ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

EXPERIMENTAL INVESTIGATION OF DIESEL ENGINE PERFORMANCE AND EMISSION CHARACTERISTICS OPERATED WITH PRODUCED BIODIESEL BLENDED FUELS

A MASTER'S THESIS

BY

NAKACHEW GENET

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Approval

This is to certify that the thesis prepared by **Mr. Nakachew Genet Mengistu** entitled "**Experimental Investigation of Diesel Engine Performance and Emission Characteristics Operated with Produced Biodiesel Blended Fuels"** submitted as a partial fulfillment for the Degree of Master of Science complies with the regulations of the University and meets the accepted standards with respect to originality, content, and quality.

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Declaration

I hereby declare that this MSc thesis work entitled "**Experimental Investigation of Diesel Engine Performance and Emission Characteristics Operated with Produced Biodiesel Blended Fuels**'' is my original work with the guidance of my advisor. In partial fulfillment of the requirements for the award of the Degree of Masters of Science in Automotive, Engineering is carried out from November 2020 to September 2021 under the supervision of Dr. Menelik Walle, Motor Vehicle Engineering Department Defense University College of Engineering, Ethiopia. It has not been present for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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Abstract

The globe is currently suffering a dual crisis of petroleum depletion and environmental degradation. Due to exponential population growth, excessive usage of fossil fuels, and limited reservoirs of these fuels. Another serious problem associated with the use of petroleum-based fuel is the increase in pollutant emissions. Biodiesels produced from various feedstocks have been considered as alternative fuels to use in diesel engines with minor modifications. In the present study, low-priced, locally available, and inedible feedstock-based fuels of waste cooking oil were chosen due to their negligible pricing compared to other biodiesel feedstock's, and for reducing waste-oil disposal. This research focuses on producing biodiesel from waste cooking oil by the transesterification method using NaOH as the catalyst in the Chemical Engineering Department laboratory, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia. The biodiesel was subsequently blended with diesel fuel in different blend ratios (B5-5% by volume biodiesel, B10, B15, B20, B25, B30, B35, and B40) and later the various blend fuel properties were tested in an Ethiopian petroleum supply enterprise laboratory to compared with biodiesel and biodiesel blend international standards. This study aim to evaluate and compare the influence of waste cooking oil biodiesel blends with that baseline data of commercial diesel fuel in a single-cylinder direct injection diesel engine under varying engine loading operating conditions at a constant speed of 1500rpm. The fuel characteristics results show that the new biodiesel meets international biodiesel standard characteristics and the various blend ratios tested in a diesel engine are also close to commercial diesel fuel and can be used as fuel for diesel engines. The experimental results indicate that increased biodiesel blends have lower average brake torque, brake power, and brake thermal efficiency (BTE) than diesel fuels by 16.79%, 4.08%, and 27.9% respectively with an increasing load percentage. Furthermore, when compared to baseline diesel fuel, the average brake-specific fuel consumption (BSFC) of biodiesel blends increased by 4.8 %. The result shows that the biodiesel blend's high oxygen content is critical for preventing the development of unburned hydrocarbon (HC) and carbon monoxide (CO), which minimizes dangerous gas emissions. Particle number concentration obtained by fueling the engine with B40 is the lowest as regards all the other tested fuels. The average reduction of CO and HC emissions was 52.2% and 60%, respectively. However, concerning NO_x, a moderate increase of the emission was observed when fueling the engine with biodiesel blends, the increment of NOx by 45.4% with respect to baseline diesel fuel.

Keywords: Biodiesel, Biodiesel Blend, Emission, Performance, Transesterification.

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List of Abbreviation and Acronyms

ASTM	American Society for Testing and Materials
AV	Acid value
B0	Pure diesel
B5	5 vol. % biodiesel blend with 95 vol. % diesel fuel
B10	10 vol. % biodiesel blend with 90 vol. % diesel fuel
B15	15 vol. % biodiesel blend with 85 vol. % diesel fuel
B20	20 vol. % biodiesel blend with 80 vol. % diesel fuel
B25	25 vol. % biodiesel blend with 75 vol. % diesel fuel
B30	30 vol.% biodiesel blend with 70 vol. % diesel fuel
B35	35 vol. % biodiesel blend with 65 vol. % diesel fuel
B40	40 vol. % biodiesel blend with 60 vol. % diesel fuel
B100	Pure biodiesel
BP	Brake power
BSFC	Brake specific fuel consumption
BT	Brake torque
CI	Compression ignition
CR	Compression ratio
CO	Carbon monoxide
CO_2	Carbon dioxide
EGT	Exhaust gas temperature
EN	European Standards
FAME	Fatty acid methyl ester
FFA	Free fatty acids
HC	Hydrocarbon
HCl	Hydrochloric acid

H_2SO_4	Sulfuric acid
IC	Internal combustion
KOH	Potassium hydroxide
LHV	Lower heating value
NaOH	Sodium hydroxide
NaCOH3	Sodium methoxide
NMR	Nuclear magnetic resonance
NOx	Nitrogen oxides
PM	particular matter
PPM	Parts per million
Rpm	Revolution per minute
Vol%	Volume percentage
w/w	weight relative to weight
WCO	Waste cooking oil
WCOME	Waste cooking oil methyl ester

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CHAPTER 1. INTRODUCTION

1.1. Background

Now a day energy development is major research that focuses on a sustainable energy solution with good emphasis on energy efficiency and the use of renewable energy sources. Alternative fuel resources were produced an important role in substituting the declining world supply of fossil fuels in diesel engine applications. Growing industrialization activity, urbanization, population growth, and mechanization have led to the need for more fossil fuel sources [1, 2]. The fossil fuel consumption was 42% in the year 1973 and 64.5% in 2014 years to the total fuel consumption, through the year 43.33% increased fuel consumption from last 41 years [1]. This scenario leads to serving limited fossil fuel resources and environmental degradation has been focused to find alternative fuels [3]. Alternative fuels were in advance worldwide acceptance as a partial solution for energy security as well as environments. Recently, alternative fuels are produced from a variety of naturally occurring resources and have been developed as an energy source [3–5]. Biodiesel is renewable energy, which is considered the most viable alternative fuel to substitute conventional diesel in boilers and internal combustion engines without engine modification and test to their relative performance and emission parameters. Biodiesel has a highly biodegradable fuel, non-toxic, low emissions, environment-friendly, and has cheaper costs [6–8]. Biodiesel is one of the potential alternative fuels and can be derived from a variety of feedstock's [2]. The main burden in the commercial supply of biodiesel was its production cost; hence, the production cost is different mostly depending on the type of oil uses. Biodiesel produced from edible oils may have cause inequality in the food chain and has generated the 'food vs. fuel' debate for decades [3].

Waste cooking oil (WCO) is another source of biodiesel production along with the various edible vegetable oil feedstock's [9]. WCOs were egestion without treatment, affects environmental pollution. The practice to use WCO for biodiesel production reduces the production cost of biodiesel and drops the environmental affliction [3]. Biodiesel was derived from WCO through the transesterification process with the presence of homogeneous catalysts [10, 11]. The experimental investigation of the reaction takes place methanol as alcohol and sodium hydroxide as catalyst [12]. The biodiesel physicochemical properties are similar to diesel fuel in many aspects. Engine performance and emission parameters were directly positive and it is better to substitute as diesel fuel [2, 13].

Generally, biodiesel is an alternative energy that can be substituted and used in the place of fossil fuels, which was blended with diesel fuel in a diesel engine without engine modification [3, 14]. Considered performance and emissions run with biodiesel operated in a single-cylinder four-stroke direct injection CI engine. The results were demonstrated that brake thermal efficiency (BTE), brake torque (BT) slightly decline, and brake specific fuel consumption (BSFC) slightly increase. In addition to that observed hydrocarbon (HC), carbon monoxide (CO), particular matter (PM) and exhaust gas temperature (EGT) significantly decline, and nitrogen oxide (NOx) and carbon dioxide (CO2) emission slightly increased. The performance of biodiesel was almost similar to diesel rather than a significant decrease in CO emission [1, 3, 14]. The prevalent energy disaster has adversely influenced the global economy [15]. The present study is one such effort that to investigates the possibility of using WCO as biodiesel sources in a diesel engine. Waste cooking oil (WCO) was easily available from restaurants, cafeterias, and household kitchens. Currently, researchers focus on the conversion of WCO into biodiesel [16].

The experiments are investigated that the potential feedstock of WCOs obtained from fast-food restaurants, cafeterias, and household kitchens in Addis Ababa, Ethiopia metropolis. WCO would be a potential alternative fuel source to edible oil for biodiesel production and well-researched area [18]. In the study of biodiesel production from waste cooking oil by the transesterification process was accept to convert waste cooking oil into biodiesel while using sodium hydroxide (NaOH) as a catalyst. The production of methyl ester is produced from a variety of mixed waste cooking oils as feedstock. In addition, the important fuel properties of biodiesel and its blends were characterized according to ASTM D6751and EN14214 standards specification to define the actual properties of neat biodiesel and its blend with diesel. The biodiesel characteristics need to observe that the kinematic viscosity, density, heating value, acid value, moisture content, and free fatty acid, cetane number, and flesh point.

Finally, the research has investigated the performance and emission of neat biodiesel from waste cooking oils and its blends as alternative fuels related to diesel fuel in a single-cylinder four-stroke compression ignition engine.

1.2. Problem of Statement

The development of industrialization and mechanization causes increased fossil fuel consumption and its usage. The scarcity of fossil fuel results in a widespread energy crisis, which affects the global economy, and again consumption of excessive fossil fuel, causes environmental hazards. To minimize the above-mentioned problems, researchers are searching for another alternative fuel that can maintain fuel scarcity, environmental pollution, mining cost, energy safety, economic outcome, import restriction, sustainable transportation solutions, agricultural economy, and rural employment. The petroleum sources from foreign importing fuels face a challenge with alarming high-energy security and influencing exchange crisis that affects the economic growth of mainly developing countries like Ethiopia. Significantly, treated WCO would be a potential feedstock partly substitute non-renewable fuels. In recent studies produced biodiesel from WCO as feedstock and investigates the possibility to use in a diesel engine [3, 15]. Waste cooking oil is one of the excellent sources of materials to produce biodiesels in a variety of vegetable oil feedstock. WCO disposal is one of the factors that affect water pollution, environments, and human health (i.e. risk of cardiovascular diseases, and cancer). Waste cooking oil (WCO) is easily available from restaurants, cafeterias, household kitchens, and fast foods on the street road. Currently, researchers focused on the conversion of WCO into biodiesel. The studies aimed to produce and characterize biodiesel from WCO products collected from fast-food restaurants and cafeterias with blending diesel to analyze engine performance and emissions. Therefore, WCO is important to identify the best agreement integration in terms of engine performance, reduce costs, and greenhouse gas emissions. Hence, the blend ratios are similar or close to the results of diesel engine performance and emissions, parameters operated in diesel fuel. Accordingly, used the production of biodiesel from WCO would help to solve mentioned problems the above.

1.3. Objective

1.3.1. Main Objective

This study main objective is to produce biodiesel from waste cooking oil and conduct an experimental analysis to detect the impact of biodiesel blend ratios on the diesel engine performance and emission parameters operated under varying loading conditions (0% to 80% with an increment of 20%) at a constant engine speed of 1500 rpm with a default compression ratio and fuel injection pressure.

1.3.2. Specific Objective

To attain the intended main objective of the thesis the following tasks were includes:

- Produce biodiesel from waste cooking oil by a trans-esterification method.
- Characterize physicochemical properties of the biodiesel and biodiesel-blended fuels, and compared with international standards.
- Conduct baseline experiment using pure diesel fuel under varying engine loads.
- Conduct major experiments to investigate the effect of biodiesel blend ratios on engine performance and emission parameters of a diesel engine operating under varying engine loads.
- Compare the results and recommend the best blend ratios close to diesel fuel engine performance and emission results.

1.4. Scope of the Study

The scope of this thesis is to produce biodiesel from waste cooking oil and characterizing its property, evaluate the performance and emission analysis of diesel engines. Moreover, the analysis focused on the investigation of the performance and emission of biodiesel-diesel blended for different samples (B5, B10, B15, B20, B25, B30, B35, and B40%v/v) compared with the baseline commercial petrol diesel in a diesel engine. Under the studies which concerned the evaluation of the engine performance (i.e., brake power, brake torque, brake thermal efficiency, and brake specific fuel consumption) and emission analysis are (i.e., CO, CO_2, HC, EGT, and NO_2) concerned with the variation of engine loads and at a constant engine speed.

1.5. Significance of the Study

The study can play a significant role to understand and enhance available energy management, in a compression ignition engine run by blended waste cooking oil biodiesel. It is to provide production and characterization of sustainable bio-based waste cooking oil derived from renewable sources and helps to develop waste management practices. The study has a great significance to assure that finding and produce an alternative fuel source from renewable and viable feedstock, which raw materials waste cooking oil from locally available. It helps to reduce the dependency on petroleum-based fuel sources.

It also motivates other researchers to study the area of bio-based fuels from waste materials. Another significance of the study is making our nation free of non-degradable petroleum-based biodiesel products in response to realizing alternative efficient, cost-effective, convenient, and to safe environments. Moreover, using biodiesel from waste cooking oil plays a significant role in minimizing water pollution and harmful product to our environment.

1.6. Organization of the Thesis

This thesis contains five chapters. **Chapter-1** deals with a general introduction including the statement of problem, objectives, the significance of the study, and the scope of the study. **Chapter-2** contains a literature review, summary, and gaps of the existing works of literature. **Chapter-3** described the materials and methodology of how to do and accomplish the thesis workflow. All the materials that need to be used in the workflow including the production and characterization of biodiesel are properly listed and described in this chapter. **Chapter – 4** deals with detailed results and discussion. The conclusions, recommendations, and future work of the study are mentioned in **Chapter- 5**.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

The previous researcher works indicated that biodiesel is an alternative fuel for petro-diesel in the transportation sector. In recent years, expanding of industrialization and mechanization has needed the transportation sector of powerful importance. The higher consumption of diesel fuel in these sectors increases environmental pollution, depletion of petroleum reserves, rising prices, etc. Biodiesel needs to reduce those problems and it has an advantage such as biodegradable, non-harmful, minimum sulfur content, etc. This biofuel has its drawbacks like lower calorific value, higher viscosity, higher cloud point, higher oxide of nitrogen emissions properties make biodiesel an ideal fuel for diesel engines. Prior research works showed that to reduce the drawback of biodiesel blending it with diesel result in enhanced fuel properties, show a good effect on engine performance, combustion, and exhaust emissions.

2.2. Reviews on Related Studies for Biodiesels

Now a day, increased energy consumption significantly in case of the changing lifestyles and growth of the population. Fossil fuel resources are limited through gradually provided the increasing energy demands, increased costs, and cause of serious environmental concerns. Due to this, different researchers focused on find alternative and renewable fuels, such as biodiesel production and extraction from various vegetable oils, animal fats, and waste materials.

Liang, et al.[19] investigates that biodiesel is proved to be the best replacement for diesel aspects with its significantly minimized greenhouse gas emissions, non-sulfur emissions, low toxicity, and biodegradability. The process that produced biodiesel from vegetable oil by transesterification process. To reduce bio-fuel cost, these days, WCO is used as feedstock and using as alkaline catalysts NaOH. The cost of feedstock accounted for 88% of the total estimated cost of production. Reusing of waste oil feedstock based on variables oil wastes availability locally, minimum cost, government support, and good emission to the environment to uses as a fuel. The primary raw materials were vegetable oil or animal fat. The study was concerned with the production of biodiesel but it does not go to experimental validation of biofuel to the standard baseline fuel to improve the fuel efficiency in CI engine application.

Indhumathi. et al.[20] describes that biodiesel was a potential alternative fuel for the present industrial-scale production methods the presence of biodiesel blended with petroleum diesel improves the parameter of cetane number. This is important since a high cetane number improves the quality of combustion, less noise, and greater durability of the engine.

Gokdogan, et al.[21] investigates biodiesel was produced from waste cooking oil using a catalyst sodium hydroxide (NaOH) and methanol (CH3OH) by the single-step transesterification method. Fuel blends were prepared in different volume blending ratios with diesel. The density values of WCO biodiesel and its blends were measured at the temperature of 15°C and the kinematic viscosity values of WCO and its blends were measured at the temperature of 40°C. The results showed that the density and kinematic viscosity of fuel samples increased compared to commercial diesel, and these properties decrease as increased blend ratio.

Ali, et al.[22] investigated that the viability of palm oil to biodiesel and characterized its property with various blending ratios. Test engine performance and evaluate the results according to ASTM D6751 maximum blending ratio 30% used. Furthermore, the blending ratio was not efficient there is a reduction of energy content and pour point. The results demonstrated almost similar BTE compared with diesel fuel and engine cyclic variation was low in biodiesel fuel. However, increases the cetane number and additives same waste food oils to become good engine cycle and compression ratio. Biodiesel is a mixture of mono-alkyl esters of saturated and unsaturated long-chain fatty acids with high viscosity, density, and poor cold-flow properties compared to mineral diesel fuel. Conclude that biodiesel an alternative fuel produced from different feedstock can blend with mineral diesel and be used as a fuel for diesel engines.

2.3. Recent Trends Biodiesel Production in the World vs Africa

In recent years, worldwide energy is a critical problem related to sources of fossil fuel reduction and raising environmental pollutions. Consequently, to be initiated the search for alternative fuels to sustainable energy and environment protection friendly. Biogas, alcohol, biofuels like biomass, vegetable oils, and synthetic fuels have been uses as conventional fuels while needing some sort of modification before being used.

Petrol diesel was a major part of the transportation fuel sources in the market through the years because of its availability and less price. However, currently, the world is finding alternative fuel products in case of global warming, demanding cost and climate change. Therefore, uses renewable alternative fuel to substitute fossil fuel without engine modification. There are different sources to produce biodiesel using vegetable oil, animal fats, and waste cooking oil. Biodiesel from WCO is the feedstock and it reduced food scarcity and vegetable oil of the feedstock. In addition to that, it is a better waste management resource and low price. From this information, biodiesel would be better alternative fuel demand in the world for the future [8].

The world's estimated energy prerequisite in the year 2030 shall be 50% more than it is today. On one hand, transportation is regularly dependent on petroleum fossil fuels energy and the world’s economy is being a huge amount of money donates on transportation. Consequently, energy uses from petroleum fossil fuels, which affects world economy and environments, like growth crude oil price, depletion of fossil fuel resources, global climatic change. Researchers and scientists concern to find alternative energy including solar, wind, and biodiesel. Biodiesel is sustainable, renewable nontoxic, biodegradable, clean energy to the environment, and uses similar to fossil fuel [7].

Africa continent occupied with available natural resources alternating from biodiversity to vast water bodies but challenged with food and energy crises. Prices of fuel are rapidly increasing. The researchers to finding the solution that produced biodiesel from vegetable oil will take more attention. However, the edible oil feedstock will not be supportable enough for the rising energy and food demands. In the future, it is needed for a basic sustainable feedstock for biodiesel production and commercialization from existing problems. A request is the World Bank 2008 reports (Figures 2.3.1 and 2.3.2). The reports point out that in 2030, biodiesel will signify about 60–80% transport fuel in Africa. Moreover, the edible oil resources would not be sustainable, more attention has been tried to non-edible oil and waste resources [23].

