REPUBLIC OF IRAQ

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
AL-FURAT AL-AWSAT TECHNICAL UNIVERSITY
ENGINEERING TECHNICAL COLLEGE NAJAF

# USING ALTERNATIVE FUELS TO REDUCE POLLUTION IN INTERNAL COMBUSTION ENGINE

ALI ABDULKADHUM ABDULZAHRAA

M.TECH
IN MECHANICAL ENGINEERING TECHNIQUES OF POWER

2024

**USING ALTERNATIVE FUELS TO REDUCE POLLUTION IN INTERNAL COMBUSTION ENGINE**

A THESIS

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

**BY**

**ALI ABDULKADHUM ABDULZAHRAA**

**Supervisor By**

**Prof. Dr. Hyder. H. Balla** **Prof Dr. Mudhaffar S. Al-zuhairy**

**2024**

بسم الله الرحمن الرحيم

(نَرْفَعُ دَرَجَٰتٍ مَّن نَّشَاءُۗ وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ )

صدق الله العلي العظيم

يوسف﴿76﴾

# DISCLAIMER

I confirm that the work submitted in this thesis is my own work and has not been submitted to other organization or for any other degree.

Signature:

Name: Ali Abdulkadhum Abdulzahraa

Date: / / 2024

**ACKNOWLEDGMENT**

All Praise be to ALLAH for his uncountable blessings and, assistance during the preparation of this work.

I want to offer my profound respects and sincere gratitude to my supervisors, **Prof. Dr. Hyder. H. Balla** and **Prof Dr. Mudhaffar S. Al-zuhairy,** for their support during the research period and guidance to accomplish this work.

Special thanks go to the head and members of the Mechanical Power Techniques Engineering department for their assistance to me. I would like to thank all lovely, helpful people who support me directly and indirectly to conduct this work.

My deepest thanks and gratitude are due to each family member, especially my dearest parents, and brothers for their patience, support, and encouragement throughout my life.

**Ali Abdulkadhum Abdulzahraa**

**2024**

## SUPERVISORS CERTIFICATION

We certify that the thesis entitled "**Using alternative fuels to reduce pollution in internal combustion engine**" submitted by **Ali Abdulkadhum Abdulzahraa** has been prepared under our supervision at the Department of Mechanical Engineering Techniques of Power, College of Technical Engineering-Najaf, AL-Furat Al-Awsat Technical University, as partial fulfillment of the requirements for the degree of Master of Techniques in Thermal Engineering.

Signature:

Name: Prof. Dr. Hyder. H. Balla

(Supervisor)

Date: / / 2024

Signature:

Name: Prof Dr. Mudhaffar S. Al-zuhairy

(Supervisor)

Date: / / 2024

In view of the available recommendation, we forward this thesis for debate by the examining committee.

Signature:

Name: Asst.Prof. Dr. Adel A. Eidan

Head mechanical Eng. Tech of power Dept.

Date: / / 2024

# COMMITTEE CERTIFICATION

We certify that we have read the thesis entitled "**Using alternative fuels to reduce pollution in internal combustion engine**" submitted by **Ali Abdulkadhum Abdulzahraa** and, as examining committee, examined the student's thesis in its contents. And that, in our opinion, it is adequate as a thesis for the degree of Master of Techniques in Thermal Engineering.

Signature:
Name: Prof. Dr. Hyder. H. Balla
(Supervisor)
Date: / / 2024

Signature:
Name: Prof Dr. Mudhaffar S. Al-zuhairy
(Supervisor)
Date: / / 2024

Signature:
Name: Asst. Prof. Dr. Mohammed A. Al-Fahham
(Member)
Date: / / 2024

Signature:
Name: Asst. Prof. Dr. Mohanad H. Hussein
(Member)
Date: / / 2024

Signature:
Name: Prof. Dr. Alaa L. Hashem
(Chairman)
Date: / / 2024

**Approval of the Engineering Technical College- Najaf**

Signature:
Name: Asst. Prof. Dr. Hassanain Ghani Hameed
Dean of Engineering Technical College- Najaf
Date: / / 2024

# LINGUISTIC CERTIFICATION

This is to certify that this thesis entitled "**Using alternative fuels to reduce pollution in internal combustion engine**" was reviewed linguistically. Its language was amended to meet the style of the English language.

Signature:

Name:

Date:

# ABSTRACT

Compression ignition engines cause negative effects on human health and global warming as a result of exhaust gas emissions that pollute the environment, in addition to the high cost of diesel fuel, which runs out one day, so attention must be paid to alternative fuels, especially for compression ignition engines. In this study, an alternative fuel was prepared in the laboratory from vegetable oils, which is biodiesel, through the process of transesterification between vegetable oil and methanyl alcohol at a molar ratio of 7:1. Then the biodiesel was washed and dried. After that, the physical and chemical properties (viscosity, density, cetane number, flash point and calorific value ) of biodiesel and comparing them with standard values for biodiesel. In this study, engine performance parameters were studied: brake power, brake thermal efficiency, brake specific fuel consumption, and volumetric efficiency. Regarding exhaust emissions, they were hydrocarbon, carbon monoxide, carbon dioxide, nitrogen oxide ,and exhaust gas temperature. were tested the biodiesel mixtures that were used (B0, B10, B20 , B30, and B40), had inconsistent engine speeds (1100, 1400, 1700, and 2000) rpm and torques (0, 2.5, 5, 7.5, 10) N.m, Brake power decreased by (0.023, 0.0187, 0.0195, and 0.018) kW, respectively, compared to fossil diesel fuel. Brake thermal efficiency decreased by (0.0975%, 1.667%, 1.057%, and 1.56%), respectively, while there was an increase in Brake specific fuel consumption by (0.0655, 0.073, 0.0945, and 0.0522) kg/kWh, volumetric efficiency decreased by (1.767%, 2.767%, 2.17%, and 2.015%), respectively, compared to fossil diesel. Regarding exhaust emissions, carbon monoxide decreased by (0.028%, 0.022%, 0.020%, and 0.027%) vol., respectively, compared to fossil diesel, while carbon dioxide increased and hydrocarbon decreased, while nitrogen oxide increased, as did an increase in temperature exhaust gases compared to fossil diesel.

## CONTENTS

## LIST OF TABLES

### CHAPTER ONE



### CHAPTER TWO



### CHAPTER THREE



### CHAPTER FOUR



LIST OF FIGURES

### CHAPTER ONE

## CHAPTER THREE



## CHAPTER FOUR



# NOMENCLATURE

| Symbol | Definition |
|---|---|
| BP | Brake Power |
| BSFC | Brake Specific Fuel Consumption |
| BTE | Brake thermal efficiency |

| | |
|---|---|
| $q_c$ | Heat of combustion |
| $\dot{m}f$ | Mass fuelflow rate |
| B.P | Brake power |
| $\tau$ | Engine torque |
| $O_2$ | Oxygen |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| HC | Hydrocarbons |
| NOx | Nitrogen Oxide |
| EGT | Exhaust Gas Temperature |
| ASTM | American Society for Testing and Materials |
| EN | European standard |
| RPM | Revolution per minute |
| CR | Compression Ratio |
| VDAS | Versatile Data Acquisition System |
| ppm | Parts per million |
| B0 | 100% diesel fuel |
| B10 | 10% biodiesel and 90% diesel fuel |
| B20 | 20% biodiesel and 80% diesel fuel |
| B30 | 30% biodiesel and 70% diesel fuel |
| B40 | 40% biodiesel and 60% diesel fuel |
| KOH | Potassium Hydroxide |
| NaH | Sodium Hydroxide |
| FSU | Former Soviet Union |
| EJ | Exajoule |
| MECSO | Methyl ester cotton seed oil |
| MERBO | Methyl ester rice brown oil |
| PND100 | Preheated palm oil |
| PND20AB | 20% Preheated oil + 80% diesel + butylated hydroxytoluene 2000 ppm |

# Chapter One

# Introduction

# CHAPTER ONE

# INTRODUCTION

## Introduction

The world is witnessing a phase of decreasing and declining unsustainable energy and, at the same time the demand for energy is increasing as a result of the increase in population growth. It is likely that there will be an increase in energy requirements by only 2% for transportation each year, in addition to the increase in energy demand in the field of industry and agriculture [1]. Therefore, it is estimated that energy requirements in 2030 will be 80% higher than those in 2010, and this will lead to an increase in greenhouse gas emissions [2]. Among the popular renewable energy alternatives (hydrogen, natural gas, syngas and biofuels), the latter is the most renewable, sustainable, efficient, environmentally friendly and ready-to-use alternative to internal combustion engines without modifications to engine designs [3]. Biofuels are liquid fuels made from vegetable oils and waste products such as agricultural crops, municipal waste, and animal fats. Biodiesel is a sustainable and renewable alternative biofuel that can be used alone or blended with petroleum diesel fuel in proportions for conventional engines without any further modification [4]. Inventor Dr. Rudolph Diesel in 1900 used the first diesel engine and powered it with peanut oil [5, 6]. However, direct use of vegetable oils in diesel engines has been problematic due to their unsuitable physical properties such as high viscosity of oils, low pour point, higher flash point, higher molecular weight of triacylglycerols resulting in incomplete combustion due to low volatility, and polymerization of unsaturated fatty acids, and the formation of carbon deposits [7]. To overcome these problems, several physical and chemical modifications, such as pyrolysis, micro-emulsification, dilution, and cross-esterification, of vegetable oils have been examined [8].

## 1.1 Traditional fuel

Climate change and global warming result from the combustion residues of conventional fuels in internal combustion engines, as well as the rise in crude oil prices and limited energy reserves that run out one day, prompted researchers to study improving fuel efficiency, reducing emissions, and maintaining a clean and pure environment as shown in figure 1.1. Therefore, researchers and academics are interested in finding an alternative fuel that replaces traditional fuel, and from renewable sources that are ineffective and have less emissions and pollution to the environment. Among the proposed alternative fuels for internal combustion and compression ignition engines is biodiesel.

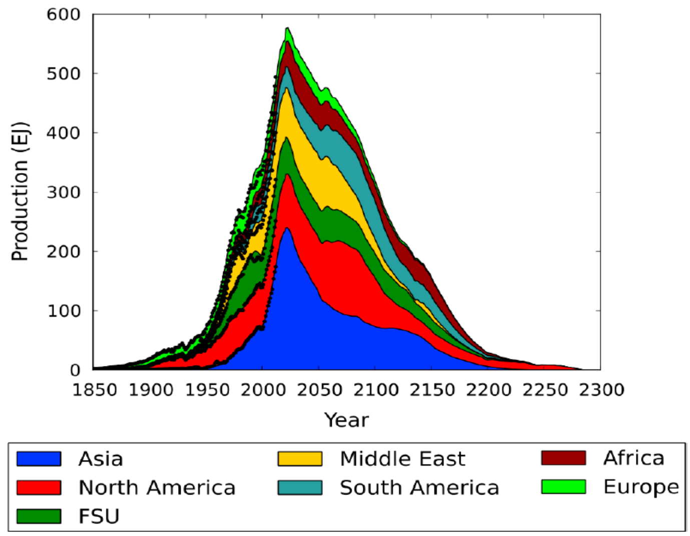



Figure 1.1 Fossil fuel use and projections (black dots represent actual production) [9].

## 1.2 Diesel Engine

The diesel engine was invented by Rudolf Diesel in Germany in 1890. Fuel combustion begins when fuel is introduced into the cylinder at the end of the compression stroke. The air is compressed by a compression ratio during the compression cycle, heating the gas above the autoignition temperature of the fuel. In the high temperature air, a quantity of diesel fuel is pumped in and ignited. Before combustion occurs and just after ignition, there is a short ignition delay followed by a sudden and rapid rise in cylinder pressure known as the pre-mixed combustion phase.

## 1.3 Performances of engines

The quality of the fuel used and its consumption have a significant impact on engine performance [10,11]. There are several factors and attributes that influence the amount of fuel a diesel engine uses, the most important of which are density, viscosity, interfacial tension and the fuel's heating value [12,13]. The control systems regulate how much fuel is injected, as a larger mass of fuel is pumped when the density of the fuel increases until it is the same required volume [14, 15].

## 1.4 Biodiesel as an alternative fuel

According to the American Society for Testing and Materials (ASTM), biodiesel is defined as monoalkyl esters derived from feedstocks that were vegetable oils or animal fats[16]. This is done through a chemical reaction called esterification, in which vegetable oils or animal fats are mixed with an alcohol and a catalyst [17]. It results in biodiesel and another substance, glycerin. Biodiesel can be used and mixed in certain proportions with regular diesel in internal combustion engines without any change in its design [18]. There are many raw materials for the production of biodiesel, as the raw materials from which biodiesel is produced can be divided into different categories, such as edible and inedible oils, waste oils, animal fats and algae fats, as shown in figures 1.2.

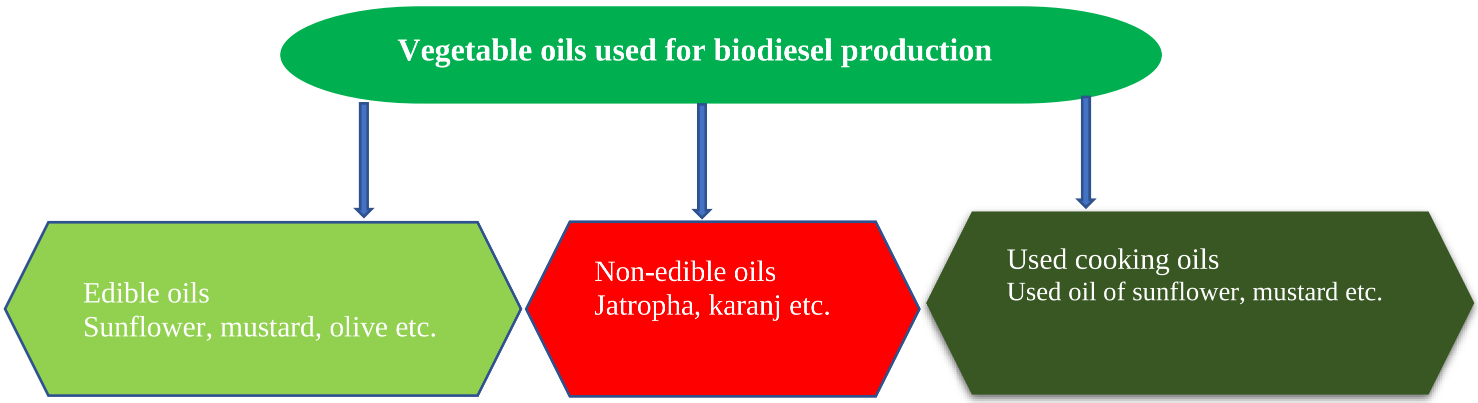



Figure 1.2 various vegetable oils used in the manufacturing of biodiesel.

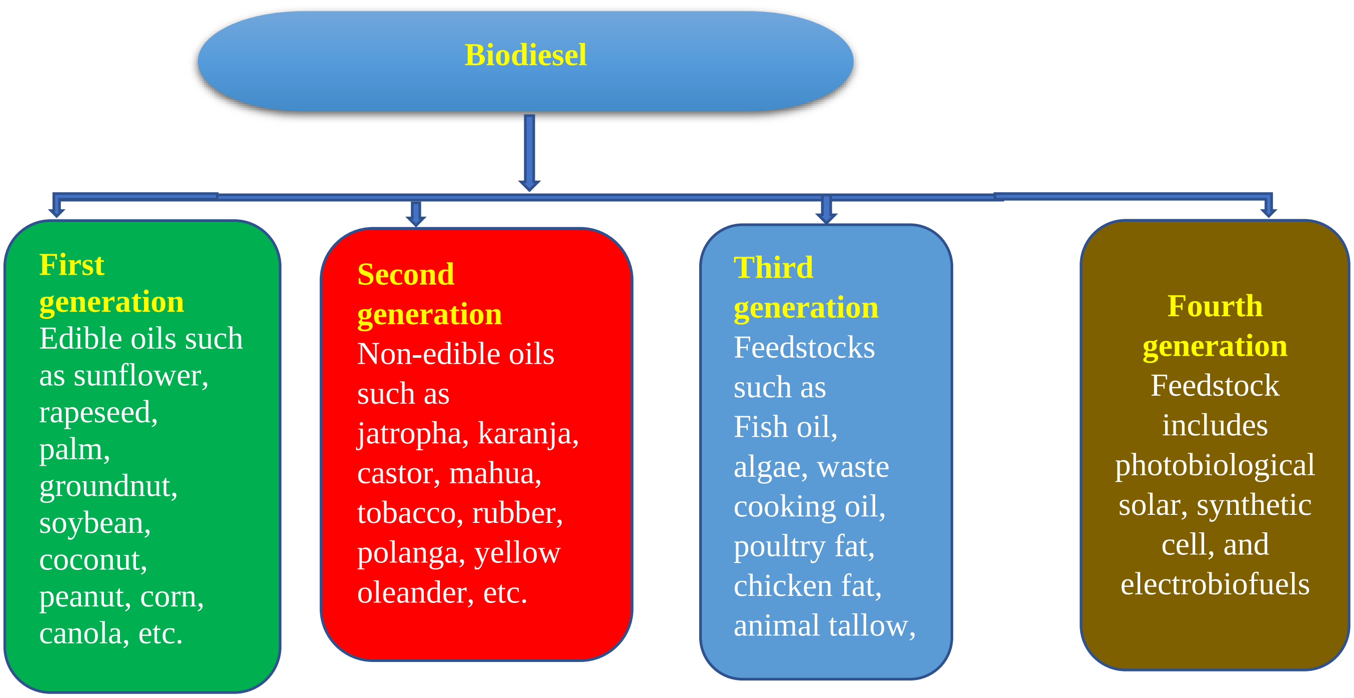



Figure 1.3 Different biodiesel feedstocks.

The increased consumption of natural energy sources as a result of the increasing population growth and civilizational development prompted many researchers to find alternative fuels such as biodiesel, because the fuel sources currently used from fossil fuels will run out one day, in addition, it pollutes the environment and harms human health.

Biodiesel is a biodegradable, non-toxic, low-emissions fuel that is a clean, sustainable alternative energy source. Therefore, biodiesel has become more popular in recent years as a useful alternative to fossil diesel that may run out in the future [19, 20]. The United States of America is one of the largest producers of biodiesel, with production in 2021 reaching (8.33 billion liters), followed by Indonesia (7.9 billion liters), and third in Brazil (6.9 billion liters) [21, 22] as shown in Figure 1.4.

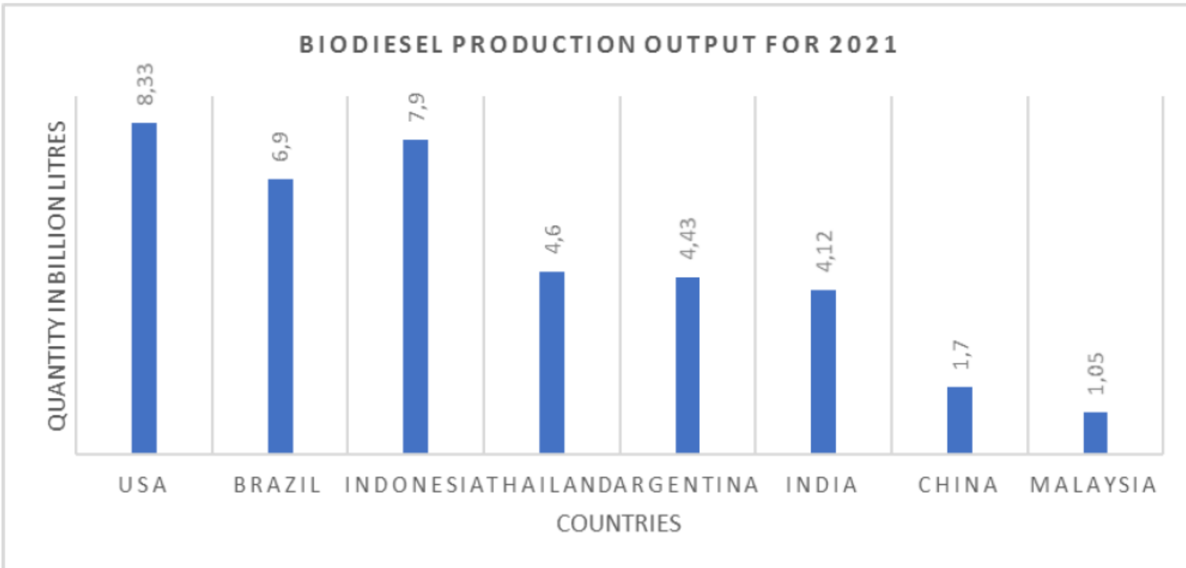



Figure. 1.4 Some countries' biodiesel production output in 2021[21].

Biodiesel has the following advantages compared to diesel fuel :

1) Biodiesel is a sustainable and renewable fuel. It can be used in diesel engines without any change in its design. It can be mixed with regular diesel in certain proportions or used in pure form.

2) It extends the life of the engine because it has a high lubrication potential, and the engine operation can be better.

3) It improves the combustion process because it contains an amount of oxygen up to 11%, reduces exhaust emissions, and there are no sulfur emissions, because it does not contain sulfur.

4) Lower dangerous in storage because the flammability is less compared to normal diesel, as the temperature of the ignition point is greater than 130 ºC, while in normal diesel it is from 60 to 80 ºC .

As for the most important disadvantages that it has compared to regular diesel:

1) High viscosity and density.

2) The calorific value is lower.

## 1.5 production biodiesel

For internal combustion engines in which diesel fuel is used, common esters are starting to be referred to as biodiesel. Biodiesel is prepared from vegetable oils or animal fats in which triglycerides react with alcohol in the presence of a catalyst to form an ester and glycerol. Figure 1.5 shows the transesterification process [23].

If they are made from methanol, esters of various vegetable oils are known as biodiesel or (fatty acid methyl ester), but if they are produced using ethanol in this case the process is slower and with low efficiency, but the last product can be considered biofuel [24, 25].

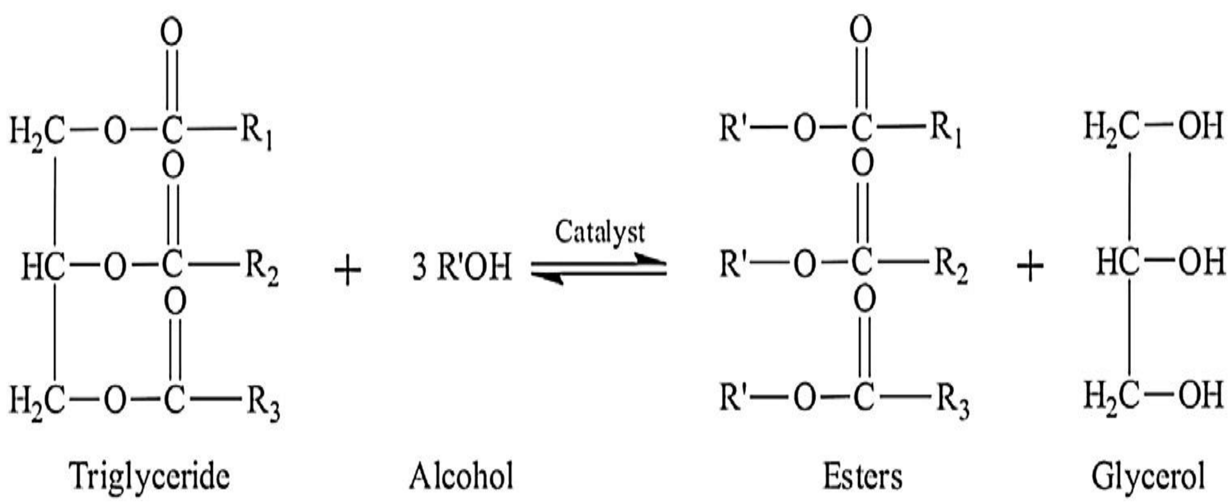



Figure. 1.5 Transesterification process [26].

## 1.6 Biodiesel Standards

Biodiesel must comply with to strict regulatory restrictions in order to meet the output requirements of a diesel engine. ASTM D6751 was developed by the American Society for Testing and Materials (ASTM) International to outline different test procedures to be used in estimating certain parameters for biodiesel blends. Biodiesel producers must meet specified standards in order to market their biodiesel on an industrial scale.

Table 1.1. ASTM D6751 and EN 14214 standards for biodiesel fuel [27, 29]

| Property | Unit | Test-Method | ASTM D6751 Limit | Test-Method | EN 14214 Limit |
|---|---|---|---|---|---|
| Kinematic viscosity at 40 ◦C | $mm^2/s$ | ASTM-D445 | 1.9–6.0 | EN-ISO3104 | 3.5–5.0 |
| Density at 15 ◦C | $kg/m^3$ | ASTM-D1298 | 880 | EN-ISO 3675/12185 | 860–900 |
| Flash point | oC | ASTMD93 | Min. 130 | ENISO3679 | Min. 120 |
| Pour point | oC | ASTMD97 | -15 to 16 | | - |
| Cloud point | oC | ASTMD2500 | -3 to 12 | | - |
| Lower heating value | MJ/kg | | 39.3-39.8 | | 35 min. |
| Acid value mg | KOH/g | | 0.5 max. | | 0.5 max. |
| Copper corrosion strip | - | | 3 max | | - |
| Water content | vol.% | | 0.05 max. | | 500a max. |
| Sulfur content (S 15 grade) | ppm | | 15 max. | | - |
| Cetane number | - | ASTM D613 | 46 - 70 | EN-ISO5165 | 51 |

## 1.7 Problem statement

Emissions of internal combustion engines have increased the problem of environmental pollution in the world, with the rate of pollution reaching 118.6 million metric tons every five years. This environmental pollution causes many health problems, such as difficulty breathing, asthma, lung diseases, cancer and heart diseases. Also, the currently used fossil fuel is non-renewable and non-sustainable, and it must run out one day. This study provides an overview of the alternative fuel, which is biodiesel, and its use as an alternative fuel for internal combustion engines that operate by compression and mixing it with regular diesel in certain proportions without changing the engine design.

## 1.8 Objectives

1- The objective of the research is to prepare an alternative fuel in a simple way, with low effort and cost.

2-Using vegetable oil, which is available and relatively inexpensive, can be used directly or after using it in cooking.

3. Use KOH as a more effective catalyst.

4- Biodiesel can be used in diesel engines or blended with diesel fuel under different conditions of loads and engine speed without any change in engine design. Encouraging the preparation of biodiesel from leftover cooking oils (disposing of waste to preserve the environment) and using it as an alternative to diesel fuel to reduce pollution.

