outcome of this phenomenon will lead to the sustained combustion of fuel until the entirety of the combustion process is finalised, hence releasing a progressively escalating quantity of thermal energy. The findings indicate that there was a drop in exhaust gas temperature (EGT) as the percentage of alcohol increased, in comparison to diesel fuel. The lower energy content of the fuel mixes and the higher latent heat of evaporation of the alcohol blends, which induces a cooling effect, are responsible for this phenomenon. In comparison to the alcohol fuel blend, it was shown that a binary blend of B20 exhibited elevated exhaust gas temperatures (EGT) across various engine loads. The aforementioned statement can be expounded upon in the following manner. Biodiesels exhibit a greater cetane number in comparison to diesel fuel, resulting in a faster onset of combustion and a reduction in the duration of the ignition delay period. The persistence of the combustion process throughout working hours can be attributed to the elevated boiling point of the chemicals present in the chemical structure of biodiesel. Moreover, the elevated oxygen concentration in biodiesel fuel, in comparison to diesel fuel, enhances the combustion process and leads to heightened exhaust gas temperature (EGT) readings [99].



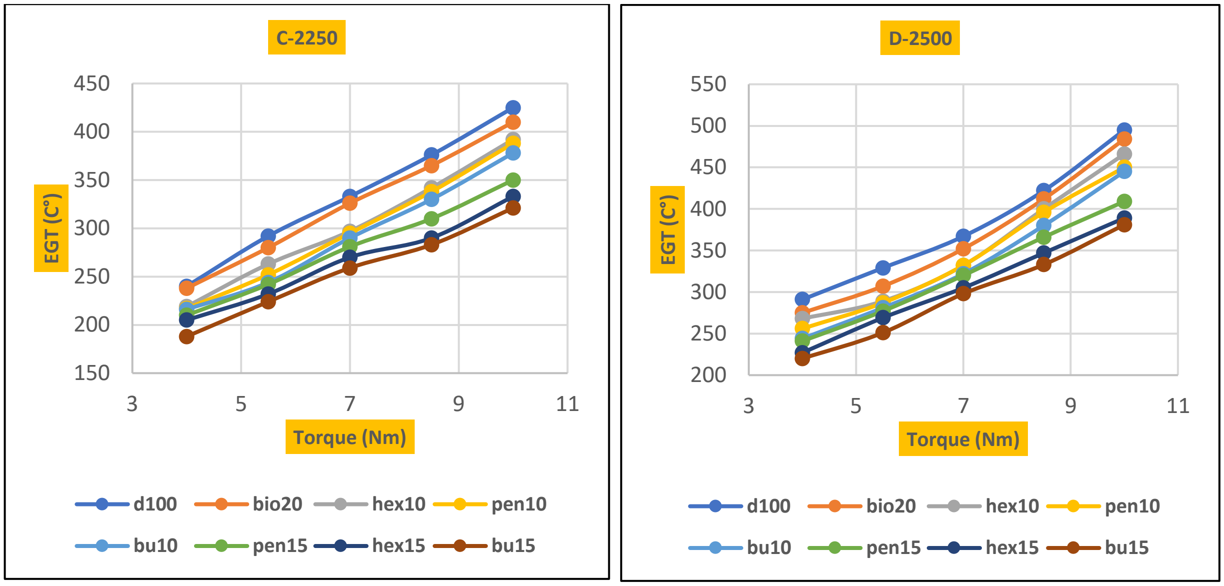


Figure (4-6): Variation of Exhaust Gas Temperature (EGT) depending on engine loads.

## 4.5 Engine exhaust emissions at variable loads and constant engine speed

### 4.5.1 Carbon monoxide (CO)

Carbon monoxide is widely recognized for its lack of color, odor, and taste. The density of the substance is marginally greater than that of ambient air. Furthermore, carbon monoxide (CO) possesses a highly poisonous characteristic that harms human health in natural environments [100]. In addition, it has been observed that even a minimal concentration of carbon monoxide (CO) might result in symptoms such as shortness of breath and headaches [101]. The generation of carbon monoxide (CO) emissions in internal combustion engines can be influenced by several characteristics, including engine speed, fuel type, injection pressure, air-fuel ratio, and injection timing. The generation of carbon monoxide emissions occurs due to the incomplete combustion of hydrocarbons present in the fuel source. Carbon monoxide (CO) is a significant characteristic in exhaust gases, as it represents the chemical energy that is lost. Additionally, the presence of carbon monoxide (CO) in the exhaust can indicate incomplete combustion resulting from an inadequate supply of oxygen within the combustion chamber. Hence, the presence of oxygen in the medium is crucial in preventing the formation of Carbon monoxide (CO) [102]. Figure (4-7) depicts the graphical representation of the fluctuation in carbon monoxide (CO) emissions in relation to engine load across all fuels that were subjected to testing.

Figure (4-7) A presents the graphical representation of the Carbon monoxide (CO) emissions for various blends of biodiesel, alcohol, and diesel fuel, as a function of the engine's load. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 1750rpm. Carbon monoxide (CO) is decreased by values of 29.54%, 35.08%, 26.77%, 50.92%, 20.0%, 46.46%, and 12.31%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-7) B illustrates the chart depicting the levels of Carbon monoxide (CO) emissions in biodiesel, alcohol, and diesel fuel blends, as influenced by variations in load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2000rpm. Carbon monoxide (CO) decreased by values of 34.48%, 43.10%, 31.3%, 53.45%, 27.59%, 48.28%, and 17.24%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-7) C presents a graphical representation of the carbon monoxide (CO) emissions data for biodiesel, alcohol, and diesel fuel blends, as influenced by variations in load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2250rpm. Carbon monoxide (CO) decreased by values of 33.60%, 39.02%, 27.20%, 52.40%, 22.00%, 46.0%, and 14.4%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-7) D presents the graphical representation of the Carbon monoxide (CO) emissions for various blends of biodiesel, alcohol, and diesel fuel as a function of the load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2500rpm. Carbon monoxide (CO) decreased by values of 32.82%, 34.87%, 29.23%, 45.13%, 23.59%, 38.46%, and 13.85%, respectively, compared to fossil diesel fuelsD100 based on engine loads.