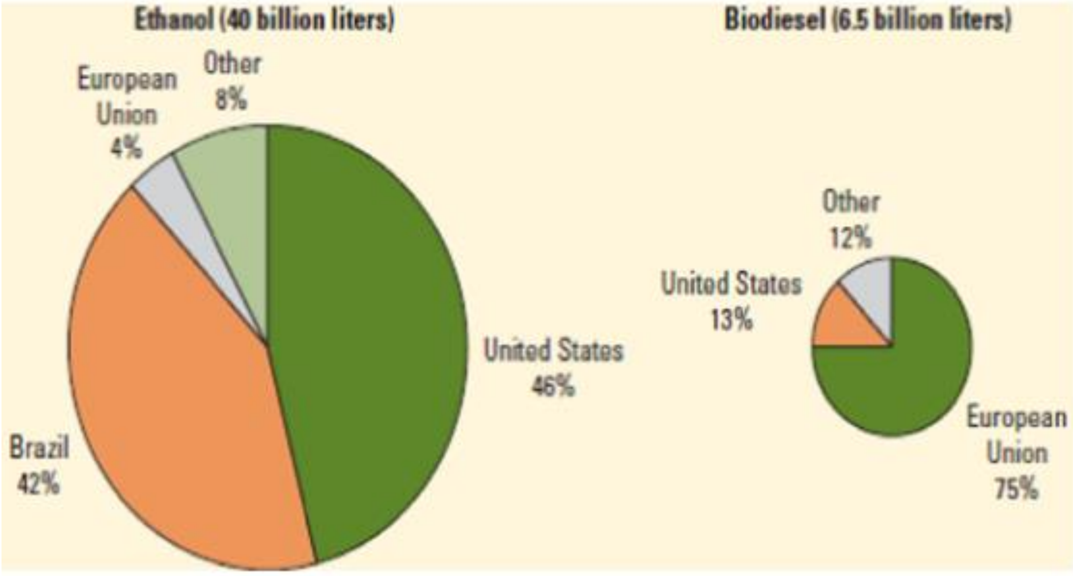

Figure 2.3.1. Origin and production volume of ethanol and biodiesel [23]

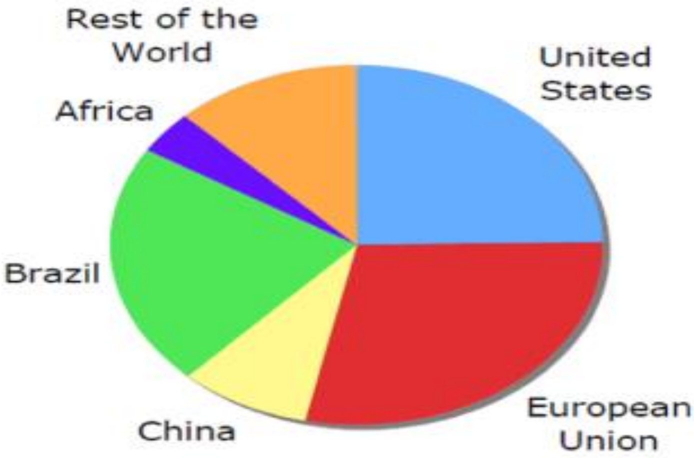

Figure 2.3.2. Expected share of global biofuel consumption in 2030 for main consumer markets [23].

2.4. Specification and Standardizations of Biodiesel

According to the American Society of Testing & Materials (ASTM) in the US standards studies cover pure biodiesel (B100) and for blending level up to 20% by volume [24]. In addition, the European standard (EN 14214) is adopted by all 31 member states of the European Committee for the standardization of biodiesel (B100) [24]. The standard ASTM D6751 describes the quality requirements and the methods of analysis used for biodiesel blended with diesel oil, applying to methyl esters as well as for ethyl esters. The ASTM and EU biodiesel property specifications with the recommended test methods are shown in table 2.4.1. As this standard was designed for neutral process and feedstock different from EN 14214 specification, some properties of ASTM D-6751 are slightly different from the European specification.

Table 2.4.1: International standard specification of pure biodiesel [24]

Property	Test method(s)	ASTM D6751	EN 14214
		Limits	Limits
Density, 15°C, kg/m^3	D4052	N/S	860–900
Kinematic viscosity, at 40°C, mm^2/s	D445	1.9-6.0	3.5–5.0
Flashpoint, °C	D93	93	120 min
Cetane number	D613	47min	51 min
Sulphur content, % mass,(ppm)	-		10max
Water content, % volume	D2709	0.05max	500 max
Oxidation stability,110°C	N/S	N/S	6.0 min
Acid value, mg KOH/g	D664	0.80max	0.50 max
Iodine value	N/S	N/S	120 max
Methanol content, % (mol/mol)	-	-	0.20 max
Free glycerol, % (mol/mol)	D6584	0.20max	0.020 max
Total glycerol, % (mol/mol)	D6584	0.240max	0.25 max
Sodium and potassium content, ppm	-	-	5.0 max

2.5. Possible Feedstock’s for Biodiesel Production

According to Saini, et al.[25] biodiesel is a biofuel produced from different raw materials, categorized into three main groups of vegetable oils (edible and non-edible), animal fats, and waste cooking oils. The algal oils are the fourth group of biodiesel raw materials recommended and increased interest with high oil productivity, however, it was required high production costs due to this limited applications.

2.5.1. Biodiesel from Animal Fats

Biodiesel produced from animal fat has been increasing around the world and it is easily biodegradable, non-toxic, renewable, and low cost to process. Alkaline catalysis was choosing at industrial plants making biodiesel because it is faster and cheaper than acid catalysis and other alternative catalysts. It can blend with fossil fuel up to 20% of biodiesel used. In addition, it decreased up to 70% raw material cost in biodiesel production [25, 26]. Biodiesel production depended on molar ratio, FFA and catalyst concentration, reaction temperature, and time to optimize an ideal transesterification process [26].

Biodiesel made from animal fats has a good ignition quality due to its high cetane number. The challenge of biodiesel production from animal fats was high FFA continents inhomogeneous base-catalyzed reaction in case of soap formation. Due to these, reason uses two-step homogenous catalysts to give high yield biodiesel [28].

2.5.2. Biodiesel from Vegetable Oil

Progress projections of biodiesels were a more massive emphasis on vegetable oils and obvious promising choices for modern energy. Currently, 95% of biodiesel production in the world was edible vegetable oils. It is easily available from local agricultural production activities, but this is a negative impact on food supply during population growth. Currently, 60% of the world population uses food crops that affect social aspects. In addition, the cost of raw materials accounted for up to 70 to 95% of the total biodiesel production cost. More over-produced biodiesel production from non-edible oil is low raw material cost. Even if the studies were investigated it is not sustainable for human consumption because of the presence of toxic compounds [29]. Edible oil resources have been social impacts and it leads attention to non-edible oil resources. It can save fossil fuel as use alternative fuel sources for sustainable biodiesel production and maintain food security. Currently, non-edible oil uses for biodiesel production in Africa is jatropha. Nevertheless, jatropha cannot single-handedly sustain biodiesel for Africa's energy security [7].

Produced biodiesel from jatropha as a promising biodiesel feedstock for Malaysia. This was accomplished by analyzing the fuel characteristics of jatropha biodiesel and its diesel mixtures. In an unmodified diesel engine, engine performance and emission characteristics of jatropha biodiesel blends (B10 and B20) and diesel fuel (B0) were investigated. Based on the experimental investigation results shows that kinematic viscosity and density were related to biodiesel jatropha biodiesel blends (B10 and B20) can be used in a diesel engine without major modification. Further, check combustion ratios and other physical and chemical properties with a standard baseline [30].

2.5.3. Biodiesel Production from Waste Cooking Oil

The widespread energy crisis has unfortunately affected the global economy. Economists suggest for many developing countries have gone uncompetitive shortage of fossil energy like Pakistan. If significantly treated WCO would be, a potential feedstock that has partly substitute non-renewable fuels [15]. This study is one such effort that investigates the possibility of using WCO in a diesel engine. Waste cooking oil is easily available in restaurants, cafeterias, and household kitchens. The present researchers focused on the conversion of WCO into biodiesel. WCO is utilized as a feedstock and requires technical treatments to increase its characteristics. [16].

WCO as a feedstock to produced biodiesel by using catalyst concentration 0.25 w/w, and alcohol to oil ratio 8.5:1 at 57.50 ◦C with 600rpm stirring speed transesterification reaction takes place. Investigates its properties, which including kinematic viscosity, lower heating value, flash point, and density of biodiesel-diesel blends, were examine using American Society for Testing and Materials (ASTM) method standards. Engine performance was evaluated and compared biodiesel blends were with diesel fuel. The average brake torque was decreased for blend biodiesel with compared diesel fuel at 3000 rpm, while average BSFC was increasing with increasing blend ratio and greater than diesel fuels. Kinematic viscosity and density of WCO were higher than original oil due to the formation of unsaturated bonds done during continuous use. This may indicate acid value, should be minimized free fatty acid before goes to in the reaction process. WCO may have high acid values were treated through the esterification process by using mineral acids such as (H_3PO_4, H_2SO_4, and HCl). Biodiesel from WCO with methanol in the reaction process was done effectively by using the transesterification process. Government was looking for alternative fuel sources to reduce the consumption of mineral fuels because a huge amount of money spending on importing mineral fuels to satisfy their energy requirements [3, 16].

Recycling part of WCO as converted to biodiesel can be decreased fuel cost and diesel fuel consumption. In the transesterification process methanol and sodium hydroxide as used mostly for biodiesel production. Because of it has gone single-stage transesterification process and it was easiest, low cost, high reaction rate, and higher yields. The maximum conversion of biodiesel in mass yields was extended up to 90.37% [31].

In conclusion, from the above researcher biodiesel production derived from WCO will be exploring as a potential resource for energy security. Biodiesel is a renewable fuel source, clean and low emission to the environment that produces from vegetable oils and animal fats. However, it has stayed reports where the cost of the raw materials is about 80% of the total biodiesel production cost [7, 15]. From this context, WCOs are a good feedstock to substitute vegetable oils for biodiesel production. WCO has an additional advantage to reduced unwanted disposal concerns in the environment. Biodiesel production from WCOs was saving 21% for crude oil and 96% for fossil energy [18]. In addition, conversion of WCO to biodiesel can be a very high product yield. Currently, the decline in fossil fuels would be solved significant problems by using renewable fuels. Waste cooking oil (WCO) would be a potential alternative to edible oil for biodiesel production and should well research area.

2.6. Methods of Biodiesel Production

Generally, four methods are uses to produce biodiesel from vegetable oils, animal fats, and waste materials. The biodiesel production methods such as direct blending, transesterification process, pyrolysis, and micro-emulsion. The alternative fuel source would be initiate to recompense the future fuel request and decrease the pollution [31, 32]. Moreover, some factors should be considered in the production of biodiesel such as property, production methodology, required equipment, production cost, etc., due to this reasons transesterification process would be used and also give a better fuel quality, high yields, and it does not need any complex special equipment [1, 2, 12, 31, 33].

2.6.1. Transesterification Process

The transesterification process was the most known for the production of biodiesels from animal fat, vegetable oil, or waste cooking oil. The reaction takes place oil reacting with alcohol in hydrolysis reaction with the presence of a base catalyst to produce biodiesel and glycerol as by-products [8, 34]. Waste cooking oils were affected human health and the environment. These studies were concerned with waste cooking oil as a feedstock, uses to convert biodiesel synthesis, and characterized its property. The transesterification reaction method uses the oils that react with methanol in the presence of homogenous base catalysts and with a required reaction time. Characterization was doing on the biodiesel physicochemical property such as density, number of free fatty acid, viscosity, calorific value, flash point, and acid number. The analysis result shows that obtained from biodiesel was almost similar to diesel fuel after the transesterification process [36]. The transesterification reaction uses a base medium as a catalyst NaOH/KOH to produced biodiesel from WCO with methanol as alcohol at 60°C [12, 24, 35, 36]. It also investigates the performance of biodiesel fuels on a diesel engine.

Evaluating diverse vegetable oils have to obtain alternative fuels, increasing reaction yields, reducing production costs, and reducing environmental pollution to become a global strategy trend for in the future. Transesterification, also known as alcoholysis, is a reversible multistep reaction in which triglycerides are transformed to diglycerides, then mono-glycerides, and lastly biodiesel and glycerol (by-product). This is a chemical process that converts carboxylic acid esters into other carboxylic acid esters. During the process, the exchange of the 'R' group of an ester with 'R' of alcohol takes place in presence of a catalyst resulting in an ester with a larger alkoxy group (starting from methyl/ ethyl esters) [13].

Alkali catalyzed transesterification is much faster than the acid-catalyzed reaction. A catalyst was used to improve the reaction rate and yield. The transesterification reaction of vegetable oil with alcohol was shown in the equation.

$$\begin{array}{llcll} CH_2OOCR^1 & & & R^1COOCH_3 & CH_2OH \\ | & & & & | \\ CHOOCR^2 & + 3CH_3OH & \overset{\text{Catalyst}}{\rightleftharpoons} & R^2COOCH_3 \quad + & CHOH \\ | & & & & | \\ CH_2OOCR^3 & & & R^3COOCH_3 & CH_2OH \\ & & & & \\ \text{Triglyceride} & \text{Methanol} & & \text{Biodiesel} & \text{Glycerol} \end{array} \tag{2.1}$$

Where, R is the alkyl group of triglyceride components (palmitic, stearic, oleic, and linoleic). To shift the transesterification reaction to the forward direction, it is necessary to use a large excess of alcohol or remove continuously one of the products from the reaction mixture.

Transesterification using basic catalyst [12, 24] the alkali catalyzed transesterification process was used to make biodiesel from waste cooking oil. The easiest, cheapest, and most yielding process was alkali catalyzed transesterification. Its reactions take place in the presence of an alkali catalyst and include alcohol and oil. This studies methanol as an alcohol mixture, shake with sodium hydroxide, and blend to heating oil at constant temperature reaction in this transesterification process to yield methyl ester and glycerol. Homogeneous alkaline catalysts have been used in this process and methanol is suitable for the transesterification process [15].

2.7. Factors Affecting the Yield of Biodiesel

The number of considerations that impact the biodiesel production process such as, amount and type of catalyst, fatty content, reaction time, reaction temperature, the molar ratio of oil to alcohol, and stirred speed influenced the purification process and reduced biodiesel yields [7]. As a result of their low prices, higher reaction speeds, and higher yields, sodium hydroxide (NaOH) and methanol (CH3OH) is commonly utilized as base catalysts in the single-stage transesterification (SST) process [31].

The relation below was used to calculate the % oil yield;

$$\text{\% Oil yeild} = \frac{volume\ of\ produced\ biodiesel}{volume\ of\ sample\ oil\ used} * 100 \quad (2)$$

Waste cooking oil as raw material with an FFA value of low can be converted into biodiesel using the transesterification method directly without going through the esterification process [38]. The drawbacks of the (WCO) to produced biodiesel as feedstock was high free fatty acid (FFA), water contents, and other solid impurities. Uses hydrolysis to remove water content in sample oil and the content of high FFA value gives to saponification. With the presence of high FFA and water content in sample oil, the reaction results have been given low biodiesel yields. To minimize the FFA amount in the oil was uses such as ion exchange resins, esterification with sodium salephit and sulphuric acid techniques, finally, distillation and filtration process followed [39].

2.7.1. The Effect of Oil to Alcohol Molar Ratio

In the transesterification reaction, the alcohol to oil molar ratio was the major factor affecting biodiesel production yield. For the transesterification reaction to proceed and prevent the reversible reaction, an excess quantity of alcohol is necessary. Studies on biodiesel production were used various molar ratios overviews such as methanol to oil from 6: 1 up to 48: 1. As result molar ratios at 6: 1 have a good value and maximum biodiesel yield, while at 12:1 molar ratios were recorded minimum biodiesel yields were compared to maximum, and decline biodiesel yields were when molar ratio greater than 12:1 methanol to oil. This shows that the reversibility behavior of the transesterification reaction [34]. Biodiesel yield was maximum and recommended for further experiments would be chosen oil methanol ratio of 1:6 [15]. The effects of methanol to oil molar ratios were good on the biodiesel refining process and for characterization. Because many reviewers use methanol in transesterification reactions due to its easy recovery, low cost, and short-chain molecular size relatively compared to ethanol [12].

2.7.2. The Effect of Catalyst

The catalyst must be balanced with oils in a conversion rate in the reactions to produce alternative fuels. Catalysts are one factor to influences the conversion rate in the reaction. Sodium methoxide (CH3ONa) catalyst was used to produce biodiesel in induction heating technology. In the making biodiesel process, which was done by induction technology the weight ratio of oil with methoxide concentration was 1:6 with temperature and 60°C and 150 minutes of reaction time for each time running. The variation of catalyst concentrations is to decide the use of best concentrations amounts to obtain good conversion results and quality standards. Usually use 1% catalyst concentrations by weight of oil will produce a relatively high yield of biodiesel 86.95% with good product quality [40].

2.7.3. The Effect of Reaction Time

The effect of reaction time in biodiesel production yields at different time intervals, 90 min,120min, and 150min at constant temperature supply was investigated constant oil to methanol 5:1 ratios with catalyst contain 0.13g can be argued that the conversion rate of fatty acid esters increases with reaction time. When the alcohol is mixed and dispersed into the oil, the reaction is slow at first, but after some time, it accelerates rapidly. When the reaction time was prolonged to 120 minutes, the yield should reach its maximum. An excess reaction time of 150 minutes or more, on the other hand, will result in a lower product yield due to the reverse trans-esterification process, which results in a loss of esters as well as additional fatty acids forming soaps [24, 40].

2.7.4. The Effect of Reaction Temperature

Investigated the effect of reaction temperature that affects biodiesel production on the mass transfer. It was observed when a reaction temperature increases, as result increased oil conversion and biodiesel mass production. However, if a reaction temperature were above 65°C, the yield of biodiesel would be decreased. It was different reviews were shown that mass biodiesel production was highly dependent on reaction temperatures. Moreover, biodiesel production in the transesterification reaction to evaluate mass transfer production resistance could be optimized for mechanical agitation speed and reaction temperature [42].

2.7.5. The Stirrer Speed

Continuous production processes and quality biodiesel supply used continuous stirred-speed considering oil changes in the feed stream during the continuous operation of the reactor. Based on reaction there are reactor variables that affect biodiesel, ester concentration (molarity), and reaction mixture temperature every after each feed oil change [43].

2.8. Properties of Biodiesel

2.8.1. Density

Fuel density is an important property for alternative fuels, which influence the atomization and combustion system on the engine. Fuel density affects fuel performance. Earlier reported the density ranges of 0.91 – 0.92 (g/cm^3) for WCO. Biodiesel from treated WCO with the alkali (NaOH) as the catalyst used would have higher fuel performance because of its lower density of 0.88(g/cm^3) [44].

2.8.2. Viscosity

The oil viscosity is usually observed as thickness or resistance to running. As reported, the viscosity of vegetable oils was influencing in the main by fatty acid composition and quantity of contaminants [45]. The main problem associated with the use of WCOs is their viscosity, which has to be, decreased down to make them use the engine in cold weather conditions [5]. To produced biodiesel from WCO and get, lower kinematic viscosity was optimum reaction parameters and used methyl alcohol as alcohol and sodium hydroxide as a catalyst in the transesterification process. Kinematic viscosity of WCO biodiesel was affected by different parameters were investigated, that as reaction temperature, the molar ratio of alcohol with oil, catalyst concentration, and reaction time [46].

2.8.3. Heating Value (HV)

Heating value is a factor of fuel parameter that affects both the thermal efficiency and combustion characteristics of an engine. Heating values also measure energy content in the fuel. It is the heat of combustion during fuel burned completely in combustion chamber released thermal energy per unit quantity of fuel. Generally, biodiesels were almost 10% lower mass-energy content (MJ/kg) than petroleum diesel due to high oxygen content. According to EN 14213, the heating value of biodiesel was recommended at least 35 MJ/kg [47].

2.8.4. Cetane Number (CN)

The cetane number (CN) is a measure of a fuel's auto-ignition quality in a combustion reaction. Higher cetane numbers show that shorter ignition times during injection of fuel. Higher numbers have been related to high compression rate and less engine roughness. Diesel fuel usually has a cetane rating between 45 and 55 while biodiesel fuel is 50 to 60. Due to this cetane number was the basic parameter of engine performance that affect the rate of ignition quality. Fuels have low cetane numbers, which is, indicates difficulty in starting, knocking, and exhaust smoke. Moreover, recommended better operating diesel engines fuels will have cetane numbers greater than 50. Biodiesels have a higher cetane number than diesel fuel because of their higher oxygen content. Cetane number of fuels specifies the degree of its ignition feature for CI engines. WCOs have high cetane ranges, which indicated that the biodiesel derived from WCO was good combustion since ASTM of 47 min was the standard. A high cetane range of fuel indicates great compression ignition and running engine [44].

