Performance Evaluation and Emission Characteristics of Used Cooking Oil Biodiesel Blended with Nanoparticles in Diesel Engine

Tamiru Hailemariam Keto

A Thesis Submitted to

The Department of Mechanical Systems and Vehicle Engineering

School of Mechanical, Chemical and Materials Engineering

A Thesis Submitted in Partial Fulfillment of the Requirement for the Award of the Degree of Master of Science in Automotive Engineering

Program: M.Sc. in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

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Advisor: Dr. Ramesh Babu Nallamothu

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We, the undersigned, members of the Board of Examiners of the final open defense by Tamiru Hailemariam Keto have read and evaluated his thesis entitled "Performance Evaluation and Emission Characteristics of Used Cooking Oil Biodiesel Blended with Nanoparticles in Diesel Engine" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master's in Automotive Engineering

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This is to certify that the thesis entitled "Performance Evaluation and Emission Characteristics of Used Cooking Oil Biodiesel Blended with Nanoparticles in Diesel Engine" submitted in partial fulfillment of the requirements for the degree of Master's in Automotive Engineering, the Graduate Program of the Department of Mechanical Systems and Vehicle Engineerin*g* and has been carried out by Tamiru Hailemariam Keto Id. No PGR/18105/11, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Dr. Ramesh Babu Nallamothu	_______________	_____________
Name of major advisor	Signature	Date

DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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Tamiru Hailemariam Keto

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This MSc Thesis has been submitted for examination with my approval as a thesis advisor.

Name:

Dr. Ramesh Babu Nallamothu

Signature: ____________________________________

Date of submission: ___________________________

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ABSTRACT

Worldwide increases in energy demand and the depletion of petroleum reserves have risen oil prices and the use of this fossil fuel causing environmental degradation. The declining petroleum reserves and environmental concerns are a primary problem related to fossil energy. A substitute energy source that has the potential to be developed in Ethiopia is biodiesel. Used cooking oil is a potential feedstock for synthesizing biodiesel. Production of biodiesel reduces environmental pollution and human health risks. A lot of previous research work was reviewed to realize the behavior of biodiesel in a diesel engine. Since biodiesel has some disadvantages like higher density, higher viscosity, lesser heating value, and short shelf life, etc. At present days with the development of fuel-borne catalysts, modifying fuel with nanoparticles to enhance its properties is attracting the attention of researchers. In this thesis work, an experiment was conducted to evaluate the performance and emission characteristics of a diesel engine run by biodiesel-diesel blend with metal oxide nanoparticles. This work proceeds through different phases such as biodiesel production by transesterification reaction, characterization, modified fuel preparation by using an Ultrasonicator, testing performance and exhaust emission of sample fuels in diesel engines, and compare it with baseline diesel fuel. Sample fuels prepared for testing were B100, B15, and B15 with nanoparticles. The engine performance test result has shown that the average BP of B15C80A40M30, B15C80A20M50 fuel was 3.57%, 3.08% and the average BSFC of B15C80A50M20 fuel was 10.4% lower than B0. The mean output BT of B15C80A40M30 fuel was 2.5% higher than pure diesel fuel. Related to exhaust gases emission test result has shown that the average CO and HC emission of B15C80A40M30 fuels was 25.7% and 20.18% lower than B0. The mean CO, CO_2 and HC emitted by B15C80A50M20 was 25.7%, 9.04%, and 20.2% lower than B0. The average O_2 emissions of B15C80A40M30 and B15C80A20M50 were 1.93% and 1.95% higher than B0, respectively. From performance and emission test results it can be concluded that B15C80A40M30, B15C80A50M20, and B15C80A20M50 can be used as alternative fuels in diesel engines, respectively.

Keywords: Used cooking oil, Biodiesel, Nanoparticles, Ultrasonicator, Diesel engine, Performance, and Emission.

LIST OF ACRONYMS AND SYMBOLS

ASTM D6751-01	American Society for Testing and Materials
ASTU	Adama Science and Technology University
Al	Aluminum
Al_2O_3	Aluminum oxide
AC	Air-cooled
B0/D100	100% diesel
B100	100% biodiesel
B15	Biodiesel 15% blended with diesel 85%
B15C80A20M50	B15+80ppmCeO_2+20ppmAl_2O_3+50ppmMgO
B15C80A40M30	B15+80ppmCeO_2+40ppmAl_2O_3+30ppmMgO
B15C80A50M20	B15+80ppmCeO_2+50ppmAl_2O_3+20ppmMgO
BP	Brake power
BSFC	Brake specific fuel consumption
BT	Brake torque
BTE	Brake thermal efficiency
CI	Compression ignition
CeO_2	Cerium oxide
CuO	Copper oxide
COD	Chemical oxygen demand
CO	Carbon monoxide
CO_2	Carbon dioxide
CRDI	Common rail direct injection
cSt	Centistokes
DI	Direct injection

DG	Diglyceride
DU	Dilla University
EGR	Exhaust gas recirculation
FAAE	Fatty acid alkyl ester
FAME	Fatty acid methyl ester
FFA	Free fatty acids
Fe_3O_4	Iron oxide
$Fe-CeO_2$	Iron doped cerium oxide
GHG	Greenhouse gas
GL	Glycerol
HC	Hydrocarbon
IL	In-line
IC	Internal combustion
kg	Kilogram
KOH	Potassium hydroxide
MG	Monoglyceride
mg	Milligram
MgO	Magnesium oxide
mm	Millimeter
ml	Milliliter
Mn	Manganese
MWCNT	Multi-walled carbon nanotubes
n-PAH	Nitro polyaromatic hydrocarbons
NaOH	Sodium hydroxide
NA	Naturally aspirated
nm	Nanometer

NPs	Nanoparticles
NO_2	Nitrogen dioxide
NO_x	Oxide of nitrogen
O_2	Oxygen
ppm	Parts per million
PCB	Polychlorinated Biphenyl
PM	Particulate matter
PAH	Polyaromatic hydrocarbons
SFC	Specific fuel consumption
SWCNT	Single-walled carbon nanotubes
TG	Triglyceride
Ti	Titanium
UCO	Used cooking oil
UHC	Unburned hydrocarbons
WC	Water-cooled
WCO	Waste cooking oil
WCOME	Waste cooking oil methyl ester
ZnO	Zinc oxide
VCR	Variable Compression Ratio

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CHAPTER ONE

1. INTRODUCTION

1.1 Backgrounds and Justification

The world is presently facing two crises: fossil fuel depletion due to the increase in energy demand and environmental degradation due to fossil fuel use. Our dependence on these energy sources threatens energy security and affects economic growth especially in fuel importing countries like Ethiopia. Almost all of Ethiopia's liquid fuel necessities are imported. This external energy source is unstable and has become a problem for the rapidly growing national economy (Mohd et al., 2013; Yakob, 2010).

The issue of energy security resulting from increased environmental concerns, depletion of petroleum resources, and several other socio-economic aspects has forced researchers to look for alternative fuels from natural resources that are low cost and environmentally friendly (Patel et al., 2015). Renewable resources like vegetable oils (e.g. Cottonseed oil), used cooking oil (UCO), animal fats, and grease are the main source of raw materials for biodiesel production. The biodiesel production cost from the edible oil may cause increases in the feedstock price because it is edible oil types and the demand for this type of oil is a reason for the rise in food issues because the yield of this types of oil became lesser than the demand results in further increases the prices tag. So it prevents by choosing biodiesel feedstock as used cooking oil which does not influence the food consumption issues also reduces the biodiesel production cost (Pavan et al., 2017; Prem & Indraj, 2015).

Used cooking oil (UCO) is the byproduct after cooking or frying food with fresh vegetable oil for an extended time at a higher temperature in the cafeteria or restaurants and it's disposed to the environment as a waste product. It's an alternative source utilized as input for biodiesel production. It's easy to collect, cheaper, and avoid environmental pollution (Arifin, 2009).

The advantage gained using UCO: Used cooking oil (UCO) contains contaminate oxides such as hydro-peroxides, dioxins, epoxides, and polymeric substances (PAHs and PCBs,) which have shown adverse health risks when fed to laboratory animals (Ramakrishna & Satish prakash, 2017). Disposal of UCOs could also have large environmental implications because of high COD (Chemical oxygen demand) like blockages of sewage pipes in kitchen sinks, sewage system corrosion of concrete, and metal element. It also influences installations in wastewater treatment plants. However, the cost of the UCO is generally low and sometimes free. From a waste management standpoint, biodiesel production from UCO is environmentally advantageous, since it delivers a cleaner way of disposing of these products. Used cooking oil as a feedstock for biodiesel leads to a far better life cycle analysis result in a higher reduction in CO_2 emission (Yakob, 2010). Used cooking oil had drawbacks like higher acid value, free fatty acid (FFA) content, viscosity, and density, etc.

Production of biodiesel from feedstocks is possible with various methods like direct utilizing/blending, micro-emulsions, thermal cracking, and the most widely familiar way is the transesterification reaction. In this chemical reaction, the main part of UCO is triglycerides (TG). It is a reaction used to convert TG into three separate ester molecules and glycerol (GL) in the presence of alcohol and a base catalyst. In this reaction, TG is first reduced to diglycerides (DG). The DGs are afterward reduced to MG. The MG is finally converted to glycerol. In each step, one mole of an ester is formed (Gnanaprakasam et al., 2013).

The transesterification reaction is influenced by various parameters, for instance, acid value, presence of FFA and water content, reaction time and temperature, alcohol type, catalyst concentration so on.

Biodiesel is an alternative fuel for the substitution of diesel fuel which is biodegradable, non-harmful, and renewable utilized in a diesel motor. Biodiesel and petro-diesel have comparable fuel properties and completely miscible on each other. It’s produced from vegetable oil or animal fats utilizing transesterification reaction in the presence of catalysts and alcohols (Alleman et al., 2016).

The production and use of biodiesel from vegetable oil have brought fundamentally up in various nations around the world such as in Europe (corn oil), USA (soybean oil), Asia (palm oil, coconut oil), India (Jatropha oil, Karanja oil) (Ramakrishna & Satish prakash, 2017) and it is a fuel which is new to Ethiopia and is neither presently marketed nor utilized. However, there is a developing interest in biodiesel advancement in Ethiopia. Both neighborhood and outside organizations are intrigued to cultivate non-eatable feedstocks like Jatropha for biodiesel production. At the research level biodiesel was produced from various oil such as Cotton oil, Jatropha oil, Caster oil were blended with diesel and NPs tested for performance and emission analysis, Regarding UCO-based biodiesel, it is currently produced at a research-level from various feedstocks such as waste sunflower oil, waste palm oil, waste cottonseed oil, etc. Many researchers compared the physical and chemical properties of UCO biodiesel fuels with diesel and it has properties like higher cetane number-49, lower calorific value, higher density, higher kinematic viscosity, higher flash. As a result of these physicochemical properties, the combustion characteristics of UCO biodiesel have shorter ignition delay, higher ignition temperature, higher ignition pressure, and peak heat release in contrast to diesel fuel. Related to engine performance parameters UCO biodiesel has lower brake power and torque due to lower heating value and higher brake specific fuel consumption due to higher fuel density, higher fuel consumption, and lower brake power in comparison to diesel fuel. Related to emissions such as HC and CO decreases and NO_X increases with WCO biodiesel compared to pure diesel(Karikalan et al., 2014).

Environmental benefits of biodiesel: Emission from diesel engines has the potential to affect the ecosystem and human health due to the consumption of diesel fuel. The pollution released from diesel engine such as THC, GHG, NO_x, CO, PM, SO_x, VOC, PAH, and n-PAH compounds (Norhafana et al., 2018). To reduce both environmental and human health impact consumption of biodiesel could reduce CO_2 and other harmful substances like pure biodiesel (78.5% less CO_2 emissions. reduce GHGs by 41%, PAH compound reduced by 75-85% and n-PAH compound reduced by 90%) in comparison to neat diesel fuel. Also, advantages gained by using biodiesel as a diesel fuel it’s easy for preparation and transportation, non-sulfur and non-aromatic content, higher combustion efficiency, higher cetane number, sustainability, and better biodegradability. However, biodiesel has its drawbacks such as higher viscosity and density, low energy content to volume ratio, higher cloud point and pour point, shorter storage life, higher nitrogen oxide emission, lower engine speed and power, excessive carbon deposition and gum formation, engine compatibility, high price, and higher engine wear, pure biodiesel is brought to full use in some engines with no modifications (Mohd et al., 2013). To improve the disadvantage of biodiesel properties it was blended with conventional diesel fuel and selected nano additives that enhance the properties of fuel were added.

1.2 Nanoparticles

At present days with the development of nanotechnology, the addition of nanoparticles (NPs) for enhancing the physical and chemical properties of fuels, improve engine performance and combustion characteristics, and reduce emission gates the attention of researchers. Properties of biodiesel and diesel fuel have its drawback to enhance these need NPs (Soudagar et al., 2018). Nanoparticles are considered as a novel and promising fuel borne catalyst to advance the fuel properties, due to their higher surface area/volume ratio, quick vanishing and shorter ignition delay physical characteristics. The size of nano additives ranges from one to a hundred nm (Shaafi et al., 2015).

A. The requirement of nano additives

The basic requirement of NPs added to diesel-biodiesel fuels in varying amounts to perform specific functions: (1) the additives should decrease the tailpipe emissions, (2) raise the viscosity index, (3) in the engine and particulates filters there is an increase in oxygen concentration, (4) ignition delay time reduced and flash point decreased, (5) fluid stability increased, and (6) decreases in wear agents onto a metal surface.

B. Types of nano additives

Nanoparticles (NPs) were derived from various sources such as Ferro material, polymeric materials, ceramics, non-organic materials, metal oxides, and their classification was based on the material, shape, size, origin, and occurrence. Metal-based NPs (Al, Mn, and Ti, etc), metal oxide-based NPs (CeO_2, ZnO, Al_2O_3 , MgO, and CuO, etc). Carbon nanotube NPs (SWCNT and MWCNT), and Magnetic nanofluid NPs (Ferrofluid (Fe_3O_4).

C. Preparation of nanofluids

Preparation of nano-additives and base fuel was done utilizing the Ultrasonicator bath. The measured amount of NPs in the varied range from 50ppm-200ppm was blended with base fuel using Ultrasonicator due to ultrasonic vibration at a high frequency (40 kHz). Furthermore, the time interval in vibrator for a mass fraction of 150ppm (0.15g) is 40 minutes and for the other three mass fractions 50ppm (0.05g), 100ppm (0.1g), and 200ppm (0.2g) were 30, 35, and 45 minutes, respectively. The dispersion and stability of NPs in the base fuel were increased. It was also observed that the NPs undissolved in the base fuel; however, it was expected that dissociative adsorption might exist between base fuel and nano additives (Soudagar et al., 2018).