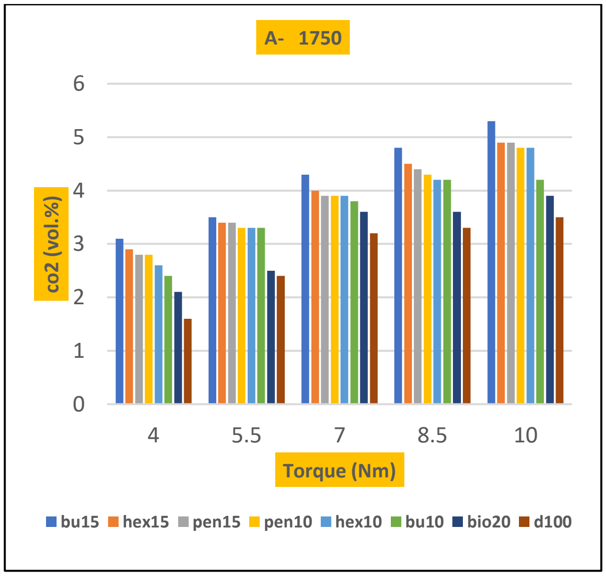
The initial observation discernible from Figure is that there is a positive correlation between load and CO emissions. This can be attributed to the inverse relationship between the air/fuel ratio and load, whereby a rise in load leads to a drop in the air/fuel ratio. The inverse relationship between the use of biodiesel and alcohol mixes in diesel fuel blends and the emissions of carbon monoxide can also be observed. The enhanced combustions observed in biodiesel and alcohol combinations, as compared to diesel, can be attributed to the lower carbon content and higher oxygen concentration present in biodiesel. The provision of an elevated quantity of oxygen and a reduced quantity of carbon in the fuel contributes to the facilitation of adequate oxygen supply to the combustion products, hence resulting in a more balanced burning of the fuel [103]. Variation in carbon monoxide emissions appears with engine load of mixtures and diesel. In all loads, the combination of biodiesel and alcohol mixtures resulted in relatively lower CO emissions than diesel. Due to the wide availability of oxygen inherent in biodiesel and alcohol mixtures. The reason for the lower co-emissions is due to improved combustion. Adapting alcohol mixtures to biodiesel leads to a decrease in viscosity, which accelerates the evaporation of fuel mixtures with air. Biodiesel has reduced compressibility and an elevated cetane number. These two criteria have also been found to be useful in reducing carbon monoxide (CO) emissions. When a fuel exhibits lower compressibility, the initiation of injection occurs at an earlier point in time, resulting in an extended duration of burning. A higher cetane number, indicative of a reduced ignition delay, results in a decreased duration of combustion and an expansion of the zones where full combustion reactions occur. It has been discovered that the emissions of carbon monoxide (CO) drop as the engine speed increases across all fuel types. This phenomenon is related to the concurrent increase in combustion temperature. [104] [105] [106]

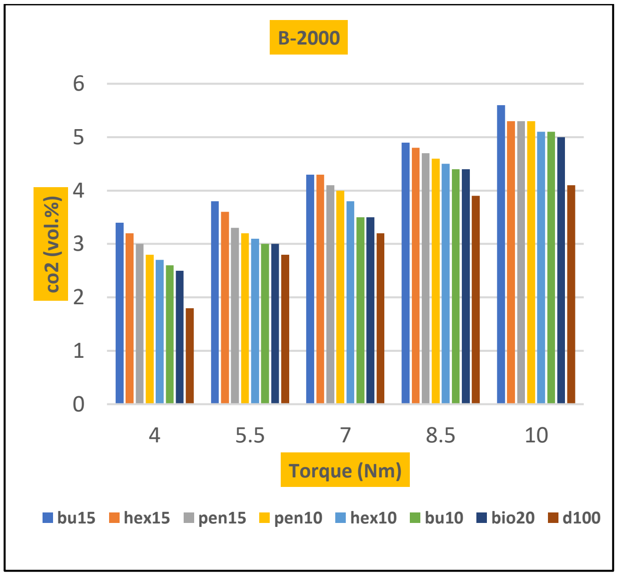
Figure (4-7): Carbon monoxide graphic according to engine load.

### 4.5.2 Carbon dioxide ($CO_2$):

The observation of $CO_2$ emissions serves as a crucial indicator for assessing the extent of full combustion occurring within the cylinder of a diesel engine. Hence, an increased presence of oxygen molecules within the cylinder may result in the production of a more thorough combustion process [107]. In the event that a sufficient quantity of oxygen molecules is present within the cylinder, the conversion of CO to $CO_2$ will occur. Figure (4-8) illustrates the variation of $CO_2$ emissions results for biodiesel and alcohol mixtures in diesel fuel blends at different loads and constant engine speed Figure (4-8) A displays the carbon dioxide ($CO_2$) emission chart for several fuel blends, including biodiesel, alcohol, and diesel fuel, as a function of the load on the engine. D80B10PEN10, D70B15PEN15 D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 1750rpm, CO2 emission increased by values of 36.43% ,38.57%, 34.29%, 40.71%, 27.86%,50.0%, and 12.14%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-8) B presents a graphical representation of the carbon dioxide ($CO_2$) emission data for biodiesel, alcohol, and diesel fuel blends, categorised according to the load on the engine. D80B10PEN10, D70B15PEN15 D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2000rpm, $CO_2$ emission increased by values of 25.95% ,29.11%, 21.52%, 34.18%, 17.72%, 39.24%, and 16.46%, respectively, compared to fossil diesel fuels D100 based on engine loads. Figure (4-8) C displays the carbon dioxide ($CO_2$) emission chart for biodiesel, alcohol, and diesel fuel blends, as influenced by variations in load on the engine. D80B10PEN10, D70B15PEN15 D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2250rpm, $CO_2$ emission increased by values of 27.78%,30.86%, 22.22%, 34.57%, 16.67%,41.36%, and 11.73%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-8) D illustrates the graphical representation of carbon dioxide ($CO_2$) emissions for biodiesel, alcohol, and diesel fuel blends as a function of the engine's load. D80B10PEN10, D70B15PEN15 D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2500rpm, $CO_2$ emission increased by values of 27.91%,30.81%, 23.26%, 34.30%, 16.86%,37.79%, and8.56%, respectively, compared to fossil diesel fuelsD100 based on engine loads.

Furthermore, the rise in engine load resulted in a parallel increase in $CO_2$ emissions throughout each test fuel evaluation. The carbon dioxide ($CO_2$) emissions of both binary and ternary blends were found to be greater than those of diesel fuel. This can be attributed to the surplus oxygen content in their chemical compositions, leading to a more thorough and complete combustion process. The ternary blends exhibited decreased density and kinematic viscosity, which, therefore, enhanced the fuel evaporation process. This, in turn, led to a continuous increase in $CO_2$ emissions [108].