## 1.9 Thesis Outline

This master's thesis is divided into five chapters:

1- The first chapter (chapter one) includes an introduction to fossil fuels, alternative fuels, biodiesel, and biodiesel specifications.

2- The second chapter (chapter two) includes previous literature that dealt with the use of biodiesel, its preparation methods, and its impact on engine performance and engine emissions.

3- The third chapter (Chapter Three) includes the materials that were used in the experiment (the practical part) in addition to the measuring devices.

4- The fourth chapter (chapter four) presents a discussion of the results obtained from the preparation of biodiesel from sunflower oil and its effect on engine performance parameters and exhaust gas emissions.

5- The fifth chapter (chapter five) deals with the conclusions drawn from the pilot study and some recommendations for future work.

# Chapter Two

# Literature Review

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

Environmental concerns and declining petroleum supplies have prompted researchers to work on developing alternative fuels. Excessive use of fossil fuels depletes reserves and also increases air pollution [30, 32]. These issues raise attention to the optimal use of existing supplies and the shift to environmentally acceptable alternative fuel [33] . One way to do this is to use biodiesel fuel along with pure diesel in CI engines. Biodiesel fuel is an option to reduce dependence on diesel fuel derived from fossil petroleum, as well as reduce emissions of exhaust gases and other pollutants produced by diesel engines [34 -38]. This chapter presents a review of studies conducted on the use of biodiesel as an alternative fuel in internal combustion engines powered by regular diesel as the subject of the current thesis.

## 2.2 Using biodiesel in internal combustion engines

Due to their many physical and chemical similarities to diesel, methyl esters are frequently referred to as "biodiesel." Diesel and biodiesel can be combined in any ratio to be utilized in internal combustion engines. Biodiesel's high flash point in comparison to fossil fuel is its biggest drawback [39, 40]. When compared to fossil diesel fuels, biodiesel helps reduce exhaust emissions [41].

## 2.3 Transesterification

Conversion transesterification, also called alcohol hydrolysis, is the most practical method for manufacturing biodiesel, which chemically mimics fossil diesel fuel. Oils and fats (triglycerides) can be converted into alkyl esters using this process. Therefore, this substance is a fuel with characteristics similar to fossil diesel fuel [42 - 44]. In transesterification, alcohol is reacted with fatty acids in vegetable or animal oils to convert them into methyl ester. Triglycerides are converted to diglycerides that react with the alcohol Methanol or ethanol to monoglycerides. Monoglycerides in turn proceed to the final step to give the methyl esters and glycerol [25, 45, 46].

The way that alcohol is used differs depending on the physical state in which it enters the process. Recent developments have demonstrated the capability and promise of employing the alcohols in the supercritical form to transesterify oils and make biodiesel. The alcohols used in the transesterification process are primarily methanol or ethanol. Previously, the alcohols used in the reaction were always in a liquid state. Methanol is the most common choice due to the fact that it is cheaper [47 ,48].

In the separation process, the glycerol layer is separated from the biodiesel layer by the difference of densities by a separation funnel. This process occurs naturally when using methanol or ethanol in the presence of a base catalyst, so the glycerol layer is down and the biodiesel up [49, 50].

Afterward, the biodiesel is washed with water at a temperature of 70 ºC to get rid of the excess methanol from the reaction and this process is repeated several times until obtaining clean water. Then the biodiesel is dried by heating it to 110 ºC for a full hour to get rid of the moisture resulting from the washing process [51–56].

## 2.4 Fuel Properties

The engine is directly affected by fuel properties such as density and kinematic viscosity. The researchers tested the viscosity of the biodiesel fuel by using viscosity measuring devices, as well as for the fuel density, the fuel viscosity was measured at a temperature of 40 ºC, and as for the fuel density, the measurement was taken at a temperature of 15 ºC. Then the researchers tested the calorific values of the biodiesel fuel using calorimeters. The same applies to the other characteristics of the fuel, such as the cetane indicator and the flash point [57–59]. Table 2.1 shows standard properties of biodiesel.

Table 2.1 Standard values for biodiesel EN-14214 [26, 60, 61].

| Properties | Standard values for biodiesel EN-14214 |
|---|---|
| Flash point | ≥120 ºC |
| Dynamic viscosity | 3.5−5 $mm^2/s$ |
| Cetane number | >51 |
| Density | 0.86−0.90 g/ml |

## 2.5 Engine performance

Diesel engine performance parameters such as fuel consumption, thermal efficiency and other engine performance parameters are affected by fuel properties. Among the most important characteristics are density, viscosity, calorific value, cetane number, and flash point. Increasing the fuel density causes a larger mass to be pumped to reach the required volume of fuel [62, 63].

### 2.5.1 Brake Power

**Sundar K. and R. Udayakumar** [64] conduct a study of a single-cylinder, four-stroke diesel engine. The average brake power obtained for B0, B20 (MECSO) and B20 (MERBO) was 2.9 kW, 2.44 kW and 2.42 kW, respectively. The combination of MECSO and MERBO produces lower brake forces at 15.86% and 16.55% when compared to the diesel brake power. The brake power of biodiesel decreases due to the lower calorific value and higher viscosity and density compared to fossil diesel.

**M M Zamberi et al.** [65] conducted practical experiments on a single-cylinder diesel engine with unmodified direct injection with variable payload and variable engine speed. He used biodiesel mixtures that he prepared from Jatropha oil in proportions of B10 and B20. The reason is due to the characteristics of biodiesel, which has a low calorific value.

**Pali Rosha et al.** [66] conducted practical experiments for a single-cylinder diesel engine, variable compression ratio, using biodiesel mixtures at a ratio of B20, the results indicated that the brake engine power is reduced compared to the normal diesel, and the reason is due to the characteristics of biodiesel, which has a low calorific value, high viscosity and density.

### 2.5.2 Brake Thermal Efficiency

**Abdulrahman Shakir Mahmood et al.** [67] showed that break thermal efficiency decreases for biodiesel mixtures compared to pure diesel. The percentages of decrease recorded for biodiesel mixtures by 5, 10, 15 and 20 are 2%, 4.2%, 5.6% and 3.8% on respectively. The test was conducted on a single-cylinder, four-stroke, direct injection diesel engine. The reason for the decrease is due to the low calorific value of biodiesel.

**Sarah Oluwabunmi Bitire and Tien-Chien Jen** [52] showed in a study of a single-cylinder diesel engine, four-stroke, direct injection, showed that the biodiesel mixtures B0, B5, B10 and B20 had break thermal efficiency of 33.1%, 30.0%, 31.1%, and 32.0% respectively. The reason for the low calorific efficiency is the low calorific value of biodiesel.

**Ali Alahmer et al.** [68] an experimental study of a single-cylinder, four-stroke, direct injection, air-cooled diesel engine, the test results indicated a decrease in the brake thermal efficiency of the biodiesel blends produced from palm oil, sunflower oil, and corn oil in comparison with fossil diesel, and the reason for the decrease is due to the characteristics of biodiesel such as viscosity and density, high and low calorific values.

**Sai Bharadwaj et al.** [69] an experimental study of a single-cylinder, four-stroke, water-cooled diesel engine, results were reported for brake thermal efficiency 34%, 33%, 24% and 36% for blends B10, B20, B30 and conventional diesel. Compared to fossil diesel, the reason for the decrease is due to the characteristics of biodiesel such as viscosity, high density, low calorific value and volatility of mixtures which cause poor combustion properties and poor solubility.

**C. Adhikesavan et al.** [70] an experimental study of a single-cylinder, stationary, direct injection, air-cooled diesel engine, they conducted experiments on biodiesel fuel prepared from fresh sunflower oil and palm oil, as well as from sunflower oil waste and palm oil waste, the results indicated a lower brake thermal efficiency of biodiesel compared to with regular diesel, the reason is that regular diesel has a higher calorific value and lower viscosity compared to biodiesel.

## 2.5.3 Brake Specific Fuel Consumption (BSFC)

**Md. Nurun Nabi et al.** [71] an experimental study of a single-cylinder, four-stroke, direct injection, air-cooled diesel engine, they conducted experiments for biodiesel fuel. The results indicated that the brake specific fuel consumption of biodiesel is higher compared to normal diesel, and the reason is that the calorific value of biodiesel is lower compared to conventional diesel.

**Bukke Devaraj Naik et al.** [72] an experimental study of a single-cylinder, four-stroke, water-cooled diesel engine, they conducted experiments on biodiesel fuel. The results indicate that the brake specific fuel consumption of biodiesel is higher compared to normal diesel, and the reason is that the calorific value of biodiesel is lower compared to conventional diesel.

**V. Vinodkumar et al.** [73] They conducted a biodiesel fuel test for a single-cylinder water-cooled diesel engine, direct injection, and the recorded results indicate that the brake specific fuel consumption is increased for biodiesel due to its lower calorific value compared to normal diesel.

**Zülfü Tosun and Hüseyin Aydin.** [74] They conducted a test of biodiesel fuel for a four-cylinder water-cooled diesel engine, direct injection, the recorded results indicate that the brake specific fuel consumption is increased when biodiesel due to the low calorific value and high viscosity possessed by biodiesel compared to regular diesel.

**Sundar K. and R. Udayakumar.** [64] They conducted a test of biodiesel fuel for a single-cylinder, four-stroke diesel engine. The recorded results indicate that the brake specific fuel consumption increases when biodiesel due to the low calorific value and high viscosity possessed by biodiesel compared to regular diesel.

**Loubna Hadhoum et al.** [75] biodiesel fuel test was conducted for a single-cylinder, four-stroke, direct injection, air-cooled diesel engine. The recorded results indicate that the brake specific fuel consumption is increased for biodiesel due to the low calorific value and high viscosity possessed by biodiesel compared to regular diesel.

## 2.5.4 Volumetric efficiency

**Pankaj Shrivastava et al.** [20] A test was conducted for biodiesel fuel for a single-cylinder, four-stroke diesel engine. The recorded results indicate that the volumetric efficiency is lower for biodiesel due to the properties possessed by biodiesel compared to regular diesel.

**Ömer Cihan** [76] A test was conducted for biodiesel fuel for a single-cylinder, four-stroke, direct injection, air-cooled diesel engine. The recorded results indicate that the volumetric efficiency is lower for biodiesel due to the properties possessed by biodiesel compared to regular diesel.

**Suleyman Simsek** [77] A biodiesel fuel test was conducted for a diesel engine at constant speed 3000 rpm, naturally aspirated, air-cooled, single cylinder, four-stroke, direct injection. Lower volumetric efficiency was observed when using biodiesel blends compared to pure diesel. The reason may be due to the characteristics of Biodiesel.

## 2.6 Exhaust emissions

### 2.6.1 Hydrocarbon (HC) Emission

**Abdulrahman Shakir Mahmood et al.** [67] A test was conducted for biodiesel fuel for a diesel engine, single cylinder, four-stroke, direct injection, variable compression ratio. The recorded results indicate a decrease in hydrocarbon emissions (HC). The reason is due to the occurrence of complete combustion as a result of the high temperature inside the combustion chamber, as well as the presence of the oxygen in biodiesel helps complete combustion. Hydrocarbon emissions for B5, B10, B15 and B20 blends decreased by 4.5, 11.8, 20 and 26%, respectively, compared to diesel fuel.

**K Mohan et al.** [78] A test was conducted for biodiesel fuel for a diesel engine, single-cylinder, four stroke, direct injection. A decrease in hydrocarbon emissions (HC) was observed. The reason is that complete combustion occurs as a result of the high temperature inside the combustion chamber, and the presence of oxygen in biodiesel helps complete combustion.

**Betty Ariani and Dedy Wahyudi** [30] A test was conducted for biodiesel fuel for a diesel engine, four-stroke, direct injection. A decrease in hydrocarbon (HC) emissions was noted. The reason is that complete combustion occurs as a result of the high temperature inside the combustion chamber, as well as the presence of oxygen in biodiesel helps in complete combustion.

**V.S Vijay and J. Gonsalves** [58] A test of biodiesel fuel for a four-stroke, water-cooled diesel engine showed an increase in hydrocarbon (HC) emissions at low temperature, but decreases with increasing fuel temperature. For example, biodiesel preheated to 100°C and 175°C, hydrocarbon emission (HC) is slightly higher than that of standard diesel, but at 250°C it decreases by 25.5%, 10.9% for load 67%, and 100%, respectively. This result is mainly due to improved atomization and formation of a homogeneous mixture at higher temperatures of the preheated fuel.

**Abhishek Sharma et al.** [79]A test was conducted for biodiesel fuel for a single-cylinder, four-stroke, water-cooled diesel engine. The results indicate a decrease in hydrocarbon (HC) emissions. The reason for the decrease is due to the complete combustion of biodiesel containing oxygen.

**Sai Bharadwaj A.V.S.L et al.** [69] A biodiesel fuel test was conducted for a single-cylinder, four-stroke, water-cooled diesel engine. The results indicate a decrease in hydrocarbon (HC) emissions, due to the presence of more oxygen molecules.and low carbon and hydrogen content in the biodiesel mixture compared to diesel fuel, which in turn leads to a complete combustion process that leads to low emissions of hydrocarbons.

**Luqman Razzaq et al.** [18] A test was conducted for biodiesel fuel for a single-cylinder, water-cooled diesel engine. The results indicate a decrease in hydrocarbon (HC) emissions. The reason for the decrease is due to the presence of a percentage of oxygen in the biodiesel, which in turn improves the combustion process and makes combustion complete. The lowest values were recorded for hydrocarbon emissions for B10, B20 and B30: 0.065, 0.062 and 0.06 g/kWh, respectively, at 2100 rpm. Over full speed The main reason behind this significant reduction in hydrocarbon emissions is the higher oxygen content in biodiesel fuel which makes combustion more complete.

### 2.6.2 Nitrogen oxide ($NO_x$) Emission

**Sundar K et al.** [64] A biodiesel fuel test was conducted for a diesel engine, single-cylinder, four-stroke, constant speed 1500 rpm, and variable compression ratio, the results indicate an increase in nitrogen oxide ($NO_x$) emissions. The cause of the increase is due to the presence of a small percentage of nitrogen in the oils. Also, higher combustion temperatures inside the cylinder lead to an increase in nitrogen oxide emissions.

**Fatih Aksoy et al.** [80] A test was conducted for biodiesel fuel for a single-cylinder diesel engine, direct injection, natural aspiration, the results indicate an increase in nitrogen oxide emissions ($NO_x$) for biodiesel mixtures B30. It makes the combustion complete, and thus the combustion temperature inside the cylinder increases, which increases nitrogen oxides ($NO_x$) emissions.

**Safaa El-Din H. Etaiw et al.** [81] A test was conducted for biodiesel fuel for a diesel engine, single-cylinder, water-cooled, 11 KW. The results indicate an increase in nitrogen oxide ($NO_x$) emissions for biodiesel mixtures compared to pure diesel. The reason for the increase in nitrogen oxide ($NO_x$) emissions can be explained by providing the conditions for the formation of $NO_X$, which is the presence of a quantity of oxygen in biodiesel.

**C. Adhikesavan et al.** [70] A test was conducted for biodiesel fuel for diesel engine, single-cylinder, air-cooled, direct injection, stationary engine. Nitrogen oxides ($NO_x$) emissions indicate the availability of conditions for the formation of ($NO_X$), which is the presence of an amount of oxygen in biodiesel, which in turn will make the combustion complete and thus increase the combustion temperature inside the combustion chamber. Also, injection timing and injection pressure have an effect on increasing $NO_x$ emissions.

**Santhanakrishnan Radhakrishnan et al.** [82] They conducted a test of biodiesel fuel for a diesel engine, single-cylinder, four-stroke, air-cooled, constant speed 1300 rpm, the results indicated an increase in nitrogen oxide emissions (NOx) for biodiesel blends produced from palm oil compared to pure diesel, The reason for the high nitrogen oxide emissions is due to the characteristics possessed by biodiesel and the amount of oxygen it contains.

**Bukke Devaraj Naik et al.** [72] They conducted a test of biodiesel fuel for a single-cylinder, four-stroke, water-cooled diesel engine, the results indicated an increase in nitrogen oxide ($NO_x$) emissions for biodiesel mixtures produced from cooking waste sunflower oil compared to pure diesel, due to the higher emissions Nitrogen oxide refers to the characteristics possessed by biodiesel and its containment of an amount of oxygen, as the formation of nitrogen oxides emission depends on the temperature, reaction time, and the oxygen content of the fuel.

**José Antonio Velez Godiño et al.** [83] They conducted a biodiesel fuel test for a diesel engine, single-cylinder, four-stroke, air-cooled, direct injection, naturally aspirated, the results indicated an increase in nitrogen oxide ($NO_x$) emissions for biodiesel mixtures compared to pure diesel, due to the increase in nitrogen oxide emissions Nitrogen refers to the characteristics of biodiesel such as high temperature due to the unbranched molecules in its composition, as well as advances in the timing of fuel injection, as well as the characteristics of biodiesel affect the composition of the mixture.

## 2.6.3 Carbon Monoxide (CO) Emission

**P. V. Elumalai et al.** [84] They conducted a biodiesel fuel test for a diesel engine, constant speed at 1500 rpm, four-stroke, water-cooled, the results indicated a decrease in carbon monoxide (CO) emissions for the biodiesel blends produced from palm oil, where the $CO_2$ decreased from PND100 and PND20, PND20AB, and PND20AN by 7.14%, 25.02%, 35.71%, and 28.57% compared to D100%, respectively. The lowest carbon dioxide emission was detected in PND20AB, about 35.71%. PND20AB was observed to have a higher internal oxygen content than the other fuels tested which enhances the oxidation reaction which results in complete combustion.

**Selvakumar Ramalingam and N.V. Mahalakshmi.** [85] They conducted a test of biodiesel fuel for a diesel engine, constant speed at 1500 rpm, direct injection, four-stroke, air-cooled, and the results indicated a decrease in carbon monoxide emissions (CO) for the biodiesel mixture compared to pure diesel. The reason for the decrease is due to the presence of a large amount of oxygen in biodiesel, which helps to make the combustion process complete, as a higher content of oxygen in biodiesel reacts with carbon monoxide (CO) and promotes the formation of $CO_2$ with advances in injection timing. CO emissions can also be further reduced with an increased ignition delay, which in turn allows full utilization of the oxygen. The increased air-fuel mixing enhances combustion, resulting in lower CO emissions than a clean diesel in operating conditions.

**Prabhu Appavu et al.** [86] They conducted a test of biodiesel fuel for a diesel engine, direct injection, single cylinder, four stroke, water-cooled, naturally aspirated, there was a decrease in carbon dioxide emissions CO by 25% compared to pure diesel, the reason for this decrease is due to the presence of an amount of oxygen in the biodiesel .

**M Zamberi et al.** [65] tested a direct-injection, single-cylinder, four-stroke, naturally aspirated diesel engine, and there was a reduction in carbon monoxide (CO) emissions when using biodiesel and mixing it with diesel, especially at high engine speeds, but CO emissions decreased carbon oxide at high engine speeds, this can be attributed to low air-fuel equivalence, low combustion temperature, and poor atomization due to density, viscosity, and flash point at low speed. As the engine speed increased, a higher ratio of air to fuel was introduced, and the cylinder temperature and pressure during combustion also increased, ensuring relatively better combustion and thus lower CO emissions.

**Ali Alahmer et al.** [68] They conducted a test of biodiesel fuel for a diesel engine, direct injection, single cylinder, four stroke, variable load, and constant speed at 1800 rpm, there was a decrease in carbon monoxide (CO) emissions when using biodiesel produced from palm oil, corn oil and sunflower oil And mixing it with diesel, the reason is that there is more oxygen in biodiesel fuel, which promotes complete combustion, an increase in the cetane number of biodiesel fuel, which leads to a decrease in the possibility of developing fuel-rich regions, which are generally associated with CO emissions, when using biodiesel, this may explain advanced combustion and injection.

### 2.7.4 Carbon Dioxide ($CO_2$)Emission

**Arnab Roy et al.** [87] They conducted a test of biodiesel fuel for a diesel engine, direct injection, single cylinder, four stroke, constant speed at 1500 rpm, water cooled. There was an increase in carbon dioxide emissions ($CO_2$) when using biodiesel, the increase reached 20% compared to with pure diesel, the reason is that there is more oxygen in the biodiesel, which promotes complete combustion and thus increases the amount of $CO_2$ emissions.

**Addisu Frinjo Emma et al.** [62] They conducted a biodiesel test of a diesel engine, compression ignition, direct injection, single cylinder, four stroke, vertical, rated speed at 1500 rpm, rated power 5.2 kW, water cooled. There was a high $CO_2$ emissions at the use of biodiesel, because biodiesel formulas contain more oxygen than regular diesel. $CO_2$ emissions increase with mixture ratio and engine loading conditions. The $CO_2$ emission at full load increases by 0.27% 0.84%, 1.15%, 1.52%, 1.97% and 3.58% for B10, B20, B30, B40, B50 and B80, respectively, compared to pure diesel. This may be due to an increase in the oxygen concentration inside the combustion chamber and complete combustion, where CO is oxidized to $CO_2$ where CO is inversely proportional to $CO_2$ under all loading conditions and mixing ratios.

**Rahim Karami et al.** [88] They conducted a biodiesel fuel test for a diesel engine, compression ignition, four-cylinder, indirect injection, four-stroke, vertical, naturally aspirated, liquid-cooled. The reason is due to the characteristics of biodiesel such as high density, where density is the mass per unit volume. If the fuel has a high density, this means that a much larger mass enters the cylinder with the same volume, because the new generation of diesel injectors that supply fuel to the combustion chamber for power generation regulate the amount of fuel by volume, not by mass. More fuel entering the engine cylinder means more emissions. The increase in $CO_2$ emissions values using biodiesel can be explained by this reason.

### 2.7.5 Exhaust Gas Temperature

**Belachew Cekene Tesfai et al.** [89] They conducted a test of biodiesel fuel for a diesel engine, compression ignition, four cylinders, direct injection, four stroke, compression ratio 18.3, the results indicated a rise in exhaust gas temperatures compared to pure diesel, the reason for the increase was due to the presence of an oxygen ratio of 10.5% in molecule, which facilitates the total combustion of fuel within the cylinder of a CI engine. Hence the temperature in the cylinder rises and thus there is a corresponding increase in the temperature of the exhaust gases.

**M.S.Gad and Mohamed A.Ismail** [26] They conducted a biodiesel test for diesel engine, pressure ignition, single-cylinder, four-stroke, air-cooled, direct injection, the results indicated a rise in exhaust gas temperatures compared to pure diesel, due to the properties possessed by biodiesel, and problems of decay and evaporation.

**Ömer Cihan** [76] A test was conducted for biodiesel fuel for a diesel engine, pressure ignition, one cylinder, four strokes, air-cooled, the results indicated an increase in exhaust gas temperatures for biodiesel mixtures B5, B10 and B20 compared to pure diesel, the reason for the increase is due to the presence of a quantity of oxygen in the biodiesel.

**L. Anantha Raman et al.** [90] They tested biodiesel for diesel engine, pressure ignition, single-cylinder, four-stroke, water-cooled, direct injection, the results indicated a rise in exhaust gas temperatures for biodiesel mixtures, the EGT for B25, B50, B75 and B100 is 6.5, 10.3, 14.8 and 17.6% higher than the elegant diesel fuel, respectively. This is due to the availability of oxygen content in biodiesel which promotes the combustion process resulting in overheating of the exhaust gas.

## 2.7 Summary For Tranesterfication Process

| No.S | No.R | Researcher name | Vegetable oil type | Transesterification reaction conditions | Results |
|---|---|---|---|---|---|
| 1 | [82] | S.Radhakrishnan et al. | Palm. Oil. | • MeOH and oil have a 6:1 molar ratio.<br>• .KOH. : 0.3 wt%<br>•60 $^oC$ reaction temperature<br>• Time reaction:45 min<br>• 340 rpm | •Density : 0.8550 g.ml$^{1-}$.<br>•Calorific value (MJ.kg$^{1-}$). 41.32.<br>•60- Cetane index<br>•4.5 cSt for kinematic viscosity<br>• 172 $^oC$, the flash point |
| 2 | [91] | Arwa Sandouqa et al. | Olive Oil. | • MeOH:oil molar ratio is 6:1.<br>• 7.5 wt% NaOH<br>•Reaction temperature: 90 $^oC$<br>• Time reaction:40 min<br>• 200 rpm | • Density 0.8764 (g/cm3)<br>•Kinematicm viscosity 7.5 mm$^2$/sec |
| 3 | [46] | S.T. Keera et al. | Castor Oil. | •9:1 molar ratio of MeOH to oil<br>• KOH. : 1 wt%<br>•Temperature of reaction: 60 $^oC$<br>• Reaction time: 30 to 120 minutes<br>• 400 rpm | • Biodiesel:95 wt%<br>• 0.9461 g/cm$^3$ density<br>• MJ/kg of calories: 38.34<br>• 43.7 Cetane Number<br>• 15.4 cSt for kinematic viscosity<br>• 194 $^oC$ flash point |
| 4 | [92] | Yuvarajan Devarajan et al. | Waste cooking oil | • Oil :0. 5L<br>• Methanol:0.25L<br>• NaOH :2.5g<br>•Time reaction: 45 min. | • 0.8829 g/ml density<br>• 38.108 MJ/kg calorific value<br>• Cetane No. 52<br>• 4.3 kinematic viscosity |
| 5 | [74] | ZülfüTosun and Hüseyin Aydin | Safflower Oil. | • 5:1 molar ratio of MeOH to oil<br>• KOH. : 3 wt % | •Density gr/cm$^3$ (API) 0.891 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | •Temperature of reaction: 55 °C<br>•Reaction time: 60 minutes<br>• 1500 rpm | • Calorific value (MJ/kg) 38.108<br>• Amount of sulfur % 0.01<br>•Kinematic viscosity mm 2 /s 4.9388 |
| 6 | [93] | Ines Simbi et al. | sunflower oil | • MeOH,oil 12:1 molar ratio<br>• CaO/Al2O3:2.5 wt%<br>• Reaction temperature 60 ºC<br>• Time reaction :5 h<br>• 1300 rpm | •98.23 wt% biodiesel<br><br>•Density gr/$cm^3$ (API) 0.8811<br>• 38.108 MJ/kg calorific value<br>•Kinematic viscosity : 5.33 $mm^2/s$<br>• Flash point 170 ºC |
| 7 | [32] | Ankur Nalgundwar et al. | Jatropha oil | • Oil :1L<br>• Methano:250 ml l<br>• NaOH: 5g<br>• Time reaction :90 minutes<br>• Reaction temperature 60 °C | • 0.8649 g/ml density<br>•39.847 MJ/kg calorific value<br>•5.48 cSt kinematic viscosity |
| 8 | [94] | S.A. Abo El-Enin et al. | rapeseed oil | • MeOH:100ml<br>• KOH:50 ml<br>•Reaction temperature:60 ºC<br>• Time reaction :60 min<br>• 1800 rpm | •90 wt% biodiesel<br>• Density 0.9461 g/$cm^3$<br>• Cetane Number 53.7<br>• Specific gravity 0.8848<br>• Kinematic viscosity 15.4 cSt<br>• Flash point: 169 ºC |
| 9 | [64] | Sundar K. and Udayakumar | cottonseed oil | • Oil :1L<br>• Methanol : 250 ml.<br>• 13 g. NaOH.<br>• 1 hour at 600 rpm.<br>• 60 °C reaction temperature | • 0.89 g/ml density.<br>•39.49 MJ/kg calorific value<br>• Cetane Number 54.0<br>•5.8 cSt kinematic viscosity |
| 10 | [95] | Shurooq T. Al-Humairi et al. | algae | •MeOH,oil 100:1 molar<br>• KOH: 0.5 M<br>•Reaction temperature: 60 ºC<br>• Time reaction :30 min<br>• 13300 rpm | • 97 wt% biodiesel |

It is noted from the above table that the best type of vegetable oil used in the preparation of biodiesel was leftover cooking oil since it is inexpensive and does not endanger food security.