D. The optimum dosage of nanoparticles

The optimized dosage of NPs can be used as additives in diesel and biodiesel fuel to improve the calorific value and cetane number, but viscosity, flash point, and density of fuel are slightly increased. The addition of NPs improves engine performance such as decreases in BSFC and increases in BTE with an increase in a dose up the rate of NPs in fuels. Reduction in exhaust emission due to adding of NPs like oxide of nitrogen (NO_x), Carbon monoxide (CO), and Hydrocarbon (HC) emission. Nano additives with fuel result in better combustion characteristics, rise in-cylinder pressure, and heat release rate (Norhafana et al., 2018).

The literature from previous research works on biodiesel and its blends with petro-diesel fuel and nanoparticles (NPs) were used to prepare nonfuel to run conventional diesel engine was better than petro-diesel in comparison. The addition of NPs in biodiesel blended fuels improving fuel properties enhances engine performance and reduces exhaust gas emission. This study work will be intended to evaluate the nanofluids prepared from used cooking oil methyl ester blended with diesel and metal oxide NPs (oxide of aluminum, cerium, and magnesium).

1.3 Statement of the problem

The issue of energy security coming about because of higher consumption of world petroleum reserves, increases in the price of fossil fuel, and ecological concerns has urged governments and scientists to search for alternative energy sources like biofuels got from biomass. Our reliance on these energy sources threatens energy security and affects economic growth mainly in fuel importing countries like Ethiopia are facing a foreign exchange crisis. Using used cooking oil (UCO) to prepare food for human and animal causes some serious health problem (risk of cardiovascular diseases, liver problem, and cancer.), and disposing UCO to the environment resulting in blockage of a sewage system and kitchen sink corrosion, pollution to river and water plant (Patel et al., 2015). The assessed yearly volume of WCO removal 536650 liters/year was collected from different cafeterias and hotels in Addis Ababa (Yakob, 2010). Accordingly, the production of biodiesel from UCO would assist with lessening the production cost, health, and environmental concern, and conserve assets by changing over risky waste into fuel. UCO biodiesel has its drawbacks like higher viscosity, lower calorific value, and lower engine performance. Also, just like petro-diesel, the usage of biodiesel and its blends as fuel causes harmful emissions and lower performance in diesel engines. Here, for these identified challenges. Biodiesel blended fuel with Al_2O_3 , CeO_2 , and MgO NPs in optimized blends of fuel will help further reduce harmful gases and improve engine performance. Therefore the goal of this study is to solve all mentioned problems.

1.3 Objectives of thesis work

1.3.1 General objective

The primary objective of this thesis work is to evaluate the performance and emission characteristics of diesel engine operated with used cooking oil biodiesel nanoparticles blends.

1.3.2 Specific objectives

The specific objectives are to:

- Produce biodiesel from UCO by transesterification reaction on a laboratory scale.
- Prepare blended fuels (B15) and B15 with metal oxide NPs using Ultrasonicator.
- Characterize the physicochemical properties of the three fuel samples biodiesel (B100), blended fuels (B15), and blended fuels with NPs (B15C80A40M30).
- Test and analyze both performance and tailpipe emission of four blended fuels (B15, B15C80A40M30, B15C80A50M20, and B15C80A20M50) in comparison with diesel (B0) as a baseline fuel.

1.4 Significance of the thesis work

The significance of the thesis work is the following

- It helps to reduce environmental pollution, avoid waste oil disposal, and negative impacts on human health.
- It helps to reduce the biodiesel production cost, access to locally produced fuel.
- It helps in giving supplemental fuel to a diesel engine.
- It assists with diminishing exhaust gases emission.
- Reduce the oil import bill and secure the oil fuel supply.

1.5 Beneficiaries

Vehicle owners, automobile industries, society, researchers in the field, and the nation overall get benefited.

1.6 Scope of this thesis work

The scope of this thesis work is to evaluate the performance and emission analysis of diesel engines run by biodiesel blended fuel (B15), and biodiesel blended fuels with nanoparticles. Collection of used cooking oil (UCO) and laboratory-scale production of biodiesel from UCO. Characterization of biodiesel and its blend with oxide of cerium, aluminum, and magnesium to understand the improvement in fuel properties. Finally, this work concerns preparing biodiesel blended fuel and blended fuels with nanoparticles (NPs) to evaluate the performance and emission analysis of the diesel engine compared with a baseline diesel fuel. The test fuels were prepared for engine test (B0, B15, B15C80A40M30, B15C80A50M20, and B15C80A20M50). Under this study, the evaluation of the performance (i.e, BP, BT, BSFC) and emission analysis (i.e CO, CO_2, HC, and O_2) concerned with the change in engine speed.

1.7 Limitation of thesis

There were a few difficulties faced through this thesis works. In this manner challenges were the unavailability of exhaust gases analyzer, diesel engine, and laboratory material and apparatus. The determinations of physicochemical properties of the biodiesel and its blends were accomplished for just certain properties (i.e calorific value, cloud point, density, kinematic viscosity, and total acidity) because of the lower budget. The evaluations of performance tests in the diesel engine were carried out for BP, BT, and BSFC. Furthermore, emission analysis was carried out for CO, CO_2, HC, and O_2. The limitation of the exhaust gas analyzer does not allow the measurement of oxide of nitrogen emission.

1.8 Organization of thesis

This thesis consists of the following 5 chapters. Chapter 1 gives an overview of the study conducted. It also included with background and justification of the study, statement of problem, objective, scope, limitation, significances, nano-additives, and organization of the study are parts of this chapter. Chapter 2 reviews the previous research works that were conducted by other people and identifying the problem. Chapter 3 is the methodology. This chapter is about the method used and the progress of thesis work such as a collection of used cooking oil (UCO), production of biodiesel through the transesterification process, characterization, preparation of modified fuels with nano additives. Chapter 4 includes the result of the experiment conducted like characterization, engine performance, and exhaust emission test results and a discussion will be set up in this chapter. Chapter 5 which is the last chapter includes a summary of findings, conclusion, and recommendation for future works. Finally, the references and appendix will be expressed.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

A literature review is the most significant activity to be implemented in all research work. Various sources like journals, books, reports, conferences, and previous research works were reviewed interrelated to blended fuels with NPs to formulate the problem and research topics. In this part different research papers were referred to in the terms of nano-additives preparation, biodiesel blending with NPs, the effect on fuel properties, effects of engine performance, combustion, and emission in a diesel engine. Also, few research works were reviewed in terms of selection of feedstock, biodiesel production, transesterification reaction, and also engine performance test and emission test. The literature review was organized as follows.

2.2 Categorization of literature review

In general, a literature review can be categorized into sixes groups:

1. Literature reviews of prior studies supporting this thesis work
2. Effect of nano additives on fuel properties and the parameters of CI engine
3. Biodiesel
4. Process of producing biodiesel and related techniques
5. Transesterification reaction
6. Biodiesel fuel properties

2.2.1 Literature reviews of prior studies supporting this thesis work

Previous research works indicated that biodiesel is an alternative fuel for petro-diesel in transportation sectors. In recent years expanding of industrialization and mechanization has made the transportation sector of powerful importance. The higher consumption of diesel fuel in these sectors increases environmental pollution, depletion of petroleum reserves, rising in prices, etc. Alternative fuel like biodiesel is needed to reduce this problem and biodiesel has its advantage such as biodegradable, non-harmful, no 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 or nanoparticles result in enhanced fuel properties and show a good effect on engine performance, combustion and exhaust emissions.

(Yakob, 2010) experimented with the production of biodiesel from waste cooking oil (WCO). By using a single step alkaline transesterification process he was synthesized biodiesel from WCO. The produced biodiesel had good physical and chemical properties aside from the kinematic viscosity of 6.3 mm^2/sec were out of the ASTM standard limit of biodiesel. At the end of his work, he concluded that WCO was a potential feedstock for biodiesel production. A biodiesel/diesel blend is utilized as an alternative fuel in a diesel engine.

(Debela, 2018) conducted his work on the production of biofuel from used cooking oil (UCO). By using the transesterification process. The produced biodiesel had very good characteristics including the calorific value 41.243MJ/Kg except higher cloud point 16℃ within the limit of ASTM specification of biodiesel. Finally, he also concluded that used UCO as a potential feedstock for biodiesel production. Biodiesel/diesel blend is used as an alternative fuel in a diesel engine.

(Hadish, 2010) has experimented on performance and emission characteristics in the four-stroke cycle diesel engine. He has produced biodiesel from Jatropha carcus seed oil and blends in five different proportions with diesel (B80, B40, B20, B10, and B5). The performance and tail-pipe emission analysis tests were accomplished for all fuel blends result indicated that B20 and B100 had less emission than all other blends. The output brake power (BP) and output brake torque (BT) of B20 was found better than all blends next to conventional diesel. The final smoke from pure biodiesel smell spicy and its smoke density was very little as compared to all sample fuels. It was concluded that the biodiesel synthesized from Jatropha carcus seed oil was run well in the CI diesel engine without significant modification.

(Ramakrishna & Satish prakash, 2017) was experimented on performance evaluation and emission analysis of waste cooking oil methyl ester (WCOME) and its blends with conventional diesel in a single cylinder, 4-strokes, and a WC diesel motor. Test fuels were B15, B25, B35, and D100 were operated in a diesel engine at variable engine load and torque vs various engine parameters (related to engine performance like BTE, mechanical efficiency, thermal efficiency, BSFC, indicated power, and also relate to emission NO_x, CO, and THC,). Finally, the author concluded that the BTE of blended fuels was decreased as compared with baseline diesel fuel at full load conditions. The BSFC was increased with the blended fuels when compared to diesel. Related to CO and HC tailpipe emissions were reduced significantly with the blended fuels when compared with D100. Relatively a slighter rise in the oxide of nitrogen emission was found while working with all blends at all loads. The energy content of B100 has a calorific value of 40985KJ/Kg. From the above analysis, the blended fuel B15 showed better engine performance at full load condition for BTE and BSFC and related to exhaust gas emission reduction NO_x, CO, and HC as compared to other blends and baseline fuel. So the B15 blend was used as an alternative fuel in the DI diesel engine.

(Ulusoy et al., 2018) was examined the performance and emission analysis of WCOME in a 4-stroke, 4-cylinders, NA diesel engine. The test fuels B10, B20, B30, B40, B15, and D100 were operated in a diesel engine at varying engine load and engine speed. The engine operating condition was at both increasing engine load and engine speed. The engine performance test was conducted for brake power and brake specific fuel consumption vs different fuels were D100, B10, B20, B30, B40, and B50. Related to exhaust gas emission test was conducted for smoke, NO_x, CO, CO_2, THC, and PM emission. At the end of the work, the author concluded that biodiesel from WCO, if energy content or calorific value 39560KJ/Kg was lower than the B10 blend, was better in both energy efficiency and reduction in emission like THC and CO than other blended fuels.

(Ranjan et al., 2018) was experimented using biodiesel produced from waste cooking oil (WCO) and its blends as followed B10, B20, and B100 with nano-additive magnesium oxide (MgO) in concentrations of 20ppm, 30ppm, 40ppm, and 50ppm in single-cylinder, WC diesel engine. The addition of MgO NPs in biodiesel fuel was significantly improved pour point (PP), cloud point (CP), cold filter plugging point (CFPP), oxygen contents, and no significant variation in density, viscosity, and moisture content in properties of biodiesel. The 30ppm concentration of MgO NPs was optimum for the improvement in CFPP, CP, and PP properties of test fuels. The operating condition of diesel engine for engine performance test and emission test was variable engine load vs BSFC, BTE, BP, and CO, CO_2, HC, NO_x, SO for all fuel blends. The engine performance test showed that fuel blended with NPs B10+30ppmMgO, B20+30ppmMgO, and B100+30ppmMgO had higher BSFC, BTE, and BP than pure biodiesel and blended fuels (i.e. B20, and B10). The emission test result indicated that blended fuels with nano additives released less CO and HC emission, but more CO_2 emissions than other fuels B100, B20, B10, and D100. Oxide of nitrogen emissions for B100, B20, B10, and blended fuel with NPs was more than baseline diesel fuel. Blended fuels with NPs were less opaque, on average 4.68% when compared to B100, B20, and B10. Fuels blended with NPs showed a high peak cylinder pressure and lesser heat release rate than biodiesel and its blends. As a result of the study, the MgO NPs at 30ppm concentration can be used as additives for biodiesel to improve properties, engine performance, and combustion characteristics and to decrease exhaust emissions when used in diesel engines.

(Aalam & Saravanan, 2015b) experimented with performance improvement of CR diesel motor using Mahua methyl ester (biodiesel) and its blend B20 with Al_2O_3 and Fe_3O_4 NPs in different concentrations 40ppm and 80ppm with the help of Ultrnasonicator. The test fuels were (B20, B20+40ppmFe_3O_4, B20+40ppmAl_2O_3), and (B20, B20+80ppmFe_3O_4, B20+80ppmAl_2O_3), and baseline diesel fuel (D100). Experiments were conducted on Kirloskar AV1, 4-strokes, single-cylinder diesel engine assisted by the CRDI system. The operating condition of a diesel motor includes engine performance, emission analysis, and combustion characteristics were SFC, BTE, HC, CO, smoke, NO_x emission, cylinder pressure, heat release rate Vs BP. The results were indicated that significant improvement in BTE was seen with NPs blended B20 at optimized operating conditions. Especially B20+40ppm Al_2O_3 were effective in improvement of BTE compared with B20+40ppmFe_3O_4. There was no significant improvement in BTE when the concentration of nano-additives was further increased. With the dispersion of NPs to B20 blended fuels, the degree of air pollutants in the tailpipe emission, such as HC, CO, and smoke, was significantly decreased when contrasted with that of B20 and diesel. At the dosage of 40ppmAl_2O_3, HC emissions will be 82ppm and the case of 40ppmFe_2O_4, it 84ppm. The smoke emission of B20 was reduced on the addition of NPs by about 15-18%, especially at full load. The nano fuel B20 with Al_2O_3 NPs showed higher cylinder gas pressure and heat release rate at optimized operating conditions. Hence, Al_2O_3 NPs is efficient in improving performance and reducing the exhaust harmful pollutants compared with Fe_2O_4 NPs from the CRDI diesel engine when using B20 as fuel.

(Sajith, A, et al., 2010) was conducted experimental investigations on the effects of CeO_2 NPs on biodiesel from jatropha in NA, 4-stroke, single-cylinder, WC compression ignition diesel engine. The addition of NPs at the dosage level from 20ppm-80ppm into biodiesel was increased flashpoint, the kinematic viscosity of biodiesel, but it did not show significant variation in the cold temperature properties of biodiesel. The prepared biodiesel and its blends were B100, B100+20ppmCeO_2, B100+40ppmCeO_2 and B100+80ppmCeO_2. The operating condition of a diesel motor includes both engine performance and emission analyses were engine load (0-6) vs BTE, HC, CO, and NO_x emission. Finally, the authors concluded that engine tests with nanofluids at vary concertation of NPs from (20–80 ppm)CeO_2 showed an enhancement in the BTE up to 1.5% of the diesel motor. Emission levels of HC and NO_x were appreciably reduced with the addition of NPs. It is agreed that CeO_2 being thermally stable encourages the oxidation of HC and reduction of NO_2, thus acting as an effective catalyst, when added in the nanoparticle form.