2.8.5. Flash Point

The flashpoint of fuel oil is a measure of fuel flammability at maximum temperature and which indicates to be stored, handled, and transport safely. If the flashpoint is, too low it causes the fuel to be subject to flashing and possible continued ignition and explosion. All the biodiesel fuels have a higher flash point than conventional diesel fuel, which represents that biodiesel, is safer for transportation and storage purposes. Despite its importance from a safety standpoint, the flashpoint of the fuel is of no significance to its performance in an engine. The auto-ignition temperature was not generally affected by fuel injection and combustion performance by variations in the flashpoint. The standard limit of the flashpoint for biodiesel minimum value is 130^{o}C. The flashpoint of biodiesel has been determined according to ASTM D 93 using a Pensky-Martens closed-cup tester [47].

2.8.6. Acid Value

Acid values are a measure of the amount of free fatty acids and were calculated based on the molecular weight of fatty acids or a mixture of fatty acids. The number of acids neutralized with a milligram of catalysts (NaOH/ KOH) needed to free acids in one gram of biodiesel. Acid values are high level it indicates that the free fatty acids could be high from oil hydrolysis and lower oil quality. According to hydrolysis reaction, oil or fat was converted into free fatty acids and glycerol. To produced biodiesel from used cooking oil decreased acid number that indicates that little free fatty acids. A high number of acid values or free fatty acids in biodiesel was difficult to use because it is corrosive to the engine. Therefore, the lower the acid number indicates the better biodiesel quality. The results have shown an optimum acid number 0.2589 mg-KOH/g at 65°C with a reaction time of 75 minutes [48].

2.9. Engine Performance and Emission Parameter

The biodiesel yield depends upon various parameters like molar ratio, reaction time and temperature, agitation speed, and catalyst type in the transesterification process. Moreover, the result of this biodiesel is used to evaluate engine performance and emission in CI engine blends with diesel. The result investigates biodiesel blended fuel was reduced significantly HC and CO emissions and slight increase NOx. Tested pure biodiesel (B100) shows high BSFC (4.2%), low BTE 3.6% and lower BP 10.8% than petrol-diesel. The widespread energy crisis has unfortunately affected the global economy. Many developing countries have gone uncompetitive shortage of fossil energy. If significantly treated WCO would be, a potential feedstock that has partly substitute non-renewable fuels [15]. All fuel experiments were conducted on a CI engine that runs at a constant speed of 1500 rpm with a 200 bar injection pressure, compression ratios of 15:1 and 17.5, and various engine loads. Brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and emissions metrics including carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NOx), and smoke that fluctuate with engine load are among the performance parameters. Demonstrate engine performance and emission metrics such as CO, HC, and NO_X on different biodiesel blends, demonstrating that biodiesel produced from WCO employing a homogeneous catalyst is suitable for use as diesel fuel blends and emits less than petro-diesel [49].

The performance and emission characteristics of a single-cylinder direct injection, variable compression ratio diesel engine powered with WCO biodiesel, and homogeneous catalysts were investigated. In comparison to normal diesel, the fuel parameters of the manufactured biodiesel were tested, including hating value, kinematic viscosity, and density. Produced biodiesel and its blend properties were examined and comparable at the different ratios with diesel oil property and ASTM biodiesel standards. Brake thermal efficiency is directly proportional to compression ratio, increasing compression ratios increases brake thermal efficiency. The prepared blend of biodiesel–diesel in volume percentages B10, B20, and B30. The engine performance and emission were examined by experimental analysis within a change of engine loads from zero loads to full loads. WCO had lower BTE than commercial diesel however, BSFC had higher than diesel fuel. And also exhaust gas temperatures (EGT), CO_2, and NOx emissions were recorded higher than diesel, while smoke opacity, CO, and HC emissions of biodiesel blends from WCO were lower than commercial diesel fuel [17].

Biodiesel derived from WCO was synthesized by using various catalysts pyrolysis process. The effect of variation in the catalyst concentration and catalyst type on biodiesel yields and pyrolysis temperature range was investigated. The result shows that sodium hydroxide (NaOH) was more effective than potassium hydroxide (KOH) as catalysts and the highest yield of around 70wt% was recorded for NaOH 1wt% concentration. NaOH catalysts were a significantly lower pyrolysis temperature range and energy consumption than KOH. Synthesized biodiesel was observed relatively similar physical properties and caloric value compared with diesel. At a higher load above 50%, BTE and BSFC were observed to be worse. Lower HC emission observed under 40% biodiesel-diesel blend ratios. CO emissions were also decreased with increasing biodiesel blend and engine load [50].

The engine performance and emissions have to predict the behavior of diesel-biodiesel blends in CI engines. B20 blends were used for experimental analysis along the entire combustion process. When compared to diesel fuel, the B20 mix performed better in engine tests. The average value of B20 showed increases in the power of 1.2%, the torque of 1.0%, and the thermal efficiency of 1.2%. In terms of soot emissions, B20 is 8.9% less polluting than diesel. These authors provide the optimal alternative for a diesel-biodiesel blend fuel's combustion emission results [51].

The emission of hydrocarbons (HC) decreased with increasing the concentration of biodiesel blends, which represents cleaner and complete combustion of the fuel. The smoke opacity of diesel, biodiesel and its blends are significantly higher at zero and part load conditions but as the load increases to a maximum level, smoke opacity is reduced effectively [52].

CHAPTER 3. MATERIALS AND METHODS

3.1. Materials

The material used for biodiesel production, synthesis, and biodiesel blends from waste cooking oil feedstock. Biodiesels derived from waste cooking vegetable oils and materials would be found from local fast-food restaurants, cafeterias, hotels, straight roads, and other commercial food establishments. For this work, waste-cooking oils were collected mixed waste oils from Ceyian City Hotel in Addis Ababa, Ethiopia, and some other restaurants, straight roads, and cafes. And also mineral diesel and chemicals were purchased from local markets [53]. Besides, a different chemical that has been used during the experimental analysis of the production of biodiesel from waste cooking oils were used most of the analytical grade chemicals: sodium hydroxide (98%), laboratory chemical methanol analytical grade (99%), isopropyl alcohol analytical grade 99%min, sodium sulphate analytical grade 99.5%, 1% solution phenolphthalein, distilled water.

3.2. Methodology

Reviewing literature in identifying the related areas of knowledge to understand how others have approached. The experimental data were collected, organized, and analyzed appropriately from various sources of WCOs. Reasoning out in each consequence in experimental analysis and testing in different parameters the implication of hypotheses with the suggestion of result confirmation or rejection. In addition, it concludes and generates an overview due to the given results. There are many methods available for the production of biodiesel from vegetable oils and animal fats. Generally, four methods have been identified to produced biodiesel from vegetable oils to enable their use in common diesel engines without operational problems: i) direct/blending with petro-diesel, ii) pyrolysis, iii) micro emulsification (co-solvent blending), and iv) transesterification. However, the transesterification reaction gives suitable results, and it leads to the products commonly known as biodiesel or alkyl esters of oils and fats [16, 31]. It would have produced and distilled used cooking oil during the transesterification process. Investigate the physicochemical properties of the produced biodiesel and blended biodiesel fuel were compare to the ASTM standards. The production of biodiesel was tested on a single-cylinder four-stroke direct-injection engine to measure its performance and emission characteristics.

3.2.1. Experimental Setup and Procedure

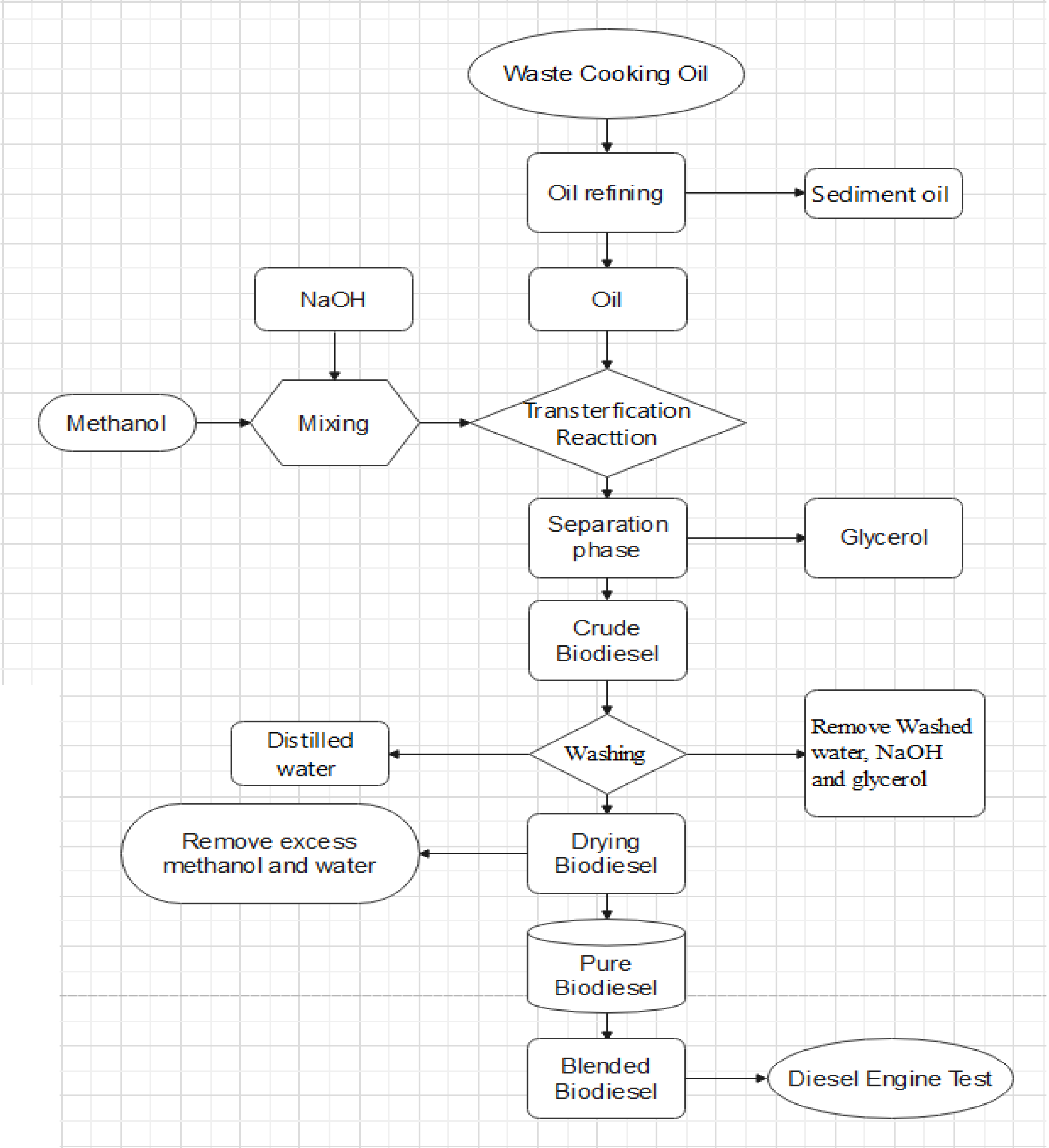

Figure 3.2.1. Methodology charts to the experiment

3.2.2. Production of Biodiesel from Waste Cooking Oil

Biodiesel is an alternative fuel made from plant or animal fats. Waste cooking oil (WCO) is a vegetable oil that has been used in the preparation of food but is no longer suitable for use in a food process.

3.2.2.1. Collection and Filtration of the Waste Cooking Oil

The waste cooking oil samples were collected from restaurants and fast-food joints in Addis Ababa, Ethiopia. Any solid particles in WCO were first removed using a vacuum pump and filter cloth for the per filtration process. Secondly, the filtered WCO was heated at 100 ◦C for 1h to remove the moisture content, followed by the cooling process riffing by using filter papers of size 80 mm diameters, funnel and then stored in airtight plastic containers (away from sunlight) until needed for analysis. Raw materials used cooking oil refer to the used vegetable oil obtained from waste cooking food, and major equipment was uses for production and characterizations shows in table 3.2.1. Normally sodium hydroxide (NaOH) catalysts in milligrams were used for the process. Excess of catalyst results gave more soapy formation and less result of biodiesel [16, 54]. Therefore, from the previous related researches, take the composition of the optimum base with alcohol value to get required biodiesels production.

Table 3.2.1: The equipment has required for the production of biodiesel

Equipment's	**Purpose**
Oil filtration cloth and paper	To separate the fine solid particles from oil
Vacuum pump	To absorb or suck oil into a continuer
Neck reactor vessel	Transesterification reaction takes place under the heating process
Condenser	Reducing vapors of methanol during the reaction
Magnetic stirrer(bar)	In a mixture reaction a given rpm to mixed
Beaker different size	Collect, mix and measure different oil samples
Digital balance	To measure NaOH in gram's
Hot plate	To heat oil and mixture reaction
Separation funnel	To settling biodiesel
Temperature sensor	Sensing reaction temperature
Viscometer	To measured viscosity
Hydrometer	To measured density
Bomb calorimeter	Heating value measured
Bruker	To measure NMR analysis
Single-cylinder CI engine	To test engine performance
Exhaust gas analyzer	To measure emission gases

3.2.2.2. Raw Material Preparation

Collected waste cooking oil has been solid particles of fast foods and other unwanted materials removed by purifying filter papers and cloth to obtain the pure waste cooking oil. The waste cooking oil was packed in a plastic container as shown in figure 3.2.2.

Figure 3.2.2. Waste cooking oil sample

3.2.2.3. Filtering the Oil

pour used cooking oil into a large clean cooking pot or large beaker and heated at 65 ^{o}c - 75^{o}c by an electric hot plate to do oil easily pour and filter into another container by using a vacuum pump and filter paper for filtration is shown in figure 3.2.3. A thermometer was used to sense the temperature. Do not use a gas burner for this or any other stage of the biodiesel creation process [1].

Figure 3.2.3. Waste cooking oil filtration

3.2.2.4. Heating the Oil

The waste cooking oil (UCO) is heated up to 65°C -80°C for 60 minutes in an electric hot plate [1], shown in figure 3.2.4 to avoid impurities and moisture content, followed by the cooling process before goes to transesterification process.

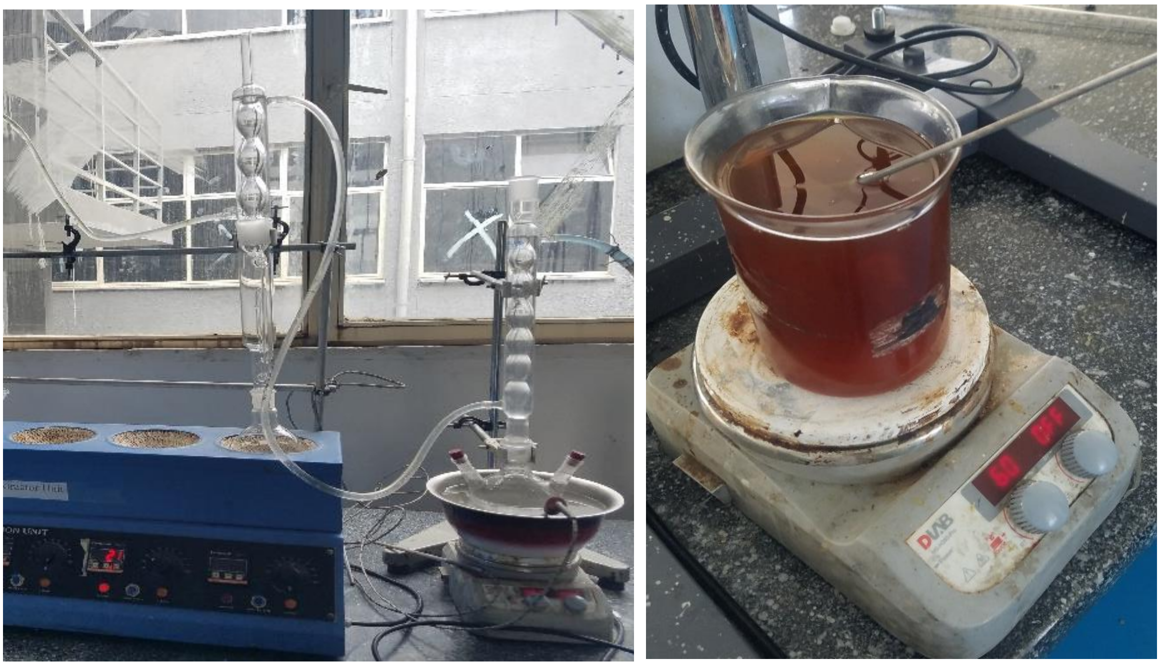

Figure 3.2.4. Heating oil

3.2.2.5. Titrate Free Fatty Acid of WCO

Check free fatty acid value before proceeding with transesterification reaction with base catalyst first calculate a free fatty acid value in waste cooking oil. The presence of FFA was widely considered as a limiting factor in the oil conversion, because of the tendency to the catalyst consumption and soap formation. The FFA contents greater than 1%w/w were caused by soap formations and difficulty in the separation of products, due to this, low biodiesel product yields were obtained [25]. In figure 3.2.5 shows, using a simple method called "Isopropyl Alcohol Method". Simply add 1g of WCO with 10ml of isopropyl alcohol and 3-5 drops of phenolphthalein indicator mix with 4g or 0.1N NaOH solution that dissolved with 1L of distilled water. The solution is poured into the burette and titrate a mixture until the pale pink color the last longing for 30 sec appears. At 0.4ml solution down that a mixture of isopropyl alcohol with oil to give pink color end that is acid value. It was very simple and more reliable. This method helps in giving oil's acid value directly and FFA through a simple relation as shown in table 3.2.2.

Table 3.2.2: Titration results

Trials	NaOH (g)	WCO (ml)	NaOH solution or titration volume in(ml)	Colour change
1	4	1	0.4	Pink
2	4	1	0.6	pink
3	4	1	0.8	pink
Average value			0.6	

The acid value WCO is the calculated volume of titration solution used*normality*molecular weight of NaOH divided by the weight of sample in grams. The average value of volume titration solution was 0.6 and the FFA is 1.2%.

$$\text{Acid value } = \frac{NaOH\ Solution\ in\ ml * N * 40}{Mass\ of\ oil} \tag{3.1}$$

Where, N= normality of NaOH, (i.e., 0.1)

$$\text{FFA \% = Acid Value/2} \tag{3.2}$$

Figure 3.2.5. Titration Processes

3.2.2.6. Density of WCO

Density was measured under ASTM D 4052 standard test method. Relative density API gravity (Specific gravity) of the liquid petroleum and crude petroleum products by hydrometer method [55, 56]. The sample WCO was homogenized by agitation before the measurement. The observed or measured specific gravity and density at ambient temperature were correct to 15 °C (in g/mL) from the conversion [57]. In table 3.2.4, it is shown the measured value of WCO density.

3.2.2.7. Kinematic Viscosity @ 40°C

The kinematic viscosity of the sample was determined using ASTM D 445, the standard test method for kinematic viscosity of transparent and opaque liquids ASTM D 445 [11]. In this test method, after a sample was full in a beaker and the viscometer sensors insert in filled oil, the time was measured for a fixed volume of the sample and display inside the viscometer at a temperature of 40°C is shown in figure 3.2.6. Then, the kinetic viscosity was calculated as the product of the measured flow time in seconds and the calibration constant of the viscometer [48]. The result is shown in table 3.2.4.