## 2.8 Engine Performance Summary

| No.S | No.R | Researcher name | Engine description | Engine Performance Parameters Ruesults |
|---|---|---|---|---|
| **1** | [96] | Mandeep Singh and Sarbjot Singh Sandhu | four cylinder, four stroke, intercooled turbocharged CI engine. | • As the biodiesel ratio in the blend grows, BTE decreases.<br>• Biodiesel has a higher BSFC than diesel fuel. |
| **2** | [73] | V. Vinodkumar and A. Karthikeyan | One cylinder, Injection type direct injection, Water-cooled. | • Due to its larger calorific value and lower kinematic viscosity and density, diesel fuel has a higher BTE than the other studied fuels.<br>• Low BSFC compared to diesel fuel and other studied fuels. |
| **3** | [97] | S.Imtenan et al. | 4- DI diesel engine with stroke, One cylinder, Radiator cooling. | • Compared to diesel fuel, biodiesel had higher brake specific fuel consumption and lower brake thermal efficiency. as well as lower engine brake power. |
| **4** | [87] | Arnab Roy et al. | four-stroke, one-cylinder, multifuel (computerized), water-cooled research engine configureuration. | • When 5% water is added to the B20CJ mixture. It increases BTE by an estimated 14% when compared to the main fuel, diesel.<br>• The BSFC values for the fuel mixture (B20C5JW) are about 16.7% higher than pure diesel fuel. |
| **5** | [26] | M.S. Gada and Mohamed A. Ismail | One-cylinder, four-stroke, Air cooled, DEUTZ F1L511. | • Cylinder peak pressures for kerosene and biodiesel blends are reduced by 2.5% and 1.5%, respectively, when compared to diesel oil for K5 and K10.<br>• Thermal efficiency has been improved by adding more gasoline or kerosene here to mix. Thermal efficiency when utilizing diesel fuel with full load. |

| | | | | |
|---|---|---|---|---|
| **6** | [98] | Mukund Kumar et al. | Kirloskar/AV.1, Multi fue, CI engine with one cylinder, four strokes, and cooling water. | • (Brake thermal efficiency) for basic diesel operation increased from 25.02% to 32.15% for hydrogen peroxide and biodiesel procedure.<br>• At greater FIPs, cylinder pressure and rate of heat release (HRR) were also found to be higher. |
| **7** | [74] | Zülfü Tosun and Hüseyin Aydin | NWK22 diesel generator, 4 cylinders, 4 strokes, direct injection, and cooling by water. | • In spite of having a lower heating value than diesel fuel due to increased combustion efficiency, the engine can transform biodiesel's chemical energy into mechanical energy with the same efficiency as diesel fuel.<br>• Biodiesel has a higher brake specific fuel consumption than diesel fuel. This is due to biodiesel fuel has less thermal value than diesel fuel. BSFC is affected by fuel quantity, density, viscosity, and heating value. |
| **8** | [99] | Rajendra Kukana and Om Prakash Jakhar | Water-cooled, One-cylinder four-stroke normally breath direct-injection diesel engine. | • W50A50 biodiesel's BSFE was comparable to that of WCO, while W75A25 biodiesel had a higher BSFE than WCO biodiesel.<br>• The concentration of BTHE in biodiesel W50A50DB20 (34.09%) and W75A25DB20 (37.25%) is higher than in diesel (33.76%). |
| **9** | [71] | Md. Nurun Nabi et al. | Water cooled, 4-stroke, only one diesel Natural aspiration direct injection engine. | • The binary and ternary mixes have lesser torque, brake power, and mean effective pressure than the source diesel fuel. The decline is driven by the combinations' low energy content and blending inaccuracies.<br>• The binary and ternary blends' brake thermal efficiency was approximately comparable to that of reference diesel, however the brake specific fuel consumption for the same blends was greater due to decreased calorific value. |
| **10** | [78] | K Mohan et al. | Diesel engine by one cylinder, 4 strokes, fixed speed, and water cooling. | • Because of fuel properties such as low density, low viscosity, and high calorific value, Brake thermal efficiency and mechanical efficiency increased by 15%. In |

| | | | | |
|---|---|---|---|---|
| | | | | comparison to ordinary diesel, the volatility of the biodiesel blend (SFC) gradually decreases. Palm grass oil particles burn and evaporate faster than diesel, resulting in lower specific fuel consumption (SFC). |

## 2.9 Engine Exhaust Emission Summary

| No. | No.R | Researcher name | Engine description | CO | $CO_2$ | HC | $NO_x$ | EGT | Smoke opacity |
|---|---|---|---|---|---|---|---|---|---|
| 1 | [73] | V. Vinodkumar and A. Karthikeyan | One cylinder, Injection type direct injection, Water-cooled. | increased | increased | increased | decreased | decreased | decreased |
| 2 | [97] | S.Imtenan et al. | 4- Stroke DI diesel engine, One cylinder, Radiator cooling. | decreased | --- | increased | decreased | --- | --- |
| 3 | [87] | Arnab Roy et al. | One-cylinder, four-stroke, multifuel (computerized), water-cooled research engine configureuration. | decreased | increased | decreased | decreased | decreased | --- |
| 4 | [98] | Mukund Kumar et al. | Kirloskar/AV. 1, Multi fue, CI engine with one cylinder, four strokes, and cooling water. | increased | --- | decreased | decreased | --- | increased |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | [74] | Zülfü Tosun and Hüseyin Aydin | NWK22 diesel generator, 4-cylinder, four - stroke, liquid-cooled, and direct injection. | decreased | decreased | increased | increased | --- | --- |
| 6 | [99] | Rajendra Kukana and Om Prakash Jakhar | Diesel engine, direct-injection, one-cylinder, 4-stroke, liquid-cooled, and normally inhaled. | increased | increased | increased | increased | increased | --- |
| 7 | [71] | Md. Nurun Nabi et al. | Natural aspiration, diesel engine, direct injection, 4-stroke, one-cylinder, and liquid-cooled. | --- | increased | --- | increased | --- | --- |
| 8 | [100] | Phyo Wai et al. | Isuzu 4JJ1 TC, four-stroke, and four cylinder, | --- | increased | --- | increased | decreased | decreased |
| 9 | [40] | Mahmoud K. Ashour and Ahmed E. Elwardany. | diesel engine, four-cylinder, HATZ-1B30-2, Electrical. | decreased | --- | --- | decreased | --- | --- |
| 10 | [101] | Erkan Öztürk | DI-diesel engine, natural aspirated, air cooled. | decreased | decreased | decreased | decreased | increased | decreased |
| 11 | [75] | Loubna Hadhoum et al. | One cylinder, naturally aspirated, four-Stroke, compression Ignition, air-cooled, direct injection. | increased | --- | decreased | decreased | --- | --- |
| 12 | [102] | M.S. Gad and | DEUTZ F1L511, single | increased | --- | decreased | increased | increased | decreased |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mohamed A. Ismail | cylinder, air-cooled, four stroke. | | | | | | |
| **13** | [72] | Bukke Devaraj Naik et al. | CI engine, single cylinder, four-stroke, water-cooled. | decreased | --- | --- | decreased | --- | decreased |
| **14** | [88] | Rahim Karami et al. | Diesel engine, four cylinder, four cycle, liquid-cooled. | decreased | increased | decreased | increased | --- | --- |
| **15** | [103] | K Mohan et al. | The IC engine, 4-stroke, Single-cylinder diesel engine. | decreased | increased | increased | decreased | --- | --- |

# Chapter Three
# Experimental Work

# CHAPTER THREE
# EXPERIMENTAL WORK

## 3.1 Introduction

This chapter describes the experimental equipment and measuring techniques used to assess the impact of adding various types of renewable fuels to a compression-ignition engine on performance and released pollutants in comparison to diesel. The TD-202 small engine test set is an instrumented engine test set for testing small single-cylinder engines such as lawn mowers, cultivators, pumps, and generators. The test kit includes a strong hydraulic dynamometer with simple operation to load the engine. This dynamometer is efficient since engine power is dissipated into the water that runs through it, eliminating the need for massive electrical supply or load resistors.

## 3.2 Biodiesel Production

### 3.2.1 Materials and methods

#### 3.2.1.1 Materials

Sunflower oil was purchased from the market in a plastic container with a capacity of 1000 ml and heated to a temperature of 80 °C to remove any impurities that may be present. Several companies manufacture oil of different origins. Methanol was purchased from the good laboratories' offices in a glass container with a capacity of 2500 ml and a purity of 99.8% Belgian origin. The catalyst was purchased from the medical laboratories. Table 3.1 shows the materials used and the country of origin, and Figure 3.1 shows a picture of the materials used in the research.

Table 3.1 The materials used and the country of manufacture in the preparation of biodiesel

| NO. | Product | Origin |
|---|---|---|
| 1 | Sunflower oil 1 liter bottle | Turkey |
| 2 | Methanol alcohol with a purity of 99.5% and a boiling point of 64.5 - 65.5 °C. | Belgium |
| 3 | Sodium Hydroxide (NaOH) and Potassium Hydroxide (KOH) | India |


Figure 3.1 Materials used in the preparation of biodiesel

### 3.2.1.2 Instruments and tools

The following devices and tools were used in the preparation process:

1- Magnetic stirrer.

2- Baker.

3- Separation funnel.

4- Thermometer.

5- Sensitive scale (Max = 500 g d= 0.001 g).

6- Electric heater.

7- Digital Tachometer.

8- Protective and safety equipment (gloves and a face mask).

Figure 3.2 shows preparation tools and equipment.


Figure 3.2 shows preparation tools and equipment

### 3.2.1.3 Transesterification experiments

Conversion reactions were carried out in batches and for each batch, 100 g of sunflower oil is placed in a flask and placed on a magnetic stirrer. The temperature is set to the desired value through the thermometer and the temperature switch in the magnetic stirrer, a quantity of methanol 12.5 g is mixed with an amount of 1 g sodium hydroxide catalyst [2, 45 ,103]. Mix the methanol with the catalyst well until all the catalyst is completely dissolved and the methoxide mixture is formed. The mixture is added to the beaker containing sunflower oil while maintaining a constant temperature and continuous stirring at 700 revolutions per minute and for an appropriate period of time not exceeding 120 minutes [27, 62]. Following the conclusion of the reaction, the mixture is moved to a separation funnel and allowed to settle for a suitable amount of time, up to 24 hours, to form two separated layers with distinct densities. Biodiesel is formed in the upper layer, while glycerin, which is heavier in density than biodiesel, forms in the bottom. After separating the biodiesel, it is washed with distilled water for three washes, and then the biodiesel is heated to a temperature of 110 °C for half an hour to get rid of the catalyst and alcohol residues. . Figure (2, 3) shows the transesterification process.

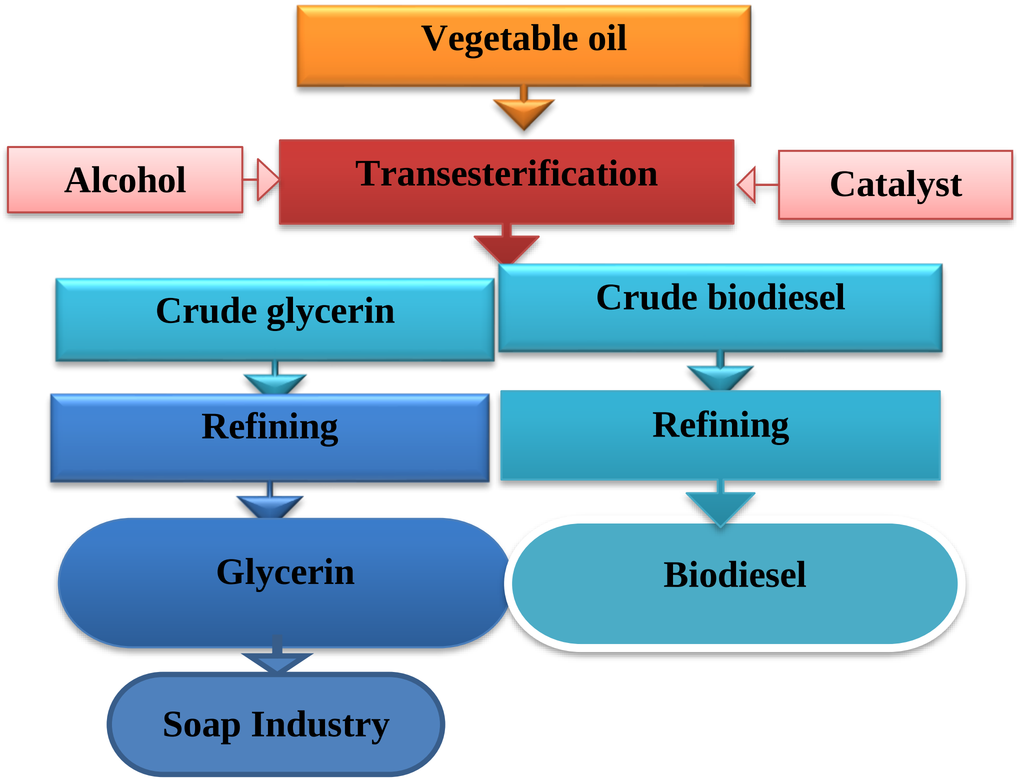



Figure 3.3 The steps in the preparing of biodiesel

$$
\begin{array}{llllll}
CH_2\text{-}COO\text{-}R & & & & R\text{-}COO\text{-}CH_3 & CH_2\text{-}OH \\
\downarrow & & & & & \\
CH\text{-}COO\text{-}R_2 & + & 3CH_3OH & \xrightarrow{(KOH\ or\ NaOH)} & R\text{-}COO\text{-}CH_3 \quad + & CH_2\text{-}OH \\
\downarrow & & & & & \\
CH_2\text{-}COO\text{-}R & & & & R\text{-}COO\text{-}CH_3 & CH_2\text{-}OH \\
\text{(Triglycerride)} & + & \text{(3Methanol)} & \xrightarrow{\text{(Catalyst)}} & \text{(3Biodiesel)} \quad + & \text{(Glycerol)}
\end{array}
$$

Figure 3.4 Transesterification process

### 3. 2.1.4. Physical properties

The physical properties of biodiesel prepared from sunflower oil and regular diesel were investigated at the Diwaniyah Refinery and Petroleum Products Distribution Company in Diwaniyah, Iraq. Table 3.2 shows the physical properties of diesel fuel and their comparison with the physical properties of biodiesel according to ASTM standards, which are frequently referred to in the literature. One of the most important of these characteristics is the kinematic viscosity characteristic that must be taken into account to maintain engine performance. The cetane number directly affects the quality and type of combustion, and the quality of fuel ignition is measured through it. Calorific value is a characteristic that has an impact on thermal efficiency and combustion properties. The flash point characteristic must be taken into account when evaluating the flammability of a fuel. Fuel density has an impact on engine performance and combustion quality. Pour point is the lowest temperature the diesel reaches in the flow, after which the fuel stops flowing and begins to freeze. Ash content is the remnants of non-combustible inorganic materials that remain after fuel combustion in air at a specified high temperature.

Table 3.2 shows the physical properties of biodiesel and diesel

| NO. | Properties of fuel | Unit | Diesel | Biodiesel | Standard Method |
|---|---|---|---|---|---|
| 1 | Density-@15°C | Kg/m³ | 830 | 892 | ASTMD-4052 |
| 2 | Flash-point | °C | 68 | 175 | ASTMD-93(A) |
| 3 | Pour-point | °C | (-)16 | (-)3 | ASTMD-97 |
| 4 | Cetane-index | - | 53.4 | 51.1 | ASTMD-4739 |
| 5 | Calorific-value | MJ/kg | 45.836 | 24.123 | Calculated |
| 6 | Viscosity @40°C | Pa.s | 0.002241 | 0.00482 | ASTMD-445 |

## 3.3 Experimental setup

The "experimental test" was influenced by three kinds of variables (surroundings, input, and output), as illustrated in figure 3.5. input variables include engine load, engine speed, and biodiesel ratio. The output variables or responses are brake thermal efficiency, volumetric efficiency, specific fuel consumption, air-fuel ratio, and exhaust temperature. Furthermore, we can consider CO, $CO_2$, HC, and NOx as output variables or responses to exhaust emissions. Ambient temperature and pressure, as well as diesel and biodiesel requirements, are examples of environmental variables.

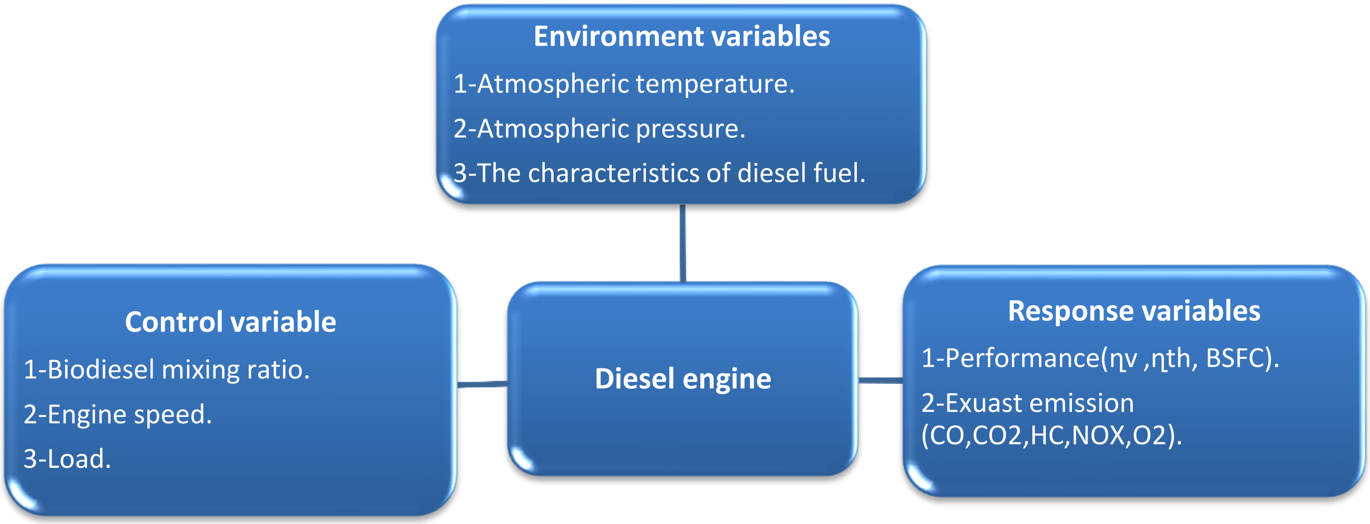
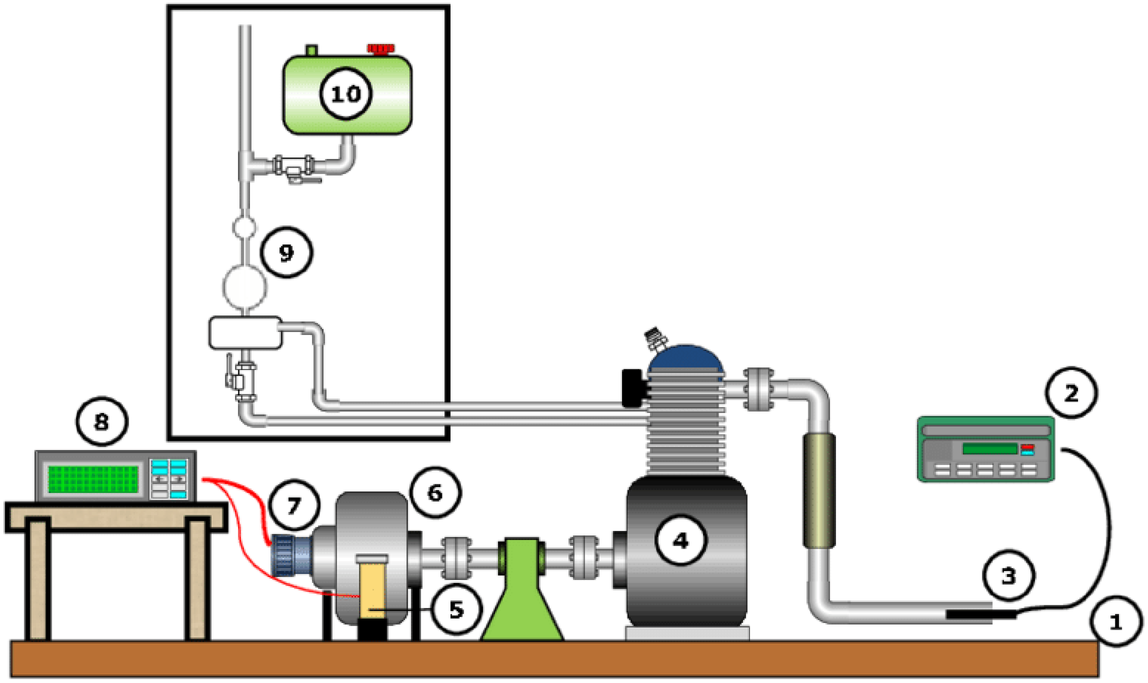



Figure 3.5 the control, environment, and reaction variable engine

The device is fully compatible with TecQuipment's Versatile Data Acquisition System (VDAS), available separately as shown in Figure 3-6. The use of VDAS enables accurate real-time data capture, monitoring, display and calculation of all relevant parameters on a PC making tests fast and reliable.




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

Figure 3.6 Schematic diagram of the components of experimental rig.

### 3.3.1 Engine Specification

The biodiesel test was carried out in the internal combustion laboratory at the Engineering Technical College / Najaf. Figure 3.7 shows a computerized and variable data logging system with sensors and instruments along with a diesel engine and eddy booster for performance and emissions testing. Biodiesel/diesel blends and their comparison to diesel.

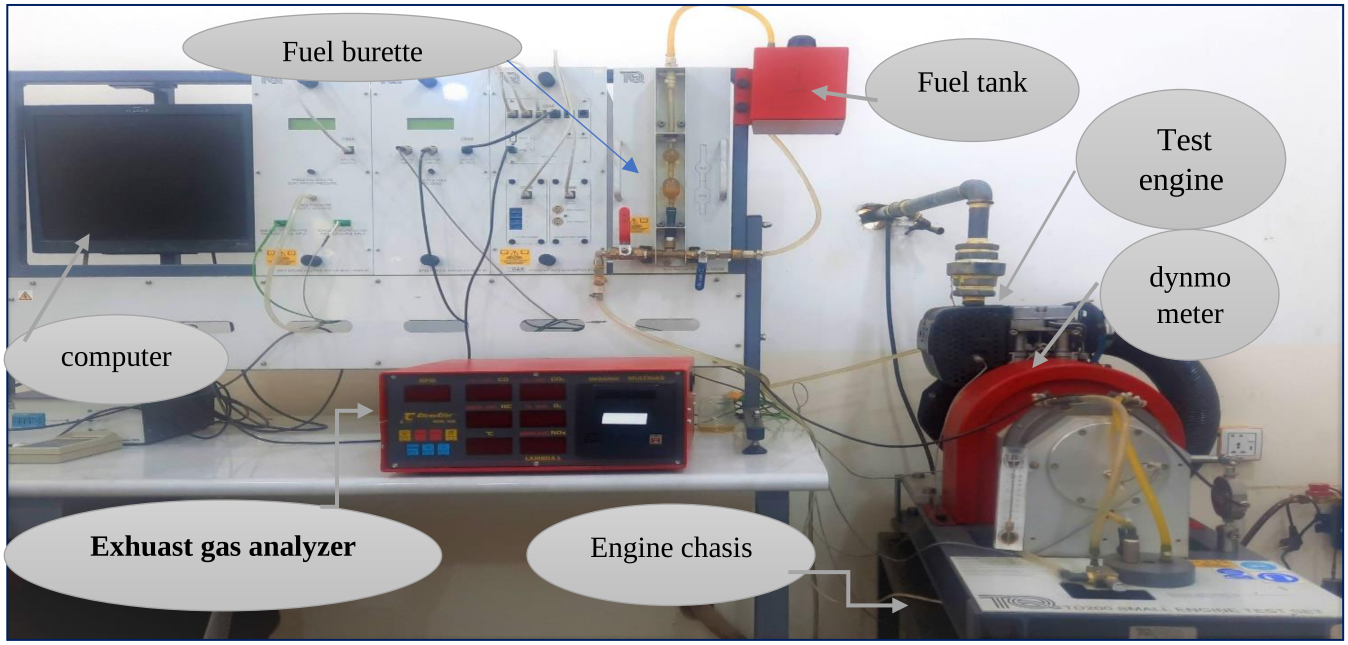



Figure 3.7. depicts the experiment's real design.

### 3.3.2 Test Engine Description

The TD202 is made from a small cooled by air single-cylinder diesel motor with:

• Overhead valves - one for inlet, one for exhaust

• Direct fuel injection

• Pressurized oil lubrication

• Recoil starter

The engine includes a governor that prevents the engine exceeding its optimum speed. The governor is a device inside the engine, linked to the fuel injection system. When the engine speed increases to a certain level, the governor forces the fuel injection system to reduce the amount of fuel that enters the cylinder. This regulates the maximum speed and engine power.