(Kumar, A, et al., 2019) investigated the effect of injection pressure on the combustion, performance, and emission characteristics of biodiesel from WCO with CeO_2 nanoparticle as an additive in a single-cylinder 4-stroke NA compression ignition engine. The test fuels were B20 and B20+80ppmCeO_2. The engine was operated with B20 at the rated injection pressure of 180 bar at loading conditions of 25-100% of the full load to obtain the baseline data and B20+80ppmCeO_2 at the rated injection pressure 210bar and 240bar with the same loading condition and the experiments were repeated. Engine operating parameter for combustion characteristics was (crank angle (degree) vs ignition delay, cylinder pressure, heat release rate, cumulative heat release, a mass fraction of burnt gases, mean gas temperature), for both engine performance and emission analysis were engine load vs BTE, BSFC, HC, NO_x emission, smoke opacity for two blended fuels. Finally, the author concluded that nano fuel (B20+80ppmCeO_2) at 240bar injection pressure improves engine combustion characteristics, leading to higher peak pressure, and higher heat release rate, and cumulative heat release. Ignition delay was reduced by 25% for B20+80ppmCeO_2 at 240 bar injection pressure compared with the neat B20 at 180 bar injection pressure. The mean gas temperature and mass of gas burnt are both higher for the blended fuel with NPs than B20. A maximum increase of 2.5% in thermal efficiency, and reduction in (BSFC-3.1%, HC-20%, NO_x -23% and 14% of smoke emission) at 240bar injection pressure was observed for blended fuels with NPs when compared with B20. In general, a higher injection pressure together with cerium oxide nanoparticle additives was helped to improve the performance of the engine and also to reduce emissions.

2.2.2 Effect of nano additives on fuel properties and the parameters of CI engine

At present for automobile fuels, the ignition of various nano additives is utilized to improve the nature of biodiesel fuel and diesel fuel to gather up the most needed performance level. The addition of NPs in diesel fuel, biodiesel fuels, and its blended fuels will assist to improve engine parameters like combustion, performance, and emission in diesel engines and also enhance fuel qualities. The selection of fuel additives will depend on the drawback of biodiesel fuel properties like calorific value, density, viscosity, toxicity, economic feasibility, auto-ignition temperature for the fuel mixing process. The fuel additives such as automotive performance enhancement products are being differentiated in terms of their application and drawbacks are metal-based additives, oxygenated additives, cetane number improver additives, antioxidant additives, ignition promoter additives, and lubricant additives, etc to understand the aims of this planned research, this section reports the outcomes of various research papers on fuel blended with NPs used in diesel engine and its effect on fuel properties and on performance characteristics

i. Effects of nano additives on fuel properties

(Fangsuwannarak & Triratanasirichai, 2013) Palm oil biodiesel blended with diesel fuel in concentration from (2-100%) and also with TiO_2 nanoparticles with a dosage of 100ppm and 200ppm and characterize the test fuel using ASTM standard procedure, They saw that viscosity was decreased by rising the amount of nano-TiO_2 as compared to palm oil biodiesel. However, the heating value was increased with rising in the concentration of additives

(Karthikeyan et al., 2014) No variation on properties like density, kinematic viscosity, and a flashpoint was notice pomoplion stearin wax biodiesel/diesel blended with the addition of zinc nano NPs. The enhancement in cetane index and heating value and was observed with the addition of NPs in blended fuels.

ii. Effects of nano additives on the parameter of the CI engine

(Mehta et al., 2014) an experiment in a single cylinder CI engine to investigate combustion characteristics, engine performance, and emission parameters. The test fuels prepared for engine tests were A1(D100+Al), F1(D100+Fe), and B1(D100+Br) NPs. These nano fuel result in a reduction of ignition delay and enhanced combustion rates. The BTE increased by 9%-A1, 4%-F1, and 2%-B1 as compared to diesel at higher loading conditions. The specific fuel consumption was reduced by 7%-A1, but it was almost the same for F1 and B1 as compared to baseline diesel at maximum loading conditions. Volumetric reduction of hydrocarbon emission was 4%- A1 and 8%-F1 and carbon monoxide emission was 25-40% for both nano fuel as compared to diesel. The NO_x emission marginally increased compared to baseline diesel because of the rise in burning temperature in the combustion chamber.

(Prabhu et al., 2015) a conducted experiment in a diesel engine to evaluate the performance and emission characteristics of fuel blends. The prepared fuel blends were B20 (neem oil methyl ester and diesel) with TiO_2 NPs or (B20+250 ppm TiO_2 and B20+500 ppmTiO_2). The fuel blend with nano additive was decreased in BSFC and increased in BTE as compared to B20 and baseline diesel. By the addition of NPs CO, HC, and smoke emission were reduced, while NO emission slightly increased as compare to biodiesel blend and pure diesel and.

(Hawi et al., 2019) Was Experimented with a four-stroke, single-cylinder, DI diesel engine to investigate the effect of fuel additives in biodiesel (produced for waste cooking oil)-diesel blend the combustion, emission, and performance characteristics in a diesel engine. The addition of iron-doped cerium oxide NPs in biodiesel–diesel blend (B30+90ppm 20%$Fe - CeO_2$) increases cylinder peak pressure up to 3.5% NO_x emission for the B30 blend was decreased by up to 15.7% with the addition of iron-doped cerium oxide nanoparticles. The addition of NPs to the D100 and B30 fuels had no significant effect on hydrocarbon emissions. Carbon monoxide emissions were decreased by up to 24.6% for B30 and 15.4% for B30 with nano additives relative to D100. Better engine performance was noted for B30 with 20% $Fe - CeO_2$ as compared to 10% $Fe - CeO_2$, regarding cylinder pressure and emissions. Additionally, the fuel blend B30 with 10% $Fe - CeO_2$ NPs noted better BSFC and BTE in low-to-medium loads compared to B0. Finally concluded that B30 20% iron-doped cerium oxide addition had better engine performance and 10% iron-doped cerium oxides addition had better BSFC and BTE.

iii. Effect of nano additives oxide of aluminum, cerium, and magnesium nanoparticles

The effect of NPs specifically select for this study was based on the drawback of biodiesel and its influence on fuel properties like density, kinematic viscosity, cloud point, calorific value, and total acidity, and also its effect on engine performance parameters like brake specific fuel consumption(BSFC), brake power (BP), and brake torque (BT), brake thermal efficiency (BTE) and emission characteristics those are carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO_2), oxide of nitrogen (NO_x) emission etc. The summary of the effect of metal oxide NPs was shown in Table 2.1, Table 2.2, and Table 2.3.

Table 2.1 Effect of aluminum oxide nanoparticles in diesel and biodiesel blend on diesel engine performance and emissions.

Aluminum oxide nanoparticles Al_2O_3(A), Diesel (D100 or B0), Biodiesel(B100)				
References	Engine Type	Test conditions	Test fuels	NPs dosage ppm
Mahalingam & Ganesan, 2018	1-cylinder, DI, diesel engine	1500pm Variables load At full load	rubber seed oil biodiesel (B100) B20,B20A10, B20A15, B20A20 compared with B0	A10ppm A15ppm A20ppm
Razek et al., 2017	1-cylinder DI diesel engine	1500pm Variables load At full load	Jatropha biodiesel(B100) B20, B20A20, B20A30, B20A40 compared with B0	A20ppm A30ppm A40ppm
Debas, 2019	1-cylinder, 4-S, NA, diesel engine	1154-3840rpm Full load	Cotton seed oil methyl ester (CSME) B20,B20C50,B20A50, B20A50C50 compared with B0	Cerium oxide (C) C50ppm, A50ppm A50C50ppm
(Aalam & Saravanan, 2015a)	1- cylinder 4-S & CRDI	1500rpm Variable load @100% load	Mahua methyl ester(MME), B20A50, B20A100 compared with B0	A50ppm A100ppm
Aalam et al., 2015	I-cylinder, 4-S, AC& CRDI	1500rpm Variable load	Zizipus jujube methyl ester (ZJME) B25, B25A25, B25A50 compared with B0	A25 ppm A50 ppm
Ramesh et al., 2016	1-cylinder 4-S diesel engine	1500rpm Variable	Poultry Litter oilMethyl Ester(PLOME)B20,B20 A30 compared with B0	A30 ppm

References	EngineType	Test conditions	Test fuelsNPs	dosage (ppm)
Sivakumar et al., 2018	1-cylinder, WC, 4-S, DI	1500rpm Variable	Pongamia methyl ester (PME),B0.B25 B25A50 and B25A100	A25ppm A50ppm
Gumus et al., 2016	1-cylinder NA,WC,4S diesel engine	1000-4000rpm Full load (BT,BP,BSFC) Variable load (CO, HC)	Diesel (D100 or B0) B0A50,B0Cu50 compared with B0	Copper oxide (CuO) Cu50ppm A50ppm
Aalam & Saravanan, 2015b	1-cylinder WC, 4S; CRDI diesel engine	1500rpm Variable load	Mahua methyl ester (MME) B20, B20I40, B20A40,B20I80, B20I80 compared with B20	Iron oxide(I) I40ppm A40ppm I80ppm A80 ppm
Mohan et al., 2015	1-cylinder 4S, AC, CI engine	1500rpm 0-16 load(kg)	Diesel compared with B0A50	A50ppm

Table 2.1 Continued

Performance and Emission characteristics Increase (↑) and Decrease(↓)							
Refer	BP kW	BT Nm	SFC or BSFC kg/kW-hr	CO %	CO_2 %	HC ppm	NPs dosage (ppm)
Mahalingam & Ganesan, 2018	-	-	SFC ↑5.7%	↑50%	-	↑29.4%	A20ppm
Razek et al., 2017	-	-	BSFC ↑13.35% ↑5%	↓22% ↓32%	-	↓7.5% ↓12%	A20ppm A40ppm

References	BP kW	BT Nm	BSFC Kg/kWhr	CO %	CO_2 %	HC ppm	NPs ppm
Debas, 2019	↑3.34%	4.41%	1.124%	↓9.7%	↓8.8%	↓18.52%	A50ppm
Aalam & Saravanan, 2015a	-	-	SFC ↑8.3%	CO ↓14%	-	HC ↓31%	A50ppm
Aalam et al., 2015	- -	- -	SFC ↓ ↓6%	g/kWhr ↓3.951 ↓6.284	- - -	g/kWhr ↓0.162 ↓0.138	A25ppm A50ppm
Ramesh et al., 2016	-	-	-	↓	-	↓	A30ppm
Sivakumar et al., 2018	-	-	BSFC↓	↓	-	↓	A50ppm
Gumus et al., 2016	↑	↑3.28%	BSFC ↓1.2%	↓11%	-	↓13%	A50ppm
Aalam & Saravanan, 2015b	-	-	BSFC ↓5.12%	↓19%	-	↓6.8%	A40ppm
Mohan et al., 2015	-	-	BSFC ↓7%,	↓25%	-	↓8%,	A50ppm

Table 2.2 Effect of cerium oxide nanoparticles in diesel and biodiesel blend on diesel engine performance and emissions

Cerium oxide nanoparticles CeO_2(C), Diesel (D100 or B0), Biodiesel(B100)				
Reference	Engine Specification	Test conditions	Test fuels	NPs dosage
Chandran et al., 2020	1-Cylinder, 4 S, AC diesel engine	1500 rpm Variable load	Tire oil biodiesel (B100) B30, B30C50, B30C100 compared with B30	C50ppm C100ppm
Seela et al., 2019	1-Cylinder, 4-S, WC diesel engine	1500 rpm Variable load	Mahua biodiesel (B100), B20, B50,B20C50,B20C100, B20C50, B50C100 comapred with B0 and B20	C50ppm C100ppm
Ramarao et al., 2015	1-Cylinder DI 4-S diesel engine	3000rpm Variable load @100% load	Cotton seed biodiesel(B100) B20, B50,B20C40, B20C80, B20C40, B50C80 compared with B0	C40ppm C80ppm
Kumar et al., 2020	1-cylinder, 4-S, WC, CI	1500rpm Variable load	Waste cooking oil (B100) Diethyl ether (DEE2%) B30,B40,B40DEE5C, B40DEE5C compared with B20	C80ppm
Prakash et al., 2019	1-cylinder, NA,4-S, WC, DI, CI	1500rpm Variable load	B0C5, B0C7.5, B0C10, B0C15 compared with B0	C5ppm- C15ppm,
Kalaimurugan et al., 2020	Kirloskar 4S, 1-cylinder, WC, DI	1500rpm Variable 0-100%	Neochloris oleoabundans algae oil (B20) blended with neat B0 B20C25,B20C50, B20C75, B20C100 compared with B20	C25ppm, C50ppm, C75ppm C100ppm.
Sajith, Sobhan, et al., 2010	1-cylinder, NA,4-S, WC, CI engine	Constant speed Variable load	Jatropha biodiesel (B100), B100C40, B100C80 compared with B100	C20ppm to C80ppm

Reference	Engine Specification	Test conditions	Test fuels	NPs dosage
Kumar, Dinesha, et al., 2019	1-Cylinder, 4-S, NA, CI engine	1500rpm 25-100% load	Waste cooking oil (WCO), Injection pressure(180,210, 240bar),B20, B20C80@180bar B20C80@210bar, B20C80@240bar compared with B20@180bar	C80ppm
Babu & V.Pandurangadu, 2018	1-cylinder, WC, 4S, DI	1500rpm Variable load	Mango seed oil methyl ester(MSME), Diethyl ether(E) B20, B20E10, B20E15, B20C25 B20C50 compared with B0	C25ppm C50ppm
Bafghi et al., 2015	A 4S, 1-cylinder, AC, CI engine	1500rpm to 2700rpm	B5, B20, B20C5, B20C15, B20C25 compared with B0	C5ppm to C25ppm
Vairamuthua et al., 2015	1-cylinder, 4S, NA, WC, CI engine	1500rpm 0-100%	Punnai Seed oil biodiesel B100, B100C20 compared with B0 and B100	C20ppm

Table 2.2 Continued

Performance and Emission characteristics Increase(s) (↑) and Decrease(s) (↓)							
Reference	BP kW	BT Nm	SFC or BSFC Kg/kW-hr	CO %	CO_2 %	HC ppm	NPs dosage
Chandran et al., 2020	-	-	BSFC ↓	↓22%	-	↓15%	C100ppm
Seela et al., 2019	-	-	SFC↑1%	↓8%	-	↓9%	C100ppm
Ramarao et al., 2015	-	-	SFC↑1%	↓7.7%	-	↓38.1%	C80ppm