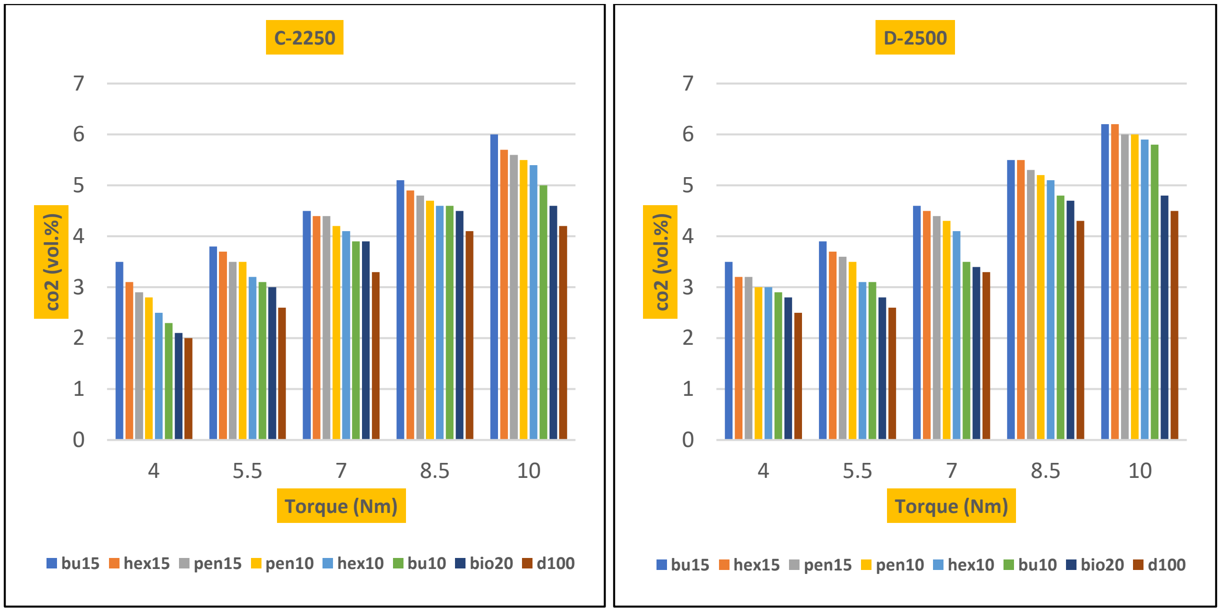


Figure (4-8): Carbon dioxide ($CO_2$) graphic according to engine load.

### 4.5.3 Unburned Hydrocarbons (UHC):

Hydrocarbon emissions are the outcome of the partial combustion of fuel inside the combustion chamber. Insufficient combustion occurs as a consequence of a lean combination of air and fuel, leading to diminished flame velocities. This phenomenon is primarily responsible for the discharge of hydrocarbon emissions [109]. The carbon deposits within the combustion chamber have a porous structure. During the compression phase, certain hydrocarbons become trapped inside the pores of the air-fuel mixture and fail to undergo combustion in the power stroke. Consequently, these hydrocarbons are subsequently released from the cylinder during the exhaust stroke [110]. The emission of unburnt hydrocarbons is contingent upon the combustion efficiency within the diesel engine. The evaluation of unburnt hydrocarbon formation primarily relies on key parameters such as cetane number, heat of evaporation, viscosity, oxygen concentration, and engine operating conditions. The primary factor contributing to the presence of unburned hydrocarbons (HC) in the combustion byproducts is attributed to either the fuel's inability to attain the required ignition temperature or the insufficient availability of oxygen within the combustion chamber. Broadly speaking, this particular instance has resulted in the fuel undergoing a state of non-oxidation or partial oxidation. Figure (4-9) illustrates the variation of HC emissions results for biodiesel and alcohol mixtures in diesel fuel blends at different loads and constant engine speeds. Figure (4-9) A displays the chart illustrating the levels of Unburned Hydrocarbons (UHC) in biodiesel, alcohol, and diesel fuel blends as a function of the load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 1750rpm. Unburned Hydrocarbons (UHC) decreased by values of 15.89%, 59.81%, 27.10%, 66.36%, 36.45%, 62.62%, and 9.35%, respectively, compared to fossil diesel fuels D100 based on engine loads. Figure (4-9) B presents the chart illustrating the levels of Unburned Hydrocarbons (UHC) in biodiesel, alcohol, and diesel fuel blends at varying engine loads. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2000rpm. Unburned Hydrocarbons (UHC) decreased by values of 16.16%, 62.63%, 27.20%, 69.3%, 36.36%, 68.69%, and11.11%, respectively, compared to fossil diesel fuelsD100 based on engine loads. Figure (4-9) C presents the chart illustrating the levels of Unburned Hydrocarbons (UHC) in biodiesel, alcohol, and diesel fuel mixes as a function of load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2250rpm. Unburned Hydrocarbons (UHC) decreased by values of

22.34%, 62.77%, 28.72%, 69.9%, 42.55%, 69.11%, and 10.64%, respectively, compared to fossil diesel fuels D100 based on engine loads. Figure (4-9) D presents the chart illustrating the levels of Unburned Hydrocarbons (UHC) in biodiesel, alcohol, and diesel fuel mixes, with variations based on the engine's load. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2500rpm. Unburned Hydrocarbons (UHC) decreased by values of 20.2%, 60.1%, 25.88%, 69.98%, 42.35%, 68.24%, and 11.76%, respectively, compared to fossil diesel fuels D100 based on engine loads.

The findings indicate that, across all fuel types examined, there is a negative correlation between engine speed and the concentration of unburned hydrocarbons (UHC). At elevated engine velocities, the atomization rate and turbulence intensify due to the atomization phenomenon of fuel within the cylinder, resulting in a more uniform mixture and decreased emissions of unburned hydrocarbons (UHC). The emission of unburned hydrocarbons (UHC) in the exhaust was shown to decrease as the proportion of biodiesel and alcohol mixtures in diesel fuel blends grew. Conversely, when compared to diesel fuel, the emission level of UHC increased as the quantity of diesel fuel in the blend increased. Insufficient oxygen in the combustion area is identified as the primary factor contributing to the elevated emissions of UHC (unburned hydrocarbons) in diesel fuel. Conversely, the increased oxygen content is seen in biodiesel and alcohol mixtures within the combustion zone facilitated enhanced combustion efficiency. This implies that the inclusion of biodiesel in the fuel mixture results in an elevation of the cetane number and oxygen content within the blend.

Consequently, this leads to enhanced combustion efficiency and a decrease in the emission levels of unburned hydrocarbons (UHC). Additionally, the reduced period of combustion allows for a sufficient amount of time to achieve a higher degree of fuel conversion [111] and [112].