The engine is lubricated by ordinary engine oil, stored in a small sump at the base of the engine body. The oil is pressurised and forced around the engine, to lubricate its moving parts and bearings. The oil passes through a fine mesh oil filter that helps to clean the oil.

The engine is based on the standard cross-flow design, so that the fuel/air mixture enters from one side of the cylinder head and is forced out as exhaust to the opposite side of the cylinder head.

Forced air-cooling is provided by the fins around the engine flywheel. As the flywheel turns, the fins force air around the cylinder by means of simple ducting.

The engine is started by a starter handle and cord, wrapped around a pulley on the flywheel. The pulley includes a clutch to disengage the cord and pulley when the engine starts. This arrangement is called a 'recoil starter'. The engine includes a speed control (often called a 'rack'). The rack directly adjusts the amount of fuel that can enter the cylinder. If the rack is moved to the minimum position, no fuel is injected to the cylinder and the engine stops. Alternatively, an engine stop button is provided. This button stops the fuel injection system.

### 3.3.3 Technical details

Table 3.3 Test rig specification

| Parameters | Details |
|---|---|
| Dimensions | Width 4 cm Height 4.5 cm Depth 3.50 cm |
| Net weight | 35 kg |
| Engine Type | 4-Stroke, Single Cylinder, Direct injection, Stationary engine, Air-cooled |
| Fuel type | Diesel |
| Fuel tank | Caramel/light brown-painted steel with vent and filter cap |
| The maximum possible power | 3.1 kW at 3000 rev.min$^{-1}$ |
| Maximum Torque | 15 N.m |
| Bore | 0.69 cm |
| Stroke/crank radius | 62 mm/31 min |
| Connected rod length | 1.04 cm |
| Engine capacity | 232 cm$^3$ |
| Compression ratio | 22:1 |
| Oil type | Multigrade SAE 5 W-40 |
| Oil capacity | 2.6 Litre |

### 3.3.4 The Hydraulic Dynamometer

Hydraulic dynamometer supplied as default to the testbed is a trunnion installed Hydraulic Dynamometer which applies load depending to the water flow rate and amount of water in its casing. An accurate needle valve regulates the flow rate and level. The torque is monitored by means of an electronic load cell built into the side of the dynamometer. The dynamometer rotational speed is measured electronically by means of an optical sensor.

The hydraulic dynamometer is a simple but efficient way to load a test engine. It is made up of two shells with radial ribs on the inside. A shaft that travels through the dynamometer is linked to a rotor with radial ribs on both sides. To allow the casing to act to a strain gauged load cell, the dynamometer is positioned in self-aligning bearings. Water enters the dynamometer through an adjustable needle valve at the top and exits through a drain at the bottom. A vent allows extra air and water to escape.

The ribs on the casing and rotor force the water to churn while the engine turns the shaft. The load cell measures the resistive torque as a result of this. Adjusting the water flow rate changes the amount of resistance, as does the height of the water in the casing. The constant flow of water through the dynamometer dissipates the heat generated by the churning of the water. The needle valve is used to control the dynamometer indirectly (an open-loop system). Despite the fact that the load control is an open-loop system, the speed can be maintained at around 100 rev/min.

A flowmeter was added to control the load of the engine (flowing water to the dynamometer), as it shown in figure 3.8

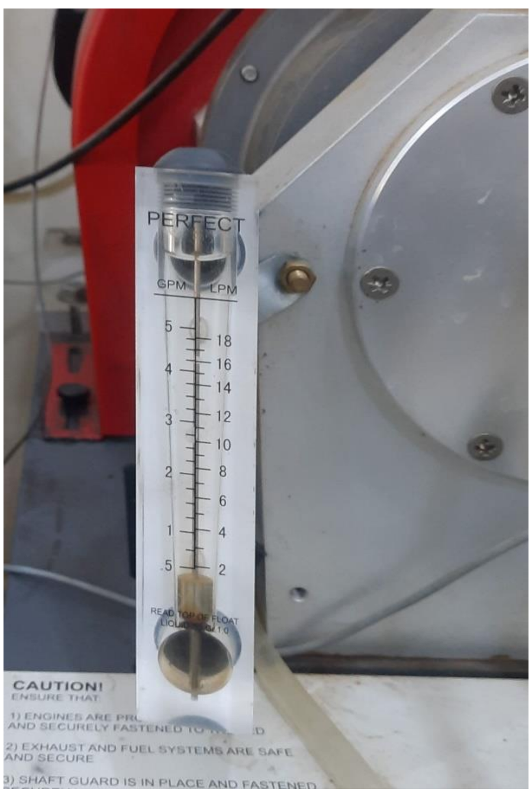



Figure 3.8 The flowmeter regulates the amount of water pumped into the dynameter.

### 3.3.5 Instrument Frame

The TD202 small engine test set's instrument modules are installed on the instrument frame. To power the Instrument Modules, the frame contains a single IEC type power inlet and many IEC type outlets. To prevent vibration transmission from the engine to the measuring devices, the instrumentation and test bed are maintained separate.

### 3.3.6 Instrument Modules

#### 3.3.6.1 Torque and Speed Display - DTS2

The torque measured on the dynamometer and the speed computed from the optical sensor pulses are displayed in this module (with time). The product of speed and torque is used to compute power show figure 3.9.

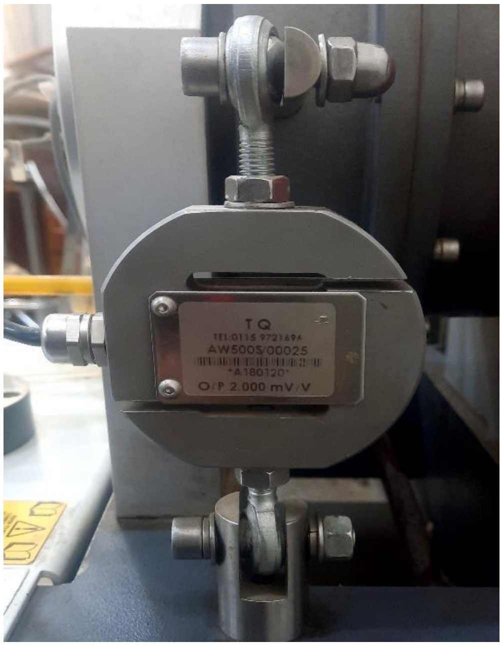



Figure 3.9 torque sensor (load cells).

#### 3.3.6.2 Engine Inlet Air and Exhaust Display - DPT1

The ambient (barometric) pressure and temperature, as well as the pressure inside the airbox, are displayed in this module. The airbox orifice dimensions, as indicated in figure. (3.10), and the pressure differential between the ambient and inside the airbox are used to compute the engine inlet airflow (Ap).

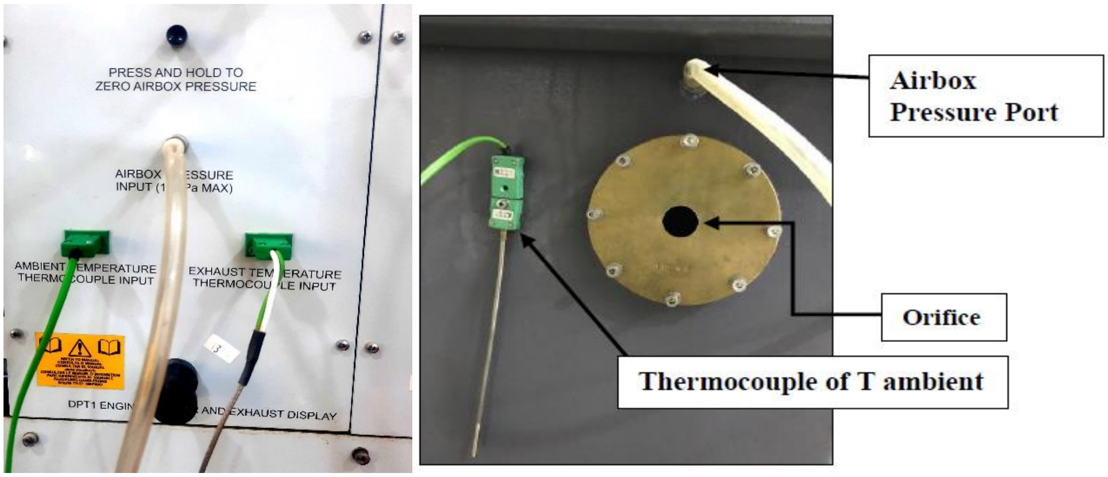



Figure 3.10 Airbox orifice with pressure port

### 3.3.6.3 Versatile Data Acquisition System – VDAS

The VDAS apparatus from TecQuipment can be used with the Small Engine Test Set and its Instrument Modules. The VDAS equipment consists of two parts (hardware and software) that enable the user to:

• Reduce errors

• Save experiment time

• Record the test results on a suitable computer

• Automatically calculate important values

• Produce high-quality graphs and results, as well as the ability to export data to a spreadsheet software for further graphing and analysis. The VDAS software and hardware are shown in Figure 3.11.

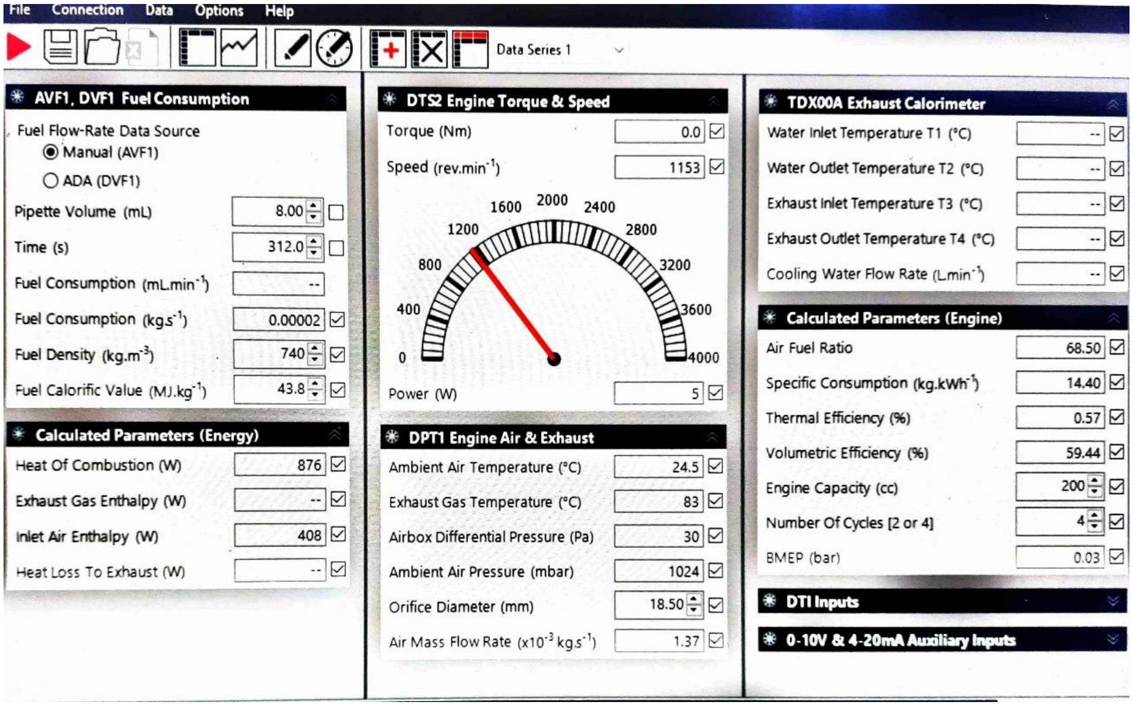



Figure 3.11 A VDAS program.

### 3.3.6.4 Volumetric Fuel Gauge - AVF1

The volumetric fuel gauge is the AVF1 which is a manually driven fuel pipette that must be used in conjunction with a proper timer or stopwatch see Figure 3.12.

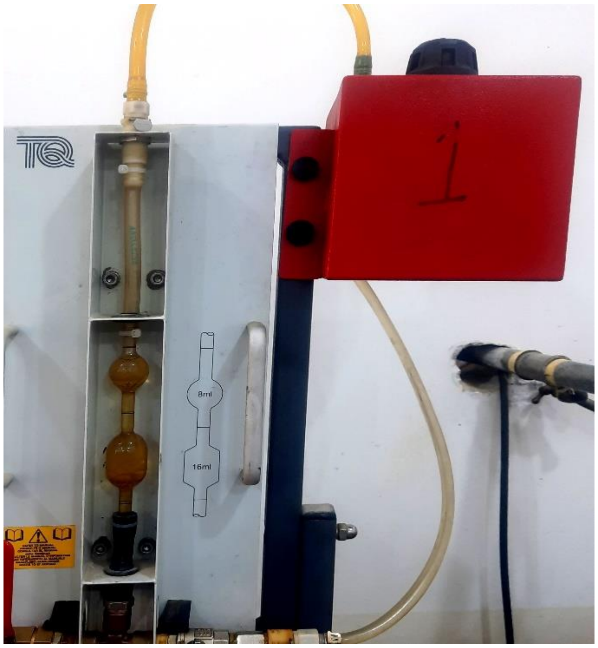



Figure 3.12 Volumetric fuel meter.

## 3.4 Gas Analyzer Unit

As demonstrated in figure. 3.13, the Techno test (MOD 488) exhaust gas analyzer is acceptable for petrol engines. It measures, displays, and prints carbon monoxide (CO), carbon dioxide (CO2), unburned hydrocarbons (HC), and nitrogen oxides (NOx) concentrations. The air/fuel ratio, which is an essential term of reference in engine tuning, is automatically determined based on these parameters. It can also be used to determine engine speed by counting the number of spark plug pulses and monitoring the temperature with a thermocouple probe. The range of measurement and resolution are listed in the table 3.4.

Table 3.4 Range of measurement and resolution for exhaust gas analyses.

| Parameter | From | To | Resolution |
|---|---|---|---|
| CO | 0 | 9.99% vol. | 0.01% |
| CO2 | 0 | 19.9% vol. | 0.1% |
| HC | 0 | 9999 ppm | 10 ppm |
| $NO_X$ | 0 | 2000 ppm | 10 ppm |


Figure. 3.13 Techno test of a gas analysis equipment (MOD 488).

## 3.5 Brake power

Brake power is the rate at which work is done; it expresses the engine's power generation, which is measured by a machine that applies an outside load to the engine and then absorbs the power that the engine produces. This measurement device can be mechanical, hydraulic, or electrical [24]. The following mathematical equation can be used to determine engine power.

$B.P = 2\,\pi\tau\,N$ ………………………… 3-1

Where:

B.P: Engine power

$\tau$ : Engine torque

$N$ : Engine revolutions per minute

## 3.6 Torque of the engine

Torque is a measure of the work done by the crank per unit of rotation (radians). Flattening the torque-velocity curve is a major objective in modern car engine design to achieve high torque at both high and low speeds.In general, compression ignition engines have more torque than spark ignition engines. Engine torque can be calculated from the following mathematical equation.

$\tau = B.P / (2\,\pi\,N)$ ………………………… 3-2

Where:

B.P: Engine power

N: Engine revolutions per minute

## 3.7 Brake-Specific Fuel Consumption (BSFC)

Specific fuel consumption is a measurement used to compare how effectively the chemical energy stored in fuel is converted into work done by the engine. There are two types of fuel consumption standards: brake and indicated. The brake specific fuel consumption (BSFC) is the fuel flow rate divided by the brake capacity and is determined by standard test measurements such as fuel flow rate, torque, and speed. The indicated specific fuel consumption (ISFC) is the ratio of the fuel mass injected during the cycle to work the cylinder and is used in mathematical simulations to compare engine performance without accounting for engine friction. The following mathematical equation can be used to calculate brake-specific fuel consumption (BSFC).

$BSFC = \dot{m}f/B.P$ ………………………3-3

Where:

B.P: Engine power

$\dot{m}f$: Mass fuelflow rate

## 3.8 Brake Thermal Efficiency (BTE)

One of the most important engine performance parameters is the brake thermal efficiency, which is denoted by the symbol (BTE) and can be defined as the actual percentage of brake power obtained from the amount of energy supplied to the engine and by the engine itself. Biodiesel and oil blends have a higher specific fuel consumption than regular diesel fuel. The lower caloric value is the reason for the higher consumption of specific fuel. The following mathematical equation can be used to calculate brake thermal efficiency (BTE).

$$\eta = B.P/(\dot{m}_f\, q_c) \quad \text{………………………… 3-4}$$

Where:

B.P: Engine power

$q_c$ : Heat of combustion

$\dot{m}_f$: Mass fuelflow rate

# Chapter Four

# Results and Discussion

# Chapter Four

# Results and Discussion

## 4.1 Introduction

This chapter presents and discusses the experimental study on the use of an alternative fuel (biodiesel produced from sunflower oil) to diesel fuel on the performance and emissions of a compression ignition engine. Experimental analysis of engine performance on diesel and biodiesel blends, validation and comparison of experimental studies are presented.

## 4.2 Transesterification Results

The trans-esterification process yielded 92% and the remainder is glycerol and losses. These losses represent the remaining catalyst, the unreacted alcohol, and what was removed from the emulsion during the wash. These are the results of many experiments, as these experiments showed that the cost of one liter of biodiesel is less than the cost of one liter of fossil diesel, as its raw materials are abundant in the market. The mixture was left for 24 hours until it separated into two layers, the top layer of biodiesel and the bottom layer of glycerol. The two materials of different densities can be separated by a separating funnel. The biodiesel process after separation is done by decanting water at 70 °C to get rid of methanol and catalyst. This process is repeated as many times as needed. The biodiesel was dried by heating it at 110 °C for 25 minutes.

Table 4-1 materials, amounts and reaction conditions

| No. | Oil / g | Oil /mole | Oil /ml | Methanol / g | Methanol / ml | Methanol /mole | Catalyst concentrations% | Catalyst /g | Reaction Time /m | Temperature /c | Yield / % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 0.8 | 0.8 | 60 | 45 | 74 |
| 2 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 0.8 | 0.8 | 60 | 50 | 77 |
| 3 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 0.8 | 0.8 | 60 | 55 | 80 |
| 4 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 0.8 | 0.8 | 60 | 60 | 88 |
| 5 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 0.9 | 0.9 | 90 | 65 | 91 |
| 6 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 0.9 | 0.9 | 90 | 65 | 89 |
| 7 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 1.2 | 1.2 | 90 | 65 | 90 |
| 8 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 1 | 1 | 90 | 65 | 92 |
| 9 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 1 | 1 | 90 | 65 | 91 |
| 10 | 100 | 0.1 | 104.07 | 12.5 | 15.776 | 0.3944 | 1 | 1 | 90 | 65 | 92 |

## 4.3 Physical properties

After biodiesel is produced from sunflower oil, the physical properties of biodiesel are measured and compared to diesel fuel, in addition to the American Society for Testing and Materials (ASTM) standards that are frequently mentioned in literature review. Tests are performed to ensure the product is biodiesel. The properties of diesel and biodiesel were previously mentioned in Chapter Three.

## 4.4 Reproducibility of results

In order to verify the reliability of the results of the experiment conducted, the diesel engine was subjected to the same series of tests three times while operating in diesel mode and biodiesel mode as shown in figure 4.1. It was determined to take the average of the data received, and any abnormal values were discarded. There is a discrepancy in the results of the tests, and the reasons for this discrepancy are the errors made by the measuring devices themselves, the differences in the surrounding environment, and the errors made by the people who conduct the tests.

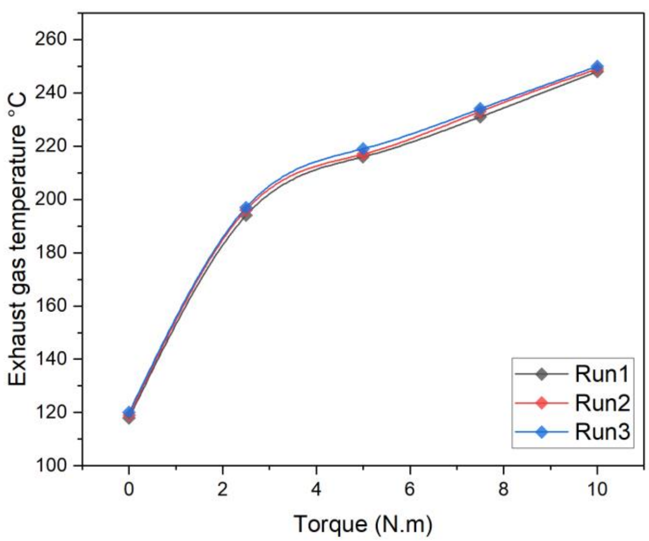



Figure 4.1 Exhaust gas temperature with engine torque

### 4.5 Comparative study

To demonstrate the comparison between the experimental results, a comparison was made between the results of Noor Ali | Duraid F. Maki [1] for a single-cylinder, four-stroke engine with direct injection at a speed of 1500 RPM, a variable compression ratio, and biodiesel mixtures prepared from waste cooking oils (B0, B10, B20, B30), and the results obtained from the present work at 1400 rpm and torque (0-10 N.m). The result of the engine used was a single-cylinder, air-cooled, direct-injected four-stroke CI engine used to test diesel and diesel/biodiesel blends. Figure 4.2 shows a working comparison of exhaust gas temperatures. Which can prove good trend compatibility.

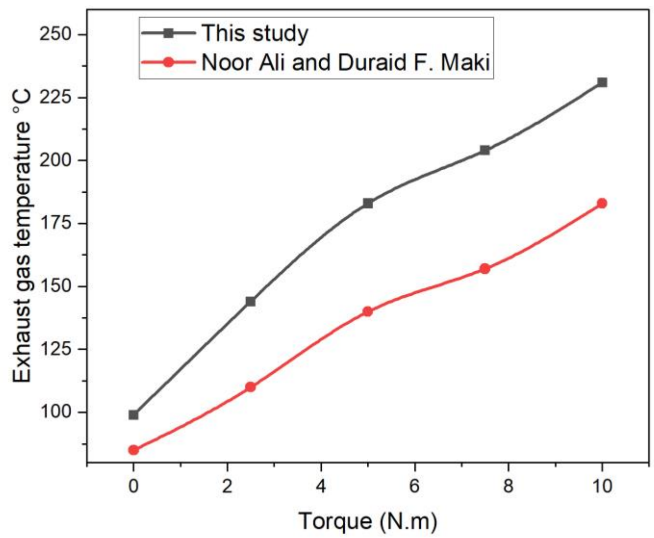



Figure 4.2 shows a working comparison of exhaust gas temperatures.

## 4.6 Experimental Results

On the engine test stand, several tests are carried out to understand more about engine performance and emissions. That is, it conditions under which the tests are conducted: Variation of engine speed and engine load as well as fuel mixtures used diesel and biodiesel. This section compares and discusses these results.

## 4.7 Effect of Biodiesel Addition on Engine Performance Characteristics

### 4.7.1 Brake Power

Engine brake power rises relatively at high engine torque. The reason for this increase is the increase in complete combustion during high load due to the increase in combustion temperature.

Figure 4.3 A. shows Brake power of B10, B20, B30, and B40, fuel blends at 1100 rpm decreased by 0.011 kW, 0.017 kW, 0.022 kW, and 0.042 kW, respectively, compared to diesel fuel, which amounted to 562 kW, based on engine torque. Figure 4.3 B. shows Brake power of B10, B20, B30, and B40 fuel blends at 1400 rpm decreased by 0.012 kW, 0.016 kW, 0.023 kW, and 0.024 kW, respectively, compared to diesel fuel, which amounted to 731 kW, based on engine torque. Figure 4.3 C. shows Brake power of B10, B20, B30, and B40 fuel blends at 1700 rpm decreased by 0.013

kW, 0.016 kW, 0.025 kW, and 0.024 kW, respectively compared to diesel fuel, which amounted to 882 kW, based on engine loads. Figure 4.3 E. shows brake power of B10, B20, B30, and B40 fuel blends at 2000 rpm decreased by 0.010 kW, 0.018 kW, 0.021 kW, and 0.023 kW, respectively, compared to diesel fuel, which amounted to 1038kW, based on engine torque.

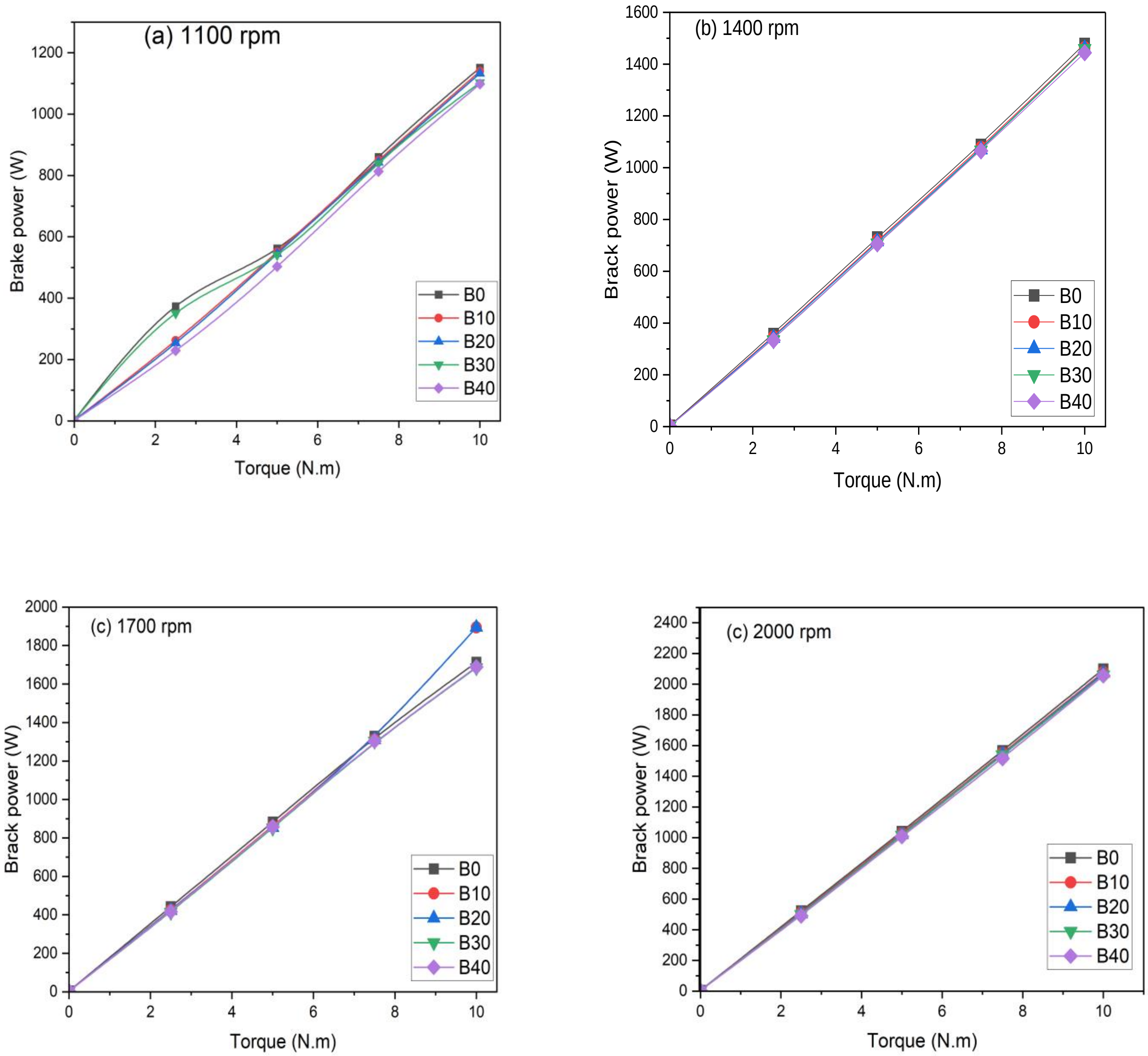



Figure 4.3 brake power diagram according to engine torque (a) 1100 rpm, (b) 1400 rpm, (c) 1700 rpm, (d) 2000 rpm.