Reference	BP kW	BT Nm	SFC or BSFC Kg/kW-hr	CO %	CO_2 %	HC ppm	NPs dosage
Kumar et al., 2020	-	-	BSFC↓less	↓52%	-	↓16%	C80ppm
Prakash et al., 2019	-	-	SFC↓3.63%	↓9.11%	↓3.12%	↓6.3%	C5ppm to C15ppm
Kalaimurugan et al., 2020	-	-	BSFC↓	-	-	-	C25ppm to C100ppm
Sajith, Sobhan, et al., 2010	-	-	Pure biodiesel	↓less		↓40%	C80ppm
Kumar, Dinesha, et al., 2019	-	-	BSFC ↓3.1%	-	-	↓20%	C80ppm
Babu & V.Pandurangadu, 2018	-	-	BSFC ↓	↑	↓	↓	C25ppm C50ppm
Bafghi et al., 2015	↑	↑	BSFC ↓	-	-	-	C15ppm to C25ppm
Vairamuthua et al., 2015			BSFC ↓	↓	-	↓	C20ppm

Table 2.3 Effect of magnesium oxide nanoparticles in diesel and biodiesel blend on diesel engine performance and emissions

Magnesium oxide nanoparticles(MgO), Diesel (D100 or B0), Biodiesel(B100)				
References	Diese engine Specification	Test conditions	Test fuels	NPs dosage
Ali et al., 2020	1-cylinder, 4-S	1500 rpm Variable load @full load	Waste cooking oil biodiesel B20M30, B40M30, B60M30 B20C30, B40C30, B60C30 compared with B0	M30ppm C30ppm
Arunprasad & Elango, 2020	1-cylinder, 4-S, NA, WC, DI	1500 rpm Variable load	B20, B20M50, B0M100 compared with B20	M50 M100
Ganesan et al., 2020	1-cylinder, 4-S, DI, WC, VCR	Constant speed Variable load @full load	Canola oil biodiesel B10 M30, B20M30, B30M30, B40M30 compared with B0	M30
Özgür et al., 2015	4-cylinder, 4-S, DI, WC	1200–3200 rpm	Rapeseed oil biodiesel(B100) B100M25ppm,B100M50ppm B100$SiO_2$25ppm B100 SiO_2 50ppm compared with B100	M25ppm M50ppm SiO_2 25ppm SiO_2 50ppm
ÖZGÜR et al., 2017	4-cylinder, 4-S, NA, WC, DI-CI	1200 -3200 rpm 100% load	B0 B0M25, B0M50, B0M100 compared with B0	M25ppm M50ppm M100ppm
Ganesan & Polina, 2017	A single-cylinder Kirloskar builds DI, 4S	Variable load	Castor oil biodiesel B20M50@200bar, 220bar ,240bar compared with other	M50ppm
Sachuthananthan et al., 2019	A Kirloskar & TV1, NA, WC, DI, CI	1500 rpm. Variable load	Plastic pyrolysis oil biodiesel (PPO) B0, B100, B100M25 B100M50, B100M75 compared with B0	M25ppm, M50ppm, M75ppm M100ppm

Table 2.3 Continued

Performance and Emission characteristics Increase(s) (↑) and Decrease(s) (↓)							
Magnesium oxide nanoparticles(MgO)							
References	BP kW	BT Nm	BSFC Kg/kWhr	CO %	CO_2 %	HC ppm	NPs dosage
Ali et al., 2020	-	-	↓2.7%	-	-	-	B20M30 ppm
Ganesan et al., 2020	-	-	SFC near B0	↓13%	↓	↑53%	M30 ppm
Arunprasad & Elango, 2020	-	-	BSFC ↓less	↓23%	-	↓5.5%	M50 ppm
Özgür et al., 2015	-	-	-	↓16.9%	-	-	M50ppm
ÖZGÜR et al., 2017	↓3.8% ↓6.1% ↓8.2%	↓4.5% ↓5.5% ↓6.4%	↑0.6%	↓12.2% - -	↓1.9% ↓6.6% ↓13.6%	- - -	M25ppm M50ppm M100ppm
Ganesan & Polina, 2017	-	-	-	↓	↑	↓	M50ppm@ 200bar to 240bar
Sachuthananthan et al., 2019	-	-	ppm ↓0.3% ↓0.28% ↓0.28% ↓0.29%	ppm ↓0.04 ↓0.025 ↓0.03 ↓0.002	-	ppm ↓33.9 ↓33.5 ↓33.3 ↓33	M25ppm M50ppm M75ppm M100ppm

Most of the research studies have indicated that the addition of nanoparticles improves engine performance and reduces emission characteristics. It was found from the literature review that the addition of metal oxide NPs plays a vital role to improve performance and reduces emission. The modification of biodiesel-diesel blend with nanoparticles is mandatory to improve performance and reduce emission. Table 2.1 to Table 2.3 shows the comparative changes of the effect of metal oxide NPs on engine performance parameters such as BP, BT, BSFC, and exhaust emissions such as HC, CO, CO_2, and O_2 in an engine.

2.2.3 Biodiesel

A. Biodiesel definition

Biodiesel is defined as mono-alkyl esters of long-chain fatty acids obtained from a renewable source, like vegetable oils, waste cooking oil, and animal fats by the process of transesterification reaction, which agrees with ASTM D6751 specification for use in a diesel engine (Moser, 2009). Bio implies sustainable and organic source, diesel refers applicable in a diesel engine. Pure biodiesel designated by B100 before blending with petro-diesel. A biodiesel blend (biodiesel fuel blend with diesel fuel) is represented by "BXX" where XX denotes the vol% of neat biodiesel in the blend (i.e. B15 is 15% biodiesel and 85% petro-diesel) (Coronado et al., 2009). Biodiesel is a substitute fuel for petro-diesel, derived from various feedstocks and is simple to use, biodegradable, non-harmful, and free of sulfur and aromatics content. Biodiesel/diesel blend is used as a vehicular fuel in a diesel engine.

B. Used cooking oil as feedstock's of biodiesel

Choosing a suitable feedstock is a key factor to bring down the production cost of biodiesel. The two fundamental prerequisites for select of suitable feedstocks are fewer production costs and large scale production. In general, the feedstock of biodiesel can be classified into four groups: (i) eatable vegetable oil, (ii) non-eatable vegetable oil (iii) reused or waste oil, and (iv) animal fats. Among those, non-eatable vegetable oils and used cooking oil are cheaper feedstocks for the production of biodiesel (Bhuiya et al., 2014).

Waste cooking oils (WCO) obtained from the frying of food by domestics, commercials, and industrial kitchens food manufacturers at temperatures from 140-200 ºC no more valuable for its intended use. Trap grease is waste fats and oils obtained from floor cleaning, utensils washing, stoves cleaning and food residues, etc. Vegetable oil used for cooking is sunflower oil, olive oil, coconut oil, palm oil, cottonseed oil, etc.

Production of used cooking oil was increasing from years to years because of increases in the number of cafeterias, restaurants, and hotels throughout the country. The previous study estimated annual WCO availability from various foodservice establishments in Addis Ababa showed in Table 2.4 below. (Yakob, 2010).

Table 2.4 Available quantities of UCO

<table>
<tr><td>Oil type</td><td>The volume of WCO disposal liter/year</td><td>Trap grease waste</td><td>The volume of WCO disposal liter/year</td></tr>
<tr><td>Sunflower</td><td>3649</td><td rowspan="3">Soybean and olive oil</td><td rowspan="3">438000</td></tr>
<tr><td>Cottonseed</td><td>7980</td></tr>
<tr><td>Palm</td><td>87021</td></tr>
<tr><td>Total</td><td>98650</td><td>Total</td><td>438000</td></tr>
</table>

C. Benefits of biodiesel use in diesel engine

Biodiesel is a locally delivered, clean-burning, sustainable substitute for oil diesel. Utilizing biodiesel as a vehicle fuel diminishes GHG emission; lessens the effect on the climate and human wellbeing, improves engine operation, simple to utilize, and so forth.

Biodiesel reduces greenhouse gas emissions: When biodiesel dislodges (displace) petroleum, it fundamentally lessens life-cycle GHG emissions (CO_2). Life cycle examination finished by Argonne National Laboratory found that GHG emissions for B100 are 74% lower than those from oil diesel. Currently, the California Air Resources Board (CARB) reported comparable qualities for its life-cycle examination of biodiesel from different sources.

Biodiesel reduces tailpipe emissions: Testing to date shows that biodiesel is completely viable with the emission control catalysts and filters that significantly decrease particulate matter (PM) and nitrogen oxides (NO_X) emissions from new diesel engines. The utilization of B20 for certain fleets that have over 90% light- and medium-duty vehicles or fleets with heavy-duty vehicles with NO_X-neutral technologies and fleets with new diesel engines,

Biodiesel and human health: Hydrocarbon (HC) and Particulate matter (PM) emissions from diesel engines might be poisonous and additionally cancer-causing. Shifting from oil diesel to high blend levels of biodiesel (B50 to B100) significantly reduced PM emissions. In any case, even low concentrations of biodiesel reduce PM emissions and provide significant health, and consistency benefits any place people get higher levels of exposure to diesel exhaust.

Biodiesel Improves Engine Operation: Biodiesel, even in a very low amount, increases the cetane number of the fuel and improves fuel lubricity. Diesel engines rely upon the lubricity of the fuel to keep moving parts, especially fuel injectors and pumps, from wearing prematurely. To address the decreased natural lubricity of ultra-low sulfur diesel, specification ASTM D975 for diesel fuel was modified to add a lubricity requirement (a maximum wear scar diameter on the high-frequency reciprocating rig [HFRR] test of 520 microns). Biodiesel can confer sufficient lubricity to diesel fuels with poor natural lubricity at blend levels as low as 1%.

Biodiesel Is Easy to Use: Finally, perhaps the greatest advantage of utilizing biodiesel is that it is easy to use. Blends of B20 or lower require no new equipment or equipment modifications. B20 can be stored in diesel fuel tanks and pumped with the same equipment as diesel fuel. B20 does present a few unique handling and use precautions, but most users can expect a trouble-free B20 experience (Alleman et al., 2016).

D. Advantage of and disadvantage of biodiesel

The properties of biodiesel delivered from different feedstocks have their advantages and drawbacks when used as an alternative fuel in diesel engines are discussed in detail.

The advantage gained by using biodiesel as an alternative fuel is like non-harmful, biodegradable, safer to handle, easily miscible with diesel, run diesel engine in pure form, reduce diesel fuel consumption and increases our energy security, easy for synthesis, reduce environmental pollution, good lubricating properties and prolongs engine life, and shorter ignition delay as compared to standard diesel.

The biodiesel used as an alternative fuel in diesel engine has also its drawback those are like causes quick food deficiencies and increased food costs, more contamination by water and cause corrosion to engine parts, more costly, less calorific value and higher could point, and higher oxide of nitrogen emission as compared to diesel fuel (Knothe & Van Gerpen, 2005).

2.2.4 Process of producing biodiesel and related techniques

Production of biodiesel from various feedstocks requires four different techniques like direct use and blending, micro-emulsion process, Pyrolysis, and transesterification process. The most convenient way to produce biodiesel from the oil of fat is the transesterification process.

Transesterification process: The transesterification reaction is the best technique to synthesize biodiesel as a main product and glycerol as a byproduct from the vegetable oil or animal fat and alcohol due to a catalyzed chemical reaction in the presence of a base catalyst under controlled temperature and pressure for a given length of time. Theoretically, a 3:1 molar ratio of alcohol to oil is necessary to complete a transesterification reaction, but in practice, the ratio needs to be higher to drive the equilibrium to a maximum ester yield because it's a reversible reaction. A produced biodiesel having good properties as fuel to run a diesel engine. The generic transesterification reaction of the vegetable oil with alcohol in the presence of a catalyst to produce biodiesel and glycerol is presented in the equation (2.1) below (Alemayehu & Abile, 2014).

$$\begin{array}{l} CH_2-O-\overset{O}{\overset{\|}{C}}-R \\ | \\ CH-O-\overset{O}{\overset{\|}{C}}-R \\ | \\ CH_2-O-\overset{O}{\overset{\|}{C}}-R \end{array} + 3R'OH \xrightleftharpoons{\text{Catalyst}} 3R'-O-\overset{O}{\overset{\|}{C}}-R + \begin{array}{l} CH_2-OH \\ | \\ CH-OH \\ | \\ CH_2-OH \end{array} \text{-------------} (2.1)$$

(Vegetable oil) (Alcohol) (Biodiesel) (Glycerol)

Where R is long hydrocarbon chains, sometimes called fatty acid chains and R' is an alkyl group of alcohol (Knothe & Van Gerpen, 2005).

2.2.4.1 Basics of Biodiesel Production

Biodiesel is produced from biological resources like vegetable oil or animal fat and alcohol in the presents of catalysts utilizing a chemical reaction known as transesterification reaction. This chemical reaction converts an oil or fat into crude biodiesel and glycerol. Biodiesel (FAME) is obtained from the washing of the crude fatty acid methyl esters. In a transesterification process, a catalyst such as acidic, enzymatic, and basic is used to speed up the reaction. A basic catalyst is the most frequently used at all production scales. In the following sections, the basic stages of the biodiesel production process will be described in detail.

Pretreatment of vegetable oils or animal fats: The transesterification reaction is affected by various parameters like free fatty acid (FFA) content and water content in the feedstocks of biodiesel. The higher value of FFA more than 2% in ester (oil or fat) reduces the conversion efficiency of the chemical reaction in the presence of basic catalysts results in the formation of soap. This produced soap prevents the separation of the biodiesel and glycerol phase and contributes to emulsion formation during the water wash. To reduce the higher content of FFA to less than 2% in the raw material we use acidic catalysts like sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) and the chemical reaction is known as acidic transesterification or esterification (Romano & Sorichetti, 2011). Esterification, as it applies to biodiesel production, is the chemical reaction by which an FFA is degraded, reacts with an alcohol in presence of acidic catalysts to produce biodiesel and water (Altic, 2010). The drawback of this chemical reaction is consuming more catalysts, slower reactions, the formation of water, increased difficulty in the separation process, and impurities in the product. Then the low FFA pretreated oil can be transesterified with an alkali catalyst to convert the triglycerides to methyl esters.

Alcohol-Catalyst Mixing: The common alcohol (methanol or ethanol) used for biodiesel production must be mixed with a basic catalyst (sodium or potassium hydroxides) before adding the oil. The mixture is stirred until the catalyst is completely dissolved in the alcohol to produce an alkoxide solution.

Chemical Reaction: The chemical reaction takes place when the alkoxide solution is charged into a closed reaction vessel and the oil is added. The reaction system requires certain conditions of time, temperature, and stirring. The reaction temperature must be near the boiling point of methanol (68℃) and closed to the atmosphere to reduce the loss of alcohol under continuous stirring. Excess methanol is normally used to obtain a higher yield.