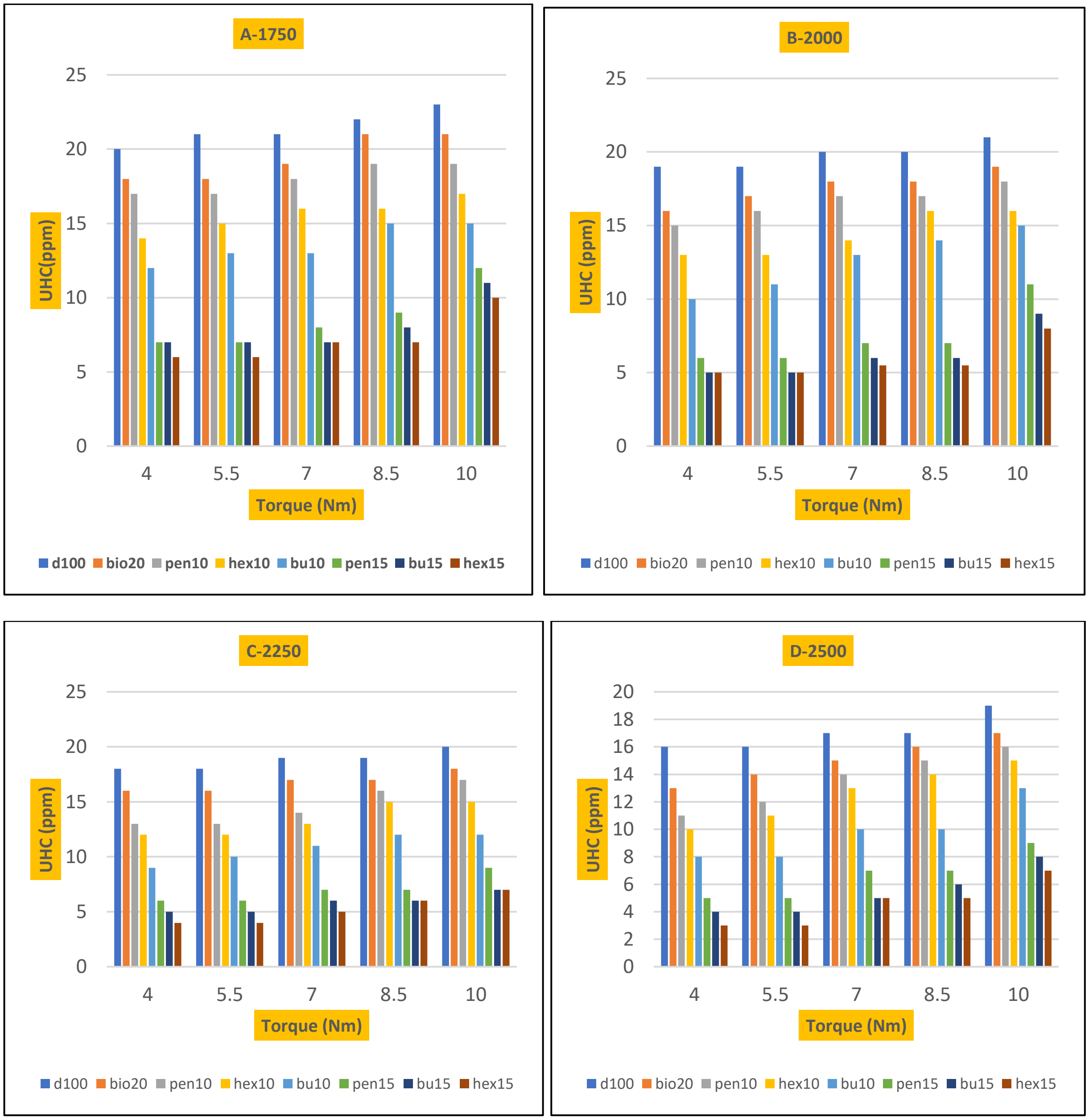


Figure (4-9): Variation of Unburned Hydrocarbons (UHC) depending on engine loads.

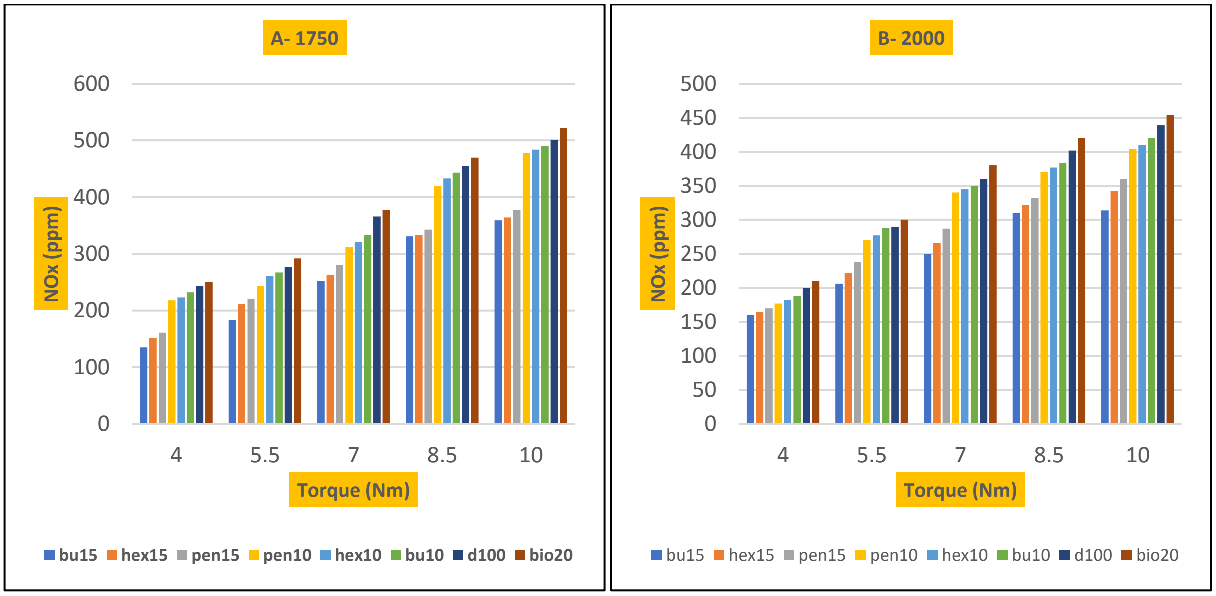
### 4.5.4 Nitrogen of Oxides (NOx):

NOx emissions are a harmful gas that has effects on both human respiratory health and the environment. The objective is to minimise it. The emission of nitrogen oxides (NOx) is primarily influenced by factors such as engine cylinder temperature, viscosity, density, cetane number (CN), heat of evaporation, and oxygen content of the fuel [113]. The composition of free air mostly of 78.6% nitrogen gas (N2), 20.95% oxygen (O2), and the rest portion comprises various additional gases [114]. As the rate of formation of nitrogen oxides emissions in diesel engines is a function of the temperature of the preservative flame, which is closely related to the maximum temperature of the cylinder. The high temperature of the preservative flame, the high temperature of the cylinder, and the oxygen content of the biodiesel resulted in higher NOx Figure (4-10) illustrates the variation of Nitrogen of Oxides (NOx): results for biodiesel and alcohol mixtures in diesel fuel blends at different loads and constant engine speed. Figure (4-10) A presents a graphical representation of the Nitrogen Oxides (NOx) levels in biodiesel, alcohol, and diesel fuel mixes as a function of the load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 1750rpm. The nitrogen of Oxides (NOx) decreased by values of 9.3%, 24.9%, 6.5%, 28.1%, 4.2%, and 31.6%, respectively, except D80B20 the (NOx) increased by (3.9%), compared to fossil diesel fuels D100 based on engine loads.

Figure (4-10) B presents a graphical representation of the Nitrogen of Oxides (NOx) data for biodiesel, alcohol, and diesel fuel blends, with variations seen based on the load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2000rpm.The nitrogen of Oxides (NOx) decreased by values of 7.6%, 18.0%, 5.9%, 22.1%, 3.6%, and 26.7%, respectively, except D80B20 the

(NOx) increased by (4.3%), compared to fossil diesel fuels D100 based on engine loads. Figure (4-10) C displays the chart illustrating the levels of Nitrogen Oxides (NOx) emitted by biodiesel, alcohol, and diesel fuel mixtures at varying engine loads. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2250rpm. The nitrogen of Oxides (NOx) decreased by values of 8.0%, 19.9%, 5.7%, 22.4%, 3.8%, and 24.9%, respectively, except D80B20 the (NOx) increased by (3.5%), compared to fossil diesel fuels D100 based on engine loads. Figure (4-10) D presents a graphical representation of the Nitrogen of Oxides (NOx) data for biodiesel, alcohol, and diesel fuel blends, categorized by load on the engine. D80B10PEN10, D70B15PEN15, D80B10HEX10, D70B15HEX15, D80B10BU10, D70B15BU15, and D80B20 fuel blends at 2500rpm. The nitrogen of Oxides (NOx) decreased by values of 4.6%, 12.7%, 3.6%, 15.1%, 3.0%, and 18.5%, respectively, except D80B20 the (NOx) increased by (4.4%), compared to fossil diesel fuels D100 based on engine loads.