### 4.7.2 Brake Thermal Efficiency (BTHE)

Fuel quality, cetane rating, fuel optimization, fuel evaporation rate, combustion chamber design, injection timing, compression ratio, and compression all have an impact on diesel engine combustion. The rate of emissions from combustion can be slowed down and the amount of fuel used can be lowered by optimizing these elements, which will also improve combustion. Combustion efficiency and cetane number are two important parameters that influence the output and emissions of diesel engines. At maximum engine rpm, the brake's peak thermal efficiency is always obtained. Based on engine torque, figure 4.4 displays the brake thermal efficiency map for a diesel and biodiesel fuel blend.

Figure 4.4 a. shows that The thermal efficiency of B10, B20, B30, and B40 fuel blends at 1100 rpm decreased by values of 0.48%, 0.89%, 1.19%, and 1.34%, respectively, compared to diesel fuel, which amounted to 17 %, Figure 4.4 b. shows that The thermal efficiency of B10, B20, B30, and B40 fuel blends at 1400 rpm decreased by values of 0.86%, 1.51%, 2.11%, and 2.19%, respectively compared to diesel fuel, which amounted to 23.8%. Figure 4.4 c. shows that The thermal efficiency of B10, B20, B30, and B40 fuel blends at 1700 rpm decreased by values of 0.23%, 0.91%, 1.37%, and 1.72%, respectively, compared to diesel fuel, which amounted to 27%. Figure 4.4 d. shows that The thermal efficiency of B10, B20, B30, and B40 fuel blends at 2000 rpm decreased by values of 0.23%, 0.92 %, 2.31%, and 2.78%, respectively, compared to diesel fuel, which amounted to 28.8 %.

In truth, biodiesel has a lower calorific value than diesel fuel; nonetheless, biodiesel promotes better combustion due to its greater cetane number and oxygen content. Furthermore, when the masses pumped are compared, biodiesel fuel is injected in a bigger mass from a fuel pump with the same volumetric capacity and has a higher viscosity.

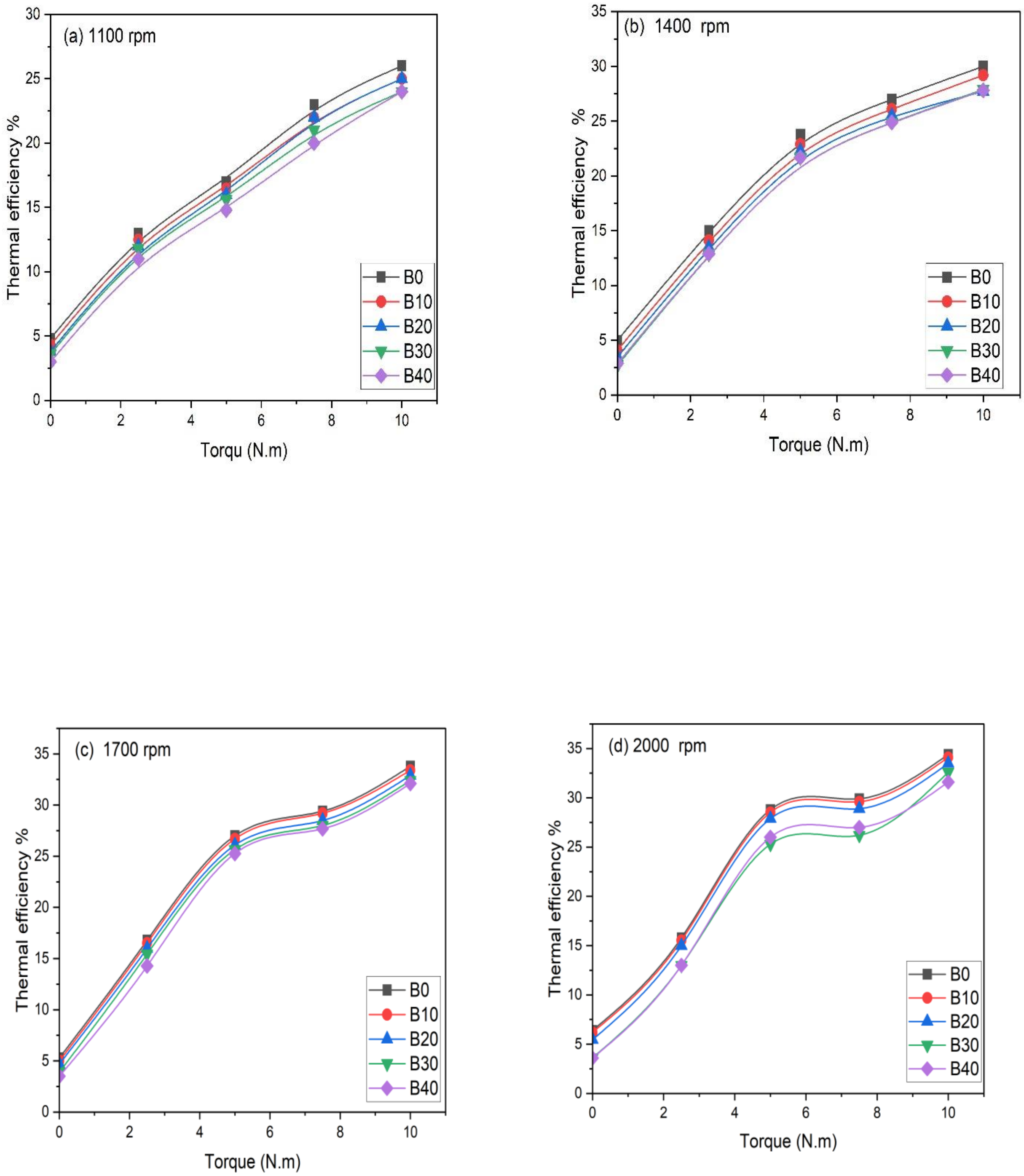



Figure 4.4 brake thermal efficiency diagram according to engine torque (a) 1100 rpm, (b) 1400 rpm, (c) 1700 rpm, (d) 2000 rpm

### 4.7.3 Brake Specific Fuel Consumption

Figure 4.5 a shows the specific fuel consumption chart for biodiesel and diesel fuel blends depending on engine torque. When comparing B10, B20, B30, and B40 fuel blends at 1100 rpm, specific fuel consumption increased by 0.032 kg/kWh, 0.041 kg/kWh, 0.068 kg/kWh, and 0.121 kg/kWh, respectively compared to diesel fuel, which amounted to 0.24 kg/kWh based on engine torque. Figure 4.5 b. shows Brake Specific Fuel Consumption of B10, B20, B30, and B40 fuel blends at 1400 rpm increased by 0.011 kg/kWh, 0.060 kg/kWh, 0.089 kg/kWh, and 0.132 kg/kWh, respectively compared to diesel fuel, which amounted to 0.31 kg/kWh based on engine torque. Figure 4.5 c. shows Brake Specific Fuel Consumption of B10, B20, B30, and B40 blends at 1700 rpm increased by 0.11 kg/kWh, 0.065 kg/kWh, 0.093 kg/kWh, and 0.11 kg/kWh, respectively compared to diesel fuel, which amounted to 0.42 kg/kWh based on engine torque. Figure 4.5 d. shows Brake Specific Fuel Consumption of B10, B20, B30, and B40 fuel blends at 2000 rpm increased by 0.021 kg/kWh, 0.029 kg/kWh, 0.046 kg/kWh, and 0.113 kg/kWh, respectively compared to diesel fuel, which amounted to 0.33 kg/kWh based on engine torque.

The fuel consumption factor is affected by the viscosity, density, and lower calorific value of the injected fuel. Since biodiesel has a lower calorific value than diesel fuel, more fuel is pumped from the fuel pump to achieve the same power output as diesel fuel, increasing specific fuel consumption. The high viscosity makes the air-fuel mixture uneven, which leads to poor combustion of the fuel. The high density leads to a larger amount of fuel entering the combustion chamber for the same volume, thus consuming more fuel.

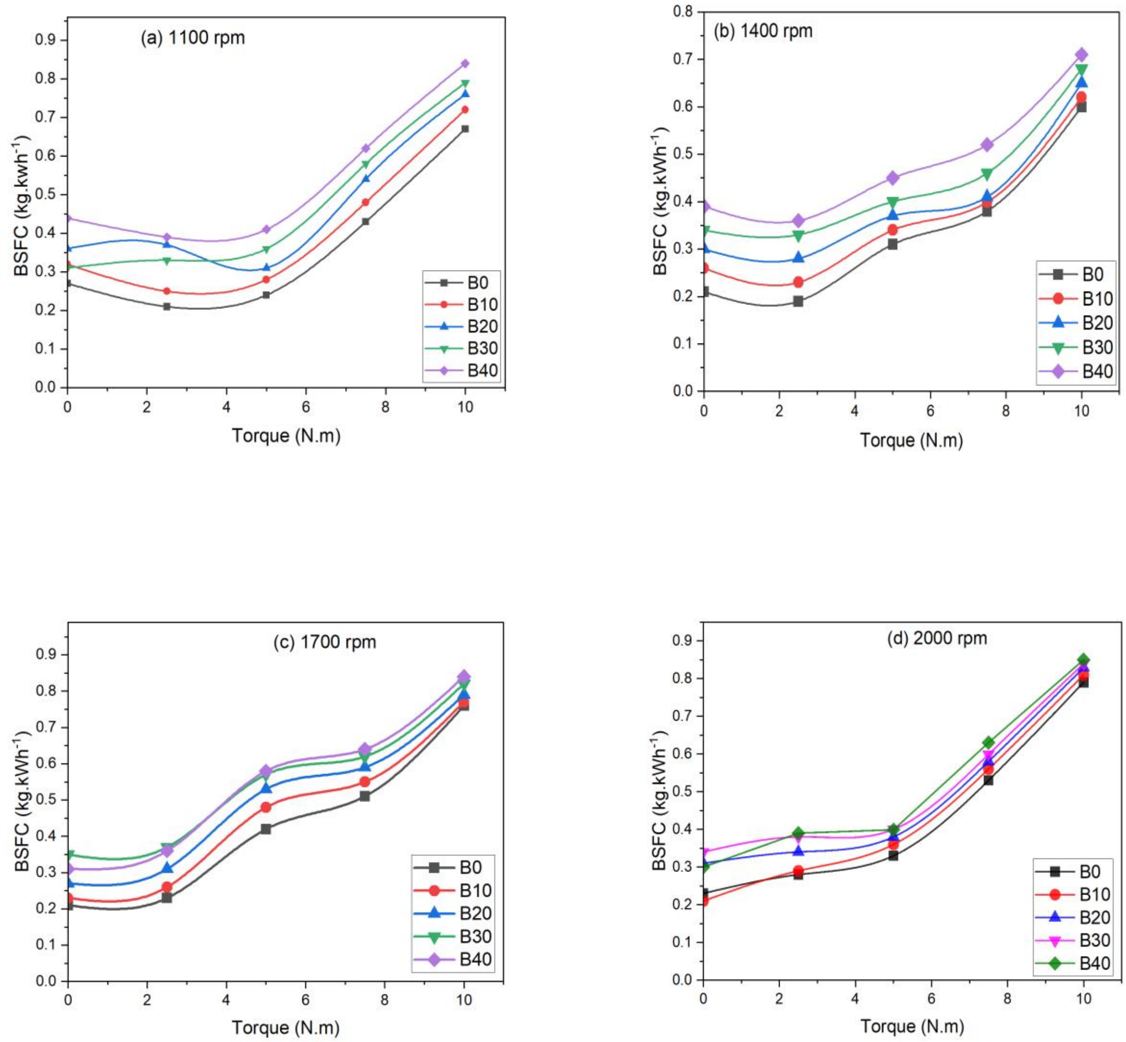



Figure 4-5 specific fuel consumption diagram according to engine torque (a) 1100 rpm, (b) 1400 rpm, (c) 1700 rpm, (d) 2000 rpm.

### 4.7.4 Volumetric efficiency

A compressor cylinder's volumetric efficiency refers to how well it compresses the gas. It is the proportion of gas supplied to piston displacement that has been adjusted for suction temperature and pressure. Re-expansion has by far the greatest impact on volumetric performance. The inlet temperature and pressure of the engine have a direct impact on volumetric performance. Figure 4.6 depicts the differences in volumetric efficiency for several tested fuels under varied loading scenarios. Studied fuels all had similar input conditions and showed negligible volumetric efficiency losses when compared to diesel.

Figure 4.6 a. shows volumetric efficiency of B10, B20, B30, and B40 fuel blends at 1100 rpm decreased by 0.78%, 1.19 %, 1.97 %, and 3.13 %, respectively compared to diesel fuel, which amounted to 82.9 % based on engine torque. Figure 4.6 b. shows Volumetric efficiency of B10, B20, B30, and B40 fuel blends at 1400 rpm decreased by 0.74 %, 1.38 %, 2.98 %, and 5.97 %, respectively compared to diesel fuel, which amounted to 82.15 % based on engine torque. Figure 4.6 c shows Volumetric efficiency of B10, B20, B30, and B40 fuel blends at 1700 rpm decreased by 0.71 %, 1.35 %, 2.88 %, and 3.74 %, respectively compared to diesel fuel, which amounted to 79.81 % based on engine torque, figure 4.6 d. shows Volumetric efficiency of B10, B20, B30, and B40 fuel blends at 2000 rpm decreased by 0.78 %, 1.33 %, 2.43 %, and 3.52 %, respectively compared to diesel fuel, which amounted to 77.49 % based on engine torque.

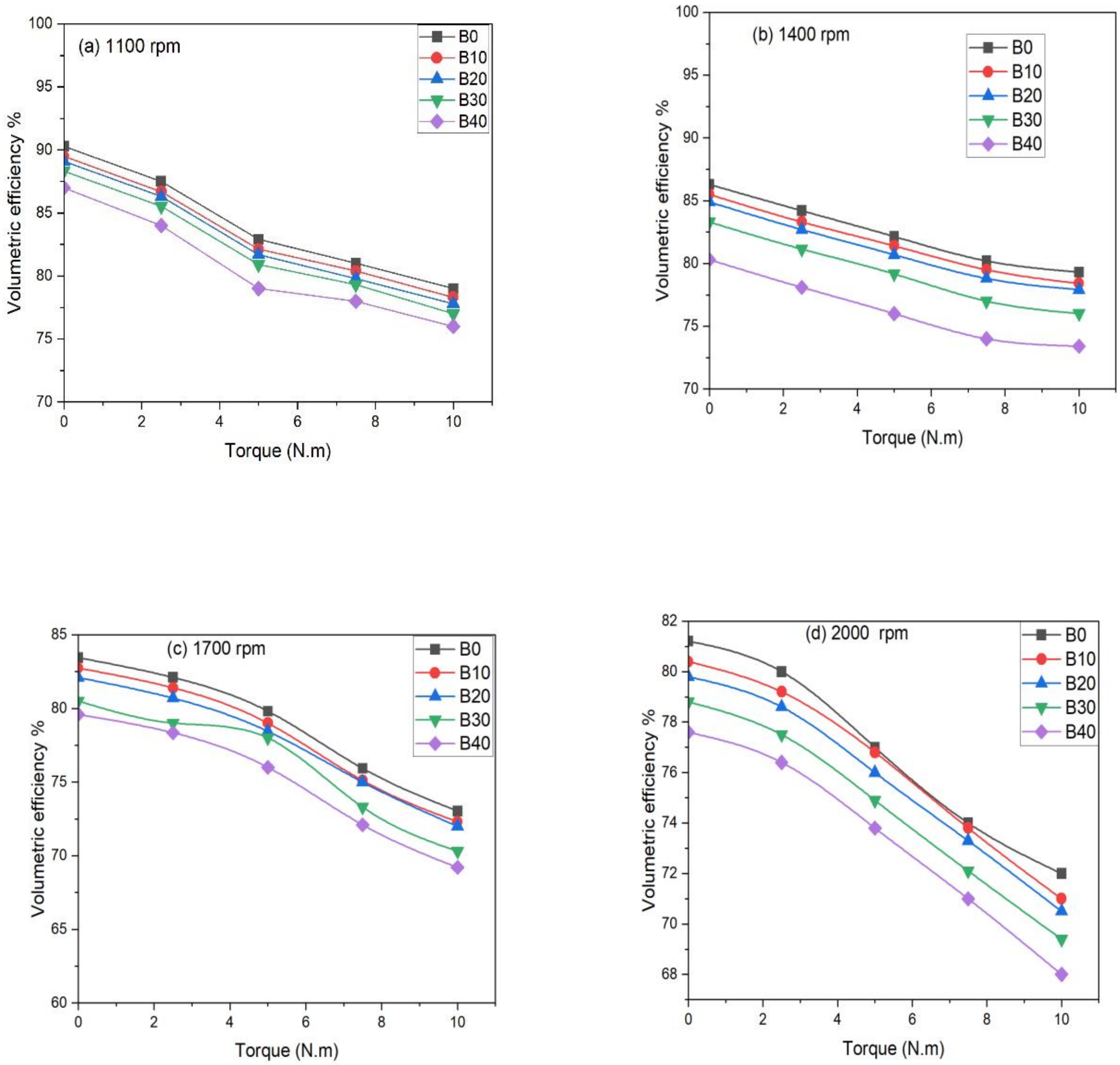



Figure 4.6 volumetric efficiency diagram according to engine torque (a) 1100 rpm, (b) 1400 rpm, (c) 1700 rpm, (d) 2000 rpm.

## 4.8 Effects of Biodiesel Addition on Engine Emission Characteristics

This section discusses the impact of adding biodiesel to diesel fuel on the emission levels of exhaust gas components. The study includes the measurement of exhaust elements such as Carbon monoxide (CO), Carbon dioxide ($CO_2$), Hydrocarbon (HC), Nitrogen oxides ($NO_X$) and Exhaust Gas Temperature (EGT).

### 4.8.1 Carbon monoxide (CO)

Carbon monoxide (CO) consists of the union of one oxygen atom with one carbon atom, and it is a gas that is harmful to human health because it is a toxic gas. It also contributes to the development of conditions and factors that pose a threat to the environment. Therefore, exhaust emissions must be reduced.

Figure 4.7 depicts the difference in CO emissions as a function of engine load. Figure 4.5 a. CO emissions based on the engine torque, for B10, B20, B30, and B40 fuel blends at 1100 rpm the CO emissions decreased by 0.016 %vol, 0.025 %vol, 0.031 % vol and 0.043 % vol, respectively compared to diesel fuel, which amounted to 0.11 %vol based on engine torque. Figure 4.7 b. shows CO emissions based on the engine torque, for B10, B20, B30, and B40 fuel blends at 1400 rpm the CO emissions decreased by 0.011 %vol., 0.021 %vol, 0.026 %vol, and 0.032 % vol, respectively compared to diesel fuel, which amounted to 0.121 %vol based on engine torque. Figure 4.7 c. shows CO emissions based on the engine torque, for B10, B20, B30, and B40 fuel blends at 1700 rpm the CO emissions decreased by 0.004 %vol., 0.015 %vol, 0.028 % vol, and 0.036 % vol, respectively compared to diesel fuel, which amounted to 0.125 %vol based on engine torque. Figure 4.7 d. shows CO emissions Based on the engine torque, for B10, B20, B30, and B40 fuel blends at 2000 rpm the CO emissions decreased by 0.013 %vol., 0.02 %vol, 0.032 %vol, and 0.043 % vol, respectively compared to diesel fuel, which amounted to 0.13 %vol based on engine torque.

There was a decrease in the formation of carbon monoxide (CO) when using biodiesel mixtures. The possible reason is the presence of an amount of oxygen in the biodiesel, in addition to the high number of cetane compared to fossil diesel, which makes the combustion process complete.

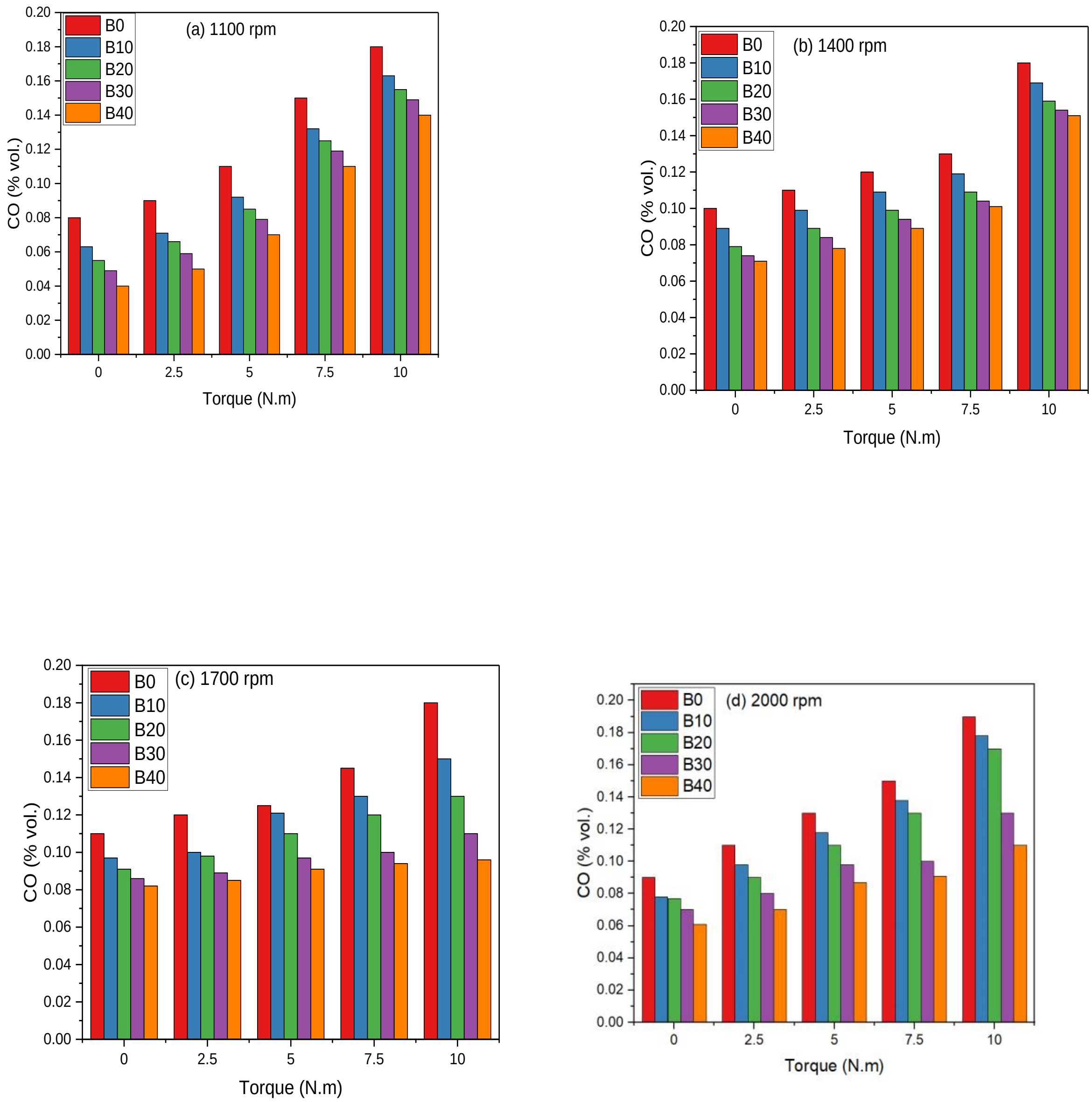



Figure 4.7 Carbon monoxide (CO) chart based on engine torque. (a) 1100 rpm, (b)1400 rpm, (c) 21700 rpm, (d)2000 rpm.

### 4.8.2 Carbon dioxide ($CO_2$)

The principal component of exhaust gas is carbon dioxide ($CO_2$). Emissions of carbon dioxide, a hazardous gas that endangers the environment. Figure 4.8 shows the difference in carbon dioxide emissions as a function of engine torque and fuel blend. Figure 4.8 a. shows the $CO_2$ emissions B10, B20, B30, and B40 fuel blends at 1100 rpm increased by an average of 0.20 % vol., 0.36 % vol., 0.9 %vol., and 0.70 %vol. respectively compared to diesel fuel, which amounted to 0.90 %vol based on engine torque. Figure 4.8 b. shows the $CO_2$ emissions of B10, B20, B30, and B40 fuel blends at 1400 rpm increased by an average of 0.17 % vol., 0.33 % vol., 0.53 %vol., and 0.65 %vol. respectively compared to diesel fuel, which amounted to 0.93 %vol based on engine torque. Figure 4.8 c. shows the $CO_2$ emissions of B10, B20, B30, and B40 fuel blends at 1700 rpm increased by an average of 0.22 % vol., 0.26 % vol., 0.52 %vol., and 0.66 %vol. respectively compared to diesel fuel, which amounted to 0.99 %vol based on engine torque. Figure 4.8 d. shows the $CO_2$ emissions of B10, B20, B30, and B40 fuel blends at 2000 rpm increased by an average of 0.14 % vol., 0.21 % vol., 0.36 %vol.,and 0.39 %vol. respectively compared to diesel fuel, which amounted to 1.12 %vol based on engine torque.