Separation of biodiesel and glycerol: After the reaction is completed, there exists glycerol and biodiesel formation. The separation of fatty acids methyl esters (FAME) from glycerin phases takes place by decantation due to different densities between the reaction products. The biodiesel phase is less dense than the glycerol phase, making biodiesel to be floated. The two products can be separated by gravity using a settling vessel or centrifuge. After the removal of glycerin at the bottom, the crude biodiesel contains impurities like remaining methanol, NaOH, MG, DG, and TG, etc.

Biodiesel washing: The crude biodiesel obtained from the transesterification reaction must be purified to remove impurities that reduce the quality of the product. This being water-soluble is removed by washing (4-6 times) the biodiesel with hot distilled water maintained at (40-50ºC). Care must be taken to avoid the formation of emulsions during water washing. After the completion of the washing process, the biodiesel may contain some traces of water. Biodiesel is heated to (110℃) to remove the trapped traces of water. The dried biodiesel is ready for characterization to determine the quality which confirms ASTM D 6751 specification

Glycerin: The glycerin is a byproduct during biodiesel production which contains traces such as catalyst and excess alcohol where neutralized. After purification glycerol is applicable in the production of soap, and cosmetics, etc. (Romano & Sorichetti, 2011). The basic stages used in the biodiesel production method are shown in Figure 2.1.

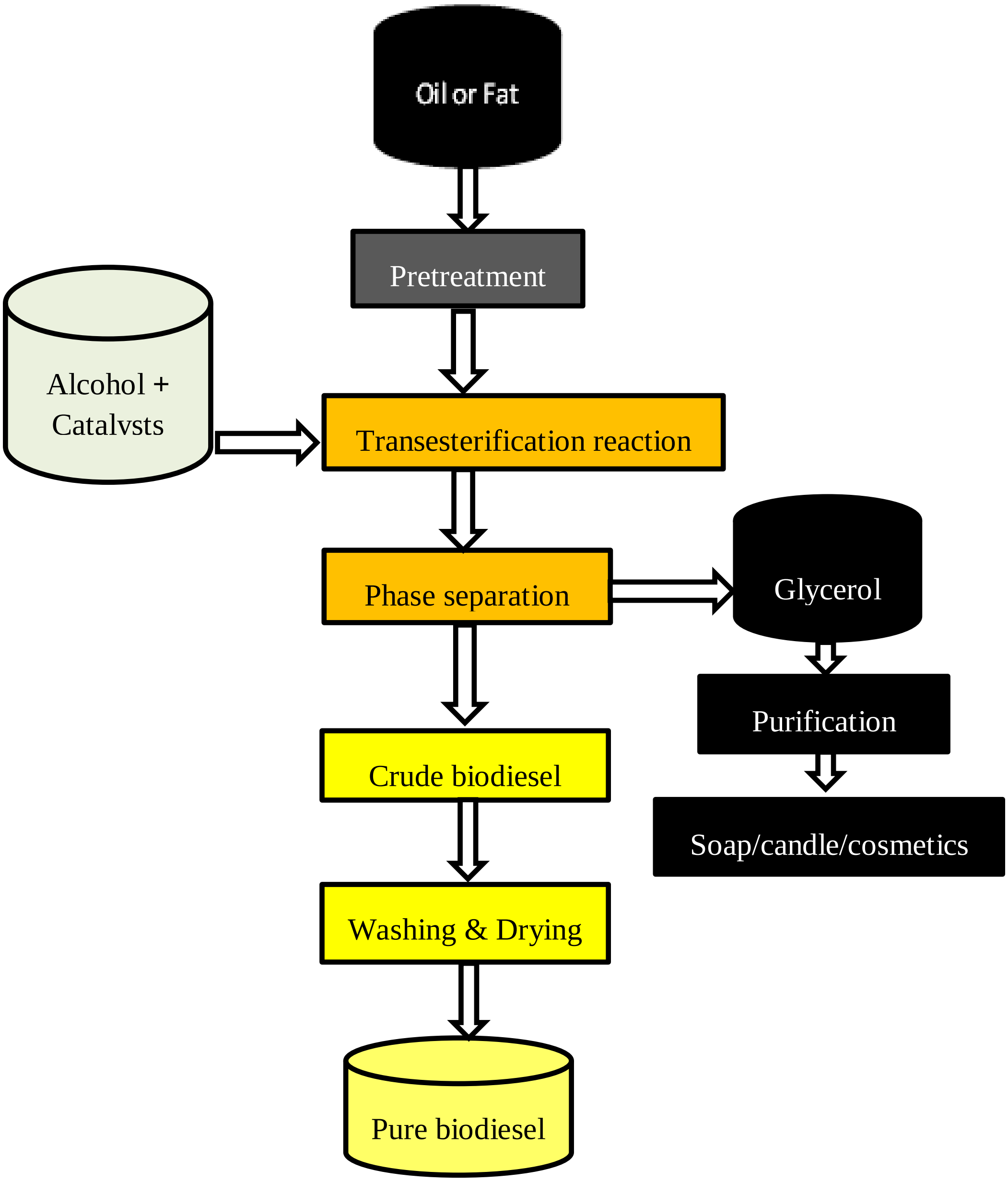


Figure 2.1 Biodiesel production pathways

2.2.5 Transesterification reaction

The chemical process by which biodiesel is prepared is known as the transesterification reaction, which involves a triglyceride (TG) react with lower alcohol in the presence of a catalyst at a higher temperature to form fatty acid alkyl esters (FAAE) and glycerol (GL). Lower alcohol methanol or ethanol is commonly used in biodiesel production the former one is lower in cost and highly reactivity nature. An alkaline catalyst such as NaOH or KOH is most frequently used in the transesterification reaction. The conversion of TG to biodiesel is a stepwise process whereby the alcohol (methanol) initially reacts with TG as the methoxide ion to produce FAME and diglyceride (DG), DG which reacts further with methanol to liberate another molecule of FAME and generate monoglyceride (MG). Lastly, MG undergoes methanolysis to yield biodiesel and glycerol. Three moles of FAME and one mole of are GL produced for every one mole of TG that undergoes complete conversion(Moser, 2009). The overall triglyceride (TG) methanolysis reaction could be presented by the following stoichiometric equation (2.1and 2.2) below.

$$\text{Triglyceride (TG)} + 3\ \text{R'OH} \rightleftharpoons 3\text{R'COOR} + \text{GL} \quad \text{- - - - - - - - - - - - - - - - - -(2.1)}$$

Where intermediate reactions in the presence of a base catalyst steps are;

$$\left.\begin{array}{l} \text{Triglyceride (TG)} + \text{R'OH} \rightleftharpoons \text{Diglyceride (DG)} + \text{R'COOR} \\ \text{Diglyceride (DG)} + \text{R'OH} \rightleftharpoons \text{Monoglyceride (MG)} + \text{R'COOR} \\ \text{Monoglyceride (MG)} + \text{R'OH} \rightleftharpoons \text{Glycerol (GL)} + \text{R'COOR} \end{array}\right\} \text{- - - - - - (2.2)}$$

Where R'OH, R', R, and R'COOR (FAME) are methanol, an alkyl group of alcohol, carbon-chain of fatty acid, and crude biodiesel respectively (Karacan & Çağatay, 2017)

The basic reaction for the conventional biodiesel process is shown in equation (2.3) below.

$$\begin{array}{l} CH_2-\text{O}-\overset{\overset{\text{O}}{\|}}{\text{C}}-\text{R}_1 \\ | \\ CH-\text{O}-\overset{\overset{\text{O}}{\|}}{\text{C}}-\text{R}_2 \\ | \\ CH_2-\text{O}-\overset{\overset{\text{O}}{\|}}{\text{C}}-\text{R}_3 \end{array} + 3\ CH_3\text{OH} \xrightleftharpoons{\text{Catalyst}} \begin{array}{l} CH_3-\overset{\overset{\text{O}}{\|}}{\text{O}}-\text{C}-R_1 \\ CH_3-\overset{\overset{\text{O}}{\|}}{\text{O}}-\text{C}-R_2 \\ CH_3-\overset{\overset{\text{O}}{\|}}{\text{O}}-\text{C}-R_3 \end{array} + \begin{array}{l} CH_2-\text{OH} \\ | \\ CH-\text{OH} \\ | \\ CH_2-\text{OH} \end{array} \text{- - - - - - - (2.3)}$$

Vegetable oil (TG) (Methanol) Biodiesel (FAME) (Glycerol)

Where R_1, R_2 and R_3 are long hydrocarbon chains, sometimes called fatty acid chains (Van Gerpen, 2005).

2.2.5.1 Factors affecting transesterification reaction

The process of transesterification achieves an intense change in the viscosity of the oil or fat. The produced biodiesel by this method is lower in viscosity, flash point, increase in cetane number, and miscibility with diesel. The yield of biodiesel through these techniques influenced by main process parameters like a molar ratio of alcohol to oil, presence of moisture and free fatty acids (FFA), catalyst type and amount, reaction temperature, mixing intensity, and reaction time (Alemayehu & Abile, 2014).

Molar Ratio Oil to Alcohol shows an important role in biodiesel yield. Methanol is a more frequently used alcohol because of its low price and better characteristics over other alcohols. Stoichiometrically the transesterification reaction requires a 1:3 molar ratio of oil to alcohol, but in actual chemical reaction higher ratio of alcohol is required to reduce the reaction time and increases the conversion of oil into biodiesel. Increase the molar ratio of alcohol increases the yield of esters up to certain limits, however further increase results in raise the cost of alcohol recovery and lessen the yield of ester. In addition to this, the ratio of oil to alcohol depends upon the types of catalyst used, i.e. in the case of alkali catalyzed transesterification 1:6 ratio of oil to alcohol is required, and in the case of acid-catalyzed transesterification 1:15 ratio of oil to alcohol is needed to drive the reaction. (Mathiyazhagan & Ganapathi, 2011).

Water and Free fatty acid (FFA) content presence of water and FFA in feedstock reduces the amount of ester formation and accelerates both the saponification and hydrolysis process result in the formation of soap and water. To obtain the maximum yield of biodiesel by alkali catalyzed transesterification reaction water content (less than 0.5%) and presence of FFA (not exceed 3%) in the feedstocks of biodiesel. However, the presence of water and FFA in the oil exceeds the above-mentioned value pre-treatment of the raw material is required i.e waste cooking oil (WCO) can be heated up to 120°C to evaporate water and acid-catalyzed transesterification is applied to reduce FFA content (Allah & Alexandru, 2016).

Mixing intensity and reaction time Most biodiesel production processes use relatively intense mixing, at least at the start of the reaction, to mix alcohol with the oil phase. If this mixing proceeds for the complete reaction, very fine droplets of glycerol can be distributed through the mixture result in difficulty of glycerol to collect requires from one hour to several hours. For this reason, mixing by shaking was generally done for five minutes as the reaction begins to progress, to reduce the time required for the collection of glycerol.

The reported time for the preparation of biodiesel by the same method was ten minutes. However higher shaking speed and longtime result in the formation of less ester and vigorous shaking for five minutes were required for better yield (Debela, 2018).

Catalyst type and concentration Transesterification reaction are also affected by the type and concentration of catalyst. The most frequently used catalyst in the transesterification reaction is sodium or potassium hydroxide (NaOH or KOH). The type and concentration of catalyst required in the transesterification process usually depend on the quality of the feedstock and method applied for the transesterification process (Alemayehu & Abile, 2014). The types of catalysts used for the synthesis of biodiesel are basic catalysts (include NaOH, KOH, and sodium methoxide), acidic catalysts (include hydrochloric acid, sulfonic acids, and sulfuric acid) or enzymatic (Lipases are the most commonly used enzymes) (Romano & Sorichetti, 2011). For a higher quality oil or fat, any type of catalyst could be used for the transesterification process. However, for low-quality feedstocks with high free fatty acids and water contents acidic catalyzed transesterification is more favorable. The yield of biodiesel generally increases with increasing the concentration of catalyst. However, further increases in the mass of catalyst resulted in a rise in the cost. Therefore, similar to the molar ratio of alcohol to oil, the optimization process is necessary to determine the optimum amount of catalyst required in the transesterification process (Alemayehu & Abile, 2014).

Reaction temperature it’s one of the most important parameters that affect the yield of ester conversion. The higher reaction rate was achieved with an increase in temperature by the reduction of oil viscosity. However, an increase in temperature beyond the optimum temperature leads to a decrease in biodiesel production because the higher temperature may accelerate the saponification of_triglycerides. Usually, the transesterification reaction temperature should be less than the boiling point of alcohol (68℃ in the case of methanol) to prevent the vaporization of alcohol. The type of catalyst and oil used determines the optimum temperature in the range of (50-60℃) for biodiesel production (Chozhavendhan et al., 2020).

2.2.6 Properties, specification of biodiesel and petro-diesel standards

2.2.6.1 Physical and chemical properties of biodiesel

Density: Fuel properties like density, cetane number, and calorific value are very important to engine performance parameters. The fuel injection system of diesel engine measure fuel by volume, so variation in the density of fuel will affect the brake power of the engine due to various mass fraction of fuel injected into the cylinder of a diesel engine. Besides, the difference in density also influences the fuel atomization during fuel injection and burning in the cylinder, so that they affect the combustion characteristic and exhaust gas emissions.

Kinematic viscosity is resistance to the flow of a fluid under gravity. These properties influence fuel flow, the size of fuel droplets, fuel atomization, and jet penetration, altogether influence the quality of combustion. For use in diesel engines, the viscosity of fuel should be within the limit of the ASTM D-6751 standard. The viscosity out of this limit affects the fuel injection system like an injector, fuel pump lubrication, fuel leakage, poor atomization, incomplete combustion, etc.(Gülüm & Bilgin, 2017).

Cloud Point (CP): The cloud point is the temperature at which a cloud of wax crystals first appears in a liquid when it is cooled down under specific conditions. The cloud point is a critical factor in cold weather performance for all diesel fuels. For biodiesel, the cloud point is typically higher than the cloud point of conventional diesel. To reduce this value blending feedstock that has relatively high in saturated fatty acids with a feedstock that has lower saturated fatty acid content or blend biodiesel with nanoparticles that delay the formation of solid crystals in the biodiesel by various mechanisms.

Flashpoint (FP): it is defined as the lowest temperature adjusted to a barometric pressure of 101.3 kPa (760 mmHg), at which application of an ignition source causes the vapors of a specimen to ignite under specified conditions of the test. For biodiesel, this test is a measure of remaining alcohol(methanol or ethanol) and determinant for flammability ordering of materials (Akhtar, 2011)

Acid number The acid number is "the quantity of base, expressed as milligrams of potassium hydroxide per gram of sample, required to titrate a sample to a specified endpoint''. The acid number is a direct measure of free fatty acids. The free fatty acids can lead to corrosion (reduced life of filters and fuel pumps) and maybe a symptom of water in the fuel. Usually, for a base-catalyzed process, the acid value after production will be low since the base catalyst will strip the available free fatty acids. However, the acid value may increase with time as the fuel degrades due to contact with air or water. This test should be performed regularly as a part of the producer Quality control program. The requirement is a maximum of 0.8 mg of KOH/g (Kilonzi et al., 2015).