It has been observed that the emissions of $\mathrm{NO}x$ tend to rise as engine load increases across various fuel types. This can be attributed to the augmented quantity of fuel combusted and a slight elevation in temperature. Furthermore, it is commonly observed that biodiesel fuel exhibits higher $\mathrm{NO}x$ emissions compared to diesel fuel. This disparity can be attributed to biodiesel's higher cetane number, greater viscosity, and increased oxygen content relative to B20 and diesel fuel. The combustion of biodiesel is characterised by its elevated flame temperatures. The phenomenon under consideration can be elucidated by employing the principles of the Energy-Gradient Theory (EGT) in conjunction with the concept of heat of evaporation. The findings indicate that the inclusion of an alcoholic component in ternary blends leads to a reduction in NOx emissions, with a higher concentration of alcohol resulting in a greater decrease. The observed phenomenon can be attributed to the high latent heat of vaporization and the reduction in the cetane number of alcohols, resulting in a decreased flame temperature. This decrease in flame temperature manifests as a cooling effect throughout the combustion process. The main influence on the combustion process and subsequent lower NOx emissions in alcohol blends is attributed to the increased latent heat of vaporization exhibited by higher alcohols [115] and [116].



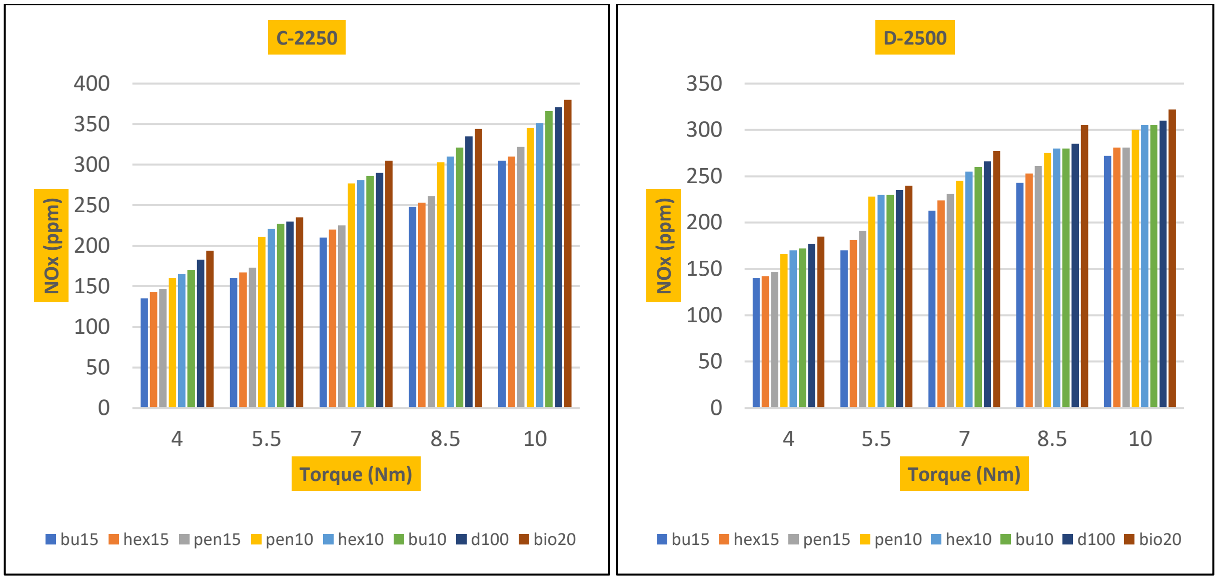


Figure (4-10): Variation of Nitrogen of Oxides (NOx)depending on engine loads.

# CHAPTER FIVE

# Conclusions and Recommendations

# CHAPTER FIVE

# Conclusions and Recommendations

## 5.1 Introduction:

This chapter provides a summary of the findings about the impact of using mixes of diesel fuel with biodiesel and higher alcohol on the performance of diesel engines and exhaust emissions. These results are based on the experimental portion of the current study. In an unmodified single-cylinder compression ignition (CI) engine, experiments were conducted at several engine speeds ranging from 1750 to 2500 (rpm) and varied engine loads, specifically (4, 5.5, 7, 8.5, and 10Nm). The objectives of this study were to repurpose waste cooking oil (WCO) for the production of biodiesel. The aforementioned study's conclusions are derived from the findings obtained in the investigation. Additionally, this study also presents recommendations for future work in the field of engines.

## 5.2 Conclusions:

1- The brake thermal performance (ηbth) of binary (biodiesel-diesel) and ternary (biodiesel-diesel-alcohols) fuel mixtures have shown a decline in comparison to fossil diesel fuels D100.

2- The fuel mixtures made up of ternary (biodiesel-diesel-alcohols) and binary (biodiesel-diesel) materials exhibited a rise in break-specific consumption of fuel (BSFC) as compared with fossil diesel fuels D100.

3- The Brake's Power (BP) exhibits a positive correlation with both engine speed and load, indicating that an increase in either of these factors leads to a corresponding increase in BP and were in similar proportions for all blends.

4- An increase in BSFC coupled with a decrease in EGT was observed for all binary and ternary blends in comparison to fossil diesel, fuels D100 .
5- The temperature of the exhaust gas exhibits a positive correlation with the engine's load. In the case of similar engine speed and load, it has been observed that exhaust gas temperatures remain consistently higher for diesel fuel in comparison to binary fuel mixes (biodiesel-diesel) and ternary fuel mixtures (biodiesel-diesel-alcohols) across all engine loads.
6- The UHC emissions decrease when ternary (biodiesel-diesel-alcohols) blends are added to diesel, but increase when binary (biodiesel-diesel) is added.
7- The utilization of binary (biodiesel-diesel) and ternary (biodiesel-diesel-alcohols) blends have been found to result in a notable decrease in exhaust gas emissions of carbon monoxide (CO) and hydrocarbons (HC) when compared to pure diesel fuel (D100). However, it should be noted that the use of these blends leads to an increase in carbon dioxide ($CO_2$) emissions in comparison to conventional diesel fuel.
8- The addition of biodiesel to diesel (D80B20) leads to a rise in NOX emissions, however, the inclusion of ternary fuel blends (biodiesel-diesel-alcohols) results in a decline in NOX emissions in comparison to fossil diesel fuels (D100).

## 5.3 Recommendations for Future Work:

Several recommendations can be considered for future work:

1. Investigating the impact of incorporating two different types of alcohol and exhaust gas recirculation (EGR) on engine performance and exhaust emissions when blended with diesel fuel.