There was an increase in the formation of carbon dioxide $CO_2$ when using biodiesel mixtures, and the possible reason is the presence of a quantity of oxygen in the biodiesel, in addition to the high number of cetane compared to fossil diesel, which makes the combustion process complete. Plants can use carbon dioxide emissions from renewable fuels to keep carbon dioxide levels in the atmosphere stable.

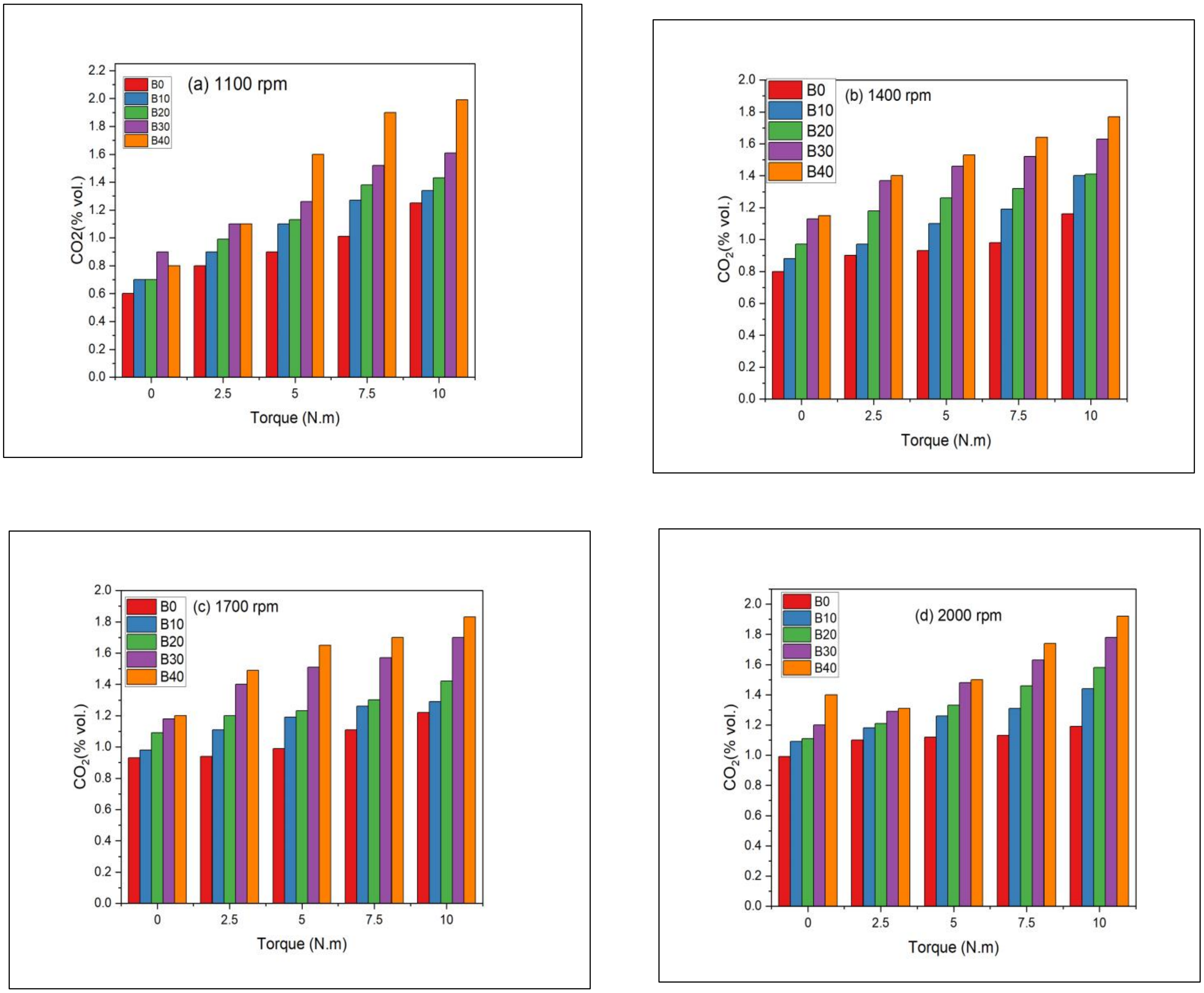



Figure 4.8 Graph of Carbon Dioxide ($CO_2$) According to Engine Torque a) 1100 rpm, b) 1400 rpm, c) 1700 rpm, d) 2000 rpm.

### 4.8.3 Hydrocarbon (HC)

As a result of incomplete combustion, some of the fuel fed to the engine is discharged as hydrocarbon (HC) emissions. Fuel absorption and emission, flame quenching and fuel evaporation, and fuel deposition in engine deposits are all variables that contribute to HC emissions. As can be seen from graph Figure 4.9, hydrocarbon emissions (HC) are lower compared to fossil diesel when using biodiesel mixtures. The differences in the amount of hydrocarbon emissions from biodiesel and fossil diesel depend on engine torque, shown in Figure 4.9 a. B10, B20, B30, and B40 blends at 1100 rpm have produced lower HC emissions in average by 0.99 ppm, 3 ppm, 5 ppm, and 5.9 ppm, respectively compared to diesel fuel, which amounted to 121 ppm based on engine torque. Figure 4.9 b. B10, B20, B30, and B40 blends at 1400 rpm have produced lower HC emissions on average by 2 ppm, 4 ppm, 7, and 13 ppm, respectively compared to diesel fuel, which amounted to 109 ppm based on engine torque. Figure 4.9 c. B10, B20, B30, and B40 blends at 1700 rpm have produced lower HC emissions on average by 2 ppm, 5 ppm, 7 ppm, and 9 ppm, respectively compared to diesel fuel, which amounted to 95 ppm based on engine torque. Figure 4.9 d. B10, B20, B30, and B40 blends at 2000 rpm have produced lower HC emissions on average by 2 ppm, 4 ppm, 5 ppm, and 7 ppm, respectively compared to diesel fuel, which amounted to 86 ppm based on engine torque.

Biodiesel with a high cetane number may lower HC emissions. The oxygen concentration of biodiesel ensured adequate oxidation in the rich air-fuel combination zones, which is why HC emissions were reduced when biodiesel and its blends were employed. The greater compression ratio of diesel engines resulted in higher exhaust temperatures. As a result, it is probable that unburned hydrocarbons in the chamber were oxidized near the exhaust exit.

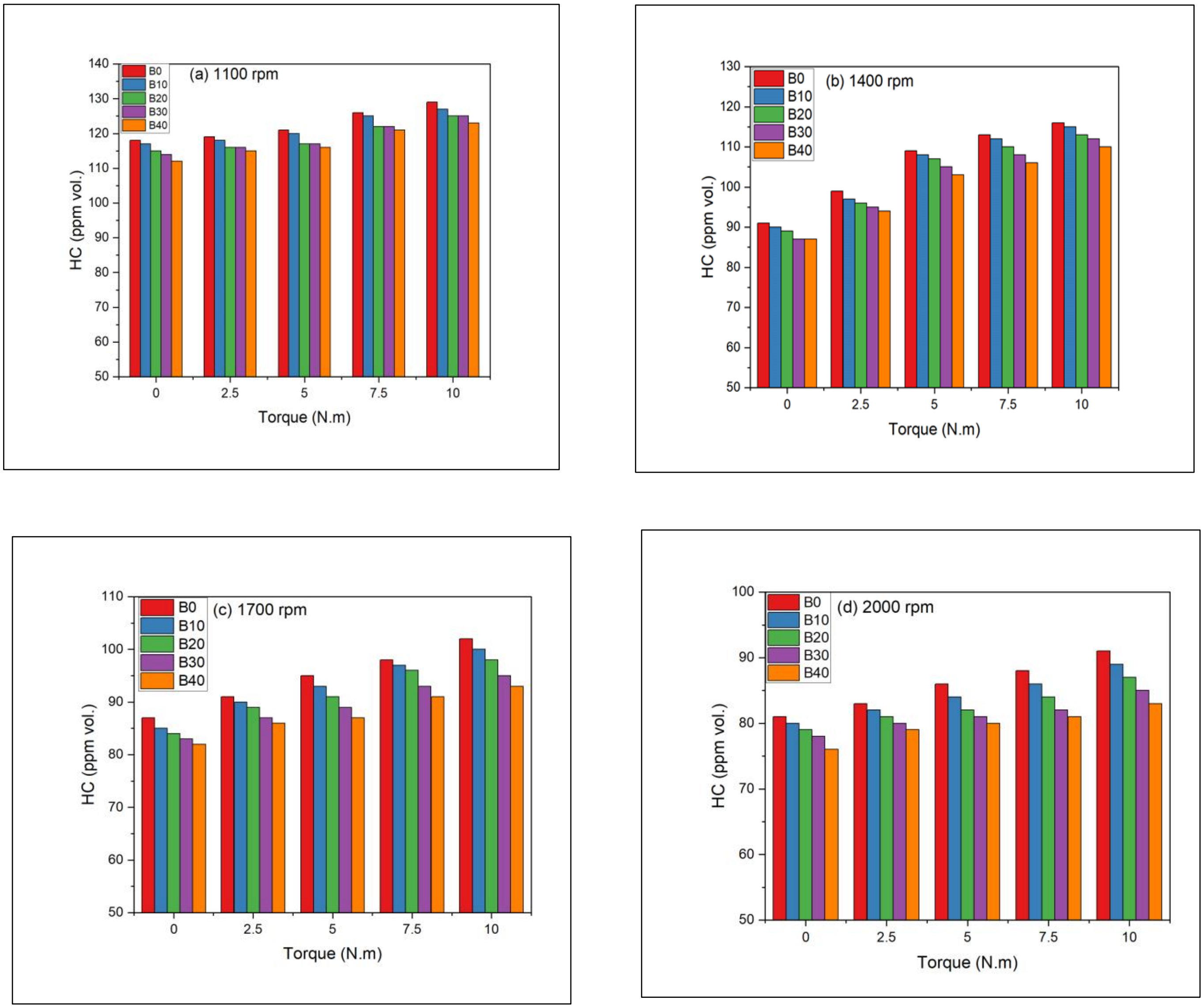



Figure 4.9 Graph of hydrocarbon emissions (HC) according to engine torque (a) 1100 rpm, (b) 1400 rpm, (c) 1700 rpm, (d) 2000 rpm.

### 4.8.4 Nitrogen oxides ($NO_X$)

The emission of nitric oxide, is a colorless, toxic gas that presents a serious risk to the environment. Nitrogen oxide ($NO_X$) is a product of internal combustion engines; it is formed from nitrogen dioxide ($NO_2$) and nitrogen monoxide (NO) in the exhaust, and its creation is affected by the burning temperature and the oxygen content of the air fed into the engine. Figure 4.10 depicts NOx shifts for diesel and biodiesel based on engine torque. Figure 4.10 (a). shows the $NO_x$ emissions of B10, B20, B30, and B40 fuels blends at 1100 rpm increased by an average of 56 ppm, 96 ppm, 146 ppm, and 194 ppm, respectively compared to diesel fuel, which amounted to 904 ppm based on engine torque. Figure 4.10 (b). shows the $NO_x$ emissions of B10, B20, B30, and B40 fuels blends at 1400 rpm increased by an average of 33 ppm, 94 ppm, 134 ppm, and 167 ppm respectively compared to diesel fuel, which amounted to 893 ppm based on engine torque. Figure 4.10 (c). shows the $NO_x$ emissions of B10, B20, B30, and B40 fuels blends at 1700 rpm increased by an average of 48 ppm, 71 ppm, 201 ppm, and 234 ppm, respectively compared to diesel fuel, which amounted to 930 ppm based on engine torque. Figure 4.10 (d). shows the $NO_x$ emissions of B10, B20, B30, and B40 fuels blends at 2000 rpm increased by an average of 49 ppm, 135 ppm, 170 ppm, and 200 ppm, respectively compared to diesel fuel, which amounted to 965 ppm based on engine torque.

The reason for the increase in nitrogen oxide emissions ($NO_X$) can be explained by the availability of conditions for the formation of $NO_X$ , which is the presence of an amount of oxygen in the biodiesel, which in turn will make combustion complete and thus increase the combustion temperature inside the combustion chamber, as well as the injection timing and injection pressure. They have an effect on increasing emissions of nitrogen oxides.

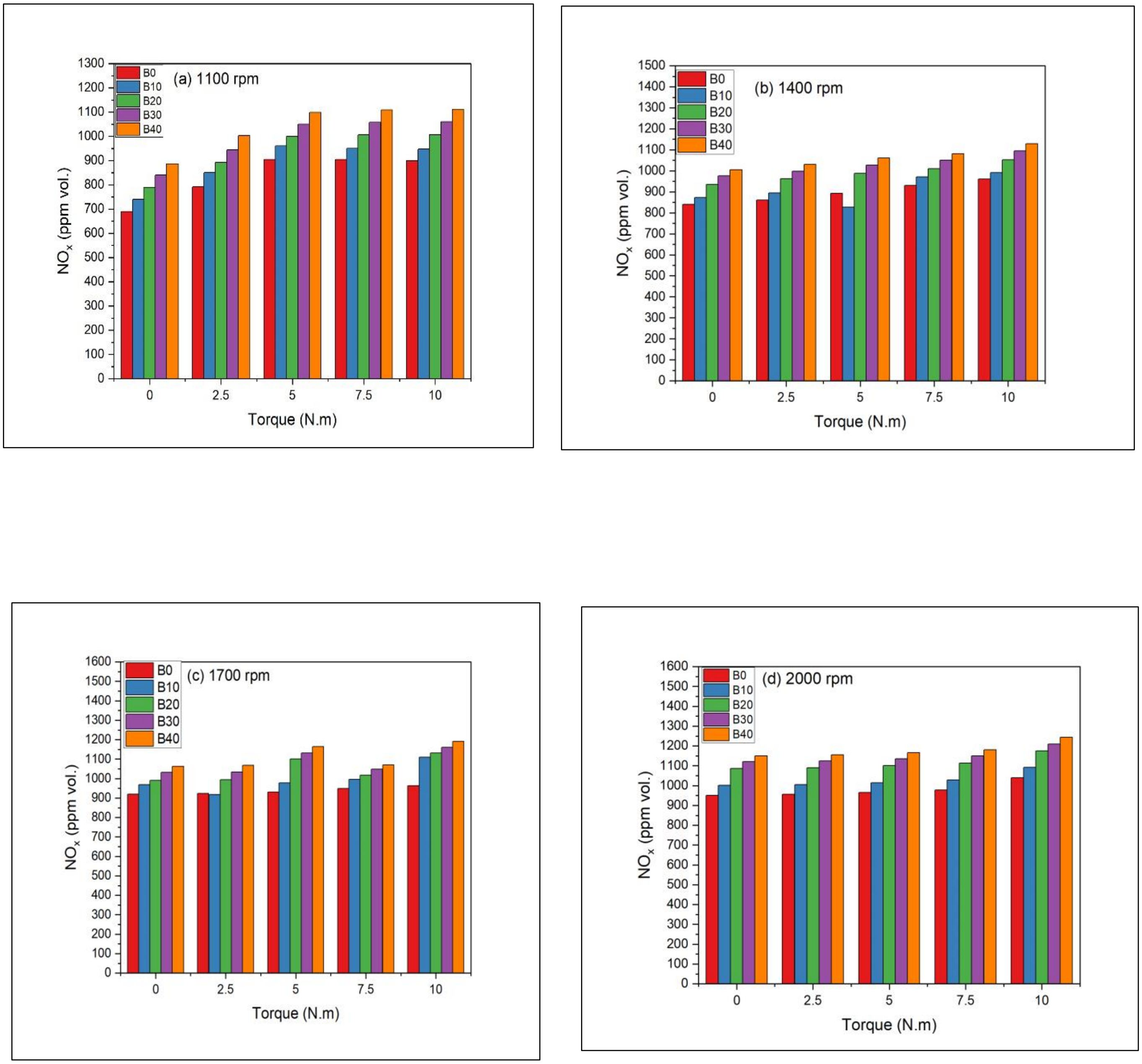



Figure 4.10 Plot of NOx according to engine torque. (a) 1100 rpm,(b) 1400 rpm, (c) 1700 rpm, (d) 2000 rpm.

### 4.8.5 Exhaust Gas Temperature (EGT)

The exhaust gas temperature indicates the efficiency of the combustion process. Figure 4.11 shows how exhaust gas temperature (EGT) varies with engine torque for various blends. EGT increased as engine torque increased for all of the fuels tested. Diesel fuel has been discovered to have a greater EGT than other fuels. This will result in continual fuel combustion until the combustion process is finished, generating increasing amounts of heat.

Figure 4.11 (a) at 1100 rpm, EGT were recorded and at mid-load there was a rise in exhaust gas temperature of about 4°C, 7°C, 9°C, and 12°C, respectively for the mixtures, B10, B20, B30, and B40, compared to diesel fuel, which amounted to 185°C based on engine torque. Figure 4.11 (b) at 1400 rpm, EGT were recorded and were higher by about 2°C, 4°C, 6°C, and 8°C, respectively for the mixtures, B10, B20, B30, and B40, compared to diesel fuel, which amounted to 198°C based on engine torque. Figure 4.11 (c) at 1700 rpm, EGT were recorded and were higher by about 3°C, 8°C, 11°C, and 13°C, respectively for the mixtures, B10, B20, B30, and B40, compared to diesel fuel, which amounted to 208°C based on engine torque. Figure 4.11 (d) at 2000 rpm, EGT were recorded and were higher by about 4°C, 7°C, 12°C, and 15°C, respectively for the mixtures, B10, B20, B30, and B40, compared to diesel fuel, which amounted to 216°C based on engine torque.

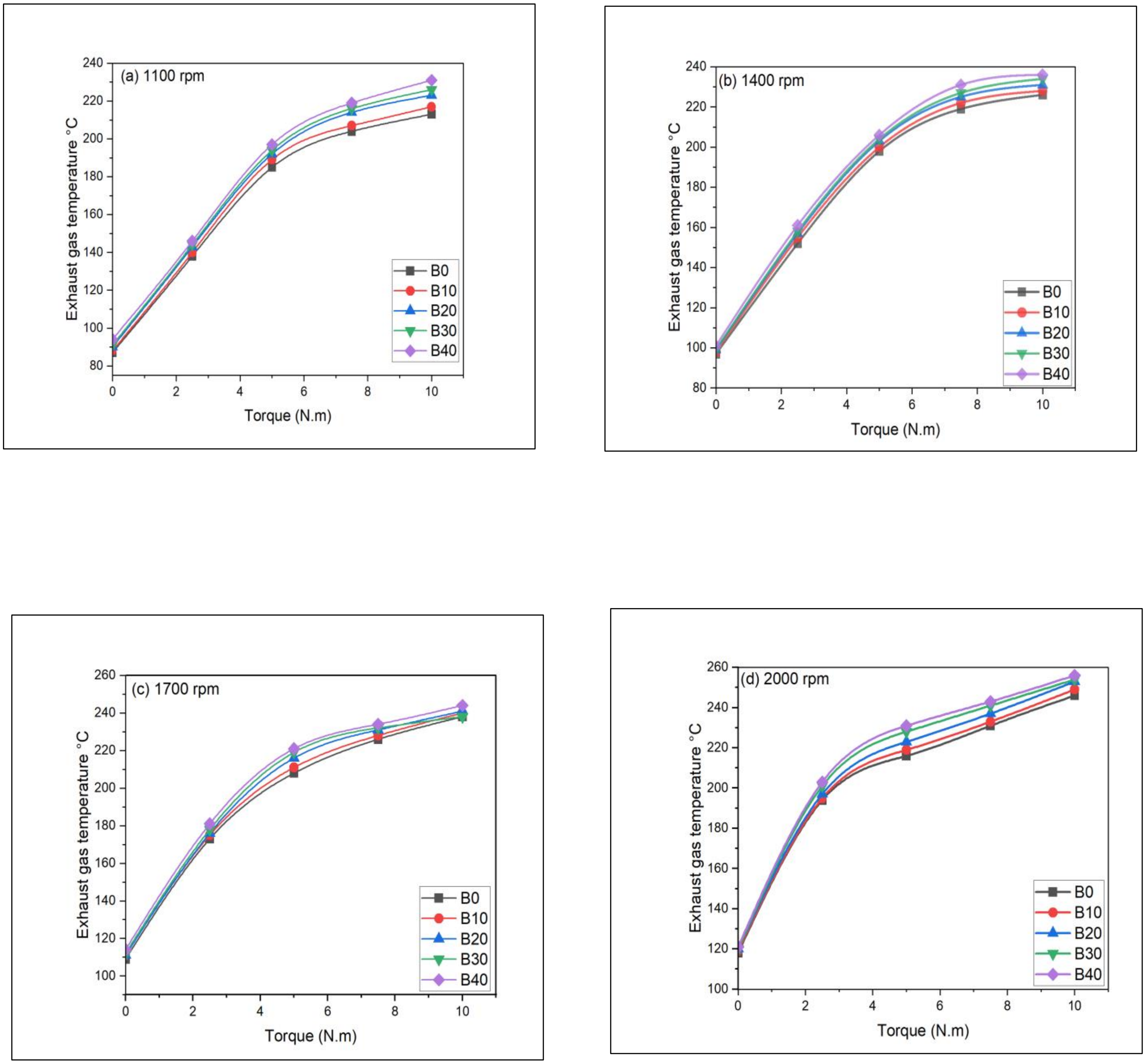



Figure 4.11 Plot of Exhaust Gas Temperature (EGT) according to engine torque. (a) 1100 rpm,(b) 1400 rpm, (c) 1700 rpm, (d) 2000 rpm.

## 4.9 The cost of biodiesel production compared to the cost of diesel production

The cost of producing one liter of biodiesel in Iraqi dinars, which includes the price of the raw material (unused sunflower oil), alcohol, and catalyst, is 1725 ID per liter, which is high compared to the price of fossil diesel fuel (400 ID per liter), according to the prices of the Iraqi Ministry of Oil, for the year 2023. While the prices of biodiesel fuel produced from sunflower oil after using it in cooking are slightly less expensive than the prices of diesel fuel, as the cost of one liter of biodiesel fuel is 225 ID, as shown in table 4-2.

Table 4-2 The cost of producing biodiesel prepared from sunflower oil.

| NO. | Material | Needing quantity to synthesized one liter of biodiesel | Iraqi Dinars/ liter of biodiesel |
|---|---|---|---|
| 1 | unused sunflower oil | 1liter | 1500 |
| 3 | Sunflower oil after using it in cooking | 1liter | 25 |
| 4 | Methanol | 130 ml | 130 |
| 5 | KOH | 10 g | 70 |

# Chapter Five

## Conclusions and Recommendtions

# CHAPTER FIVE

## CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

In this study, performance and emission characteristic of biodiesel fuel with diesel were experimentally studied in a single-cylinder CI engine without any modifications at various engine speeds (1100 – 2000 rpm) with engine torque (0, 2.5, 5, 7.5, 10) N.m. The following conclusions of this study are drawn based on the results of the study:

1. Biodiesel was prepared by esterification, potassium hydroxide was used as a catalyst with methanol instead of sodium hydroxide, which is used by the majority of researchers. The catalyst that was used was better than sodium hydroxide due to its rapid dissolution with methanol and obtaining an effective yield, in addition to its cheap price. A return of 92% was obtained.

2. Engine power decreased when using biodiesel mixtures compared to regular diesel due to the properties of biodiesel, most notably the high density, high viscosity, and low calorific value compared to regular diesel fuel.

3. The thermal efficiency of the engine with biodiesel mixtures decreased compared to regular diesel due to the high viscosity, high density, and low calorific value of biodiesel.

4. The increase in specific fuel consumption due to the calorific value of regular diesel was higher than the calorific value of biodiesel by a difference of (3.713 MJ/kg).

5. The volumetric efficiency of biodiesel blends decreased due to the properties that biodiesel possesses compared to fossil diesel.

6. The increase in nitrogen oxide emissions was due to the presence of a small percentage of nitrogen in vegetable oils. The high combustion temperatures inside the cylinder also lead to an increase in nitrogen oxide emissions.

7. Carbon monoxide emission decreased while carbon dioxide emission increased due to the presence of more oxygen in biodiesel, which promotes complete combustion. The higher cetane number of biodiesel also reduces the likelihood of developing fuel-rich zones, which are generally

associated with CO emissions, when using diesel fuel. Biochemically, this may explain the advanced combustion and injection.

8. Hydrocarbon emissions decreased due to complete combustion as a result of the high temperature inside the combustion chamber, as well as the presence of oxygen in biodiesel, which helps in complete combustion.

9. The temperature of the exhaust gases increased compared to fossil diesel. The reason for the increase is due to the presence of a percentage of oxygen in biodiesel, which facilitates the total combustion of fuel inside the CI engine cylinder, and then the temperature in the cylinder rises and thus there is a corresponding increase in the temperature of the exhaust gases.

10. The experimental result conducted for biodiesel blend is acceptable and satisfactory in the diesel engine without any change in the engine design.

11. Lack of optimal preparation of fuel mixtures in a good and ideal way is one of the reasons that affects the performance of engine parameters and exhaust emissions.

12. The biodiesel that was prepared is considered a renewable energy, environmentally friendly, refreshing for rural areas and creating new job opportunities. It should be urged and encouraged, as biodiesel is considered the fuel of the future, an alternative to fossil diesel.

## 5.2 Recommendations for Future Work

The present work deals with the use of alternative fuel prepared from sunflower oil to reduce environmental pollution. However, there are several useful recommendations that can be followed in the future:

1- Using potassium hydroxide as a catalyst or finding a better catalyst in the process of preparing biodiesel.

2 - The percentage of free fatty acids must be less than 0.005 and the humidity must be less than 0.001 in the vegetable oil used in the preparation process to avoid the primary treatment process.

3 - Improving the physical and chemical properties of biodiesel by adding nanomaterials to make the properties more similar to those of fossil diesel.

4 - Conducting an experimental analysis of a single-cylinder four-stroke (variable compression ratio) using biodiesel blends.

5- Using the exhaust gas recycling method to reduce exhaust gas emissions.

6 - Studying the effect of biodiesel on the air-to-fuel ratio.