Water and sediment. This refers to free water droplets and sediment particles suspended in the pure biodiesel (B100). The allowable level for B100 is set at the same level as for conventional diesel fuel. Poor drying techniques during manufacturing or contact with excessive water during transport or storage can cause B100 to be out of specification for water content. Excess water can lead to corrosion and provides an environment for microorganisms. Fuel oxidation can also raise sediment levels, so this test can be used in conjunction with an acid number, oxidation stability, and viscosity to determine if fuels have oxidized too much during storage (Alleman et al., 2016).

Ash content. The ash number is a measure of the quantity of metals found and contained in a fuel sample specimen. The ash number is determined under the standard ASTM D482 method. An ash can result from soluble metallic soaps, abrasive solids, and unremoved catalysts. Higher ash content more than the limited value in biodiesel fuel causes damage to engine components like rapid wear of the fuel system (fuel pump), piston, piston rings, and also fuel system deposition, early failure of the fuel filter.

The calorific value or heat of combustion is the amount of energy available from a sample of fuel. It is a measure of heat obtained through the combustion of a unit mass of fuel that produces the maximum possible output limit of power or heat that can be obtained from a fuel. Fuel is defined as a substance that undergoes a physical and chemical change in return releasing large amounts of heat energy to do work. The calorific value is measured in a bomb calorimeter using the standard ASTM D2015 method(Maroa).

Copper strip corrosion. It's also a vital property of biodiesel because it determines whether or not the fuel tends to corrode an engine. Corrosion is a chemical action that destroys the surface of a metal by oxidation alone, or in combustion with a chemical process Free fatty acid and some sulfur compounds that exist in biodiesel may cause corrosion. This is not a healthy scenario for compression ignition engines. Copper strip corrosion tests are recommended for all biodiesel especially before transportation and storage (Kaisan et al., 2016).

Cetane number The cetane number reflects the ability of a fuel to self-ignite at the conditions in the engine cylinder. In general, adequate cetane value is required for better engine performance. The cetane number of biodiesel from different feedstocks was from 48 to 60. This is much higher than the typical 43 to 47 observed for petroleum diesel fuel. The cetane number is typically estimated for petroleum diesel fuel using the cetane index.

However, a cetane index is not an accurate predictor of the cetane number for biodiesel because it provides faulty information for biodiesel. A cetane engine must be used to determine the cetane number for biodiesel (Schumacher et al., 2004)

2.2.6.2 Specification of biodiesel and petro-diesel standards

The American Society for Testing and Materials (ASTM) International Organization set standard specifications for both biodiesel and petro-diesel fuels by ASTM-D975, ASTM-D6751 respectively. It determines the quality of fuel to be used in diesel engines. Some of the test methods, standard limits, and characteristics of fuel are listed in Table 2.5 and Table 2.6 show the fuel properties of biodiesel blends B6-B20. (Alleman et al., 2016).

Table 2.5 Comparison of biodiesel and petrodiesel properties.

Properties	Methods Test	Fuel standard	
		ASTM-D6751	ASTM-D975
		Biodiesel	Petro-diesel
Density @ 20 (g/mL)	D 1298	0.88-89	0.85
Kinematic Viscosity @40℃ (mm^2/sec)	D445	1.9 to 6.0	1.3 to 4.1
Specific gravity @15 ℃ (kg/m^3)	D1298	0.88	0.85
Cetane number	D 613	47 to 60	40 to 55
Cloud point (℃)	D2500	-3 to 15	-35 to 5
Pour point (℃)	D97	-5 to 10	-35 to-5
Flashpoint (℃)	D 93	130 to 170	60 to 80
Water content (vol %)	D2709	0.050 max	0.050 max
Copper strip Corrosion	D130	No.3 max	No.3 max.
Acid number (mg KOH/g)	D 664	0.8 max	0.5 max
Sulfur, wt %s	D5453	0 to 0.0015	0.0015 max
Carbon, wt %	-	77	87
Hydrogen, wt %	-	12	13
Oxygen, wt %	-	11	0
High calorific value (Btu/gal)	D240	~127,960	~138,490
Low calorific value (Btu/gal)		~119,550	~129,488S

Table 2.6 Biodiesel blended fuel properties.

Property	Test Method	Grade
		B6 to B20
Kinematic Viscosity @40℃ (mm^2/sec)	D445	1.9 – 4.1
Cetane number, min.	D 613	40
Cloud point (℃)	D2500	Report
Distillation Temperature, °C, 90% Evaporated, max.	D86	343
Flashpoint (℃), min	D 93	52
Acid number (mg KOH/g)	D 664	0.3
Sulfur Content, (µg/g or ppm) mass %, max. mass %, max.	D5453 D2622 D129	15 0.05 0.50
Ramsbottom carbon residue on 10% bottoms, mass %, max.	D524	0.35
One of the following must be met: (1) Cetane index, min. (2) Aromaticity, vol%, max.	 D976-80 D1319-03	 40 35
Ash Content, mass %, max.	D482	0.01
Water and Sediment, vol%, max.	D2709	0.05
Copper Corrosion, 3 h @ 50°C, max.	D130	No. 3
Oxidation Stability, hours, min.	EN15751	6
Lubricity, HFRR @ 60°C, (micron), max.	D6079	520

Summary of literature review the previous related work showed that the production of biodiesel from used cooking oil (UCO) was possible with little variation in the ASTM standard. According to previous research works on the production of biodiesel from UCO and testing its physicochemical properties were done. To improve fuel properties, engine performance, and reduce emission addition of individual nanoparticles oxide of aluminum, cerium, and magnesium on biodiesel blend was conducted. Though very few related works have been carried out for the three nanoparticles as an additive in UCO biodiesel, the performance evaluation and emission characteristics for the three nanoparticles as additives in UCO biodiesel blends were limited. Because of this, the present work mainly committed to evaluating the performance and emission characteristics of a single-cylinder, four-stroke air-cooled, and DI diesel engine fueled with three nanoparticles in different dosage dispersed biodiesel blend compared with blended fuel and pure diesel.

CHAPTER THREE

3. MATERIALS AND METHODS

This section describes the methodology used to effectively achieve the specific objectives of the study by utilizing different materials and methods. These are the collection of used cooking oil (UCO), determination of acid value, biodiesel production, characterization of test fuels, and preparation of biodiesel blend with metal oxide NPs. Testing performance, and exhaust emission of test fuels in a diesel engine. The materials and apparatus required to carry out this work are listed below.

3.1 Materials

Materials Used cooking oil, Methanol, Potassium hydroxide, Ethanol and Petroleum-ether, Phenolphthalein, Distilled water, Petro-diesel fuel, and metal oxide NPs,

A. Specification of metal oxide nanoparticles

Table 3.1 Specification of nanoparticles

Name (Molecular formula)	Purity	Average NPs size	Appearance	Quantity
Cetyletrimethyl Ammonium Bromide or CTAB ($C_{19}H_{42}BrN$)			White	200g
Cerium oxide(CeO_2)	99.5%	20-30 nm	Yellow	100g
Aluminum oxide (Al_2O_3)	99.9%	30-50nm	White	10g
Magnesium oxide (MgO)	99.9%	30-50nm	White	10g

Apparatus Volumetric flasks, Beakers, Measuring cylinders, Separator funnels and stands, Safety equipment's, Thermometer, Hot plate, Magnetic stirrer, Oven, Aluminum foil, Ultrnasonicator cleaner, Digital balance, diesel engine, and exhaust gases analyzer.

A. Specification of diesel engine

The engine that is used in the study CT 100.32 a single-cylinder, four strokes, air-cooled diesel engine at Ethiopian Dilla DU. The engine's specifications are summarized in Table 3.2.

Table 3.2 Specification of a diesel engine

Specification and Technical Data	Dimensions
Engine type	Air-cooled single cylinder 4-stroke diesel engine
Company	Hatz
Type	1B30-2
Fuel	CT 100.32 (Diesel)
Number of cylinder	1
Bore	80 mm
Stroke	69 mm
Crank length	34.5 mm
Rod length	114.5 mm
Output power at 3500 rpm	5.5 kW
Oil capacity	1.1 L
Stop solenoid	12 V
Compression ratio	22: 1
Length x Width x Height	370 mm x 330 mm x 450 mm
Weight approx.	35 kg

B. Specification of exhaust gas analyzer

Table 3.3 Specification of Infralyt Smart exhaust gas analyzer

Specification and Technical Data	Dimensions
Carbon monoxide	0 - 10% vol.
Carbon dioxide	0 - 20% vol.
Hydrocarbon	0 - 2500ppm vol.
Lambda	0 - 999
Oil temperature	0 - 130°C
Accuracy classes	1 and 0
Working temperature	5 - 45°C
Length x Width x Height	330 x 260 x 205mm
Weight approx.	7 kg
Operating voltage and frequency	230V, 50/60Hz, 1 phase or 120V, 60Hz, 1 phase

3.2 Collections of materials

The used cooking oil originated from sunflower and palm oil was collected from student cafeteria, distilled water, analytical grade chemical methanol, potassium hydroxide, apparatus obtained from Ethiopia Adama ASTU. Metal oxide NPs were purchased in India. Commercial diesel fuel was purchased from Ethiopia Adama Oil Libya. A single-cylinder four-stroke diesel engine used was located at Ethiopia Dilla DU.

3.3 Method

The procedures followed to accomplish this work were the production of biodiesel by transesterification reaction in the presence of a base catalyst potassium hydroxide and methanol, preparation of biodiesel blend with metal oxide NPs at Ethiopia Adama ASTU. The characterization of test fuels at Ethiopian Petroleum Supply Enterprise Laboratory. Exhaust emission analysis, and performance test on CT 100.32 a single-cylinder diesel engine at Ethiopia Dilla DU. The flow chart of the methodology of this study is shown in Figure 3.1 below.

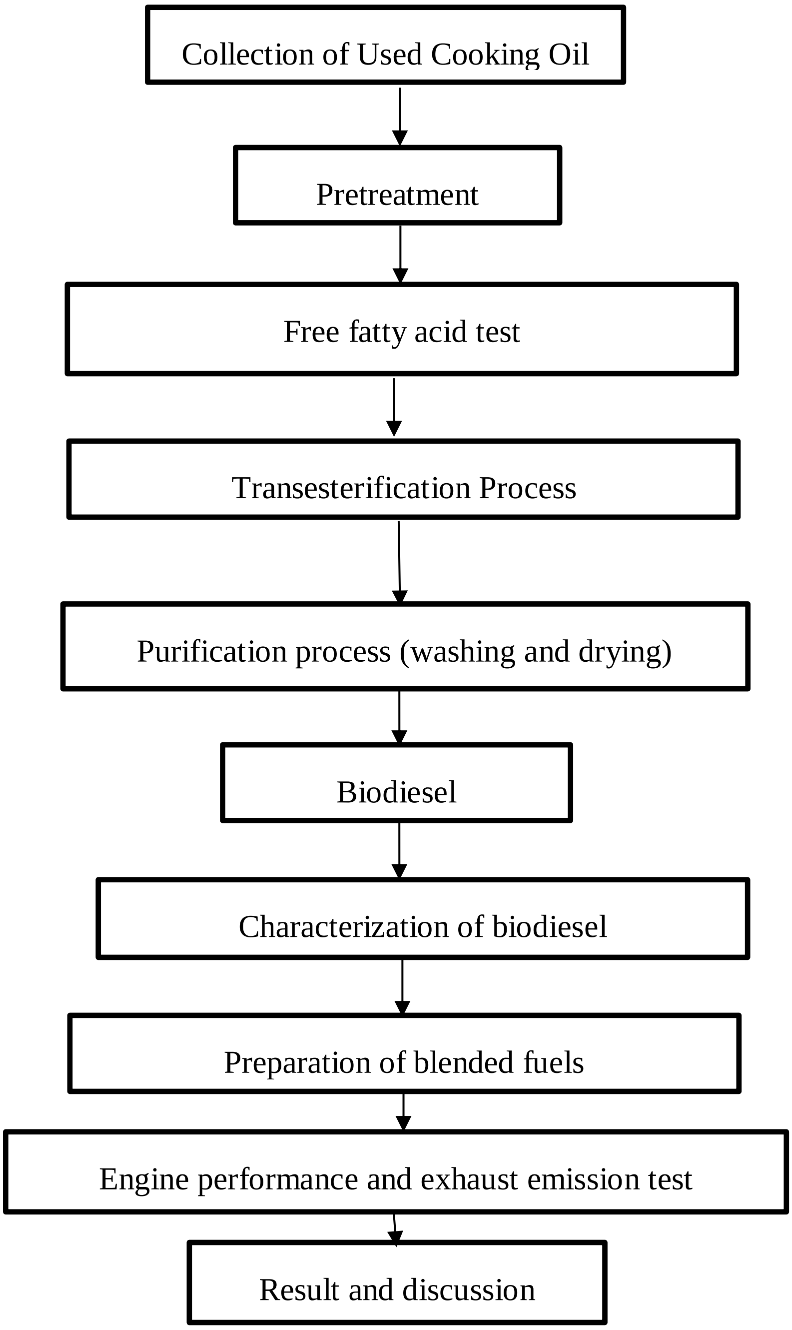


Figure 3.1 Flow chart of the methodology

3.4 Experimental setup and procedure

This thesis work was accomplished mainly based on the following experimental setup and procedures. These are a collection of used cooking oil (UCO), pretreatment of UCO, transesterification reaction, separation of glycerin from biodiesel, purification of biodiesel (washing and drying), determination of methyl ester yield and characterization of biodiesel, preparation of biodiesel/diesel blend, and blended fuels with nanoparticles, exhaust emission analysis and performance test of blended fuels.

3.4.1 Collection of used cooking oil

Used cooking oil (UCO) used in the thesis work was obtained from student cafeteria Ethiopia Adama ASTU Figure 3.2.

Figure 3.2 UCO obtained from student cafeteria Ethiopia Adama ASTU

3.4.2 Pre-treatment of used cooking oil (UCO)

A. Preparation of UCO

The collected UCO was permitted to stand for about 2 to 3 days so that impurities would settle in the bottom and the liquid portion was decanted. The remaining residues in oil and solid particles, like charred food and other non-oil material were removed by filtering the decanted UCO through a clean double-layer of light woven cotton material. Then, the filtered UCO sample obtained was investigated for acid value and free fatty acid content before the transesterification reaction.

B. Determination of acid value of UCO by titration

In the alkali catalyst transesterification process the level of free fatty acid content above 3wt. % in used cooking oil (UCO) will lead to the formation of soap and water (Liu et al., 2018).

The acid value was calculated by the acid-base titration technique Potassium hydroxide (KOH) was used as a catalyst. The acid value dividing by two gives free fatty acid content in the sample oil.