Figure 3.2.6. Viscosity measurement

3.2.2.8. Transesterification Reaction using Alkali Catalyst

The transesterification reaction is the most widely utilized biodiesel synthesis method [16, 40]. The reaction of a triglyceride found in waste oil with methanol in the presence of an alkaline catalyst yields fatty acid methyl esters and glycerol. Sodium hydroxides as a base-catalyzed transesterification process are used normally for biodiesel production because, sodium hydroxides are more effective and reactive [12, 33, 35]. The free fatty acid (FFA) level of a WCO oil was just 1.55% (less than 2%), so it doesn't need an esterification process to convert FFA into methyl ester [6]. The oil was processed by transesterification reaction directly to produce biodiesel. The biodiesel production process by transesterification reaction was make using three main components those are vegetable waste oil, alcohol (methanol), and a base catalyst (NaOH) have been used in the laboratory experiments. As shown in figure 3.2.7 1000ml three-neck flask reactor equipped with a magnetic stirrer, electric thermostat, and condenser was used in all experimental tests. The reactor was connected to an oil bath heated with an electric thermostat, which was capable of controlling the temperature. The procedures for biodiesel production by transesterification reaction were heating

500ml oil in a three-neck flask temperature range from 55- 65°C and then adding the methanol and sodium hydroxide solution with 600rpm agitator speed were used to mix the solvents and it became dark in color. This was then heated to a constant temperature of about 60°C for 90 minutes [3]. Most commercial transesterification reactions are conducted with alkaline catalysts [16, 31]. This is due to the faster transesterification reaction and partly to the fact that alkaline catalysts were less corrosive to industrial equipment than acidic catalysts. The generated biodiesels were let to sit for at least 8 hours after the transesterification process and any methanol evaporation [31, 57]. In table, 3.2.3 shows the composition mixture of the biodiesel samples (A, B, C, D, and E). Mixing of the methanol and the catalyst in a 500ml beaker using the mixing ratio of methanol and catalyst concentration respectively. A quantity of methanol was poured into a beaker and the sodium hydroxide pellet was place in the weight balance to get exactly the weight and mix with methanol and stirred manually until the catalyst completely dissolved in methanol. The methanol and sodium hydroxide solution were poured into the warm waste cooking oil in a 1000 ml three-neck flask and stirred vigorously using a magnetic stirrer at 600 rpm for 90 minutes.

Table 3.2.3: Simple composition

S.NO	Samples	UCO (ml)	Methanol (ml)	NaOH grams	Time (minutes)	Temperature (°C)	Glycerol (ml)	Biodiesel (ml)
1	A	500	124	3.56	90	60	174	450
2	B	500	110	3.4	75	60	170	440
3	C	500	100	3.1	90	60	180	420
4	D	600	131	4.15	120	60	231	500
5	E	500	110	3.4	90	60	170	440

Figure 3.2.7. Transesterification process

3.2.2.9. Separate Biodiesel

The mixture was allowed to settle for 8 - 24 hours in a separating funnel [59]. After settling in the separations processes the top layer was biodiesel mainly composed of fatty acid methyl esters and the bottom layer (i.e. glycerol, salts, excess methanol, soap, and other residual) were separate is shown in figure 3.2.8.

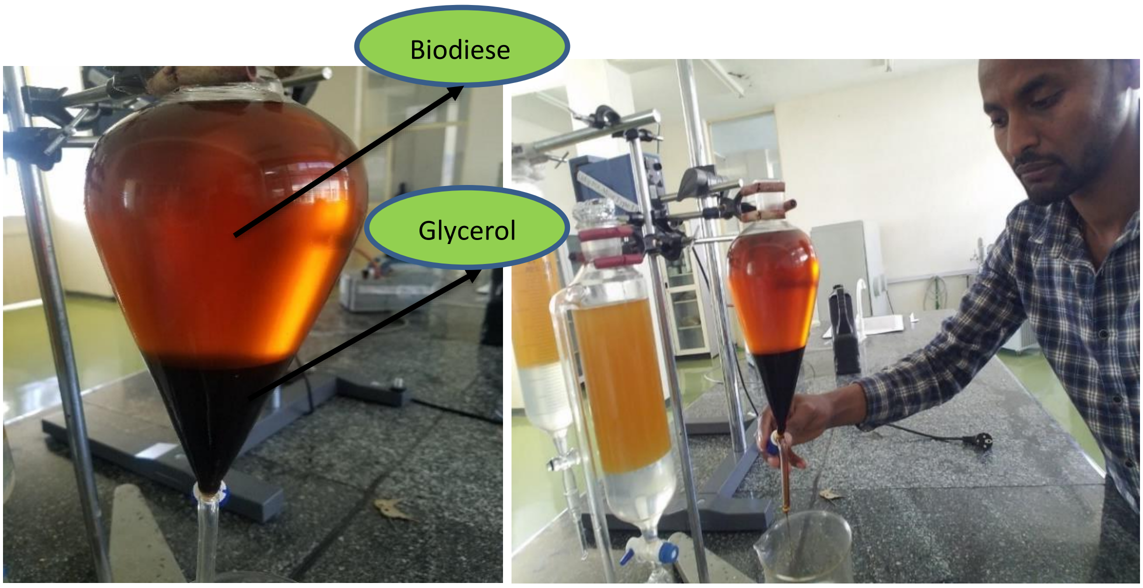

Figure 3.2.8. Separation biodiesel process

3.2.2.10. Washing and Drying Biodiesel

The washing and drying process after phase separation was at the top layer methyl ester (biodiesel) wash and removed glycerol or unwanted material for each sample production. The reduced excess amount of catalyst and other impurities present was wash by using warm distilled water at 60°C after the separation process is shown in figures 3.2.9 (a &b). The mixture was different in density and allowed to settle under gravity for 6–8hr in a separating funnel. The lower layer consists of impurities that drained out it. Biodiesel was washed by the warm distilled water, the process continuously for each sample biodiesel production, and drained washed water after a couple of hours settled. Once removed from the glycerol, the biodiesel was cleaned by gently washing it with warm water to remove any remaining catalysts or soaps, which degraded the biodiesel's quality. This technique produces a clear amber-yellow liquid with a viscosity similar to that of petro-diesel. In some systems, the biodiesel is further distilled to eliminate minor quantities of color bodies, resulting in colorless biodiesel [31, 57]. In figure, 3.2.10 shows the washed sample biodiesel was dry by placing it on a hot plate (oven) to evaporate the excess water. Finally, the quantity of biodiesel was a measure, collected in the sample holder, and recorded for each sample runs.

Figure 3.2.9. (a). washing biodiesel (b). Washed biodiesel

Figure 3.2.10. Drying biodiesel and packed

3.2.2.11. Biodiesel Yield

The biodiesel yield (% V/V) after the transesterification processes were washed and dried biodiesel and calculated relative amount of volume to used waste cooking oil [12, 16, 59].

$$\text{Biodiesel yield} = \frac{Volume\ of\ Biodiesel\ Produced}{Volume\ of\ Oil\ Used} * 100 \qquad (3.3)$$

3.2.3. Characterization of Biodiesel

The production of biodiesels from waste cooking oil was produced by using a base-catalyzed transesterification reaction and characterized physicochemical properties. The characterized physical and chemical properties were density, kinematic viscosity, lower heating value, flash point, cetane number, and free fatty acid content. Those properties were investigated and analysis biodiesel from waste cooking oil feedstock.

3.2.3.1. Determination of Density

The air-fuel ratio and energy content of the air-fuel mixture largely depend on fuel density within the combustion chamber of a diesel engine [36]. In general, the density of biodiesel is slightly higher than petro-diesel and it was augmented by increasing biodiesel percentage in blends [14, 35]. Table 4.1 shows density variations with blend percentage variations. It was getting those biodiesels from waste cooking oils having a higher density of 0.8790 g/L at 15°C and the density of diesel is 0.844 g/L at 15°C ASTM D4052 test method. In addition, the density of biodiesels has 0.8756 g/L at 20°C the same trend of decreased diesel density 0.840 g/L at 20°C. Moreover, increasing the density of biodiesel blends in percentage (0.20%, 0.41%, 0.63%, 0.84%, 1.02%, 1.22%, 1.42%, 1.63%and 3.98% at B5, B10, B15, B20, B25, B30, B35, B40 and B100 blend percentage respectively. Waste cooking oil density of biodiesel varies slightly with the increasing biodiesel percentage in blends. Since density was strongly influence by temperature, the quality standards state the determination of density at 15°C using the same procedure for determining the density of oil.

3.2.3.2. Kinematic Viscosity

Viscosity is the most important factor of fuels that affects the flow of the fuels and it was a critical property as it affects injection behavior [61]. The kinematic viscosity was defined as the resistance to the flow of a liquid over another due to internal friction. The same procedure was used to determine the kinetic viscosity of the biodiesel as discussed in the characterization of waste cooking oil. The kinematic viscosity of biodiesel is shown in table 4.1. High viscosity leads to poor atomization and vaporization, formation of shoots, etc. [3, 60]. The data shows from various research articles based on the viscosity of many feedstock's at various biodiesel blend percentages shows higher viscosity than petrol diesel. Biodiesel blend from WCO was slightly increasing to petrol diesel except for B30 (the percentage value of 13.55%). Waste cooking oil biodiesel blend shows that the viscosity variation was good in the ASTM D445 test method working range.

3.2.3.3. Lower Heating Value (LHV)

The heat of combustion of fuel oil, or lower heating value, is a measurement of the amount of heat released per unit mass of biodiesel fuel during complete combustion, expressed in kilojoules per kilogram. Calorific value was measured by a bomb calorimeter in Ethiopia Petroleum Supply Enterprise. In general, biodiesel has a lower calorific value than diesel because of its higher oxygen content [44, 61]. Among the data presented in table 4.1, it was found that WCO biodiesel contains a significantly lower calorific value of 38,280 kJ/kg and the calorific value of diesel fuel was nearly 42,500 kJ/kg. The heating value of blended biodiesel was higher than biodiesel and slightly lower than diesel. The heating value decreased marginally with the increasing percentages of biodiesel blended. The value of WCO pure biodiesel was 9.92% lower than petro-diesel. More researchers studied 12% of the calorific value biodiesels was lower than diesel fuel as normally. This value was agreed upon and related to other papers [46, 61].

3.2.3.4. Determination of the Flashpoint (FP)

A flashpoint of the biodiesel was determined using an open cup method. A cup was filled with the biodiesel sample and was heated by a Bunsen burner [46, 55]. A hand thermometer was inserted into the cup to read the temperature. A small open flame was maintained from an external supply of gas. Periodically, the flame was passed over the surface of the biodiesel. The surface of the biodiesel caught fire when the flash temperature was achieved. The temperature at this moment was reported as flash point temperature. In general, biodiesel has a higher flash point than petro-diesel [47]. For determining the flashpoint of oil open cup method test is used, thus the flashpoint of the waste cooking oil biodiesel was approximately 172°C. The temperature shows that the oil was appropriate for using and storing since its high flash point opposes spontaneous combustion. The flashpoint of the biodiesel was recommended between 159 to 195°C [4]. Flashpoint shows the first temperature where biodiesel is going up into flames. The average flashpoint of pure biodiesel was almost double to compared diesel fuel. It showed an increasing trend of flashpoints for biodiesel blends in table 4.1. The flashpoint value of the biodiesel fulfills ASTM D6751 standards (≥130) and EN14214 standards (≥120). Therefore, the flashpoint of biodiesel was good for handling, storage, or transportation [47].

3.2.3.5. Acid Value

The acid value was a measure of the total acidity of the fatty, which have been liberated by hydrolysis from the triglycerides due to the action of moisture, temperature, or enzyme lipase [3]. In this study, the acid value was found to be 0.0935mgNaOH/g as shown in table 3.2.4 which was in between standard specifications. The titration method was used to determine the acid value. The required solutions were prepared with the required concentration as shown in table 3.2.4. The acid value of the oil was also calculated as:

$$\text{Acid Value} = \frac{V * C * 40}{M} \quad (3.4)$$

Where, C=concentration of NaOH

V = Volume of Titrated Solution

M = Mass of Sample

3.2.3.6. Determinations of Free Fatty Acid Content of Biodiesel

The high FFA content in the transesterification reaction for used cooking oils in biodiesel production was given as a negative effect. The presence of high FFA contents was in the used cooking oil, vegetable oils, or animal fats base-catalyzed transesterification reactions that lead to soap formation. The result could be difficult to separate biodiesel from glycerol [25]. The result value was as shown in table 3.2.4.

3.2.3.7. Nuclear Magnetic Resonance (1HNMR and 13CNM) Spectrometer

Nuclear magnetic resonance (NMR) spectroscopy is commonly employed for monitoring the transesterification reaction for the conversion of biodiesel analysis [48, 62, 63]. The conversion of WCO to fatty acid methyl esters (biodiesel) was determined in ^{1}HNMR and ^{13}CNM has been performed using a 400MHz ^{1}HNMR spectrometer (Bruker) and 5mm diameter ^{1}HNMR tube. To analyze the sample (10-15mg) was poured into an NMR tube and then diluted with 0.5-0.6ml deuterated chloroform (CDCL3) as a solvent. Main parameters number of scan (NS), 4; spectra width 8278.146Hz. Line broadening for exponential window function, 0.0HZ; relaxation delay, 5 sec; temperature 293.9K were set for scanning. The conversion of WCO to biodiesel was calculated from analysis according to equation [63].

$$FAME\ Conversion(\%) = 100 * \frac{2\ \text{I}\circ\text{CH3}}{3\ \text{I}\alpha\text{CH2}} \quad (3.4)$$

Where;

I∘CH3 = integration value of methoxy protons

IαCH2 = integration value of α-methylene protons

The derived from factors 2 and 3 from the fact that the methyl carbon possesses two protons and alcohol (methanol derived) carbon has three attached protons [63]. ^{1}HNMR and *^{13}C NMR* spectrum of waste cooking methyl ester is shown in figures 3.2.11 and 3.2.12.

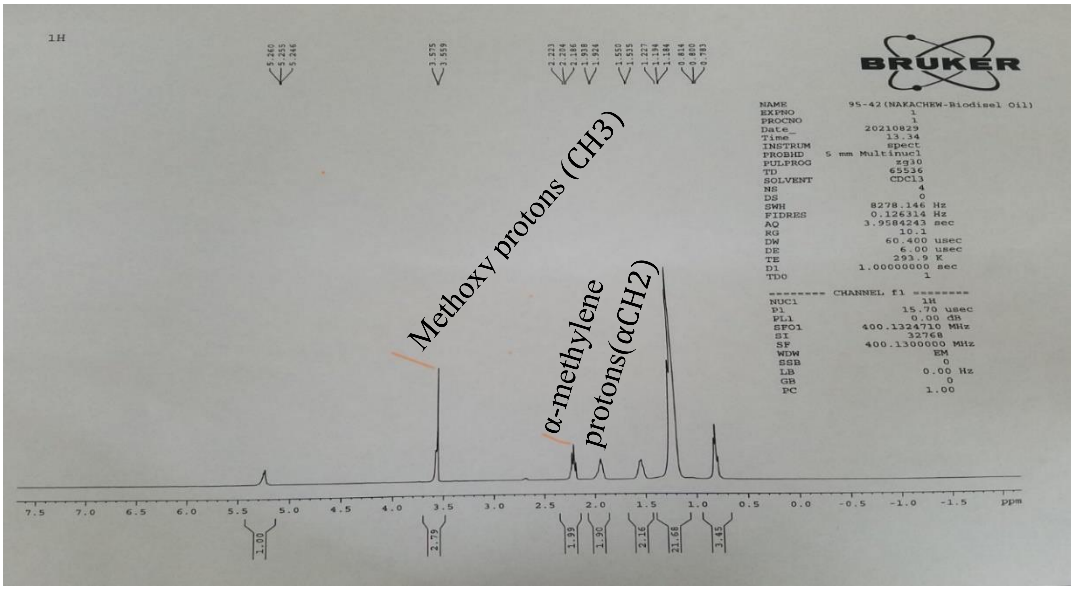

Figure 3.2.11. ^{1}H NMR spectrum of waste cooking oil biodiesel

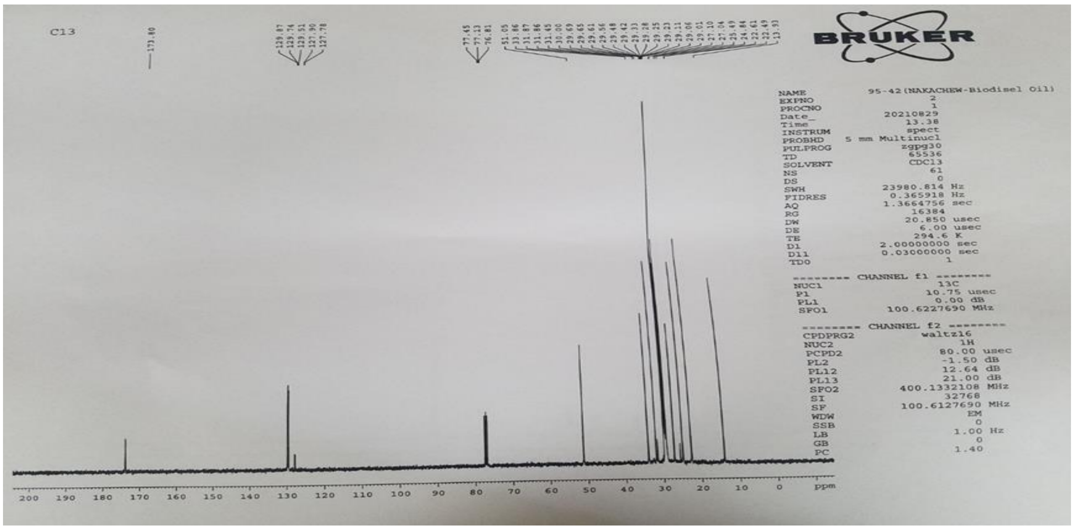

Figure 3.2.12. ^{13}C NMR spectrum of WCO biodiesel with labeling

3.2.4. Blends of Biodiesel and Properties

Biodiesel blend with regular diesel fuel is prepared by mixing biodiesel and diesel in required proportions under appropriate conditions. Most of the world uses a system representing the "B" factor to shows the volume of biodiesel in any fuel mixture [15] may accomplish blending biodiesel with diesel. As shown in figure 3.2.13 the biodiesel blends were prepared by using IKA'EUROSTAR 60 control mixers at 10°C temperature in a large beaker and homogenized by 300rpm agitation speed for 30 min. Eight blends (5%, 10%, 15%, 20%, 25%, 30%, 35%, and 40%v/v) were prepared to investigate the effect of the blending ratios on biodiesel–diesel blend properties and engine performance. Examined some properties of the waste cooking oil, biodiesel, and biodiesel–diesel blends according to ASTM D6751 specification. These properties include calorific value, kinematic viscosity, density, flash point, and acid value is shown in table 3.2.4. The acid values of the waste cooking oil and its biodiesel were determined by the titration method. Blending has done in an open beaker containing refinery biodiesel components produced and diesel components mixed in a required volume blend ratio, finally collected in a pure bottle in one liveliness as shown in figure 3.2.13.

Figure 3.2.13. Biodiesel mixed sample

In addition consider change of physicochemical property blend consistency for biodiesel blending, density, calorific value, and viscosity changes in the biodiesel and test accurate blended properties.

Table 3.2.4: Fuel properties of WCO, methanol, biodiesel, diesel and blend diesel [24].

Property	waste cooking oil	methanol	pure biodiesel	pure diesel	biodiesel standard	
					ASTM D6751	EN 14214
Density, at 15 °C (kg/m3)	910	791.3	879	820-860	890-910	860-900
Kinematic Viscosity at 40 °C, mm2/s	29.23	0.58	4.64	1.9-5.5	1.9-6.0	3.5-5.0
Acid value, mg	2.4	0.02	0.0935	0	≥0.8	≥0.5
Free fatty acid, mg	1.2	0.01	0.04675	0	-	-
Flash point (°C)	223	11-12	156	≥55	≥130	≥120
Gross calorific value (MJ/kg)	33.3-35.7	19.58	38.28	42.5	-	-

3.2.5. Engine Setup

Biodiesel blends obtained from WCO with diesel (B5, B10, B15, B20, B25, B30, B35, and B40 volume percentage) were used to run in the CI engine. The diagram of the test diesel engine ring is shown in figure 3.2.14. The experimental setup for the experiment was consist of TBMC 3, a computer-controlled test bench for a single-cylinder four-stroke, engine, 2.2kW, air-cooled, direct injection diesel engine connected with AM-1(Electric motor control). The specification of the CI engine is shown in table 3.2.5. Initially, the engines operated with pure diesel fuel to collect baseline/reference data, and later on performance with biodiesel, blends were tested. The engine performance; brake torque (BT), brake power (BP), brake thermal efficiency (BTE), and brake specific fuel consumption (BSFC) at different load conditions engine speeds 1500rpm were tested and reported in the following sections.