# REFERENCE


[1] N. Ali and D. F. Maki, "Combustion characteristics of CI engine fueled with WCO biodiesel/diesel blends at different compression ratios and EGR," Heat Transf., no. March, 2023, doi: 10.1002/htj.22859.

[2] F. Ullah, L. Dong, A. Bano, Q. Peng, and J. Huang, "Current advances in catalysis toward sustainable biodiesel production," J. Energy Inst., vol. 89, no. 2, pp. 282–292, 2016, doi: 10.1016/j.joei.2015.01.018.

[3] P. Sharma and Bibhuti B. Sahoo, "Application of machine learning and Box-Behnken design in optimizing engine characteristics operated with a dual-fuel mode of algal biodiesel and waste-derived biogas," Int. J. Hydrogen Energy 2022, doi: 10.1016/j.ijhydene.2022.04.152.

[4] H. Jamo and E. Tolufase , "Effect of Addition of Titanium Oxide Nanoparticles on the Viscosity of Olive Oil," Sci. World J., vol. 17, no. 1, p. 2022, [Online]. Available: www.scienceworldjournal.org

[5] A. Salih Abbas and T. Salah Othman, "Production and Evaluation of Biodiesel from Sheep Fats Waste," Iraqi J. Chem. Pet. Eng., vol. 13, no. 1, pp. 11–18, 2012, doi: 10.31699/ijcpe.2012.1.2.

[6] P. L. Boey, G. P. Maniam, and S. A. Hamid, "Performance of calcium oxide as a heterogeneous catalyst in biodiesel production: A review," Chem. Eng. J., vol. 168, no. 1, pp. 15–22, 2011, doi: 10.1016/j.cej.2011.01.009.

[7] S. Veluru, H. T. Hamzah, T. B. M, and V. R. Poiba, "A Review on Biodiesel Production from Various Feedstocks by Transesterification," vol. 1258, pp. 1–23, 2022, doi: 10.1088/1757-899X/1258/1/012024.

[8] A. E. Atabani, "Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production," Renew. Sustain. Energy Rev., vol. 18, pp. 211–245, 2013, doi: 10.1016/j.rser.2012.10.013.

[9] Y. Zhang, Y. Zhong, S. Lu, Z. Zhang, and D. Tan, "A Comprehensive Review of the Properties, Performance, Combustion, and Emissions of the Diesel Engine Fueled with Different Generations of Biodiesel," Processes, vol. 10, no. 6, 2022, doi: 10.3390/pr10061178.

[10] A. R. Singh, S. K. Singh, and S. Jain, "Effect of Biodiesel on Engine Performance and Emissions," Lect. Notes Mech. Eng., vol. 4, no. December 2021, pp. 383–393, 2022, doi: 10.1007/978-981-16-8341-1_31.

[11] Y. S. M. Altarazi, "A review of engine performance and emissions using single and dual biodiesel fuels: Research paths, challenges, motivations and recommendations," Fuel, vol. 326, no. July, p. 125072, 2022, doi: 10.1016/j.fuel.2022.125072.

[12] H. Mazaheri , "An overview of biodiesel production via calcium oxide based catalysts: Current state and perspective," Energies, vol. 14, no. 13, pp. 1–23, 2021, doi: 10.3390/en14133950.

[13] R. Sedghi , "Turning biodiesel glycerol into oxygenated fuel additives and their effects on the behavior of internal combustion engines: A comprehensive systematic review," Renew. Sustain. Energy Rev., vol. 167, no. August, p. 112805, 2022, doi: 10.1016/j.rser.2022.112805.

[14] J. López-Fernández, D. Moya, M. Dolors Benaiges, F. Valero, and M. Alcalà, "Near Infrared Spectroscopy: A useful technique for inline monitoring of the enzyme catalyzed biosynthesis of third-generation biodiesel from waste cooking oil," Fuel, vol. 319, Jul. 2022, doi: 10.1016/j.fuel.2022.123794.

[15] H. Hosseinzadeh-Bandbafha et al., "Biodiesel antioxidants and their impact on the behavior of diesel engines: A comprehensive review," Fuel Process. Technol., vol. 232, no. March, p. 107264, 2022, doi: 10.1016/j.fuproc.2022.107264.

[16] T. M. I. Mahlia , "Patent landscape review on biodiesel production: Technology updates," Renew. Sustain. Energy Rev., vol. 118, no. April 2019, p. 109526, 2020, doi: 10.1016/j.rser.2019.109526.

[17] S. K. Elshehawy, E. O. Elgendi, and A. S. Shehata, "Construction waste management: For biodiesel production process," Energy Reports, vol. 8, no. November, pp. 67–76, Nov. 2022, doi: 10.1016/j.egyr.2022.06.095.

[18] L. Razzaq , "Effect of biodiesel-dimethyl carbonate blends on engine performance, combustion and emission characteristics," Alexandria Eng. J., vol. 61, no. 7, pp. 5111–5121, 2022, doi: 10.1016/j.aej.2021.10.015.

[19] A. Inayat, C. Ghani, F. Jamil, A. S. Alobaidli, H. M. Bawazir, and N. A. A. Ali, "Biodiesel production from date seeds via microwave assisted technique," 5th Int. Conf. Renew. Energy Gener. Appl. ICREGA 2018, vol. 2018-Janua, pp. 61–63, 2018, doi: 10.1109/ICREGA.2018.8337617.

[20] P. Shrivastava, T. N. Verma, and A. Pugazhendhi, "An experimental evaluation of engine performance and emisssion characteristics of CI engine operated with Roselle and Karanja biodiesel," Fuel, vol. 254, no. May, p. 115652, 2019, doi: 10.1016/j.fuel.2019.115652.

[21] M. M. Usman Bello1*, Chinedu M. Agu2, Dahiru A. Ajiya1, Auwal A. Mahmoud1, Livingstone Udopia3, Nuruddeen M. Lawal1, Aisha A. Abdullahi1, "Review Article: Biodiesel, in a quest for sustainable renewable energy: A review on its potentials and production strategies," J. Chem. Rev., 2022.

[22] G. C. Brêda , "Current approaches to use oil crops by-products for biodiesel and biolubricant production: Focus on biocatalysis," Bioresour. Technol. Reports, vol. 18, no. March, 2022,

doi: 10.1016/j.biteb.2022.101030.

[23] M. G. U. Islam, M. T. Jan, M. Farooq, A. Naeem, I. W. Khan, and H. U. Khattak, "Biodiesel production from wild olive oil using TPA decorated Ccid heterogeneous catalyr–Al ast," Chem. Eng. Res. Des., vol. 178, pp. 540–549, 2022, doi: 10.1016/j.cherd.2021.12.040.

[24] J. Martins and F. P. Brito, "Alternative fuels for internal combustion engines," Energies, vol. 13, no. 15, 2020, doi: 10.3390/en13164086.

[25] P. Maheshwari , "A review on latest trends in cleaner biodiesel production: Role of feedstock, production methods, and catalysts," Journal of Cleaner Production, vol. 355. Elsevier Ltd, Jun. 25, 2022. doi: 10.1016/j.jclepro.2022.131588.

[26] M. S. Gad and M. A. Ismail, "Effect of waste cooking oil biodiesel blending with gasoline and kerosene on diesel engine performance, emissions and combustion characteristics," Process Saf. Environ. Prot., vol. 149, pp. 1–10, 2021, doi: 10.1016/j.psep.2020.10.040.

[27] A. N. Amenaghawon, N. I. Evbarunegbe, and K. Obahiagbon, "Optimum biodiesel production from waste vegetable oil using functionalized cow horn catalyst: A comparative evaluation of some expert systems," Clean. Eng. Technol., vol. 4, p. 100184, 2021, doi: 10.1016/j.clet.2021.100184.

[28] T. M. I. Riayatsyah , "Biodiesel production from reutealis trisperma oil using conventional and ultrasonication through esterification and transesterification," Sustain., vol. 13, no. 6, 2021, doi: 10.3390/su13063350.

[29] O. D. Samuel , "Performance comparison of empirical model and Particle Swarm Optimization & its boiling point prediction models for waste sunflower oil biodiesel," Case Stud. Therm. Eng., vol. 33, no. March, p. 101947, 2022, doi: 10.1016/j.csite.2022.101947.

[30] B. Ariani, D. Wahyudi, N. Architecture, and U. M. Surabaya, "Numerical Comparison of B20 Biodiesel and Petroleum Diesel in terms of Performance , Combustion , and Emission at Constant Speed," vol. 1095, pp. 1–7, 2022, doi: 10.1088/1755-1315/1095/1/012018.

[31] P. M. Rastogi, A. Sharma, and N. Kumar, "Effect of CuO nanoparticles concentration on the performance and emission characteristics of the diesel engine running on jojoba (Simmondsia Chinensis) biodiesel," Fuel, vol. 286, no. P1, p. 119358, 2021, doi: 10.1016/j.fuel.2020.119358.

[32] A. Nalgundwar, B. Paul, and S. K. Sharma, "Comparison of performance and emissions characteristics of di CI engine fueled with dual biodiesel blends of palm and jatropha," Fuel, vol. 173, no. January, pp. 172–179, 2016, doi: 10.1016/j.fuel.2016.01.022.

[33] M. Y. E. Selim, S. B. Al-Omari, and A. A. J. Al-Aseery, "Effects of steam injection to dual fuel engine on performance, noise and exhaust emission," SAE Tech. Pap., vol. 4970, 2009, doi: 10.4271/2009-01-1831.

[34] M. H. Esfe and M. Afrand, “An updated review on the nanofluids characteristics: Preparation and measurement methods of nanofluids thermal conductivity,” Journal of Thermal Analysis and Calorimetry, vol. 138, no. 6. Springer Netherlands, pp. 4091–4101, Dec. 01, 2019. doi: 10.1007/s10973-019-08406-2.

[35] Colin R. Ferguson, Ed., Internal Combustion Engines, Third Edit. Colorado State University, USA.

[36] B. HENRICSON and E. RAJAKOSKI, “Studies of oocytogenesis in cattle.,” Cornell Vet., vol. 49, pp. 494–503, 1959.

[37] H. A. Alalwan, A. H. Alminshid, and H. A. S. Aljaafari, “Promising evolution of biofuel generations. Subject review,” Renew. Energy Focus, vol. 28, no. 00, pp. 127–139, 2019, doi: 10.1016/j.ref.2018.12.006.

[38] S. Khan , “Biodiesel Production From Algae to Overcome the Energy Crisis,” HAYATI J. Biosci., vol. 24, no. 4, pp. 163–167, 2017, doi: 10.1016/j.hjb.2017.10.003.

[39] E. Bazhdan, S. Tamjidi, P. Rouhi, and H. Esmaeili, “Synthesis of KOH@CaO Catalyst by Sol-gel Method for Highly Efficient Biodiesel Production from Olive Oil,” Phys. Chem. Res., vol. 9, no. 1, pp. 43–55, 2021, doi: 10.22036/pcr.2020.243603.1807.

[40] M. K. Ashour and A. E. Elwardany, “Addition of two kerosene-based fuels to diesel–biodiesel fuel: Effect on combustion, performance and emissions characteristics of CI engine,” Fuel, vol. 269, no. March, p. 117473, 2020, doi: 10.1016/j.fuel.2020.117473.

[41] B. A. Oni, S. E. Sanni, A. J. Ibegbu, and T. E. Amoo, “Investigating the emissions and performance of hydrogen enriched-biogas-Parinari polyandra biodiesel in a direct injection (DI) engine,” Int. J. Hydrogen Energy, vol. 47, no. 69, pp. 29945–29955, 2022, doi: 10.1016/j.ijhydene.2022.06.292.

[42] M. S. A. Mohammed and Hyder H. Balla, “Biodiesel fuel for internal combustion engine,” 2021.

[43] M. Y. Khan, P. S. Rao, B. S. Pabla, and S. Ghotekar, “Innovative biodiesel production plant: Design, development, and framework for the usage of biodiesel as a sustainable EDM fluid,” J. King Saud Univ. - Sci., vol. 34, no. 6, Aug. 2022, doi: 10.1016/j.jksus.2022.102203.

[44] N. Tshizanga, E. F. Aransiola, and O. Oyekola, “Optimisation of biodiesel production from waste vegetable oil and eggshell ash,” South African J. Chem. Eng., vol. 23, pp. 145–156, 2017, doi: 10.1016/j.sajce.2017.05.003.

[45] M. Salaheldeen, A. A. Mariod, M. K. Aroua, S. M. A. Rahman, M. E. M. Soudagar, and I. M. R. Fattah, “Current state and perspectives on transesterification of triglycerides for biodiesel production,” Catalysts, vol. 11, no. 9, 2021, doi: 10.3390/catal11091121.

[46] S. T. Keera, S. M. El Sabagh, and A. R. Taman, “Castor oil biodiesel production and

optimization," Egypt. J. Pet., vol. 27, no. 4, pp. 979–984, 2018, doi: 10.1016/j.ejpe.2018.02.007.

[47] J. Xue, T. E. Grift, and A. C. Hansen, "Effect of biodiesel on engine performances and emissions," Renew. Sustain. Energy Rev., vol. 15, no. 2, pp. 1098–1116, 2011, doi: 10.1016/j.rser.2010.11.016.

[48] S. Nogales-Delgado, J. M. Encinar, and Á. González Cortés, "High oleic safflower oil as a feedstock for stable biodiesel and biolubricant production," Ind. Crops Prod., vol. 170, 2021, doi: 10.1016/j.indcrop.2021.113701.

[49] P. Kalita, B. Basumatary, P. Saikia, B. Das, and S. Basumatary, "Biodiesel as renewable biofuel produced via enzyme-based catalyzed transesterification," Energy Nexus, vol. 6, no. December 2021, p. 100087, 2022, doi: 10.1016/j.nexus.2022.100087.

[50] E. C. Linganiso , "Biodiesel Production from Waste Oils: A South African Outlook," Sustain., vol. 14, no. 4, Feb. 2022, doi: 10.3390/su14041983.

[51] Y. Essamlali, O. Amadine, A. Fihri, and M. Zahouily, "Sodium modified fluorapatite as a sustainable solid bi-functional catalyst for biodiesel production from rapeseed oil," Renew. Energy, vol. 133, pp. 1295–1307, 2019, doi: 10.1016/j.renene.2018.08.103.

[52] S. O. Bitire and T. C. Jen, "Performance and emission analysis of a CI engine fueled with parsley biodiesel–diesel blend," Mater. Renew. Sustain. Energy, vol. 11, no. 2, pp. 143–153, 2022, doi: 10.1007/s40243-022-00213-4.

[53] Y. S. Pradana, H. Sudibyo, E. A. Suyono, Indarto, and A. Budiman, "Oil Algae Extraction of Selected Microalgae Species Grown in Monoculture and Mixed Cultures for Biodiesel Production," Energy Procedia, vol. 105, pp. 277–282, 2017, doi: 10.1016/j.egypro.2017.03.314.

[54] C. Bae and J. Kim, "Alternative fuels for internal combustion engines," Proc. Combust. Inst., vol. 36, no. 3, pp. 3389–3413, 2017, doi: 10.1016/j.proci.2016.09.009.

[55] H. M. A. Hassan , "Biogenic-mediated synthesis of the Cs2O-MgO/MPC nanocomposite for biodiesel production from olive oil," ACS Omega, vol. 5, no. 43, pp. 27811–27822, 2020, doi: 10.1021/acsomega.0c02814.

[56] M. W. Rahman, A. K. Mondal, M. S. Hasan, and M. Sultana, "Biodiesel production from a non-edible source of royna (Aphanamixis polystachya) oil," Energy. Sustain. Soc., vol. 12, no. 1, pp. 1–12, 2022, doi: 10.1186/s13705-022-00360-6.

[57] A. Tuan Hoang , Understanding behaviors of compression ignition engine running on metal nanoparticle additives-included fuels: A control comparison between biodiesel and diesel fuel, vol. 326, no. December 2021. 2022. doi: 10.1016/j.fuel.2022.124981.

[58] V. V. S and J. Gonsalves, "Performance study of using preheated biodiesel in a diesel

engine," J. Mech. Eng. Sci., vol. 16, no. 2, pp. 8820–8828, 2022, doi: 10.15282/jmes.16.2.2022.01.0697.

[59] H. Brännström, H. Kumar, and R. Alén, "Current and Potential Biofuel Production from Plant Oils," Bioenergy Res., vol. 11, no. 3, pp. 592–613, 2018, doi: 10.1007/s12155-018-9923-2.

[60] N. S. El-Gendy, S. F. Deriase, A. Hamdy, and R. I. Abdallah, "Statistical optimization of biodiesel production from sunflower waste cooking oil using basic heterogeneous biocatalyst prepared from eggshells," Egypt. J. Pet., vol. 24, no. 1, pp. 37–48, 2015, doi: 10.1016/j.ejpe.2015.02.004.

[61] P. Liu and Y. Zhang, "Optimization of biodiesel production from oil using a novel green catalyst via development of a predictive model," Arab. J. Chem., vol. 16, no. 6, p. 104785, 2023, doi: 10.1016/j.arabjc.2023.104785.

[62] A. F. Emma, S. Alangar, and A. K. Yadav, "Extraction and characterization of coffee husk biodiesel and investigation of its effect on performance, combustion, and emission characteristics in a diesel engine," Energy Convers. Manag. X, vol. 14, no. March, p. 100214, 2022, doi: 10.1016/j.ecmx.2022.100214.

[63] E. Öztürk, Ö. Can, N. Usta, and H. S. Yücesu, "Effects of retarded fuel injection timing on combustion and emissions of a diesel engine fueled with canola biodiesel," Eng. Sci. Technol. an Int. J., vol. 23, no. 6, pp. 1466–1475, 2020, doi: 10.1016/j.jestch.2020.06.008.

[64] S. K. and R. Udayakumar, "Comparative evaluation of the performance of rice bran and cotton seed biodiesel blends in VCR diesel engine," Energy Reports, vol. 6, pp. 795–801, 2020, doi: 10.1016/j.egyr.2019.12.005.

[65] M. M. Zamberi, F. N. Ani, M. F. Abdollah, N. W. M. Zulkifli, and N. Tamaldin, "Microwave assisted Jatropha curcas biodiesel production and the effects on the diesel engine performances," IOP Conf. Ser. Mater. Sci. Eng., vol. 991, no. 1, pp. 1–8, 2020, doi: 10.1088/1757-899X/991/1/012080.

[66] P. Rosha, S. K. Mohapatra, S. K. Mahla, H. M. Cho, B. S. Chauhan, and A. Dhir, "Effect of compression ratio on combustion, performance, and emission characteristics of compression ignition engine fueled with palm (B20)biodiesel blend," Energy, vol. 178, pp. 676–684, 2019, doi: 10.1016/j.energy.2019.04.185.

[67] A. S. Mahmood, H. I. Qatta, S. M. D. Al-Nuzal, T. K. Abed, and A. A. Hardan, "The effect of compression ratio on the performance and emission characteristics of C.I. Engine fuelled with corn oil biodiesel blended with diesel fuel.," IOP Conf. Ser. Earth Environ. Sci., vol. 779, no. 1, pp. 1–13, 2021, doi: 10.1088/1755-1315/779/1/012062.

[68] A. Alahmer, H. Alahmer, A. Handam, and H. Rezk, "Environmental Assessment of a Diesel Engine Fueled with Various Biodiesel Blends: Polynomial Regression and Grey Wolf

Optimization," Sustain., vol. 14, no. 3, 2022, doi: 10.3390/su14031367.

[69] S. B. Sai, N. Subramaniapillai, M. S. B. Khadhar Mohamed, and A. Narayanan, "Effect of rubber seed oil biodiesel on engine performance and emission analysis," Fuel, vol. 296, no. March, p. 120708, 2021, doi: 10.1016/j.fuel.2021.120708.

[70] C. Adhikesavan, D. Ganesh, and V. Charles Augustin, "Effect of quality of waste cooking oil on the properties of biodiesel, engine performance and emissions," Clean. Chem. Eng., vol. 4, p. 100070, Dec. 2022, doi: 10.1016/j.clce.2022.100070.

[71] M. N. Nabi, W. K. Hussam, H. M. M. Afroz, A. Bin Rashid, J. Islam, and A. N. M. M. I. Mukut, "Investigation of engine performance, combustion, and emissions using waste tire Oil-Diesel-Glycine max biodiesel blends in a diesel engine," Case Stud. Therm. Eng., vol. 39, no. September, p. 102435, 2022, doi: 10.1016/j.csite.2022.102435.

[72] B. Devaraj Naik, U. Meivelu, V. Thangarasu, S. Annamalai, and V. Sivasankaralingam, "Experimental and empirical analysis of a diesel engine fuelled with ternary blends of diesel, waste cooking sunflower oil biodiesel and diethyl ether," Fuel, vol. 320, no. March, p. 123961, 2022, doi: 10.1016/j.fuel.2022.123961.

[73] V. Vinodkumar and A. Karthikeyan, "Effect of manifold injection of n-decanol on neem biodiesel fuelled CI engine," Energy, vol. 241, no. X, p. 122856, 2022, doi: 10.1016/j.energy.2021.122856.

[74] Z. Tosun and H. Aydin, "Combustion, performance and emission analysis of propanol addition on safflower oil biodiesel in a diesel engine," Clean. Chem. Eng., vol. 3, no. April, p. 100041, 2022, doi: 10.1016/j.clce.2022.100041.

[75] L. Hadhoum, F. Zohra Aklouche, K. Loubar, and M. Tazerout, "Experimental investigation of performance, emission and combustion characteristics of olive mill wastewater biofuel blends fuelled CI engine," Fuel, vol. 291, no. November 2020, p. 120199, 2021, doi: 10.1016/j.fuel.2021.120199.

[76] Ö. Cihan, "Experimental and numerical investigation of the effect of figure seed oil methyl ester biodiesel blends on combustion characteristics and performance in a diesel engine," Energy Reports, vol. 7, pp. 5846–5856, 2021, doi: 10.1016/j.egyr.2021.08.180.

[77] S. Simsek, "Effects of biodiesel obtained from Canola, sefflower oils and waste oils on the engine performance and exhaust emissions," Fuel, vol. 265, no. December 2019, p. 117026, 2020, doi: 10.1016/j.fuel.2020.117026.

[78] K. Mohan, R. Sharfaraaz Ismail, S. Rudresh, K. S. Sanjayram, and A. Vinodh Kumar, "An Engine performance analysis and emission characteristics of IC engine using mixture of canola and pongamia oil as biodiesel," IOP Conf. Ser. Mater. Sci. Eng., vol. 1145, no. 1, p. 012097, 2021, doi: 10.1088/1757-899x/1145/1/012097.

[79] A. Sharma, N. A. Ansari, A. Pal, Y. Singh, and S. Lalhriatpuia, "Effect of biogas on the

performance and emissions of diesel engine fuelled with biodiesel-ethanol blends through response surface methodology approach," Renew. Energy, vol. 141, pp. 657–668, 2019, doi: 10.1016/j.renene.2019.04.031.

[80] A. Uyumaz , "An Experimental Investigation on The Effects of Waste Olive Oil Biodiesel on Combustion, Engine Performance and Exhaust Emissions," Int. J. Automot. Eng. Technol., vol. 8, no. 3, pp. 103–116, 2019, doi: 10.18245/ijaet.578227.

[81] S. El-din H. Etaiw, M. Elkelawy, I. Elziny, M. Taha, I. Veza, and H. Alm-Eldin Bastawissi, "Effect of nanocomposite SCP1 additive to waste cooking oil biodiesel as fuel enhancer on diesel engine performance and emission characteristics," Sustain. Energy Technol. Assessments, vol. 52, no. PC, p. 102291, 2022, doi: 10.1016/j.seta.2022.102291.

[82] S. Radhakrishnan, Y. Devarajan, A. Mahalingam, and B. Nagappan, "Emissions analysis on diesel engine fueled with palm oil biodiesel and pentanol blends," J. Oil Palm Res., vol. 29, no. 3, pp. 380–386, 2017, doi: 10.21894/jopr.2017.2903.11.

[83] J. A. V. Godiño, M. T. García, and F. J. J. E. Aguilar, "Experimental investigation and modelling of biodiesel combustion in engines with late direct injection strategy," Energy Reports, vol. 8, pp. 7476–7487, 2022, doi: 10.1016/j.egyr.2022.05.279.

[84] P. V. Elumalai, B. Dhinesh, J. Jayakar, M. Nambiraj, and V. Hariharan, "Effects of antioxidants to reduce the harmful pollutants from diesel engine using preheated palm oil–diesel blend," J. Therm. Anal. Calorim., vol. 147, no. 3, pp. 2439–2453, 2022, doi: 10.1007/s10973-021-10652-2.

[85] S. Ramalingam and N. V. Mahalakshmi, "Influence of high pressure fuel injection system on engine performance and combustion characteristics of Moringa Oleifera biodiesel and its blends," Fuel, vol. 279, no. May, p. 118461, 2020, doi: 10.1016/j.fuel.2020.118461.

[86] P. Appavu, V. R. Madhavan, J. Jayaraman, and H. Venu, "Palm oil-based biodiesel as a novel alternative feedstock for existing unmodified DI diesel engine," Int. J. Ambient Energy, vol. 43, no. 1, pp. 222–228, 2022, doi: 10.1080/01430750.2019.1636884.

[87] A. Roy, Y. Dabhi, H. Brahmbhatt, and S. K. Chourasia, "Effect of emulsified fuel based on dual blend of Castor-Jatropha biodiesel on CI engine performance and emissions," Alexandria Eng. J., vol. 60, no. 1, pp. 1981–1990, 2021, doi: 10.1016/j.aej.2020.12.003.

[88] R. Karami, M. Hoseinpour, M. G. Rasul, N. M. S. Hassan, and M. M. K. Khan, "Exergy, energy, and emissions analyses of binary and ternary blends of seed waste biodiesel of tomato, papaya, and apricot in a diesel engine," Energy Convers. Manag. X, vol. 16, no. August, p. 100288, 2022, doi: 10.1016/j.ecmx.2022.100288.

[89] B. C. Tesfa, R. Mishra, and A. M. Aliyu, "Effect of biodiesel blends on the transient performance of compression ignition engines," Energies, vol. 14, no. 17, 2021, doi: 10.3390/en14175416.

[90] L. A. Raman, B. Deepanraj, S. Rajakumar, and V. Sivasubramanian, “Experimental investigation on performance, combustion and emission analysis of a direct injection diesel engine fuelled with rapeseed oil biodiesel,” Fuel, vol. 246, no. February, pp. 69–74, 2019, doi: 10.1016/j.fuel.2019.02.106.