The procedures used followed acid-base titration is the following

1. A measured 20g sample of oil was poured into 250 milliliters (ml) Erlenmeyer flask

2. Measured 50ml of ethanol, 50ml of petroleum-ether, and 1ml of indicator solution (phenolphthalein) and mixing all together obtained 101ml of titration solvent which was added to the flask.
3. The mixture was stirred until the sample was entirely dissolved by the solvent. Followed, the mixture was titrated with standardized 0.1N KOH solutions by shaking vigorously to a green-black endpoint.
4. Blank titration was performed on 100 ml of the titration solvent and 1 mL of the indicator solution by a similar procedure.

The Acid value and FFA content were calculated by the following two equations (3.1 and 3.2):

$$\text{Acid value} = \frac{(A-B)\times N\times 56.1}{W} \quad (3.1)$$

A = Volume in ml of standard KOH used in the titration

B = Volume in ml of standard KOH used in titrating the blank

N = Normality of standard KOH, W = Weight of the sample in gram

56.1= Weight of KOH (Sum of a mass of K=39.1, O=16, and H=1)

$$\%FFA = \frac{\text{Acid value}}{2} \quad (3.2)$$

The acid value calculated was also used to estimate the amount of KOH required neutralizing FFA in addition to KOH needed for transesterification. The FFA contained in the UCO can be neutralized by a base catalyst KOH to produce soap (impurity) and potassium methoxide catalyst for transesterification reaction.

The UCO in this study had an acid value of 2 mg KOH/g and 1% by weight of FFA content so the result recommended base-catalyzed transesterification reactions. The acid value and FFA content in the three samples UCO were shown in table 3.1 below.

Table 3.4 Acid value and Free Fatty acid content of UCO

Test No	Wt of UCO, g	Normality of KOH, N	The volume of KOH, ml	The volume of KOH for blank titration, ml	Acid value, mg KOH/g	% FFA content
1	20	0.1N	7.28	0.12	2.008	1.004
2	20	0.1N	7.25	0.12	1.999	0.999
3	20	0.1N	7.23	0.12	1.994	0.997
	Average				2.0	1.0

To neutralize the FFA in the feedstock additional KOH was required which was calculated as followed.

$\frac{\%\mathrm{FFA}\times 0.197}{0.86}=\frac{1\times 0.197}{0.86}$=0.21%, it indicates that 0.21% of the triglycerides (TG) weight of additional KOH is needed. The factor 0.197 represents the ratio of the mass KOH to the mass of FFA, 0.86 reflects (86% purity KOH). Therefore, a total of 1.2% of the TG weight of KOH is required since 1% of the triglycerides weight of KOH is required for the transesterification process.

3.4.3 Laboratory scale transesterification reaction

The easy way to produce biodiesel is called transesterification reaction or alcoholysis. In this reaction, the displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis, except that alcohol is employed instead of water. Used cooking oil (UCO), excess methanol, and a base catalyst potassium hydroxide (KOH) were used as an input to produce biodiesel and glycerol (byproduct) by alcoholysis(Fukuda et al., 2001). The various procedures adopted in the preparation of biodiesel from UCO is discussed in detail below.

A. Measuring and Preheating of the used cooking oil (UCO)

Measuring 390g of the UCO in a beaker was dried to remove water by preheating to 0-100℃ for 30 minutes using a hot plate to further reduce reaction time then when the temperature of UCO fell about 60℃ which was ready for transesterification reaction were shown in Figure 3.3.

Figure 3.3 Measuring and preheating of UCO before transesterification reaction

B. Measuring and preparation of methoxide solution

Measured 4.7g of KOH in the concentration of 1.2 wt % to UCO was pre-mixed with 65g of methanol and continuously agitated until the catalyst was dissolved using a magnetic stirrer to form methoxide solution for each experimental condition before methoxide solution form for transesterification reaction measured potassium hydroxide (KOH) and methanol were shown in Figure 3.4.

Figure 3.4 Measuring of potassium hydroxide and methanol

C. Transesterification reaction

In each experiment, 390 grams of preheated UCO at about 60℃ fed with a meth-oxy solution in a one-liter separator funnel serving as a batch reactor. Then the mixture was vigorously shaken in all directions by hand for 5 minutes and left undisturbed in a stand for 5 hours for phase separation. In phase separation, biodiesel gets separates from the glycerol phase. Glycerol is heavier than biodiesel it was settled down at the bottom due to gravity(Debela, 2018). Figure 3.5 Separator funnel with mixture allow standing for five hours.

Figure 3.5 Allow standing for five hours

D. Separation of biodiesel and glycerin

The products of the reaction were allowed to settle for 5 hours in the separator funnel. The phase separation process of raw biodiesel and glycerol was based on the density difference between two reaction products and due to gravity. Thus, the reaction products are separated into two layers; the upper layer (crude methyl ester) and the lower layer (glycerin). First glycerin was removed and then crude biodiesel was collected into a clean plastic bottle/ Figure 3.6 shows the separation of phase. After separating the phases, the impurity like residual KOH, methanol, and soap was washed from the crude biodiesel with distilled water.

Figure 3.6 Separation of crude biodiesel and glycerin phase

E. Purification process

The crude biodiesel was cleaned by washing with warm refined water to eliminate water-dissolvable impurities like remaining methanol, glycerol which decreased the nature of biodiesel properties. Around half v/v at 45℃ of clean deionized warm water was added to the crude biodiesel at each progression of washing. The separator funnel was shaken gently for 2 minutes and the blend was then permitted to settle to 30 minutes to isolate biodiesel and water layers. The water (milky color) was taken out as waste from the bottom phase. The process has been repeated a minimum of six times until the water stays clear which demonstrates the biodiesel is reasonably clean were shown in Figure 3.7. Then washed biodiesel was collected in a clean plastic bottle and ready for the next process.

Figure 3.7 First and final (sixth step) biodiesel washing

After completion of the washing process, clean biodiesel was dried on a hot plate to 110℃ for 45 minutes as shown in Figure 3.8. The final product nearest to gold color was ready for characterization of fuel properties

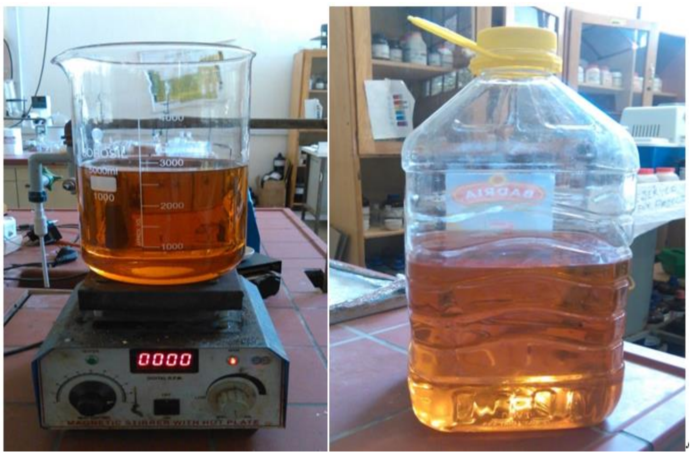


Figure 3.8 Process of drying biodiesel and collected pure biodiesel

3.5 Biodiesels yield

The biodiesel yield is the mass percentage of the purified biodiesel relative to the initial mass of UCO introduced into the transesterification process (Oluwole et al., 2014)

After the purification process, the biodiesel yield was then determined as followed.

Biodiesel yield(%)= $\frac{Wt\ of\ purified\ biodiesel}{Wt\ of\ UCO} \times 100\% = \frac{345g}{390g} \times 100\% = 88.46\%,$

Where Wt, the weight of purified biodiesel or UCO

The yield of pure biodiesel obtained from a single experiment was 88.46% the input parameter was Wt of UCO (390g) and Wt of pure biodiesel (345g).

3.6 Used cooking oil biodiesel blend preparation

A. Biodiesel blending

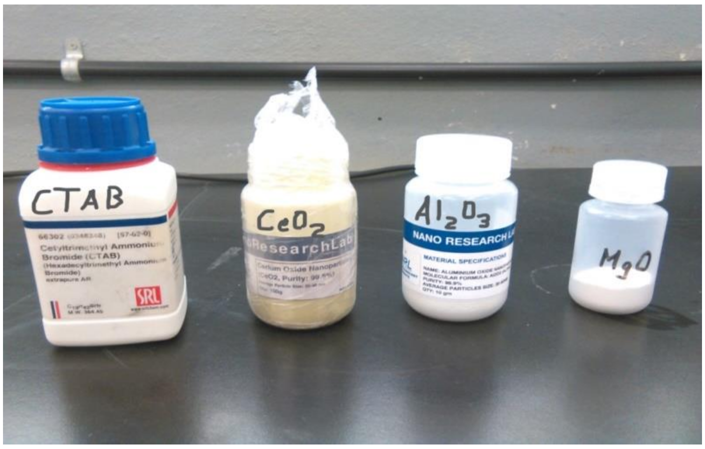
The blends of the used cooking oil methyl ester with petro-diesel were prepared. The optimum blend was prepared at B15 (15%biodiesel and 85%diesel). The procedure followed for blending biodiesel and diesel is given below:-

a. Take a plastic bottle of 1.5 Liter
b. The blends were prepared for 1000ml amount.
c. The blends B15 was prepared by taking 150ml of biodiesel and 850ml of diesel.
d. The blends were prepared by vol% and handshakes for about 2 minutes.
e. After blends were prepared, they were collected in 1-liter plastic bottles.

B. Nanoparticles (NPs) blending:

The process of adding NPs to the fuel is done with the aid of an ultrasonicator. This technique is the best-suited method to disperse the NPs in the base fuel, as it facilitates possible agglomerate NPs back to the nanometer (nm) range. The necessary quantity of the NPs for each experimental sample was precisely estimated utilizing an electronic balance and was blended with the fuel employing an ultrasonicator, passing ultrasonic waves for 40 minutes at a higher frequency (40 kHz) to produce a uniform suspension. The blended fuels with NPs were utilized directly after preparation, to avoid any settling or for sedimentation to occur. Equipment and materials used for the preparation of blended fuels with NPs were the following and shown in Figure 3.9 below.

a). Ultrasonicator cleaner b). Electronic balance



c) CTAB, CeO_2, Al_2O_3, and MgO nanoparticles respectively.

Figure 3.9 a) Ultrasonicator cleaner, b) Electronic balance, and c) NPs

The procedures followed during the preparation of NPs were mentioned below

a. For the blending of oxide of cerium, aluminum, and magnesium NPs in biodiesel, to prepare the first fuel sample (B15C80A40M30) taken B15 one liter by volume diesel/biodiesel blended fuels and then measure the (0.08g (80ppm) of CeO_2; 0.04 g (40ppm) of Al_2O_3, and 0.03 g (30ppm) of MgO). A measure of 0.15 g (150ppm) of CTAB is a cationic surfactant and it forms an envelope on the surface of the NPs. Add first measured CTAB to 1-liter blended fuels (B15) in a plastic bottle and followed by adding measured three NPs on their respective order. After the addition of NPs, it is shaken well for about 2 minutes.
b. For the second (B15C80A50M20) and third (B15C80A20M50) fuel samples measure (0.08g of CeO_2, 0.05g of Al_2O_3, 0.02 g of MgO) and measure the (0.08 g of CeO_2, 0.02 g of Al_2O_3, 0.05g of MgO) respectively. Measure 0.15 g of CTAB for each fuel sample and follow the same procedure as mentioned before.

c. Fill partially the Ultrasonicator cleaner with water and put three sample fuels with NPs in plastic bottles onto it. Set the Ultrasonicator on optimum condition (set time at 40minutes and frequency at high (40KHz)) Figure 3.10.

Figure 3.10 Preparation of blended fuels with NPs in Ultrasonicator cleaner.

Then take three blended fuel samples. Neat biodiesel, blended fuels, and blended fuel with NPs prepared for characterization and engine tests are shown in Figure 3.11 below.

Figure 3.11 Pure biodiesel, blended fuels, and blended fuels with NPs.

3.7 Characterization of used cooking oil biodiesel and its blends

The characterization of sample fuels was conducted using ASTM standard test methods at the Ethiopian Petroleum Supply Enterprise Laboratory. Thus before running a diesel engine with test fuels the quality must be determined. During this study characterization of the test, fuels were done for density, calorific value, cloud point, viscosity, and total acidity. Fuel samples prepared for the properties test were pure biodiesel (B100), biodiesel blended fuel B15 (15%biodiesel+85%diesel) and biodiesel blended fuel with NPs B15C80A40M30 (B15+80ppmCeO_2+40ppmAl_2O_3+30ppmMgO).

3.8 Engine experimental setup and test procedure

The test engine used in the experimentation was CT 100.32 a single-cylinder; four-stroke, air-cooled diesel engine with a direct injection system at Ethiopia Dilla DU. It has a compression ratio (CR) of 22:1 and a rated power of 5.5 kW at 3500 rpm. For measuring the engine performance parameter such as the power output of the diesel engine used in the experiment, an air-cooled asynchronous motor was coupled with an engine shaft and it was loaded with the help of a frequency converter. The detail specification of the diesel engine is given in Table 3.2. The exhaust gases emission from diesel engine was measured using infralyt smart exhaust gas analyzer it measures the composition of exhaust gases such as carbon monoxide (CO), unburned hydrocarbons (HC), Oxygen (O_2), Carbon dioxide (CO_2), fuel/air ratio lambda (λ), and the oil temperature in the diesel engine. The detail specification of infralyt smart exhaust gas analyzer was given in Table 3.3. The engine was operated at full load condition at variable engine speed 2000rpm-3400rpm. The performance parameters evaluated were brake power (BP), brake torque (BT), and brake specific fuel consumption (BSFC). To evaluate the exhaust emissions, the concentration of CO, HC, O_2, and CO_2were monitored using exhaust gases analyzing unit. Table 3.5 shown the experimental test matrix and Figure 3.12 show a schematic diagram of the experimental setup.