Table 3.2.5: Engine specification

S.No	Parameters	Descriptions
1	Engine type	Single cylinder 4 stroke Compression ignition, air-cooled engine
3	Bore x stroke	69mm x 60mm
5	Swept volume	224 cm3
6	Compression ratio	21:1

7	R.P.M	3600 max
8	Max torque	10.4Nm@2400
9	Max power output	2.2kW
10	Fuel consumption	267g/kW.h

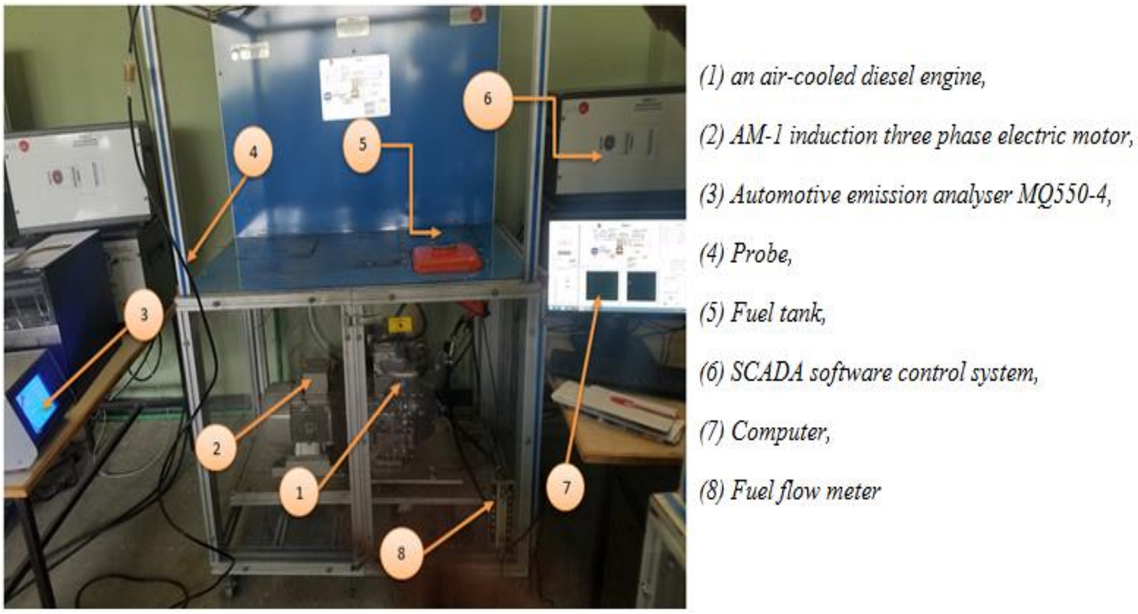

Figure 3.2.14. Photographic view of a TBM3-02 diesel engine

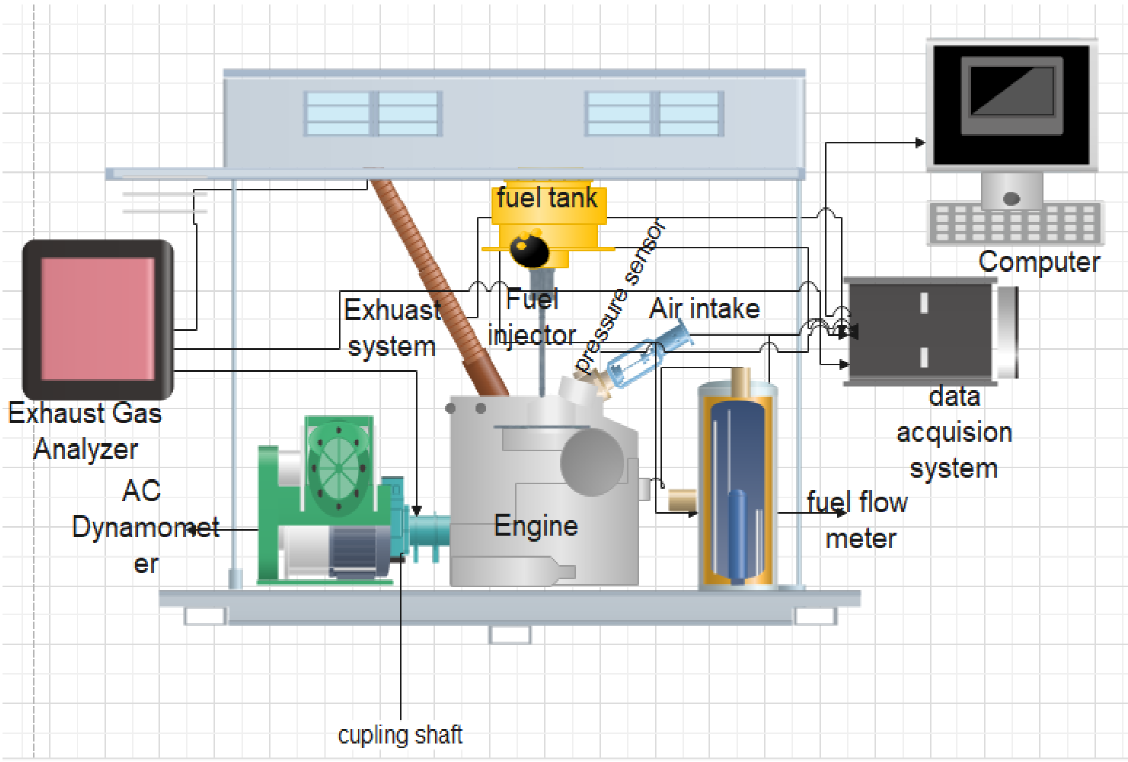

Figure 3.2.15. Experimental setup engine diagram

3.2.6. Engine Performance Parameter

The performance of the diesel engine was assessed in terms of brake power, brake thermal efficiency, brake specific fuel consumption, and brake torque when utilizing diesel and WCO biodiesel mixes with diesel fuel. The experiments were conducted at constant engine speed with different engine load conditions. The parameters such as BP, BT, BTE, and BSFC were evaluated for the same engine speeds and with varying engine loads.

3.2.6.1. Brake Torque and Brake Power

The brake torque and brake power were studied at constant engine speed and various load conditions for biodiesel (100%), biodiesel blends, and pure diesel engines. Brake torque is the torque available at the flywheel in N.m. The dynamometer on the TBMC3-02 test stands used to load the engine from minimum (zero loads) to maximum. Brake power is the power available at the delivery point at the engine crankshaft. The brake power of the engine at different operating conditions was determined and read directly from the integrated software on the computer screen. By doing this in steps, torque values are displayed on the computer, which is integrated with the TBMC3-02 test stand.

3.2.6.2. Brake Thermal Efficiency

Brake thermal efficiency was the ratio of output brake power to the energy supplied by the fuel. For pure diesel mode and it was calculated as.

$$\dot{m}f = v' * \rho \qquad (3.5)$$

Where;

$\dot{m}f$ = Mass flow rate of fuel in kg/h

v' = volume flow rate in m^3 /hr

ρ=density of fuel in kg/ m^3

$$\text{BTE}\ (\%) = \frac{BP * 3600}{\dot{m}f * \text{LCV}} * 100 \qquad (3.6)$$

Where:

Bp = brake power in KW

BTE = brake thermal efficiency

LCV = lower calorific value of the fuel in MJ/kg

3.2.6.3. Brake Specific Fuel Consumption

Brake specific fuel consumption **(**BSFC) for biodiesel blends and diesel as a function of engine speed. Biodiesel blends were investigated with lower heating value (LHV), viscosity, and densities compared to diesel due to atomization fuel injection. Compare and observed higher fuel consumption relate to a percentage of biodiesel blends and commercial diesel fuel. Specific fuel consumption was the measure of the engine's ability to produce power by utilizing the energy content of the fuel. The specific fuel consumption of an engine should be minimized for the desired power output to optimize engine performance [65]. Brake-specific fuel consumption is the ratio of the mass flow rate of fuel consumed by the engine to the brake power in which the engine is producing. When the testing engine run in diesel fuel mode, BSFC was calculated as:

$$\text{BSFC} = \frac{3600 * \dot{m}\text{f}}{BP} \tag{3.7}$$

3.2.6.4. Exhaust Gas Emission Analysis

Exhaust gas emission is a substance that was discharged into the atmosphere from any opening of the exhaust valve or port of the engine. In complete combustion was the air-fuel mixture was stoichiometric the product of combustion would consist of carbon dioxide (CO_2) and water (H_2O) and water vapor only. The emission parameters of a biodiesel blend fuel with petrol diesel in a diesel engine such as CO, CO2, HC, EGT, and NOx were measured by using an exhaust gas analyzer during an engine operated in pure diesel and biodiesel blends at each load condition. During the experiments, exhaust gases were measure using Automobile Exhaust Gas Analyzer MQ550-4 (which is found in Addis Ababa Science and Technology Institute, Ethiopia) as shown in the figure.3.2.16

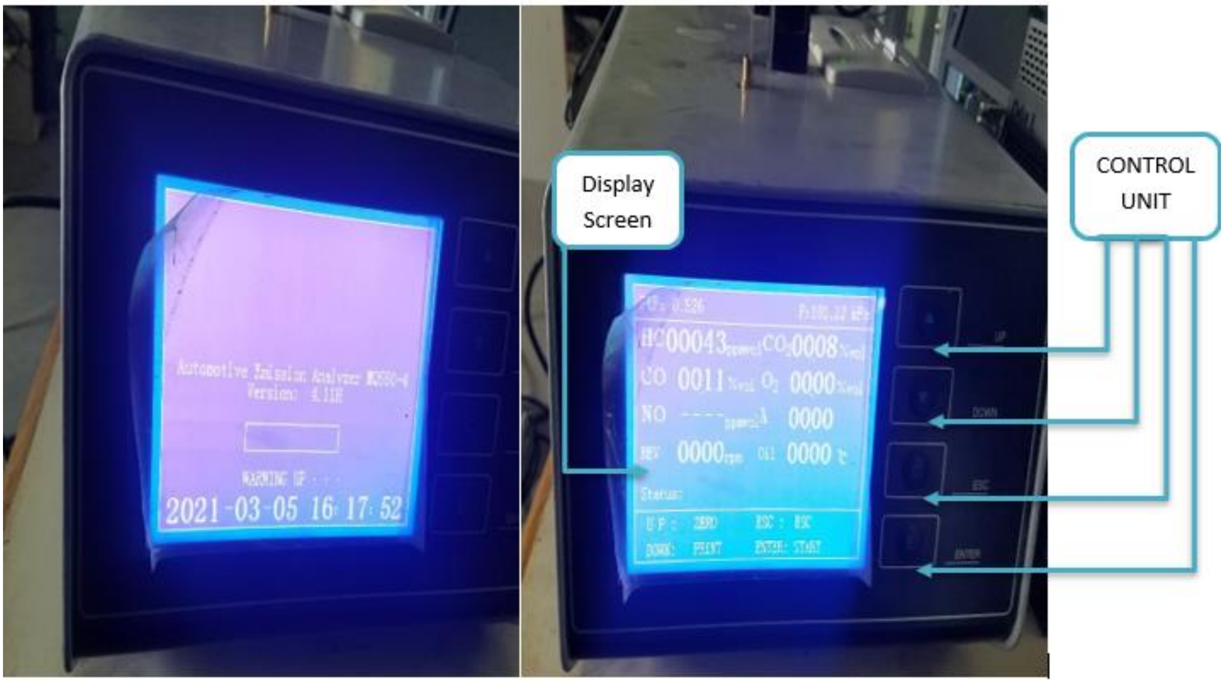

Figure 3.2.16. Photographic view of emission analyzer

Table 3.2.6: Exhaust analyzer measuring range

Item	Resolution	Measurement range	Allowed error	Relative error
HC	1ppm	0-5000ppm	± 12ppm	±5%
		5001-9999ppm		±10%
CO	0.01%Vol	0.00-10% Vol	±0.06%	± 5%
		10.01-16.00% Vol		±10%
CO2	0.1% Vol	0.0-18.0% Vol	±0.5%	±5%
NOx	1ppm	0-4000ppm	±25ppm	±4%
		4001-5000ppm		±8%
O2	0.02% Vol	0.0-25.0% Vol	±0.1%	±5%

3.2.7. Measuring Procedure

Initially connect /tern on a power source and plug in the exhaust gas analyzer. Since the sensitive element, the smoke feeler in a gas analyzer was connected to the exhaust manifold. Before starting measurement, the probe I tip was inserted into the exhaust pipe of the engine. Then run engines for at least 10-15 minutes by using commercial fuel to the heated the probe tip. The exhaust gases were measured to following a strict procedure. Exhaust gases were displayed on the gas analyzer through the sampling tube and sensing it and then measurement was started by pressing the record icon on the control unit of the analyzer. The content of the exhaust gas was starting to display on the gas analyzer unit. The readings of HC (in ppm), NOx (in ppm), CO_2 (in % Vol.), and CO (in % Vol.) for each test were allowed to stabilize from 2 to 5 minutes and the results were recorded and print the recorded value.

Table 3.2.7: The engine test matrix

Experiments		Operating Condition					Outcomes of the Experiment
		CR	IP(kpa)	IT(^{O}C) 25.09	Speed(rpm) Constant	Varying Load (%)	
Test Fuel	Base Line D100	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	Analysis of BT, BP, BTE, BSFC, CO, CO_2, HC, NO_X, EGT.
	B5%,D95%	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	
	B10%,D90 %	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	
	B15%,D85 %	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	
	B20%,D80 %	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	
	B25%,D75 %	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	
	B30%,D70 %	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	
	B35%,D65 %	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	
	B40%,D60 %	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	
	B100%(Pure biodiesel)	21:1	Default 101.29	Default	1500rpm	0, 20, 40, 60, 80.	

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1 Waste Cooking Oil (WCO)

The waste cooking oil is easy to collect from domestic usage fast foods and restaurants, which is available and cheaper than other oils (refine oils). Biodiesel produced from WCO is advantageous economically and environmentally beneficial as it provides a cleaner way of disposing of waste products [9, 54, 63]. Those oils are significant feedstock as the raw material to produce biodiesel. Biodiesel production from WCO as a raw material with methanol reaction time and sodium hydroxide as a catalyst in the single-step transesterification process. Biodiesel blends from 5 to 40%v/v can be tested in a diesel engine. The effects of biodiesel produced from WCO on performance and exhaust emission compared to regular diesel fuel and has to contribute performance increase and emission reduction were experimentally investigated at all loads.

4.2 Biodiesel Yield

The biodiesel yield was 90% (V/V) after the transesterification reaction process-using methanol as alcohol and NaOH catalyst as shown in equation (3.3). In the production processes after washed and dried biodiesel was calculated relative amount of biodiesel produced with the volume of waste cooking oil used [16, 59].

Note; 10% of transesterification reaction process was glycerol and soap formation solid sedimentary

4.3 NMR Analysis

Nuclear magnetic resonance spectra were recorded on a Bruker spectrometer at ambient temperature using a dual (^{1}H ^{13}C) gradients probe. When the FAME yield was estimated, an inaccuracy of ±2% error was discovered. [48, 62]. The $^{1}HNMR$ and $^{13}CNMR$ biodiesel synthesized is shown in figures 3.2.11 and 3.2.12, respectively. Calculate the percentage value of conversion of biodiesel from WCO in equation (3.4). FAME conversion is 93.46% from the NMR analysis result.

4.4 Characterization of Biodiesel–Diesel Blends Fuel

The physicochemical properties of biodiesel made from WCO were determined by using ASTM standard test methods for biodiesel, biodiesel-diesel blends, and commercial diesel fuels at Ethiopia Petroleum Supply Enterprise laboratory. The methods employed for characterization were summarized in table 4.1.

Table 4 1: Characteristic property of biodiesel blends

Property	Test method	ASTM limits	Biodiesel Blend Test Result									
			Bio 0%	Bio 5%	Bio 10%	Bio 15%	Bio 20%	Bio 25%	Bio 30%	Bio 35%	Bio 40%	Bio 100%
density@15 ºC (g/ml)	D4052	0.820 - 0.860	0.844	0.8457	0.8475	0.8494	0.8512	0.8527	0.8545	0.8562	0.858	0.8790
density@20 ºC (g/ml)	D4052	0.820 - 0.870	0.840	0.8419	0.8439	0.8458	0.8478	0.8497	0.8510	0.8536	0.8556	0.8756
Kinematic viscosity@ 40ºc (mm^2/s)	D445	1.9-6	3.901	3.9379	3.9741	4.0118	3.9046	4.0855	3.4355	4.1596	4.1966	4.6400
Flashpoint Closed cup) (°C)	D93	≥130	Min 55	130.78	135.78	134.56	133.34	133.71	130	124.56	140.0	156
Calorific value,(MJ/kg)	Calculated	42-46MJ/kg	42.5	42.31	42.26	42.19	41.84	41.80	41.77	41.07	40.58	38.28

It was observed that the densities of the blended fuel samples increased with an increase in the percentage of WCO in the blend and decreased with an increased temperature for all fuel samples under test. This shows that as the volume of biodiesel in the fuel blends is raised, the density of the fuel blends increased. From table 4.1 the results indicated that the density of pure diesel oil is lower than the density of WCO biodiesel and their blends. In the table, 4.1 shows that the kinematic viscosity (KV) of biodiesels and blends was tested at a temperature of 40℃ a test method D445. A slightly increase in kinematic viscosity was found with diesel-biodiesel blend fuels with an increase in biodiesel volume in comparison to diesel fuel. The KV of biodiesel was increased with increasing the percentage of biodiesel blends due to the KV of pure biodiesels have relatively higher than commercial pure diesel. In addition, the calorific value of biodiesel is lower than diesel fuel due to its lower energy content and high oxygen content. The calorific value of biodiesel blends was observed to decrease with increasing biodiesel percentage.

4.5 Engine Performance Test and Emission Characteristics

The results of engine performance and emission characteristics are shows with the help of graphs. The performance of the engine when using diesel and WCO biodiesel blended fuel was evaluated for BT, BP, BTE, and BSCF and emissions parameters such as CO, CO_2, NOx, EGT, and HC. The experiments were conducted with varying engine load and speed control modes were discusses in the following sections.

4.5.1 Brake Torque (BT)

Figure 4.5.1 shows that the variations of brake torque versus engine load at constant engine speed (1500rpm) for biodiesel blends and commercial diesel fuel. Recorded the brake torque of the baseline diesel fuel with biodiesel blends in TBMC3 computer-controlled test bench single-cylinder engine. The tendency of the graph (figure 4.5.1) brake torque biodiesel blends shows to have a very close value with each other and lower than compared to pure diesel. The WCO biodiesel has lower average brake torque than diesel fuels 16.79% and 13.35% is record at 20%load and 40% load respectively. However, the brake torque of biodiesels were more approaches to diesel fuel at lower and higher loads.