2. Studying the impact of incorporating nanoparticle additives and exhaust gas recirculation (EGR) on both engine efficiency and exhaust emissions when using diesel mixes.
3. Exploring the impact of employing hot exhaust gas recirculation (EGR) on the performance of a compression ignition (C.I) engine as well as its emissions.
4. Studying the impact of raising the beginning temperature of fuel mixes on the performance of compression-ignition (C.I) engines.
5. Examining the impact of utilizing oxygenated fuel additives in conjunction with a cetane number enhancer on the combustion and emission properties of a compression ignition (C.I) engine.

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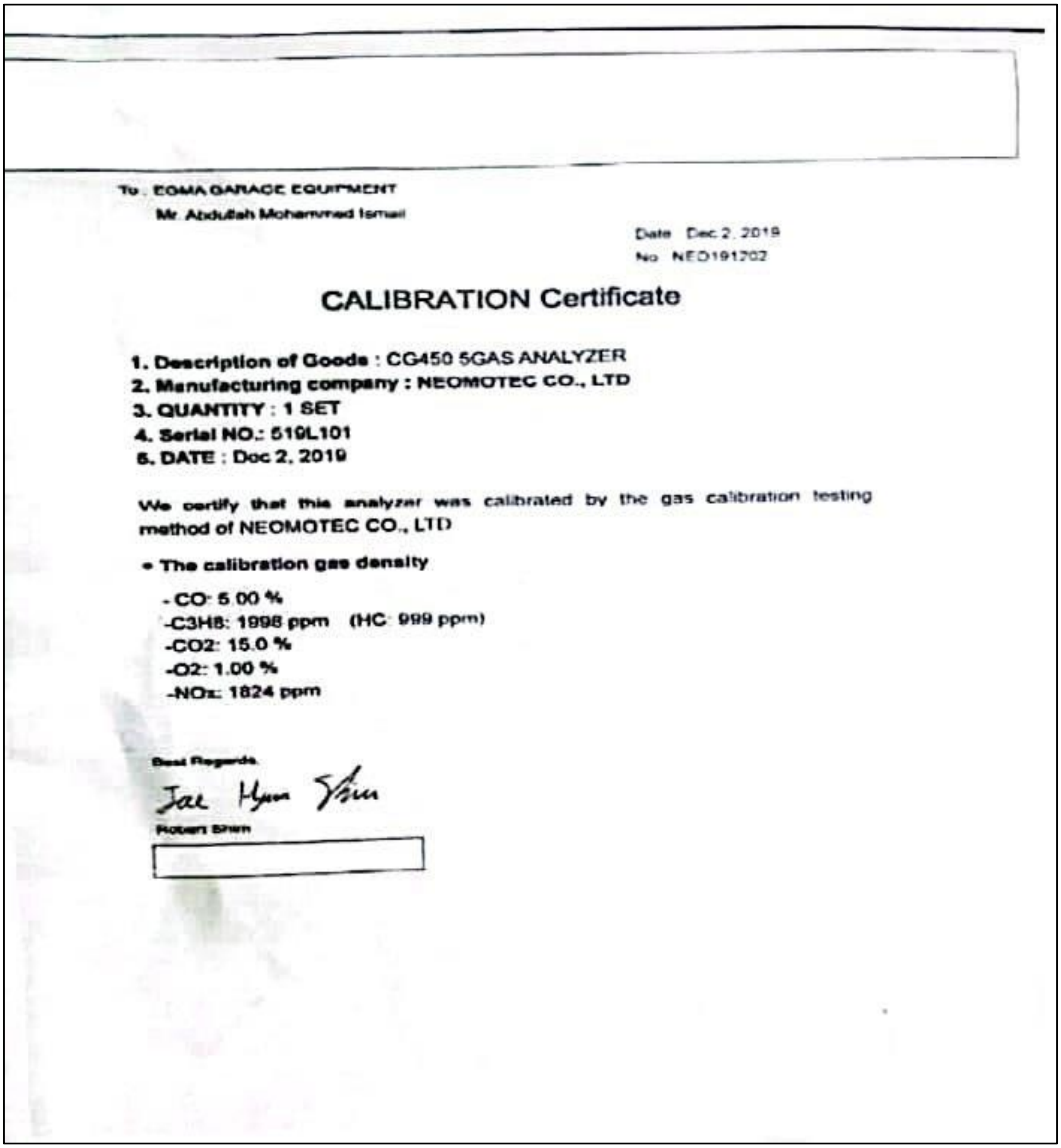
# Appendix-A
## A1 : Gas analyzer calibration certificate



To . EOMA GARAGE EQUIPMENT
Mr. Abdullah Mohammed Ismail

Date Dec 2, 2019
No NED191202

**CALIBRATION Certificate**

1. **Description of Goods** : CG450 5GAS ANALYZER
2. **Manufacturing company : NEOMOTEC CO., LTD**
3. **QUANTITY** : **1 SET**
4. **Serial NO.: 519L101**
5. **DATE** : **Doc 2, 2019**

**We certify that this analyzer was** calibrated by the gas calibration testing **method of** NEOMOTEC CO., LTD

- **The calibration gas density**

  - CO: 5.00 %
  - C3H8: 1998 ppm (HC: 999 ppm)
  - CO2: 15.0 %
  - O2: 1.00 %
  - NOx: 1824 ppm

**Best Regards**

Jae Hyun Shin

**Robert Shin**

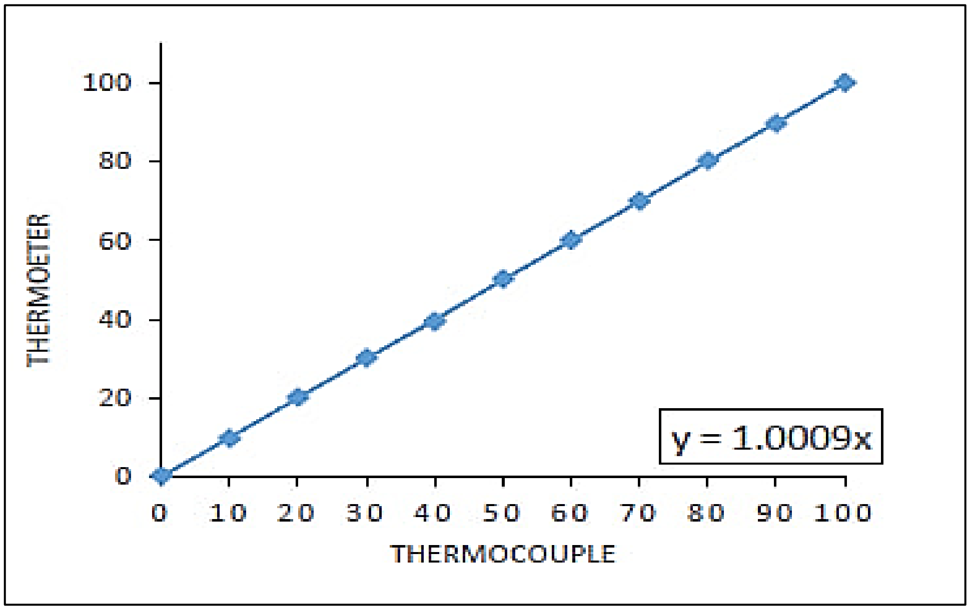
## A2 : Specifications of the gas analyzer

| Trademark Name | Neomotech |
|---|---|
| Model Number | CG-450 |
| Repeatability | Less than ±2% FS |
| Warm-up time | 2~8 minutes |
| Response time | 10 second (more than 90%)O2, NOx less than 20sec |
| Sample colecting quantity | 4~6 L/min |
| Power supply | AC110V~AC220V ±10% 50Hz~60Hz |
| Operation temperature (˚C) | 0 ˚C~40 ˚C |
| Measuring Method: O2, NOx | Electrochemical cell |
| Measuring Method: HC, CO, CO2 | NDIR method |
| Auto Zero | 20sec |
| Fuel selectable | Gas oil/Gasoline/LPG/Alchohol |