[91] A. Sandouqa, M. Al-Shannag, and Z. Al-Hamamre, “Biodiesel purification using biomass-based adsorbent manufactured from delignified olive cake residues,” Renew. Energy, vol. 151, pp. 103–117, 2020, doi: 10.1016/j.renene.2019.11.009.

[92] Y. Devarajan, R. kumar Jayabal, D. Ragupathy, and H. Venu, “Emissions analysis on second generation biodiesel,” Front. Environ. Sci. Eng., vol. 11, no. 1, pp. 1–6, 2017, doi: 10.1007/s11783-017-0891-0.

[93] I. Simbi, U. O. Aigbe, O. Oyekola, and O. A. Osibote, “Optimization of biodiesel produced from waste sunflower cooking oil over bi-functional catalyst,” Results Eng., vol. 13, no. December 2021, p. 100374, 2022, doi: 10.1016/j.rineng.2022.100374.

[94] S. A. Abo El-Enin, N. K. Attia, N. N. El-Ibiari, G. I. El-Diwani, and K. M. El-Khatib, “In-situ transesterification of rapeseed and cost indicators for biodiesel production,” Renew. Sustain. Energy Rev., vol. 18, pp. 471–477, 2013, doi: 10.1016/j.rser.2012.10.033.

[95] S. T. Al-Humairi, J. G. M. Lee, and A. P. Harvey, “Direct and rapid production of biodiesel from algae foamate using a homogeneous base catalyst as part of an intensified process,” Energy Convers. Manag. X, vol. 16, no. May, p. 100284, 2022, doi: 10.1016/j.ecmx.2022.100284.

[96] M. Singh and S. S. Sandhu, “Effect of boost pressure on combustion, performance and emission characteristics of a multicylinder CRDI engine fueled with argemone biodiesel/diesel blends,” Fuel, vol. 300, no. March 2020, p. 121001, 2021, doi: 10.1016/j.fuel.2021.121001.

[97] S. Imtenan, “Emission and performance improvement analysis of biodiesel-diesel blends with additives,” Procedia Eng., vol. 90, pp. 472–477, 2014, doi: 10.1016/j.proeng.2014.11.759.

[98] M. Kumar, S. Bhowmik, and A. Paul, “Effect of pilot fuel injection pressure and injection timing on combustion, performance and emission of hydrogen-biodiesel dual fuel engine,” Int. J. Hydrogen Energy, vol. 47, no. 68, pp. 29554–29567, 2022, doi: 10.1016/j.ijhydene.2022.06.260.

[99] R. Kukana and O. P. Jakhar, “Performance, combustion and emission characteristics of a diesel engine using composite biodiesel from waste cooking oil - Hibiscus Cannabinus oil,” J. Clean. Prod., vol. 372, no. August, p. 133503, 2022, doi: 10.1016/j.jclepro.2022.133503.

[100] P. Wai, “Experimental investigation of the influence of ethanol and biodiesel on common rail direct injection diesel Engine’s combustion and emission characteristics,” Case Stud.

Therm. Eng., vol. 39, no. August, p. 102430, 2022, doi: 10.1016/j.csite.2022.102430.

[101] E. Öztürk, “Performance, emissions, combustion and injection characteristics of a diesel engine fuelled with canola oil-hazelnut soapstock biodiesel mixture,” Fuel Process. Technol., vol. 129, pp. 183–191, 2015, doi: 10.1016/j.fuproc.2014.09.016.

[102] M. S. Gad, R. El-Araby, K. A. Abed, N. N. El-Ibiari, A. K. El Morsi, and G. I. El-Diwani, “Performance and emissions characteristics of C.I. engine fueled with palm oil/palm oil methyl ester blended with diesel fuel,” Egypt. J. Pet., vol. 27, no. 2, pp. 215–219, 2018, doi: 10.1016/j.ejpe.2017.05.009.

[103] K. Mohan, M. Sri Bharani Tharaan, V. Sriram Muthu Mani, M. Srihari, and S. Rohit Saran, “An Effect of Engine Performance and Exhaust Emissions using Palma Rosa grass oil as Biodiesel,” IOP Conf. Ser. Mater. Sci. Eng., vol. 1145, no. 1, p. 012075, 2021, doi: 10.1088/1757-899x/1145/1/012075.

# APPENDIXES

## Appendix (A): List of publications

1- Accept of the paper (Review paper for biodiesel alternative fuel)

### Submission Summary

**Conference Name**
4th INTERNATIONAL CONFERENCE ON ARCHITECTURAL & CIVIL ENGINEERING SCIENCES

**Paper ID**
44

**Paper Title**
Review paper for biodiesel alternative fuel

**Abstract**
Petroleum is quite significant in the industry, transportation, agriculture, and other businesses related to transportation. The availability of conventional fossil fuels for internal combustion engines causes environment issues. If one day we run out of fossil fuels, There are no suitable alternatives that are substantially effective. Therefore, there is no escape from the need to look for alternative fuels. In this study, potential and present raw material resources, such as palm oil, olive oil, castor oil, cooking oil, Safflower oil, sunflower oil, Jatropha oil, rapeseed oil, cottonseed oil and algae for biodiesel production, as well as a variety of other vegetable oils and animal fats, can manufacture biodiesel. Given the positive potential in this study, The findings of this study are expected to have a significant impact on biodiesel production in the future and inspire additional research into the manufacture of biodiesel from existing sources.

**Created on**
12م 6:50:36 2022/12/

**Last Modified**
15م 9:53:02 2022/12/

**Authors**
**Sabih Muhodir** ( Cihan University-Erbil ) < sabih.alzuhairy@cihanuniversity.edu.iq>
ali aljabiri ( najaf ) < ali.ms.etcn3@student.atu.edu.iq>

**Primary Subject Area**
Environmentally Sustainable buildings

**Conflicts of Interest**
Sabih Muhodir - sabih.alzuhairy@cihanuniversity.edu.iq
- a co-author

**Submission Files**
Review paper for biodiesel alternative fuel - Copy.docx (2.4 Mb, 12م 6:49:25 2022/12/)

**Submission Questions Response**
**1. Submission Requirements**
*The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).*
Agreement accepted

**2. Submission Requirements**
*The submission file is in OpenOffice, Microsoft Word, or RTF document file format.*
Agreement accepted

**3. Submission Requirements**
*Where available, URLs for the references have been provided.*
Agreement accepted

**4. Submission Requirements**
*The text adheres to the stylistic and bibliographic requirements outlined in the Author Guidelines.*
Agreement accepted

**5. Comments for the Chair**

*Comments for the Chair*
Thanks

2- Accept of the paper (**Effect of biodiesel on engine performance parameters : A review**)

4th International Conference on Recent Innovations in Engineering (ICRIE2023)

**OFFICIAL ACCEPTANCE LETTER**

September 25, 2023

Manuscript ID: # 20

Dear Ali A.Al-jabiri, Hyder H. Balla, Mudhaffar S. Al-zuhairy

**Congratulations!** It is my pleasure to inform you that after the blind peer review, your paper entitled **"Effect of biodiesel on engine performance parameters: A review"** has been accepted for presentation at the 4th International Conference on Recent Innovations in Engineering (ICRIE 2023) conference which will be taking place from September 13th to 14th 2023 in Duhok city, Kurdistan Region-Iraq. Accordingly, your manuscript is accepted for publication in a Special Issue in the Journal of the University of Duhok (JUD), Volume 26, Issue 2, 2023.

You are cordially invited to present your paper at the ICRIE2023 at the Conference Hall of the University of Duhok.

Thank you for considering submitting your Research with ICRIE2023. Please do not hesitate to contact us if you have any further questions.

Respectfully Yours,
Prof. Dr. James H. Haido, ICRIE2023 Chairman

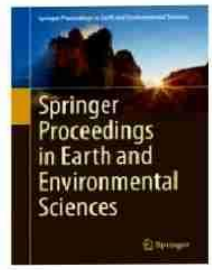
https://icrie.uod.ac/ 13-14 Sept 2023 info.icrie@uod.ac

3- Accept of the paper (Effect of biodiesel produced from sunflower oil on engine emissions characteristics)

SPRINGER NATURE

Springer PAPERTRUE Scopus

**Paper ID**: ICES2023_ 113
**Date**: 19 November 2023




## Letter of Acceptance

**Paper Title:** Effect of biodiesel produced from sunflower oil on engine emissions characteristics
**Author (s):** Ali A.Al-jabiri, Hyder H. Balla, Mudhaffar S. Al-zuhairy

Congratulations!

Based on the recommendations of the Technical Program Committee of Editorial Board Approval of (ICES_2023), we are pleased to inform you that your manuscript has been Accepted as a REGULAR paper and will be processed for Publication in the Springer Series "**Springer Proceedings in Earth and Environmental Sciences**" [Electronic ISSN: 2524-3438; Print ISSN: 2524-342X] (**Scopus Indexed**). Your paper Shall appear in the ICES_2023 Special Issue at Springer Proceedings in Earth and Environmental Sciences. Please remember that your presence at the ICES conference is required, and the camera-ready file should adhere to Springer guidelines and rules. Final acceptance is conditional upon accepting your paper in the last step.

We will encourage more quality submissions from you and your colleagues in the future.

*sincerely yours*

AlHeety

**Prof. Dr. Emad Abdulrahman Al-Heety**
Chair of Scientific Committee
Conference Editor

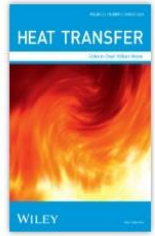
**General Series Name:** springer proceedings in earth and environmental sciences
***Series ISSN***: 2524-3438, 2524-342X
https://www.springer.com/series/16067

**CAUTION:** This Acceptance Letter is Issued by ICES Conference Editors, All Approval and other Inquiries Should be addressed to them only through the Conference official emails and approval of Editorial Board and Patrons Committee, as all Accepted Papers will be Process for Possible Publication in the Springer Proceedings in Earth and Environmental Sciences and the Final Decision upon Publish of your Paper will processed at Final camera ready, remember that All instructions of Editorial Board Members should be follow accurately and Writing Quality.

+964 781 608 9162
+964 781 916 6679
ices.uoanbar.edu.iq
ices2023@uoanbar.edu.iq

4- Publish the paper (Using renewable alternative fuel and studying their impact on the performance and emissions of compression ignition engines)

HEAT TRANSFER




Early View
Online Version of Record before inclusion in an issu

ORIGINAL ARTICLE

## Using renewable alternative fuels and studying their impact on the performance and emissions of compression ignition engines

Ali A. Al-jabiri, Hyder H. Balla, Mudhaffar S. Al-Zuhairy

First published: 19 February 2024 | https://doi.org/10.1002/htj.23029

Read the full text › PDF TOOLS SHARE



## Abstract

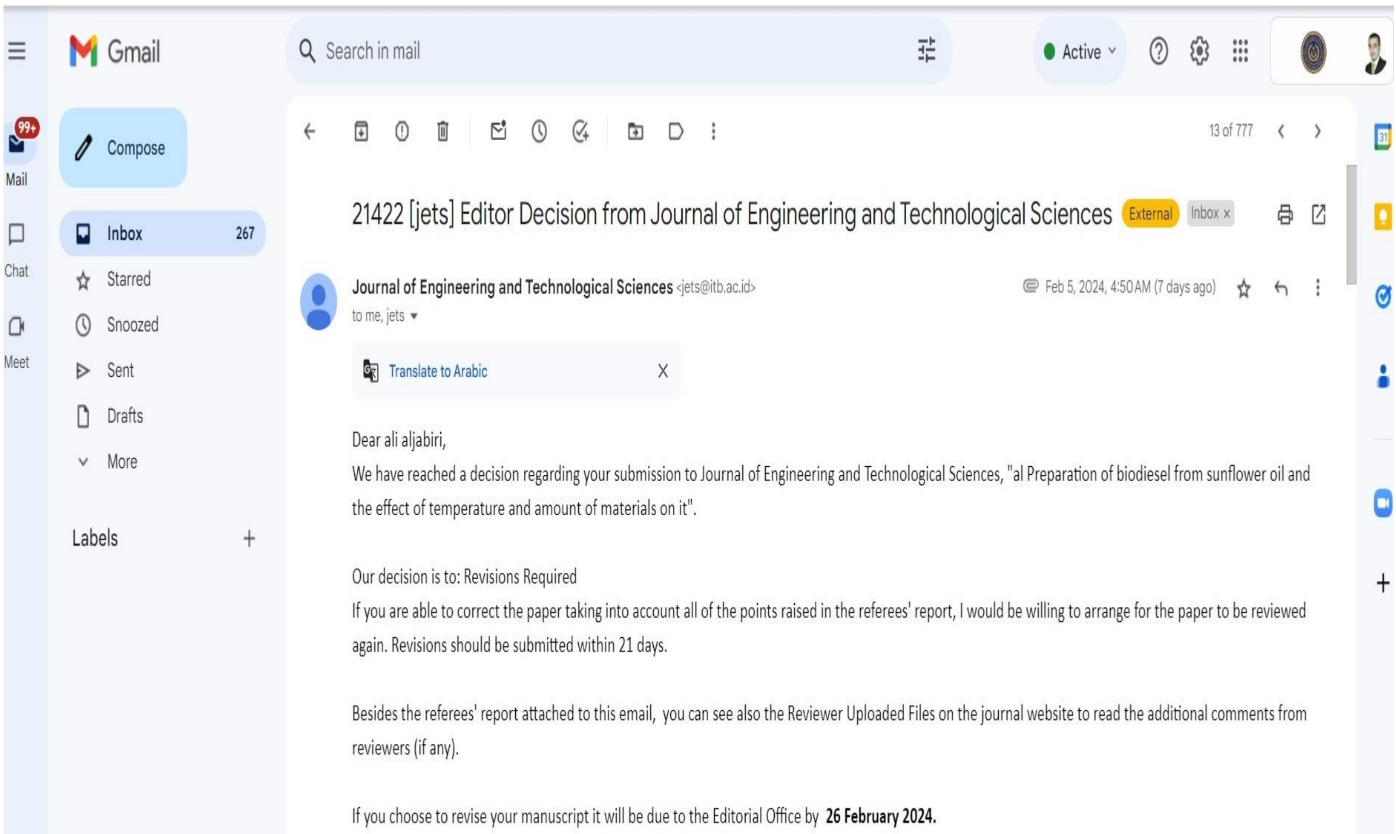
This practical study examined the effect of engine torque on engine performance and emissions. The most important parameters of engine performance are thermal efficiency, brake power (BP), and specific fuel consumption. As for exhaust emissions, the most important of which are hydrocarbons (HCs), carbon monoxide (CO), and nitrogen oxides ($NO_x$). The experiment was conducted for a single-cylinder, four-stroke compression ignition engine. Mixtures (B0, B10, B20, B30, and B40) were taken from biodiesel prepared from sunflower oil by the esterification method. The engine speed was fixed at 1700 rpm, and torque variable was from 0 to 10 N m. The results indicated a decrease in engine BP by an average of 19.5 W, a decrease in thermal efficiency by an

References Related Information

### Recommended

Fuels for Engines and the Impact of Fuel Composition on Engine Performance

5- Accept of the paper (Preparation of biodiesel from sunflower oil and the effect of temperature and amount of materials on it)



21422 [jets] Editor Decision from Journal of Engineering and Technological Sciences External Inbox

**Journal of Engineering and Technological Sciences** <jets@itb.ac.id> Feb 5, 2024, 4:50 AM (7 days ago)

to me, jets

Translate to Arabic

Dear ali aljabiri,

We have reached a decision regarding your submission to Journal of Engineering and Technological Sciences, "al Preparation of biodiesel from sunflower oil and the effect of temperature and amount of materials on it".

Our decision is to: Revisions Required

If you are able to correct the paper taking into account all of the points raised in the referees' report, I would be willing to arrange for the paper to be reviewed again. Revisions should be submitted within 21 days.

Besides the referees' report attached to this email, you can see also the Reviewer Uploaded Files on the journal website to read the additional comments from reviewers (if any).

If you choose to revise your manuscript it will be due to the Editorial Office by **26 February 2024.**

6- Submit the paper to the journal International Journal of Engine Research (Effect of Biodiesel Produced from Sunflower Oil on Engine Performance Parameters and Emission using Advanced Optimization with AMT Machine Learning and AWO Optimizer)

APPENDIXES

Appendix (B): Participation certificate

SPRINGER NATURE Springer ASIAN JOURNAL OF WATER, ENVIRONMENT AND POLLUTION Journal of CLIMATE CHANGE Scientific.Net

ICES INTERNATIONAL CONFERENCE ON ENVIRONMENT & SUSTAINABILITY

CONFERENCE PUBLICATION

CONFERENCE ORGANIZERS

Paper_ID: 113

Date: 29 November 2023

INTERNATIONAL CONFERENCE ON ENVIRONMENT & SUSTAINABILITY

NOVEMBER 29-30, 2023 ANBAR, IRAQ

CERTIFICATE OF ATTENDANCE

**This Certificate is Awarded to**

Ali A.Al-jabiri

To acknowledge attendance and active participation in the **ICES_2023** Conference proceedings and activities, this certificate is hereby issued, confirming the recipient's valuable presence at our conference.

Wishing to you the Best of Luck

**Prof. Dr. Emad Abdulrahman Al-Heety**

Scientific Committee Chair

ICES_2023 Conference

**Prof. Dr. Essmat Ramzi**

Dean of College of Science

University of Anbar

ICRIE 2023 4th INTERNATIONAL CONFERENCE ON RECENT INNOVATIONS IN ENGINEERING

University of KURDISTAN Hewlêr

# CERTIFICATE OF ORAL PRESENTATION

This is to certify that

**Dr. Ali A. Al-jabiri**

Has successfully presented a scientific paper titled

**Effect of biodiesel on engine performance parameters: A review**

in the 4th International Conference on Recent Innovations in Engineering ICRIE 2023,
University of Duhok, College of Engineering,
$13^{th}$ – $14^{th}$ September 2023.

James H. Haido

Professor Dr. James H. Haido
Chairman of the Conference & Dean of Engineering College

# APPENDIXES

## Appendix (C): Important facilitation books

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة الفرات الأوسط التقنية
المعهد التقني / النجف

بسمه تعالى

Repuplic of Iraq
Ministry of Higher Education
& SCIENTIFIC RESEARCH
Al-Furat Al-Awsat Technical University
AL -Najaf Technical Institute

العدد /
التاريخ /
Ref :
Date :

الى / شركة توزيع المنتجات النفطية / قسم السيطرة النوعية – فرع الديوانية

م / تسهيل مهمة

تحية طيبة . . . . . . .

من مبدأ التعاون بين مؤسسات التعليم العالي والبحث العلمي ومؤسسات الدولة .
يرجى تفضلكم بالموافقة على تسهيل مهمة السيد (م. علي عبد الكاظم عبد الزهرة- طالب دراسات عليا) لغرض اجراء الفحوصات للبايوديزل المنتج وتحت اشراف السيد (أ.م. د حيدر حسن عبد حسين – عميد المعهد).

شاكرين تعاونكم معنا ...مع التـقدير

أ.م. د حيدر حسن عبد حسين
العميـــد
2023/1/١٨

نسخة منه الى:
- الشعبة العلمية / ملفة العلمية.....مع الاوليات.
- ملفة الكتب الصادرة.

جمهورية العراق - النجف الاشرف - شارع نجف - مناذرة
Email:inj_int@atu.edu.iq
Email:njf_tins@yahoo.com
www.inj.atu.edu.iq

---

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة الفرات الأوسط التقنية
المعهد التقني / النجف
الشعبة العلمية

بسمه تعالى

Repuplic of Iraq
Ministry of Higher Education
& SCIENTIFIC RESEARCH
Al-Furat Al-Awsat Technical University
AL -Najaf Technical Institute

العدد /
التاريخ /
Ref :
Date :

الى / جامعة القادسية

م / تسهيل مهمة

تحية طيبة . . . . . . .

من مبدأ التعاون بين مؤسسات التعليم العالي والبحث العلمي.
يرجى تفضلكم بالموافقة على تسهيل مهمة السيد (م. علي عبد الكاظم عبد الزهرة- طالب دراسات عليا) لغرض اكمال متطلبات رسالة الماجستير وتحت اشراف السيد (أ.م. د حيدر حسن عبد حسين – عميد المعهد).

شاكرين تعاونكم معنا ...مع التـقدير

أ.م. د حيدر حسن عبد حسين
العميـــد
2023/1/١٨

نسخة منه الى:
- الشعبة العلمية / ملفة العلمية.....مع الاوليات.
- ملفة الكتب الصادرة.

جمهورية العراق - النجف الاشرف - شارع نجف - مناذرة
Email:inj_int@atu.edu.iq
Email:njf_tins@yahoo.com
www.inj.atu.edu.iq

---

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة الفرات الأوسط التقنية
المعهد التقني / النجف
الشعبة العلمية

بسمه تعالى

Repuplic of Iraq
Ministry of Higher Education
& SCIENTIFIC RESEARCH
Al-Furat Al-Awsat Technical University
AL -Najaf Technical Institute

العدد /
التاريخ /
Ref :
Date :

الى / جامعة الكوفة / كلية العلوم – قسم الكيمياء / المختبرات
م/ تسهيل مهمة

تحية طيبة . . . . . . .

من مبدأ التعاون بين مؤسسات التعليم العالي والبحث العلمي ومؤسسات الدولة .
يرجى تفضلكم بالموافقة على تسهيل مهمة الطالب (م. علي عبد الكاظم عبد الزهرة/ طالب دراسات) بالدخول الى مختبرات كليتكم لغرض تحضير وقود الديزل الحيوي.

شـــاكرين تعاونـــكم معنا
...مع التـقدير...

أ.م. د حيدر حسن عبد حسين
العميـــد
2022/12/

نسخة منه الى:
- الشعبة العلمية / ملفة تسهيل مهمة...مع الاوليات
- ملفة الكتب الصادرة.

جمهورية العراق - النجف الاشرف - شارع نجف - مناذرة
Email:inj_int@atu.edu.iq
Email:njf_tins@yahoo.com
www.inj.atu.edu.iq

---

the physical properties of diesel and biodiesel

| NO. | Fuel Properties | Unit | Diesel | Biodiesel | Standard Method |
|---|---|---|---|---|---|
| 1 | Density @15°C | Kg/m³ | 830 | 892 | ASTMD4052 |
| 2 | Flash point | °C | 68 | 175 | ASTMD 93(A) |
| 3 | Pour point | °C | (-)16 | (-)3 | ASTMD 97 |
| 4 | Cetane Index | - | 53.4 | 51.1 | ASTMD 4739 |
| 5 | Calorific Value | MJ/kg | 45.836 | 24.123 | Calculated |
| 6 | Viscosity @40°C | Pa.s | 0.002241 | 0.00482 | ASTMD 445 |

# الخلاصة

تسبب محركات الاشعال بالضغط اثار سلبية على صحة الانسان والاحتباس الحراري نتيجة انبعاثات غازت العادم التي تلوث البيئة، بالإضافة الى ارتفاع تكلفة وقود الديزل والذي قد ينفذ في يوما ما, لذلك يجب الاهتمام بانواع الوقود البديل. وخاصة لمحركات الاشعال بالضغط، في هذه الدراسة تم تحضير وقود بديل مختبريا من الزيوت النباتية وهو الديزل الحيوي بواسطة عملية الاسترة التبادلية بين الزيت النباتي وكحول الميثانل بنسبة مولية قدرها 7:1 ثم يتم غسل وتجفيف الديزل الحيوي, بعد ذلك تم حساب الخواص الفيزيائية والكيميائية ( اللزوجة والكثافة والرقم السيتاني ونقطة الوميض والمحتوى الحراري) للديزل الحيوي ومقارنتها مع القيم القياسية للديزل الحيوي. تم في هذا العمل دراسة معلمات أداء المحرك هي القدرة المكبحية و الكفاءة الحرارية المكبحية واستهلاك الوقود النوعي المكبحي والكفاءة الحجمية, فيما يخص انبعاثات العادم هي الهايدروكاربون وأول أوكسيد الكاربون وثاني أوكسيد الكاربون واوكسيد النيتروجين ودرجة حرارة غازات العادم, كانت نسب الخلط هي ( B0, B10, B20, B30, و B40 ) وكانت سرعات المحرك غير ثابتة ( 1100, 1400, 1700, و 2000 دورة في الدقيقة) وعزم دوران غير ثابت ( 0, 2.5, 5, 7.5, 10 نيوتن.متر), انخفضت القدرة المكبحية بمقدار ( 0.023, 0.0187, 0.0195, و 0.018 كيلو واط) على التوالي مقارنة بوقود الديزل الاحفوري, وانخفضت الكفاءة الحرارية المكبحية بمقدار( 0.0975%, 1.667%, 1.057,% , و 1.56%) على التوالي, بينما كان هناك ارتفاع في استهلاك الوقود النوعي المكبحي بمقدار ( 0.0655, 0.073, 0.0945, 0.0 و 0.0522 كيلو كغرام / كيلوواط . ساعة ), وانخفضت الكفاءة الحجمية بمقدار ( 1.767%, 2.767%, 2.17%, و 2.015%) على التوالي مقارنة بالديزل الاحفوري. وفيما يخص انبعاثات العادم فقد انخفض اول أوكسيد الكاربون بمقدار ( 0.028%, 0.022%, 0.020%,0.027% ) vol على التوالي مقارنة بالديزل الاحفوري, بينما ازداد اكاسيد الكاربون وانخفض الهيدروكاربون اما أوكسيد النتيروجين فقد ازداد وكذلك كانت هناك زيادة في درجات حرارة غازات العادم مقارنة بالديزل الاحفوري.

# استخدام الوقود البديل لتقليل التلوث في محركات الاحتراق الداخلي

**رسالة مقدمة الى**

**قسم هندسة تقنيات ميكانيك القوى**

**كجزء من متطلبات نيل درجة الماجستير في**

**هندسة تقنيات ميكانيك القوى/ الحراريات**


**تقدم بها**

**علي عبدالكاظم عبدالزهرة الجابري**

**ماجستير في هندسة تقنيات ميكانيك القوى**


**اشـــــــراف**

**الاستاذ الدكتور**

**حيدر حسن العبدلي**

**الأستاذ الدكتور**

**مظفر الزهيري**

**1445 هـ**

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة الفرات الاوسط التقنية
الكلية التقنية الهندسية/النجف

# استخدام الوقود البديل لتقليل التلوث في محركات الاحتراق الداخلي

علي عبدالكاظم عبدالزهرة الجابري
ماجستير في هندسة تقنيات ميكانيك القوى

1445هـ