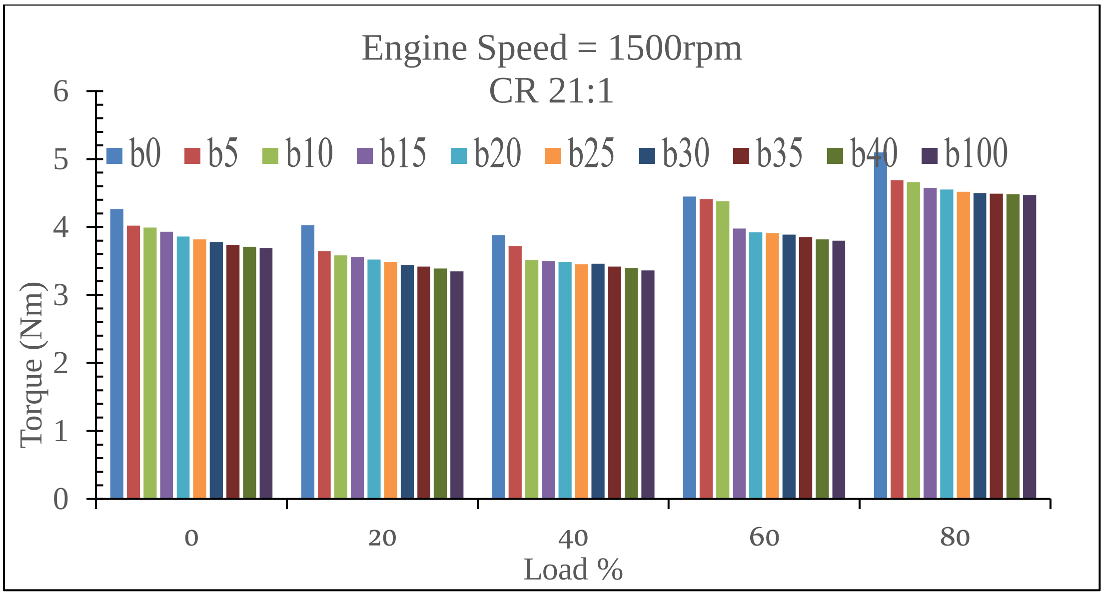

Figure 4.5.1. Brake Torque vs Load for various blends

Figure 4.5.1, shows that at lower loads slightly decreased brake torque and increasing as engine load increases for both modes of operation. The brake torque of diesel with biodiesel blend fuel was lower than the diesel fuel due to the lower calorific value of biodiesel. The blending ratio of biodiesel with diesel fuel increases the brake torque slightly decreases. The results are agreed with the latest study [1, 64].

4.5.2 Brake power (Bp)

The brake power of the engine at different operating conditions was determined and read directly from the integrated software on the computer screen. Figure 4.5.2 shows the variation of brake power versus engine load at constant speed1500rpm condition for biodiesel blends and commercial diesel. The trends for biodiesel blends were getting similar to the commercial pure diesel. Brake power for pure diesel and biodiesel blends increases with the increase in engine load.

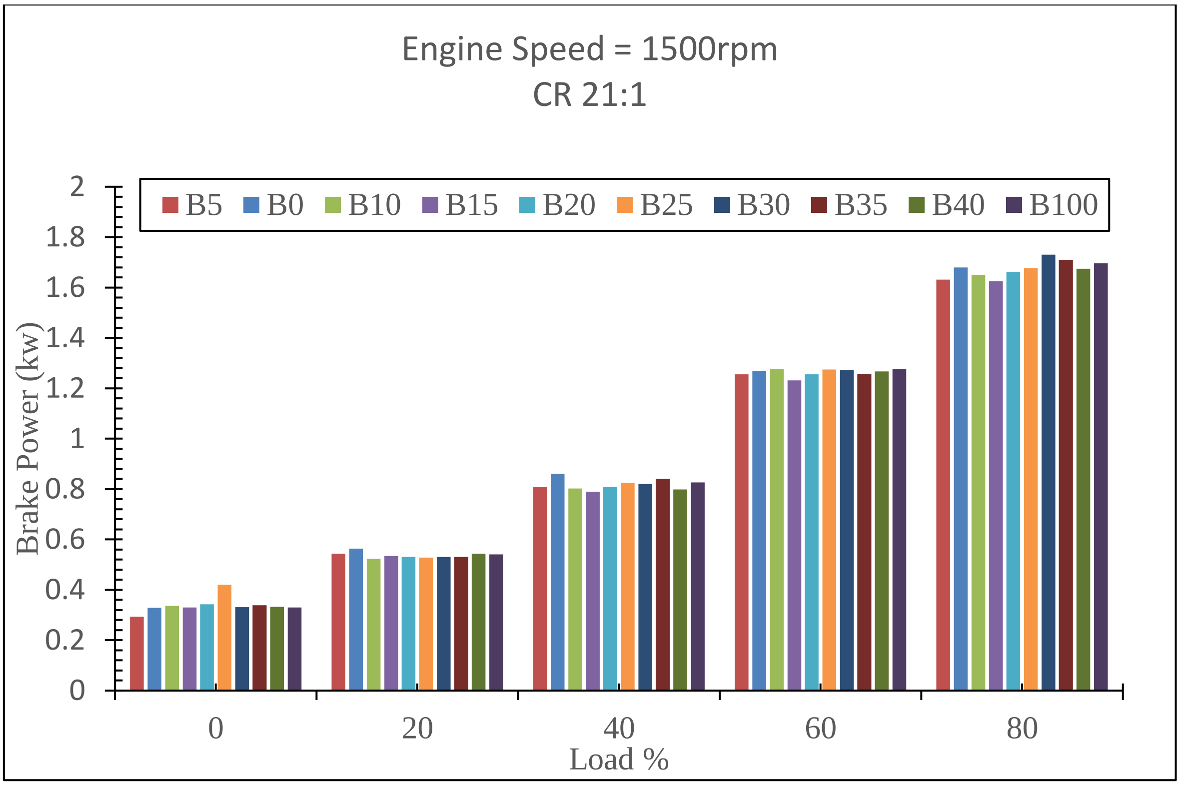

Figure 4.5.2. Brake power vs Load for various blends

A close resemblance occurred at lower engine loads were indicates the power output between biodiesel from WCO and diesel fuels. However, at a higher engine load, a clear gap appeared between the biodiesel (B100) and the reference diesel fuel (B0). The figure, 4.5.2, which is, plotted the engine brake power at lower to higher engine loads. B15 has measured lower average brake output (4.08%) than diesel fuels at 1500-rpm. B25 has measured a maximum average brake power (0.44%) greater than neat diesel fuel at 1500-rpm engine speed. Results in brake power increase as engine load increasing to some extent vary brake power from biodiesel blends and diesel fuels during the test. As the biodiesel flow rate increases, the power has a small reduction throughout the entire load range compared to reference fuel. In the case of the lower calorific value of biodiesel as well as higher viscosity, and poor atomization than neat diesel fuel. As fuel viscosity increases, it requires higher injection pressures to break fuel drops into very fine droplets and easily to spraying in injection and combustion systems. Generally, the average power value drops for biodiesel blends compared to commercial diesel at 1500rpm was found to be 3.69 % ,2.46 %,4.08 %, 2.26 %, -0.446%, 0.403%, 0.574%, 1.75 %, 0.701 % for biodiesel blends (B5, B10, B15, B20, B25, B30, B35, B40, and B100 respectively. The result was agreed with the reference [15, 44, 65].

4.5.3 Brake Thermal Efficiency

Figure 4.5.3 shows the variation of brake thermal efficiency for various blends under different loads for a diesel engine having a CR=21:1 and atmospheric pressure. Figure 4.5.3 observed that brake thermal efficiency for diesel has the highest value and B100 has the least value compared to other blends of diesel fuel. The brake thermal efficiency (BTE) of a diesel engine at different biodiesel blends with compression ratios 21:1 increased with increasing engine loads as shown in figure 4.5.3. The lower heating value of biodiesel blend reflects into slightly reduced performance than diesel fuel. In addition, the reason might be the higher viscosity and density; it can direct the reduction of brake thermal efficiency. The higher thermal efficiency may be due to better atomization, spray characteristics, and air-fuel mixtures, which results in improved combustion. The mixing of biodiesel in diesel fuel yields almost similar thermal efficiency at lower loads but it decreased at higher loads due to lower heating values relative to diesel fuel. Initially, the thermal efficiency of the engine was good by fueling biodiesel blends. Bio-diesel molecules (i.e., the methyl ester of the oil) include some oxygen, which contributes to the combustion process.

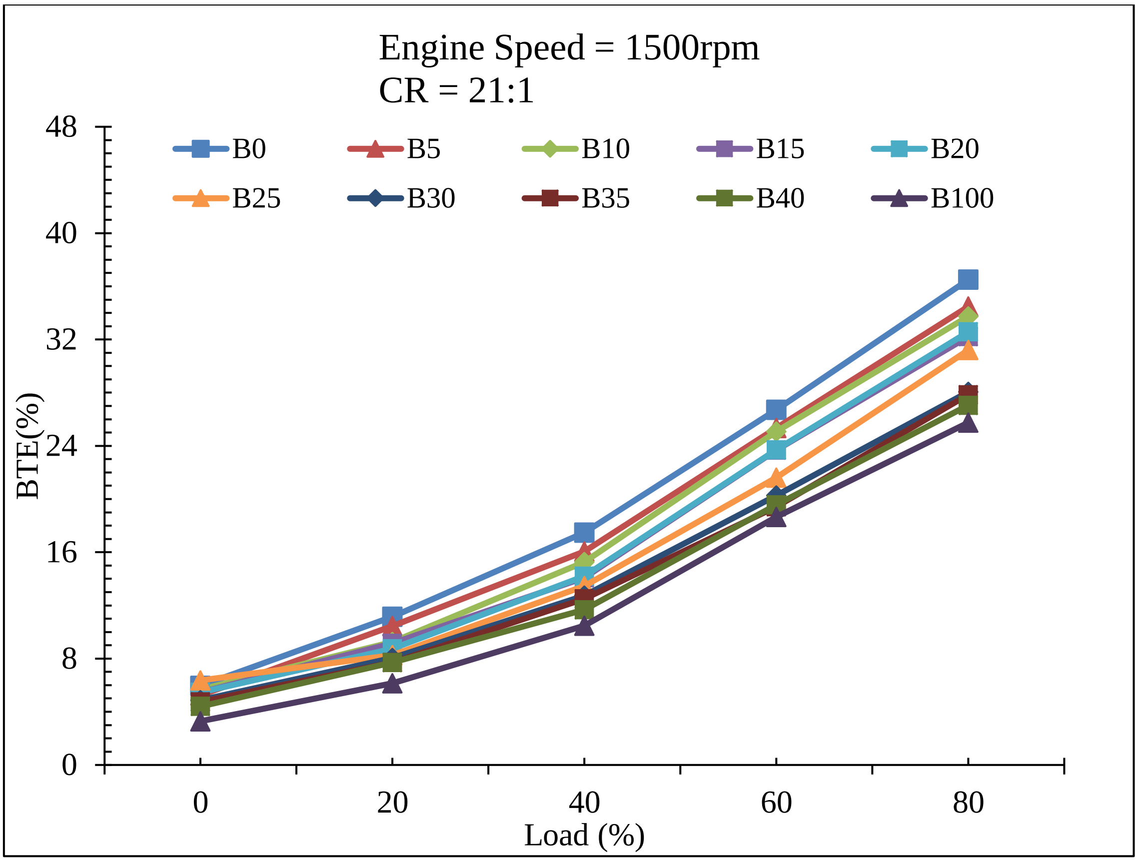

Figure 4.5.3. Brake Thermal Efficiency vs Load for various blends

The thermal efficiency trend was reversed after a certain limit of loads with respect to diesel, and it began to decrease as the blend concentration increased at increasing loads. Brake thermal efficiency attains maximum for all biodiesel blends and diesel fuel test at 80% load operating condition. From figure 4.5.3 the average BTE reduction for biodiesel blends compared to commercial diesel at 1500rpm was found to be 6.3%, 8.9%,13.4%, 13.3%, 17.2%, 24.3%, 26.1%, 27.9% and 34.2% for biodiesel blends (B5, B10, B15, B20, B25, B30, B35, B40, and B100 respectively. These results were agreed with the previous works reported by other researchers [49, 66, 67].

4.5.4 Brake Specific Fuel Consumption

The fuel consumption is determined by measuring the number of milliliters consumed by the engine for the given time volume flow and brake power. As shown in figure 4.5.4, the brake-specific fuel consumption was determined for waste cooking methyl ester-diesel fuel blends versus engine loads.

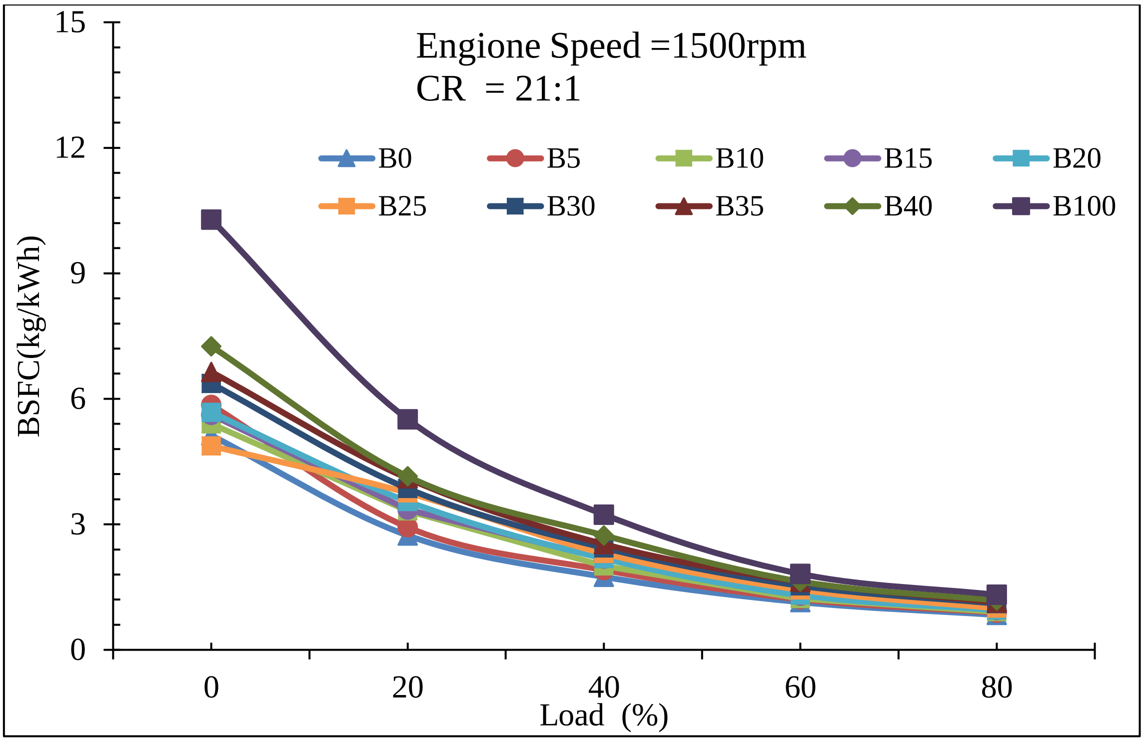

Figure 4.5.4. Brake specific fuel consumption vs Load for various blends

From the figure, 4.5.4 was observed that as a load increased, BSFC decreased for all fuel tests. Diesel fuel has the lowest BSFC throughout the test. Both the blends and neat diesel fuel have higher BSFC at lower loads and a slightly reduced consumption rate at higher engine loads was observed. The results fuel consumption had increased as blends percentage increased up to 60% engine load and at higher load fuel consumption above 60% load almost closets all fuel tests. At a lower load, B25 has a lower BSFC was decreased by 4.8%, due to power produced 0.44% more than diesel fuel, since power is inversely proportional to BSFC. BSFC decreases at higher powers it is evident that for increased brake power. Hence when the load increases, BSFC reduced that was always advisable to operate the engine at maximum load for maximum output from the fuel [3, 64, 66]. The curves showed that the specific fuel consumption at a lower load is high. According to the researchers, believe a major portion of the fuel consumption was to overcome the engine friction. It was possible to see that the trend of the curves for all blends was similar to comparable with that of the diesel fuel. However, the BSFC increases as the percentage of biodiesel increase in the blends. This might be the case of biodiesel has an oxygenated fuel. The higher fuel viscosity was also may reduce the quality of fuel atomization, and the results could be higher gas emission and fuel consumption. The increasing BSFC for biodiesel blends was understandable as the biodiesels have less energy than diesel. The higher the waste cooking oil contents in the biodiesel, the lower calorific values, higher viscosity, and density, resulting in higher BSFC.

4.6 Engine Emission Parameters

The emissions of the engines when using biodiesels from WCO blends with diesel fuel were evaluate for oxides of nitrogen, carbon monoxide, carbon dioxide, exhaust gas temperature, and unburned hydrocarbons. The exhaust emissions of a specified fuel are an important issue for future controlling its emissions through different options. Consequently, searching alternative fuels, which results in less emission, or optimizing the engine operating parameters. Many emission regulations were created to control pollutants generated by automobiles and other propelled vehicles, but they can also be used to control emissions from industries, power plants, and diesel generators. Now emissions of CO, CO_2, HC, EGT, and NO_x emission were measured with regarding diesel fuel emissions. Measured by using Automobile Exhaust Gas Analyzer SV-50 when the engine runs in diesel fuel mode at each load with different biodiesel blends discussed and compared to neat diesel fuel emissions.

4.6.1 Carbon Monoxide Emissions

The emission of CO obtained from waste cooking oil biodiesel blends in volume percentage B5, B10, B15, B20, B25, B30, B35, and B40, compared to baseline commercial diesel fuel versus engine load at a constant speed (1500 rpm) and varying loads (0 - 80 %) were tested and presented in figure-4.6.1. The incomplete combustion process of fuel inside the cylinder is responsible for the formation of CO emissions, which decreased on using higher engine loads. Increasing engine load will increase the temperature inside the cylinder, and consequently will help to enhance the complete combustion of the fuel. The CO emission depends on the oxygen content, carbon content, and combustion efficiency of fuel [1, 52, 68]. During combustion, the carbon present in the fuel oxidizes to form CO emissions was converted into CO_2. However, if the available oxygen is lower, it causes incomplete combustion and hence comes with a higher CO value. Figure 4.6.1 shows that CO emissions were decline by adding waste cooking oil blended biodiesel fuel at all engine loads, due to, biodiesel has high oxygen content. The result showed that CO emissions reduced as engine loads increased, indicating that biodiesel generated from WCO has a high oxygen content, which promotes full combustion in the cylinder and lowers CO emissions. The higher the engine load, the lower the CO emissions for all fuel tests. This is also due to better evaporation and mixing of air and fuel at higher loads for higher in-cylinder temperatures. The higher biodiesel percentage in biodiesel-diesel blends decreased CO emissions at low and medium load conditions. It was believed that a higher O_2 concentration in the air-fuel mixture, which can improve combustion and enhance further CO oxidation. It was indicated that the shorter ignition delays, increasing the degree of mixing intensity and improved burning efficiency. The reason behind this would have the presence of enough oxygen content to improve the combustion process. The CO emissions of biodiesel blends decreased by 9.4%, 16.6%, 23.3%, 25%, 30%, 33.3%, 39.4%, 46.6% and 52.2% for biodiesel blends B5, B10, B15, B20, B25, B30, B35, B40, and B100% respectively, compared to that of pure diesel fuel. The result is similar to the reference [68–70].