# Appendix B : Calibration

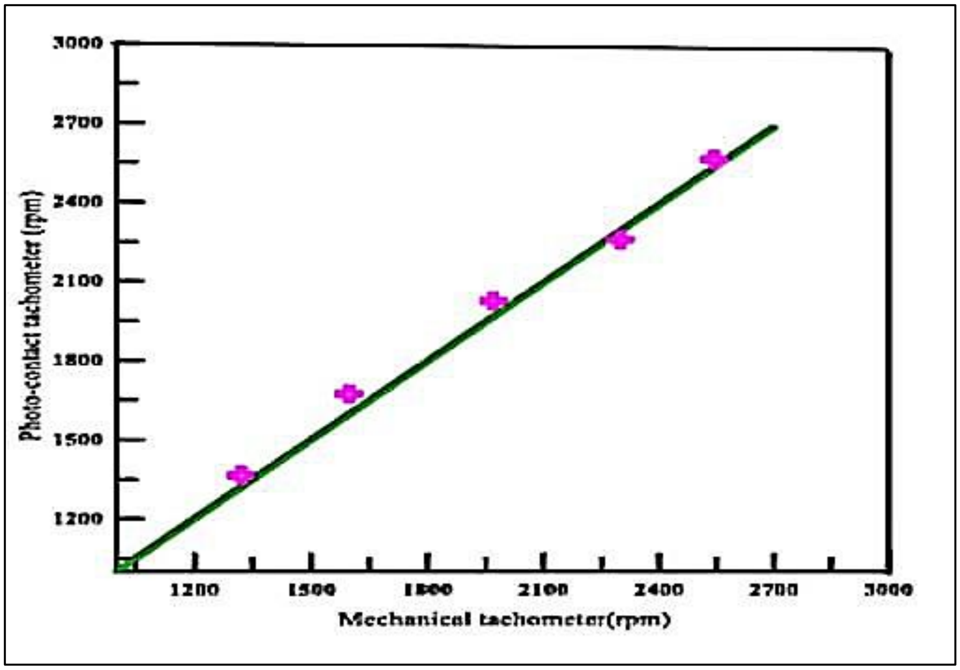
## Exhaust gas temperature thermocouple

The error percentage is 1%.

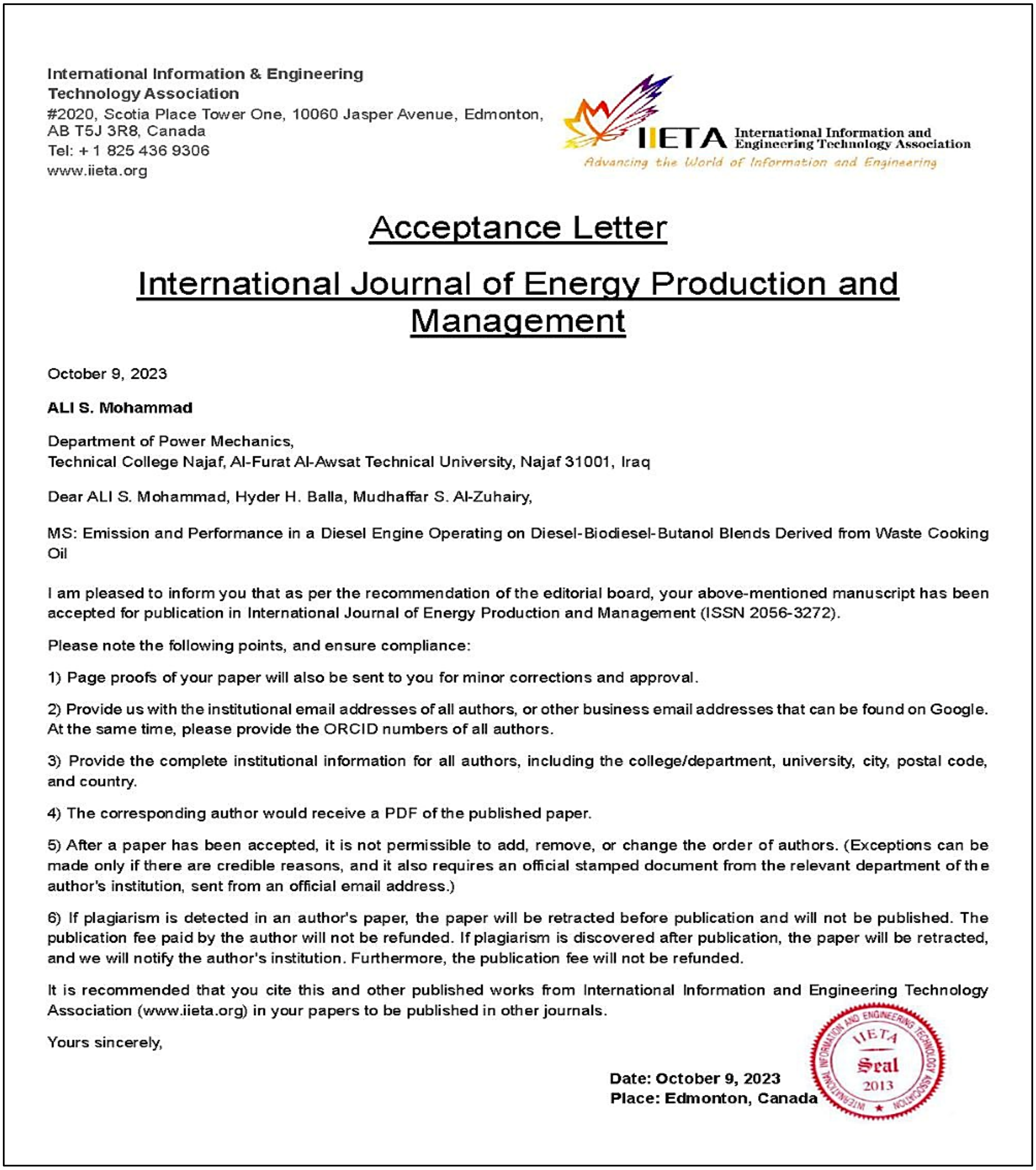


## Mechanical Contact Hand-Tachometers

The error percentage is 2.5%.