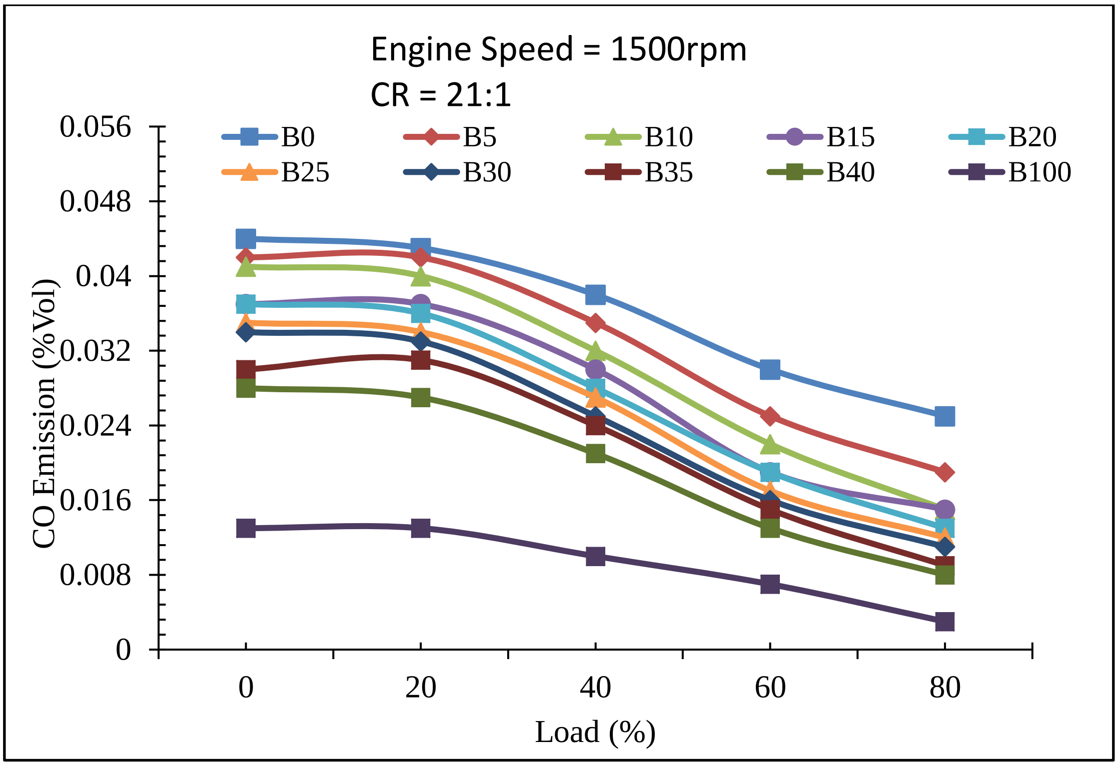

Figure 4.6.1. CO emission vs Load for various blends @1500 rpm

4.6.2 Carbon Dioxide Emissions

Figure 4.6.2, shows the variation of CO_2 emissions for waste cooking oil biodiesel blends B5, B10, B15, B20, B25, B30, B35, B40, B100, and pure diesel fuel versus loads. Diesel engines have better combustion efficiency, so the CO_2 emissions in diesel engines are produced due to the complete combustion of fuel inside the combustion chamber [71, 14]. From figure 4.6.2, it was observed that increasing the engine loads, CO_2 emissions slightly increased for all fuel tests. Due to the increase of the peak cylinder temperatures, which leads to improving the combustion process and thus the CO_2 emissions increased. Biodiesel derived from waste cooking oil was increasing the percentage of blend biodiesel increased CO_2 emissions and higher than in pure diesel fuel in case of higher oxygen continent and higher compression temperature. The cause of increasing can explain that the use of biodiesel blends has significantly improved the combustion process. Moreover, it indicates complete combustion of fuel inside the cylinder were increased CO_2 emissions.

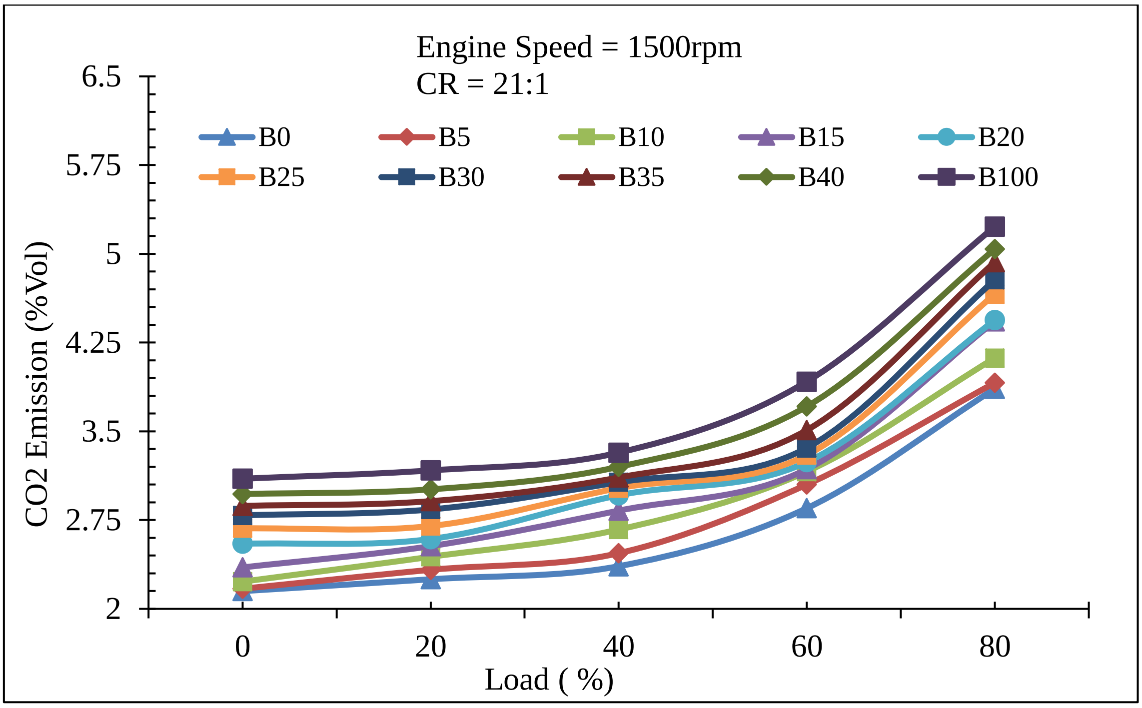

Figure 4.6.2. CO2 emission vs Load for various blends @1500 rpm

Additionally, biodiesel blends have might be increased fuel flow rate at high loads, due to increased temperatures and increased CO_2 emission within a load. The average CO_2 emissions increased by 3.3%, 7.8%, 12%, 14.6%, 17.6%, 20%, 22.2%, 24.8% and

28.1% for blended biodiesel fuels, B5, B10, B15, B20, B25, B30, B35, B40 and B100% respectively compared to the pure diesel fuel. The results were agreed with the previous works of literature [49, 71, 72].

4.6.3 Hydrocarbon Emissions

Hydrocarbon emission for biodiesel- diesel blends and diesel fuel with respect to the percentage of loads were illustrated in figure 4.6.3. The hydrocarbon (HC) emission of waste cooking oil biodiesel is lower than diesel for all blended fuel tests and load conditions. The HC emission behaves similarly to that of CO high at lower engine load and lower at high load. The reason could be attributed to the better air-fuel mixture and higher evaporations at high engine loads. Additionally, for high in-cylinder combustion temperature were improved the burning fuel combustion process when increasing engine load. Figure 4.6.3 reveals that the increased biodiesel blends percentage, decreased HC emission when the proportion of waste cooking oil biodiesel in diesel fuel increases. The event indicated the presence of higher oxygen concentration in waste cooking oil to improves combustion efficiency and reduced unbruned HC emissions [1, 8, 31]. As shown in figure 4.6.3 the unburned hydrocarbon emission affects the engine performance unfavorably due to incomplete combustion of fuel. The hydrocarbon emissions decreased with engine load due to an increase in cylinder temperature. In the graph at lower loads, the HC exhaust emissions were maximum. As the biodiesel ratio increases, unburned hydrocarbon (HC) decreased for all engine loads. It showed that the HC emissions of waste cooking oil biodiesel blend B5, B10, B15, B20, B25, B30, B35, B40 and B100 were less by 4.5%, 11.6%, 20%, 21.9%, 27%, 34.1%, 39.3%, 43.2%, and 60% respectively, compared with pure diesel fuel [11, 71, 73].

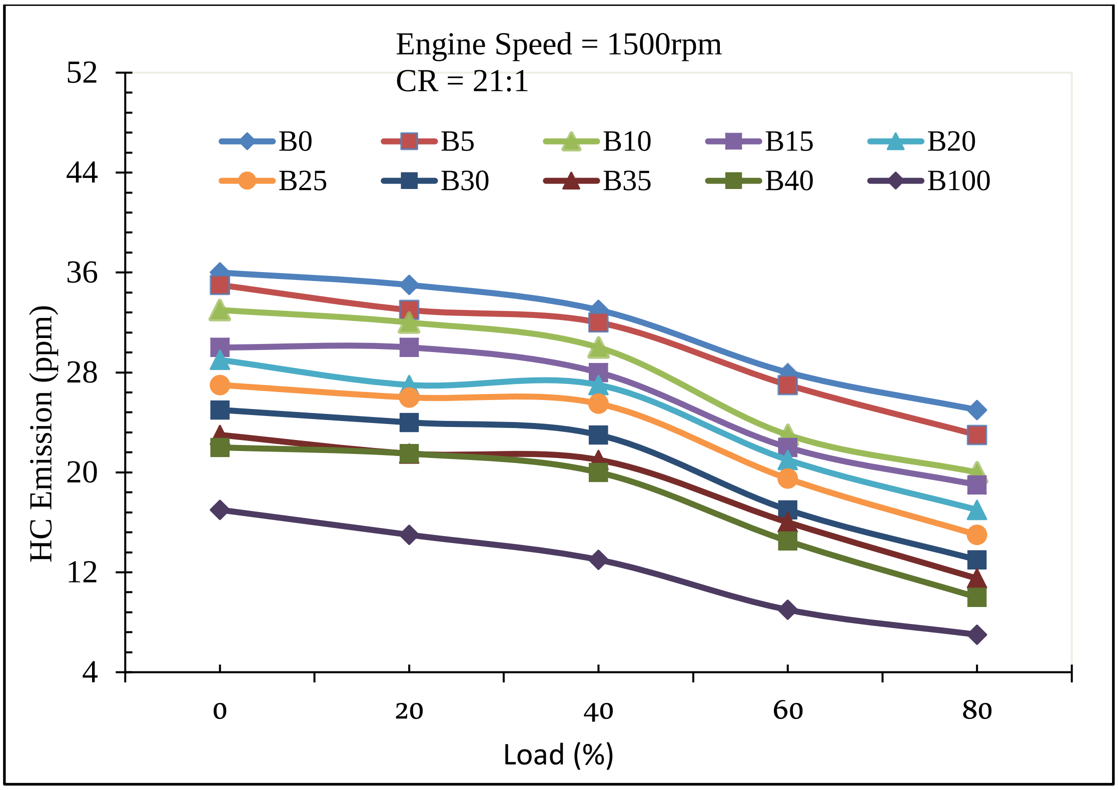

Figure 4.6.3. HC emission vs Load for various blends @1500 rpm

4.6.4 Nitrogen Oxide Emissions

The oxides of nitrogen in the emissions consist of nitric oxide (NO), and nitrogen dioxide (NO_2) [69]. Figure 4.6.4 shows the relation of nitrogen oxides for pure diesel and waste cooking oil blends with diesel verse the percentage of engine load. It was observed that the amount of nitrogen oxide increased with increasing engine loads. Increasing WCO blends with diesel, NOx increased with load increases. This was because as the load increases the engine power releases a high rate of heat and the concentration of oxygen leading to increased levels of nitrogen oxides. Moreover, the reasons were leading to the increment of the NOx emissions in diesel engines. The high flame temperatures in a peak cylinder inside the combustion chamber with the help of high oxygen concentration when engine load increased, NOx emissions were increased and reduced the ignition delay and increase the amount of fuel entering the cylinder [31, 71, 74].

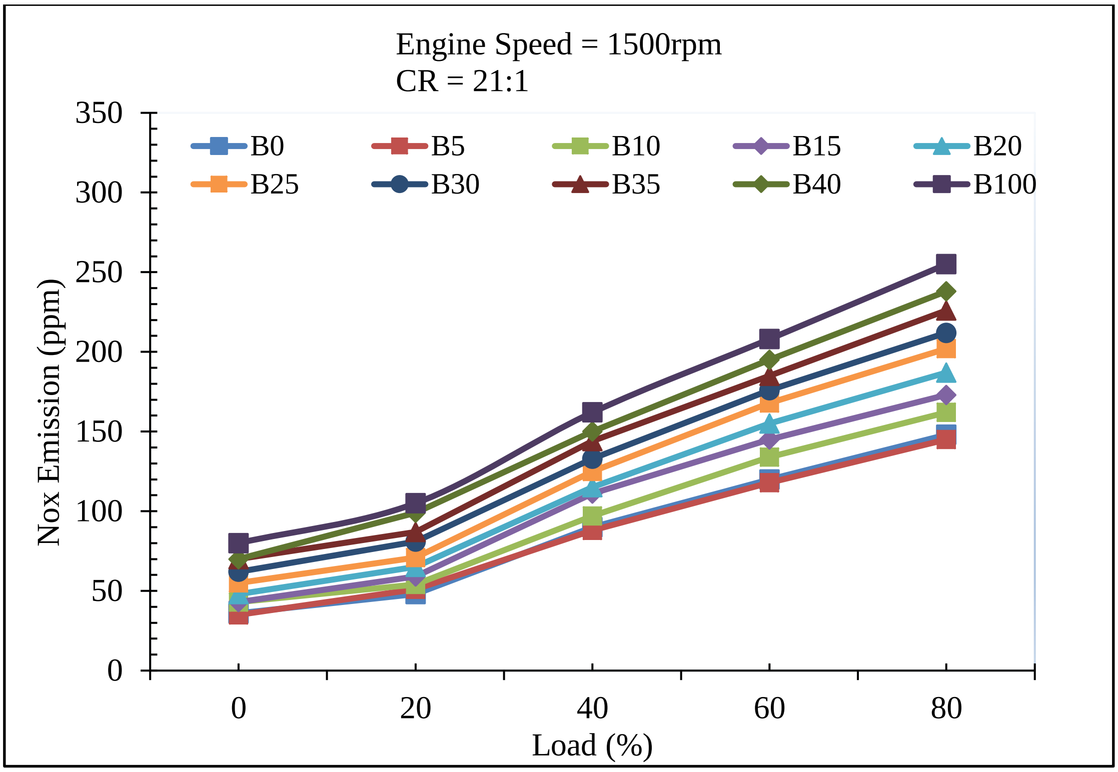

Figure 4.6.4. NOx emission vs Load for various blends @1500 rpm

NOx emissions at zero loads were almost similar for all fuel tests, but throughout the graph, and it was observed that the increase of NOx emissions for all used fuels on increasing the engine loads. Thus, results indicated that increased the amount of burned fuel inside the combustion chamber and increasing the cylinder temperature. In addition, increased NOx emissions with increasing the percentage of waste cooking oil biodiesel blends for all engine loads compared to the pure diesel fuel. Because biodiesels have high oxygen content relative to diesel. When compared to pure diesel, NOx emissions for biodiesel blends derived from waste cooking oil biodiesel blends with diesel fuel decreased by 1.02%, while all others increased. B10, B15, B20, B25, B30, B35, B40, and B100 were increased by 9.7%, 16.7%, 22.4 %, 28.8 %, 33.4 %, 37.9%, 40.9 %, 45.4 %, respectively. The results were agreed with articles [31, 67, 71].

4.6.5 The Effect of Biodiesel on Exhaust Gas Temperature (EGT)

The relation of the exhaust gas temperature (EGT) and percentage of engine load is shown in figure 4.6.5 for different biodiesel blend fuels. EGT was increasing with increasing loads as observed. The lowest EGT was observed for B35 (30.78◦C) at 20% engine loads and the highest EGT (35.898 ◦C) was observed for B15 at maximum load

(80%). Biodiesel (B100) produced from waste cooking oil was illustrates as a very close value of EGT with diesel at 20% engine load. However, biodiesel (B100) was slightly higher EGT compared to pure diesel fuel. It might be the cause of lower heating value and viscosity nature to increase heat [31, 49].

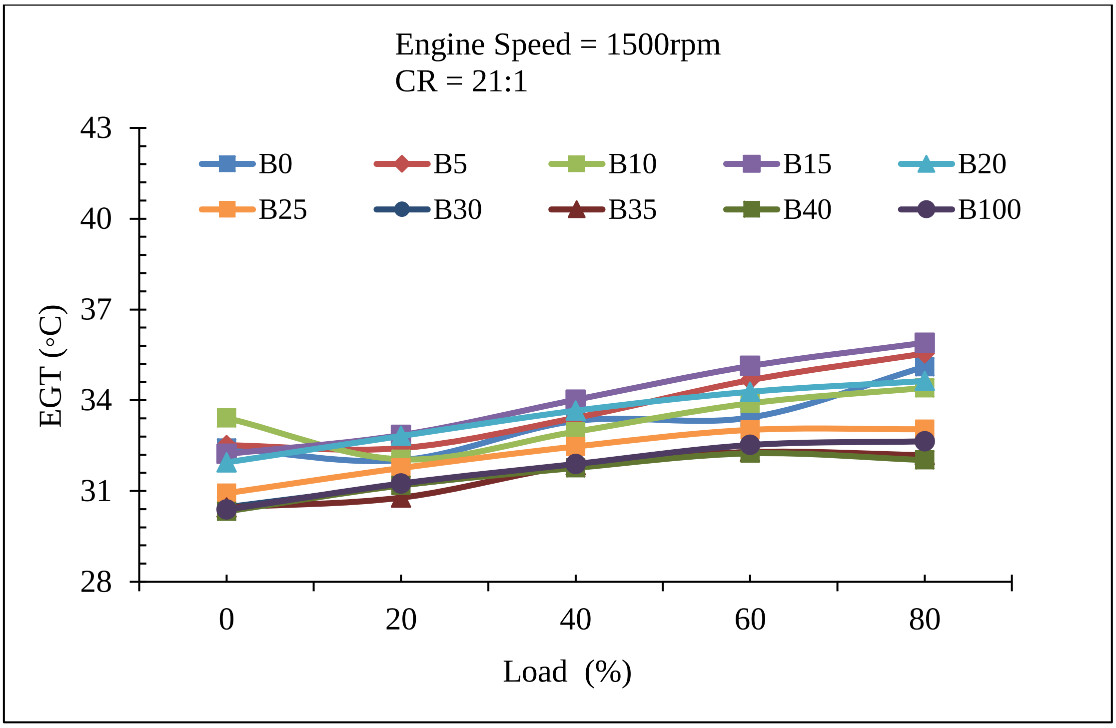

Figure 4.6.5. Exhaust gas temperature vs load for various blends @1500 rpm

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this thesis study, biodiesel from waste cooking oil was produced by transesterification method using NaOH as a catalyst and used as investigated fuel. The engine is fueled with different waste cooking oil biodiesel blends and pure diesel fuel to compare the engine characteristics, including engine torque, engine power, brake specific fuel consumption, brake thermal efficiency, and emissions of CO, HC, CO_2, and NOx. Waste cooking oil as raw material for biodiesel production and can be used as a renewable energy source. It is produced by using the transesterification process easy, fast, and visible for the biodiesel production process. The fuel characterizations were done in Ethiopia Petroleum Supply Enterprise and Addis Ababa Science and Technology University, the result of physicochemical properties was in the range of ASTM D6751 and EN14214 biodiesel specifications. WCO biodiesels and their blends with diesel fuel have a slightly higher kinematic viscosity, flash point, and density; however, it has lower heating values. The biodiesel yield (% v/v) after the transesterification reaction process was 90% using 500 ml sample oil by using methanol to oil molar ratio (6:1) and 3.5g of NaOH catalyst.

This study focused on the effect of waste cooking oil biodiesel blends (B5, B10, B15, B20, B25, B30, B35, and B40) on a single-cylinder direct injection diesel engine. Engine performance and emission parameters were investigated experimentally. Based on the experiments, the main conclusions are summarized as follows.

- The oxygen-containing properties of higher percentage blend ratios of B40 biodiesel enhance the combustion process, which helps to reduce CO and HC emissions. More CO_2 is released due to improved fuel consumption and complete combustion. CO and HC emissions for all fuels are lower at high load conditions. The increment of biodiesel percentage and its blends were lower CO and HC emissions. However, the oxygen content in B40 biodiesel has a higher density and does not contribute to heat generation, which results in higher fuel consumption with respect to pure diesel fuel.
- Although the engine brake power of different blend ratios slightly dropped at low (20%) and medium (40%) engine load due to the lower of its heat value, it slightly increased at high engine load since the lower viscosity of blended fuels enhanced

air-fuel mixture formation in the combustion chamber. Furthermore, brake-specific fuel consumption (BSFC) decreases as the load increases as the biodiesel increases in the blend. This is because of the lower calorific values of biodiesel. Furthermore, it was initiated to improve exhaust emissions. However, the BSFC of the test engine running on high percentage ratios of biodiesel (B25, B30, B35, and B40) increased at almost all engine load conditions.

- By using B40 biodiesel, the NOx emissions show a relatively complex trend under different engine loads. Oxidation is a significant factor for NOx generation. The oxygen-containing properties of B40 biodiesel increase the oxygen concentration slightly after combustion, which increases the proportion of NOx. Regarding CO_2 and EGT, emissions were increased with the increase of loads.

  In general, the emission results (CO and HC) obtained with B40 fuel lie below in commercial diesel fuel results, however, the amount of NOx emission significantly increased and engine fuel consumption was also higher. Hence, the blend fuels (B5, B10, and B15) results obtained lie in between those obtained for diesel fuel.

5.2 Recommendations and Future Work

Based on this research-produced biodiesel from waste cooking oil and blend with regular diesel fuel. A future research focus will be on engine combustion characteristics (in-cylinder pressure, heat release rate, combustion duration) under varying engine loads for the same biodiesel blended fuels in a single-cylinder direct injection diesel engine. For future research, we will focus to scale up a percentage of biodiesel ratios and tested in a diesel engine with increased compression ratio and fuel injection pressure at moderate engine load to improve fuel atomization and mixing rate, and combustion efficiency, this may lead to improve engine overall efficiency

- Further investigation to that optimization of biodiesel blends for both biodiesel–diesel and biodiesel–biodiesel from various biodiesel feedstock's to get infer properties and some superior qualities by using additive materials.
- In-depth instrumental analysis, for instance, the effect of temperature, reaction time, and catalyst type on biodiesel yield for batch process system.
- The property of glycerol was not determined, but glycerol has relevance in cosmetics and soap industries the property of glycerol should be analyze and purify for further applications.

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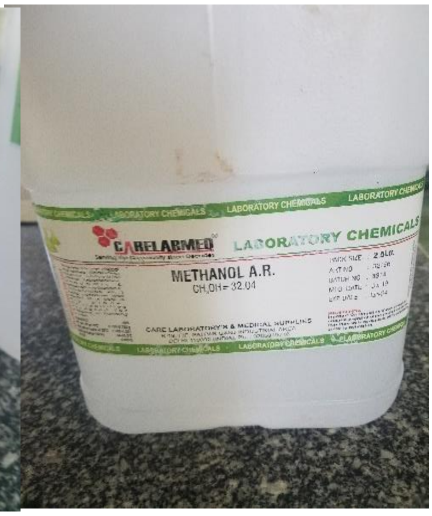
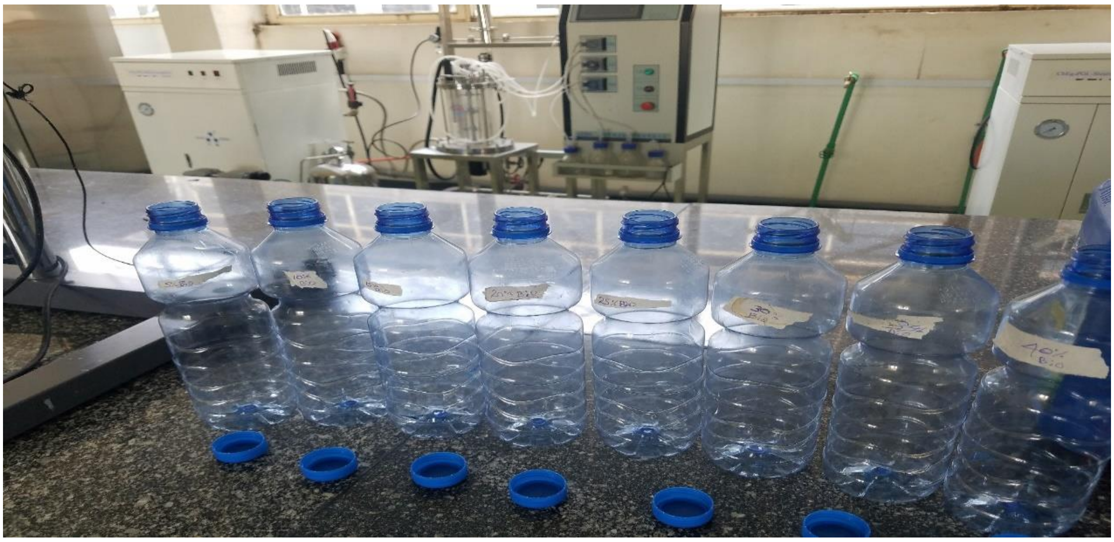
APPENDIX

Appendix A: Chemicals Used



Appendix B: Transesterification Setup

Appendix C: Biodiesel Blending



Appendix D Biodiesel Characterization Result

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Direct: (251) - 011-551 00 45,
(251) - 011-552 60 30,
(251) - 011- 554 19 04,
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Addis Ababa - Ethiopia

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ETHIOPIAN PETROLEUM SUPPLY ENTERPRISE

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Ref. No. 3675/6.1.3.4.4/2013

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ለሜካኒካል ምህንድስና ት/ቤት ክፍል
አዲስ አበባ

ጉዳዩ:- የነዳጅ ምርመራ ውጤት ስለማሳወቅ

በቀን ጥር 05/2013 ዓ.ም በቁጥር አ/አ/ሳ/ቴ/ዩ/ኤ/ሜ/ም/ኮ/9082/2013 በተጻፈ ደብዳቤ የአውቶሞቲብ ኢንጅነሪንግ ተማሪ በሆኑት ናቃቸው ገነት የተዘጋጀ ሶስት (03) የባዮዲዝል ናሙና እንዲፈተሽላቸው በተጠየቅነው መሠረት የናሙናው ፍተሻ ውጤት በዚህ ሸኝ ደብዳቤ በ 01 ገጽ አባሪ በማድረግ የላክን መሆኑን በአክብሮት እንገልፃለን።

ከሠላምታ ጋር

[illegible] አራጋው
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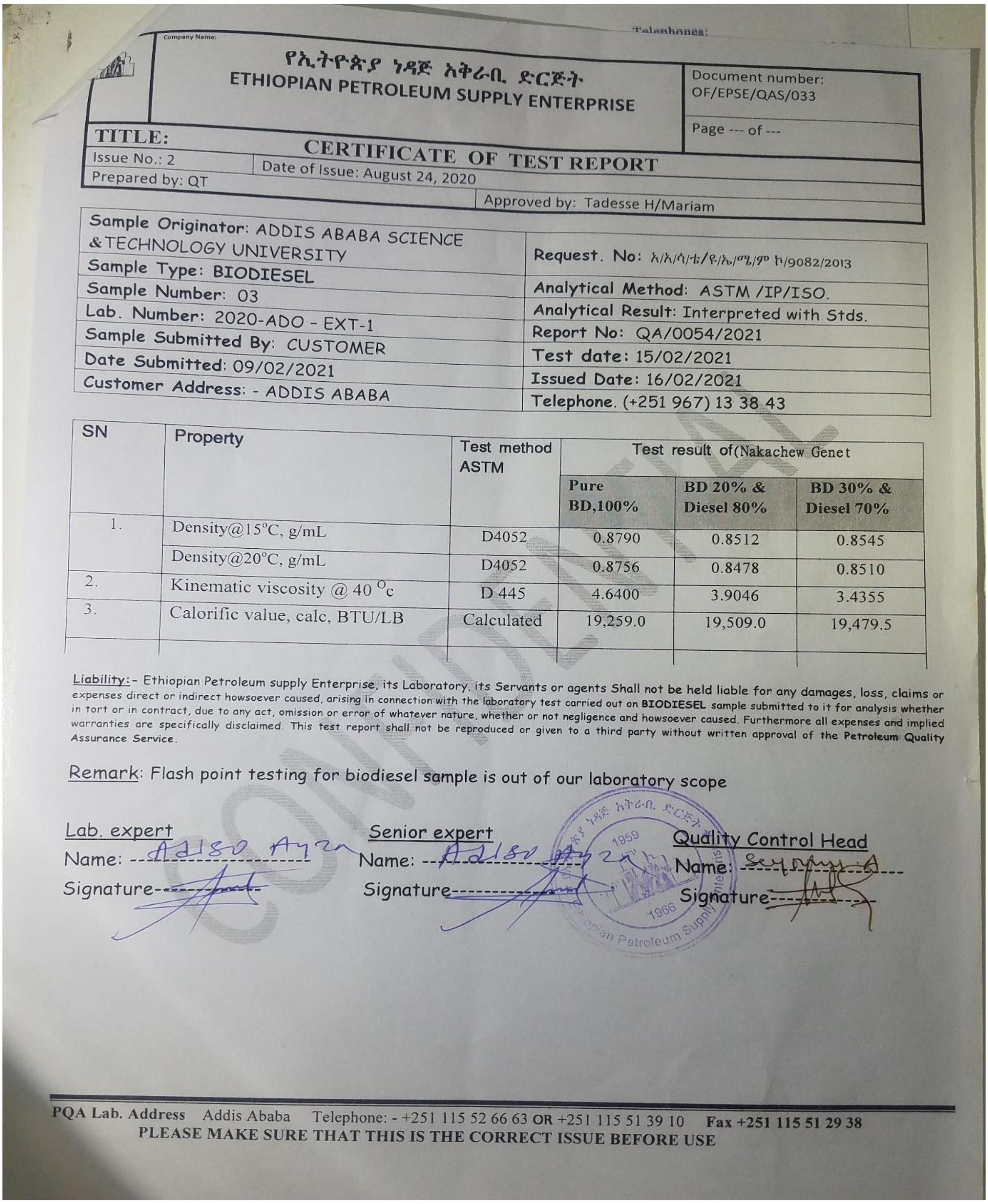
የኢትዮጵያ ነዳጅ አቅራቢ ድርጅት * 1959 1966 * Ethiopian Petroleum Supply Enterprise

ጥራቱን የጠበቀ የነዳጅ ምርት በማቅረብ የአገራችንን ልማት ለማፋጠን በሚደረገው ርብርብ ውስጥ የድርሻችንን እንወጣለን!



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ETHIOPIAN PETROLEUM SUPPLY ENTERPRISE

Document number: OF/EPSE/QAS/033

Page --- of ---

TITLE: **CERTIFICATE OF TEST REPORT**

Issue No.: 2 | Date of Issue: August 24, 2020

Prepared by: QT | Approved by: Tadesse H/Mariam

Sample Originator: ADDIS ABABA SCIENCE &TECHNOLOGY UNIVERSITY	Request. No: አ/አ/ሳ/ቴ/ዩ/ኬ/ሜ/ም ኮ/9082/2013
Sample Type: BIODIESEL	Analytical Method: ASTM /IP/ISO.
Sample Number: 03	Analytical Result: Interpreted with Stds.
Lab. Number: 2020-ADO - EXT-1	Report No: QA/0054/2021
Sample Submitted By: CUSTOMER	Test date: 15/02/2021
Date Submitted: 09/02/2021	Issued Date: 16/02/2021
Customer Address: - ADDIS ABABA	Telephone. (+251 967) 13 38 43

SN	Property	Test method ASTM	Test result of(Nakachew Genet		
			Pure BD,100%	BD 20% & Diesel 80%	BD 30% & Diesel 70%
1.	Density@15°C, g/mL	D4052	0.8790	0.8512	0.8545
	Density@20°C, g/mL	D4052	0.8756	0.8478	0.8510
2.	Kinematic viscosity @ 40 °c	D 445	4.6400	3.9046	3.4355
3.	Calorific value, calc, BTU/LB	Calculated	19,259.0	19,509.0	19,479.5

Liability:- Ethiopian Petroleum supply Enterprise, its Laboratory, its Servants or agents Shall not be held liable for any damages, loss, claims or expenses direct or indirect howsoever caused, arising in connection with the laboratory test carried out on **BIODIESEL** sample submitted to it for analysis whether in tort or in contract, due to any act, omission or error of whatever nature, whether or not negligence and howsoever caused. Furthermore all expenses and implied warranties are specifically disclaimed. This test report shall not be reproduced or given to a third party without written approval of the **Petroleum Quality** Assurance Service.

Remark: Flash point testing for biodiesel sample is out of our laboratory scope

Lab. expert — Name: Addisu Ayza — Signature

Senior expert — Name: Addisu Ayza — Signature

Quality Control Head — Name: Seyoum A — Signature

CONFIDENTIAL

Ethiopian Petroleum Supply Enterprise 1959 1966

PQA Lab. Address Addis Ababa Telephone: - +251 115 52 66 63 OR +251 115 51 39 10 Fax +251 115 51 29 38

PLEASE MAKE SURE THAT THIS IS THE CORRECT ISSUE BEFORE USE

$$\text{Biodiesel yield} = \frac{Volume\ of\ biodiesel\ produced}{Volume\ of\ oil\ used} * 100$$

$$= \frac{450}{500} * 100 = 90\%$$

$$FAME\ Conversion(\%) = 100 * \frac{2\ \text{I}{\circ}\text{CH3}}{3\ \text{I}\alpha\text{CH2}}$$

$$C(\%) = 100 * \frac{2*2.79}{3*1.99} = 93.46$$

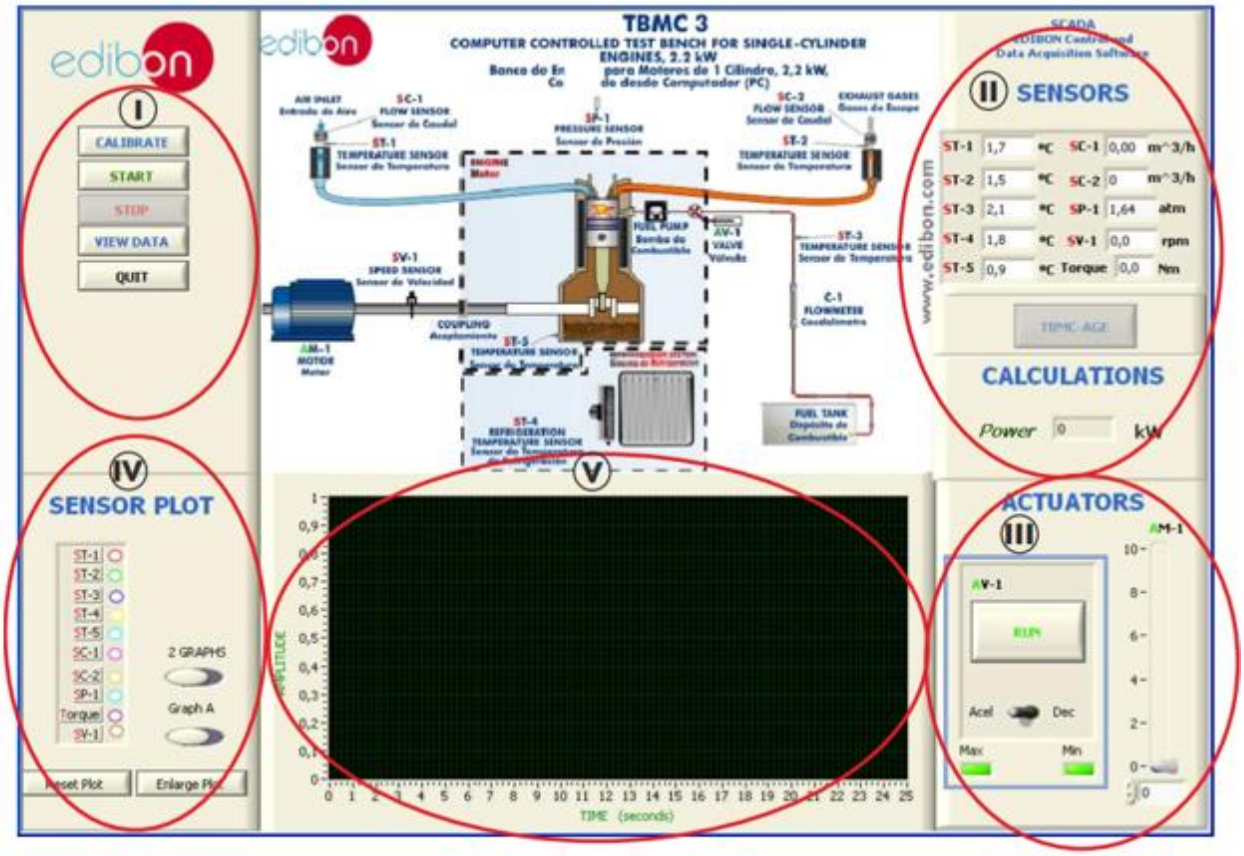
Where;

I∘CH3 = integration value of methoxy protons

IαCH2 = integration value of α-methylene protons

The derived from factors 2 and 3 from the fact that the methyl carbon possesses two protons and alcohol (methanol derived) carbon has three attached protons [63]. ^{1}HNMR and ^{13}C *NMR* spectrum of waste cooking methyl ester is shown in figures 3.11 and 3.12.

Appendix E: Experimental Engine



I =Main software operation possibilities.

II=Sensors displays, real-time values, and extra output parameters. Sensors: ST=Temperature sensor. SC= Flow sensor. SP=Pressure sensor. SV=Speed sensor.

III =Actuators controls. Actuators: AV-1=Control valve (for accelerate and decelerate). AM- 1=Electric motor control.

IV=Channel selection and other plot parameters.

V =Real-time graphics displays.

Appendix F: Uncertainty in Emission Constituents

An uncertainty or error analysis is necessary to establish the bounds on the accuracy of the estimated parameters. Evaluations of some unknown uncertainties from known physical quantities were obtained using the following general equation:

$$\frac{Uy}{Y} = \left[\sum_{i=1}^{n}\left(\frac{1\partial Y}{Y\partial Xi}Uxi\right)^{2}\right]^{1/2}$$

In the equation cited, Y is the physical parameter that is dependent on the parameters, xi. The symbol U_Y denotes uncertainty in Y.

For each emission parameter, the uncertainties measurement errors are established in table 3.7. Uncertainty in emission constituents is obtained by computing its Resolution/Range.

$$\Delta CO/_{CO} = {}^{(Resolution}/_{Range)}co * 100$$

$$\Delta CO2/_{CO2} = {}^{(Resolution}/_{Range)}co2 * 100$$

$$\Delta \mathrm{H}C/_{HC} = {}^{(Resolution}/_{Range)}Hc * 100$$

$$\Delta \mathrm{NOX}/_{\mathrm{NOX}} = {}^{(Resolution}/_{Range)}\mathrm{NOX} * 100$$

Overall measurement uncertainty for emission parameters

Emission parameter	Baseline (Diesel) mode uncertainty (%)	Blended biodiesel mode uncertainty (%)
CO emission	±0.1	±0.1
CO_2 emission	±0.55	±0.55
HC emission	±0.02	±0.02
NO_X emission	±0.025	±0.025

List of Publication

Energy Conversion and Management

Experimental Investigation of Biodiesel Blended Fuel Combustion Efficiency for Single Cylinder Diesel Engine

--Manuscript Draft--

Manuscript Number:	
Article Type:	Original research paper
Section/Category:	1. Energy Conservation and Efficient Utilization
Keywords:	Biodiesel, Emission, Performance, Transesterification, Waste Cooking Oil
Corresponding Author:	Nakachew Genet Addis Ababa Science and Technology University ETHIOPIA
First Author:	Nakachew Genet
Order of Authors:	Nakachew Genet
Abstract:	Biodiesel production from waste cooking oil (WCO) is a potential feedstock to alternative fuel sources. Produced alternative fuel sources were to have a strong emphasis on energy efficiency to substitute the declining world supply of fossil fuels while also improving emission characteristics in diesel engine applications. The development of industrialization and mechanization causes increased fossil fuel consumption and its usage. This study aimed at an experimental investigation of biodiesel blended fuel combustion efficiency for single-cylinder diesel engines under varying engine loads at constant engine speed 1500rpm. The transesterification process was used to produce biodiesel by using NaOH as catalysts. Eight sample biodiesel blends were prepared from B5% to B40%v/v by increasing 5% and B100% to investigate the effect of biodiesels on engine performances. The experimental result reveals that increased WCO biodiesel blends have lower average brake torque, brake power, and brake thermal efficiency than diesel fuels by 16.79%, 4.08%, and 27.9% respectively with an increasing load percentage. In addition, the average BSFC of biodiesel blends was increased by 4.8% than baseline diesel fuel. Related to exhaust gases emission test results were shows that the average CO and HC emissions decreased by 52.2% and 60% with increasing loads and blends and the increment of CO2 and NOx by 28.1% and 45.4% respectively than baseline fuel with increasing blends and loads. Biodiesel derived from WCO was less costly and environmentally friendly and viable to substitute petro-diesel.
Suggested Reviewers:	Dr.PRABHAKAR SEKAR prabhakar@kiot.edu.et
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