# Appendix C :



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## Acceptance Letter

## International Journal of Energy Production and Management

October 9, 2023

**ALI S. Mohammad**

Department of Power Mechanics,
Technical College Najaf, Al-Furat Al-Awsat Technical University, Najaf 31001, Iraq

Dear ALI S. Mohammad, Hyder H. Balla, Mudhaffar S. Al-Zuhairy,

MS: Emission and Performance in a Diesel Engine Operating on Diesel-Biodiesel-Butanol Blends Derived from Waste Cooking Oil

I am pleased to inform you that as per the recommendation of the editorial board, your above-mentioned manuscript has been accepted for publication in International Journal of Energy Production and Management (ISSN 2056-3272).

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Date :

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**التاريخ :** ٢٦ / ٩ / ٢٠٢٣

إلى/ الباحث علي سعدون محمد المحترم
الباحث حيدر حسن باله المحترم
الباحث مظفر صادق الزهيري المحترم

م/ قبول البحث والنشر

نهديكم أطيب التحية..

بعد إطلاع المقيمين على بحثكم الموسوم :-

**Biodiesel Production from Waste Cooking Oil (WCO) using Transesterification**

من الناحية العلمية وبعد عرض النتائج على هيئة التحرير في جلستها الثامنة لعام (2023) المنعقدة بتاريخ (2023/9/24) , فقد قررت الهيئة قبول بحثكم في مجلة القادسية للعلوم الهندسية وسوف ينشر في المجلد السابع عشر/ العدد القادم.

...مع فائق التقدير والاحترام ...

أ.د. خالد عبد الحسين جبير
رئيس هيئة التحرير
2023/ 9 /

نسخة منه الى:-
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- الأضبارة الخاصة بالمحاضر .

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ص ب ١٧٦٧٠١٩٩٦ هاتف ٠٠٩٦٤٠٣٦٦٣١٧٥٣

# الخلاصة

لسنوات عديدة، كان الوقود المشتق من النفط خيارًا شائعًا لتلبية احتياجات الطاقة. ومع ذلك، فإن التركيز المتزايد على الحفاظ على بيئتنا وإيجاد مصادر جديدة للطاقة قد حفز الرغبة في خيارات متجددة ونظيفة. أصبحت أنواع الوقود البديلة لمحركات الديزل شائعة بشكل متزايد، وخاصة تلك القابلة للتجديد. لقد عرّفتنا هذه الدراسات على خيارات الوقود الصديقة للبيئة والمجدية اقتصاديًا. ظهر وقود الديزل الحيوي والكحول كبدائل محتملة لمحركات الديزل. إحدى المزايا الرئيسية لأنواع الوقود هذه هي أنها متجددة ويتم إنتاجها محليًا. باستخدام محرك ديزل مبرد بالهواء، ذو اسطوانة واحدة، يعمل بالضغط، استخدمت دراستنا الديزل العراقي النقي (D) كنقطة مرجعية قبل تحضير العديد من خلطات الوقود. الغرض من هذا العمل هو إجراء دراسات تجريبية وإثبات إمكانية استخدام خليط الوقود الحيوي المكون من (الكحول) والديزل الحيوي (مخلفات زيت الطهي) في محرك الديزل وتقييم أداء المحرك والانبعاثات. يستلزم عملنا إنشاء خلطات مختلفة:[D100، D80B20، D80B10PEN10، D70B15PEN15، D80B10HEX10، D70B15HEX15، D80B10BU10، D70B15BU15]، وتم اختبار وقود الديزل ومخاليط الوقود عن طريق تغيير الحمل على المحرك (4، 5.5، 7، 8.5، 10 نيوتن متر)، وسرعة المحرك ثابتة (1750، 2000، 2250، 2500 دورة في الدقيقة). للحصول على انبعاثات غاز العادم يتم قياسها من المحرك بواسطة محلل غاز العادم (أول أكسيد الكربون CO، وثاني أكسيد الكربون CO2، والهيدروكربونات UHC غير المحترقة، وأكاسيد النيتروجين [NOx]). كانت معلمات أداء المحرك هي قوة الفرامل (Bp)، واحتراق الوقود الخاص بالفرامل (BSFC)، ودرجة حرارة غاز العادم (EGT) والكفاءة الحرارية للفرامل (bth) التي يتم قياسها من المحرك. بالنسبة لسرعة المحرك الثابتة مع الحمل المتغير، أظهرت نتائج العمل التجريبي أنه عند إضافة مزيج وقود الديزل الحيوي والكحوليات العالية إلى الديزل، يزيد استهلاك الوقود الخاص بالفرامل [D80B10PEN10، D70B15PEN15، D80B10HEX10، D70B15HEX15، D80B10BU10، D70B15BU15، وD80B20] بالقيم 5.19%، 10.99%، 7.63%، 21.68%، 12.01%، 15.93%، و3.82% على التوالي، مقارنة بوقود الديزل. بينما بالنسبة لنفس الخلطات فقد حدث انخفاض في الكفاءة الحرارية بقيم 5.19%، 10.99%، 7.63%، 21.68%، 12.01%، 15.93%، و3.82%، على التوالي، مقارنة بوقود الديزل. كان لزيادة تركيز الكحوليات الأعلى تأثير على درجة حرارة غاز العادم (EGT) بالمقارنة مع وقود الديزل، ووُجد أن الخلطات الثلاثية تقلل الكفاءة الحرارية للفرامل (ηbth) مع زيادة استهلاك الوقود المحدد للفرامل (BSFC)، واظهرت

النتائج ان EGT لوقود الديزل أعلى من أنواع الوقود الأخرى، وكان الانخفاض في درجة حرارة غاز العادم (EGT) بنسبة (6.7%، 11.7%، 18.9%، 10.9%، 7.95%، 17.8%، 22.6%). لنفس الخلطات على التوالي، مقارنة بوقود الديزل ومن حيث انبعاثات غازات العادم، انخفضت انبعاثات ثاني أكسيد الكربون CO ومركبات UHC في وقود الديزل الحيوي والمخاليط الكحولية الأعلى باستثناء أكسيد الكربون $CO_2$، بينما زادت أكاسيد النيتروجين باستخدام مخاليط الديزل الحيوي (D80B20) مع انخفاض السلوك المعاكس مع مخاليط الكحول الأعلى.

# دراسة الأداء والانبعاثات للمحرك باستخدام الوقود المتجدد

**رسالة مقدمة الى**
**قسم هندسة تقنيات ميكانيك القوى في الكلية التقنية الهندسية – النجف – جامعة الفرات الاوسط التقنية كجزء من متطلبات نيل شهادة الماجستير في هندسة تقنيات ميكانيك القوى/ الحراريات**

**تقدم بها**
**علي سعدون محمد الغزالي**

**بأشراف**

**الاستاذ الدكتور**
**حيدر حسن عبد**

**الاستاذ الدكتور**
**مظفر صادق الزهيري**

**2023**
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**جامعة الفرات الأوسط التقنية**
**الكلية التقنية الهندسية/النجف**

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**ماجستير في هندسة تقنيات ميكانيك القوى /الحراريات**

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