Table 3.5 Experimental test matrix

Engine operating parameters		Test fuels	Evaluating Parameters
	Test condition		
Fixed CR 22.1 Fixed fuel IP Fixed fuel IT	Full engine load 2000rpm-3400rpm	B0 or D100 B15 B15C80A40M30 B15C80A50M20 B15C80A20M50	Performance parameters i. BP ii. BT iii. BSFC Emission parameters i. CO emission ii. HC emission iii. CO_2 emission iv. O_2 emission

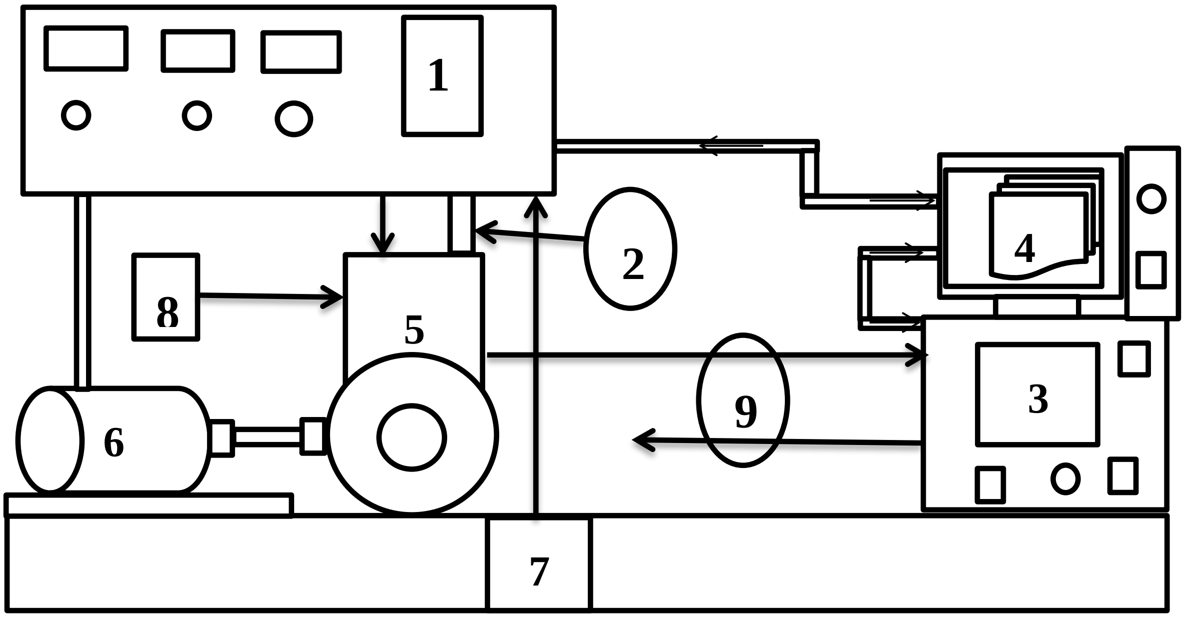


Figure 3.12 Schematic diagram of the experimental setup

(1) Test stand	(4) Desktop computer	(7) Fuel tank and fuel intake line
(2) Fuel flow tube	(5) Diesel engine	(8) Air filter and air intake line
(3) Exhaust gas analyzer	(6) Asynchronous motor	(9) Exhaust gas line

A diesel engine and a synchronizer motor were connected to the test stand and the Test stand was connected to a desktop computer. The desktop computer and exhaust pipe of the diesel engine were connected with the exhaust gases analyzer.

Test stand and diesel engine test stand (CT 110) and CT 100.32 a single-cylinder 4-stroke air-cooled diesel engine were the two basic important units to determine engine performance and the result was simply displayed on the desktop computers. Engine operating conditions were full or partial load at variable speed the output measurements were thermal efficiency, mechanical efficiency, BP, BT, BSFC, etc. The desktop computer connected to the test stand record performance test results and exhaust gases analyzer record emission both display and record data. The setup of the test stand and exhaust gas analyzer was shown in appendix B and C, respectively.

Exhaust gas analyzer the exhaust gas analyzing unit (CT 159.02) can be used for emission analyses to measure the exhaust gas composition Oxygen (O_2), Carbon monoxide (CO), Carbon dioxide (CO_2) and Hydrocarbon (HC), the fuel/air ratio lambda (λ), and the oil temperature in the engine. This unit is connected to both tailpipes of diesel engines and desktop computers. The desktop computer and exhaust gases analyzer is used to display the obtained results

The engine performance test measurement was done for BP, BT, and BSFC, exhaust gases emission test measurement was done for CO, CO_2, O_2, and HC emission was part of the thesis work. Figure 3.13 shown a photographic experimental setup.

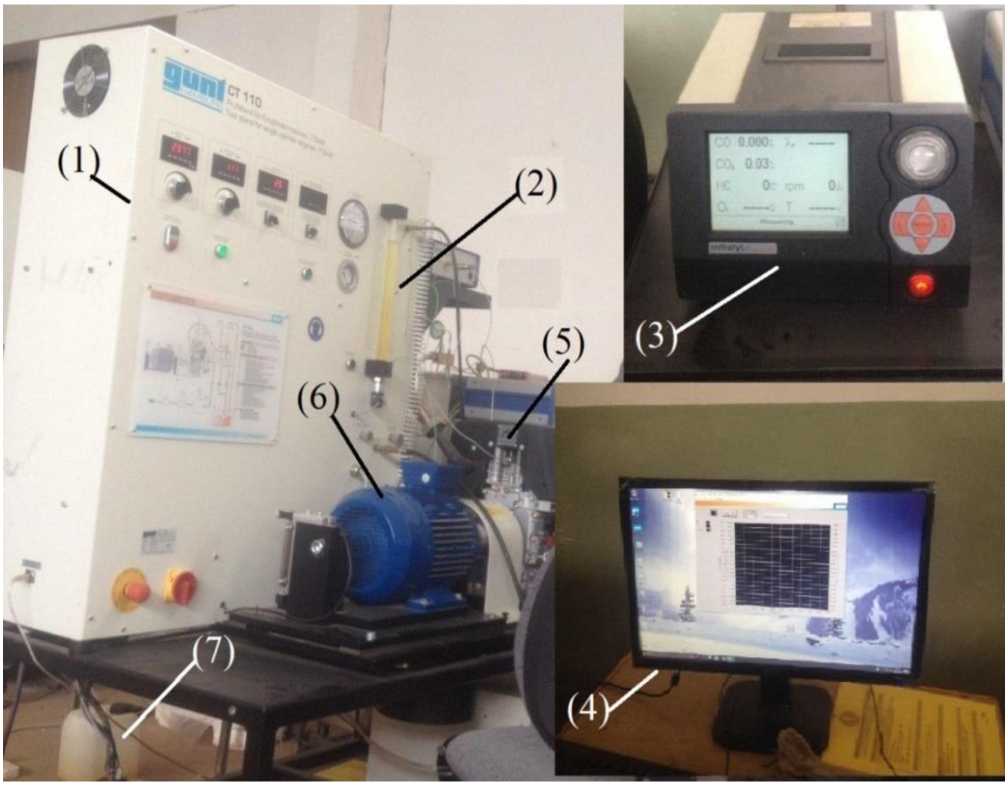


Figure 3.13 Photographic a view of an experimental setup

(1) Test stand (CT 110) (4) Desktop computer

(2) Fuel flow tube (5) Diesel engine (CT 100.32)

(3) Exhaust gas analyzer (CT 159.02) (6) Asynchronous motor, (7) Fuel tank

3.8.1 Test procedure

Initially, set up all material that was utilized to adjust the test stand of the diesel engine.

The engine was at the start fuelled with baseline diesel fuel (B0) to deliver the baseline data, and then it was fuelled with B15, B15C80A40M30, B15C80A20M50, and B15C80A50M20. The fuel was found into the fuel tank independently to test and recorded the results on the output.

Prepared test fuels were tested on diesel engine between 2000rpm-3400 rpm with the interval of 200 rpm at full load condition

Starting the Engine

Preparations

1. Connect test staned to the mains electricity.

2. Check that the EMERGENCY STOP (A) is released. To release, pull the button until it clicks into place.

3. Turn on the master switch (B).

4. All connections between the engine and the test stand must be set up. The air hose and exhaust hose must be connected, and the outlet of the exhaust hose must be outdoors.

5. Make sure that the safety cover for the coupling is bolted to the test stand base plate.

6. Check the engine oil level.

7. Before starting the engine, the fuel line to the engine and the measuring tube on the test stand must be filled so that top up fuel using the button (G) Figure 3.14

8. The fuel valve for draining the measuring tube must be closed.

9. The engine stop solenoid must be released by operating the "Ignition" switch on the test stand.

10. The speed regulator must be set to "Start".

Starting

1. Set the speed adjusting knob (D) for the asynchronous motor to approx. "5".

2. Set the torque adjusting knob (F) to a maximum torque of "10".

3. Turn on the ignition with the push button (E).

4. Turn on the asynchronous motor by pressing the "Starter/Brake" button (C) (green) on the test stand.

5. When the C engine starts up, turn off the asynchronous motor with the "Starter/Brake" (C) (red) button.

6. The C engine now runs at idle speed.

7. When the engine is warm, turn choke to position RUN.

8. Allow the engine to warm up without load for approx. 5 minutes.

Operating the Engine

Once the engine has been started, it should be left to warm up for a while prior to the start of the experiments.

Full and partial load characteristic curves are to be recorded on the engine.

The experiment result was conducted and recorded through a desktop computer with an exhaust analyzer displayed.

Each experiment was repeated twice, where the average values of the tests are taken.

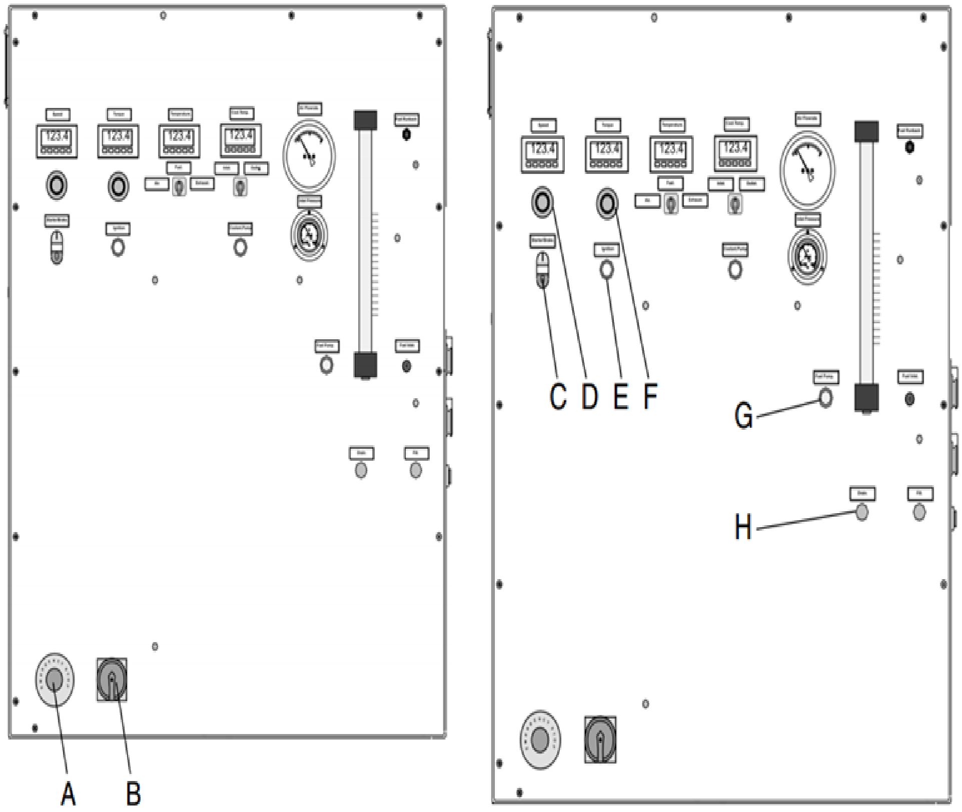


Figure 3.14 Controls

3.8.2 Data Analysis

During the experiment performance and exhaust gas emission parameters were recorded from the test stand, desktop computer, and exhaust gases analyzer. The data were collected and plotted against engine speed at full load conditions. Engine parameter measured during the experiments were BP, BT, BSFC related to engine performance and CO, HC, CO_2, and O_2 emission related to exhaust gas emissions.

Brake power (BP): is an engine performance parameter that mainly determines the net power available at the flywheel. The power P, delivered by an engine and absorbed by a dynamometer is the product of the torque and angular speed (Kaisan & Pam, 2013). The brake power of the engine at full load conditions was determined using the equation (3.3).

$$BP=\frac{2\pi NT}{60}(kW) \text{ --(3.3)}$$

Where BP= brake power (kW)

N= angular speed (rpm)

T= torque in (Nm)

Brake torque(BT) is an engine performance parameter that mainly determines the torque available at the flywheel. The torque applied by the engine on the dynamometer is BT (Kaisan & Pam, 2013). The brake torque of the engine at full load conditions was determined using the equation (3.4).

$$BT=\frac{BP60}{2\pi N}(Nm) \text{ -- --------------------(3.4)}$$

Where BT= brake torque(Nm)

BP= brake power (kW)

N= angular speed (rpm)

Brake specific fuel consumption (BSFC) is an engine performance parameter that mainly determines the amount of fuel consumed by the engine in 'kg/hr' to develop '1 kW' brake power(BP) at an engine speed(N). The consumption rate of fuel is the product of the volume flow rate of the fuel and the density of the fuel (Kaisan & Pam, 2013). The BSFC of the engine at full load conditions was determined using the equation(3.5).

$$BSFC=\frac{\dot{m}_f}{BP}(kg/kW\text{-}hr) \text{ --(3.5)}$$

But for $\dot{m}_f=\dot{v} \times \rho_f$,

Where BSFC=brake specific of fuel consumption (kg/kW-hr)

$\dot{m}_f$=mass flow rate (kg/hr), BP=brake power(kW)

$\dot{v}$=volumetric flow rate(m^3/hr)

ρ_f= density of fuel(kg/m^3).

Exhaust gases emission the substance which is discharged into the atmosphere from any opening of the exhaust port of the engine is called exhaust emissions. In complete combustion was the air-fuel mixture is stoichiometric the product of combustion would consist of carbon dioxide(CO_2) and water (H_2O) and water vapor only. However, due to incomplete combustion of fuel and hence the exhaust gas consists of a variety of components most important of them are carbon monoxide (CO), hydrocarbon (HC), and oxid of nitrogen(NO_X) etc.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Collection of used cooking oil (UCO)

Used cooking oil was collected from the student cafeteria of ASTU, after frying vegetables and other food items. The collection of UCO after frying various vegetables and food was taken from 8 liters of oil sample was collected. This oil sample was allowed to stand for a few days so that none oil materials settle down and followed by decanting and filtering. After filtering the debris the final volume of oil was 7.8 liter

4.2 Methyl ester yield

The biodiesel yield obtained by a transesterification process from used cooking oil (UCO) under a reaction condition was given in Table 4.1. This chemical reaction requires UCO, and methanol as a reactant, and potassium hydroxide (KOH) as a base catalyst to yield methyl ester. The maximum yield of biodiesel from UCO after the purification process was 88.46%.

Table 4.1 Optimum condition of the transesterification process.

UCO, gm	FFA, %	Methanol, gm	Molar ratio %	KOH, gm	Reaction temp ℃	Reaction time, mn	Yield, %
390	0.986	65	1:6	4.7	60	5	88.46

4.3 Biodiesel and its blended fuel characteristics results

The determination of the physicochemical properties of methyl ester and its blends was done at Ethiopian Petroleum Supply Enterprise Laboratory. The characterization result and certificate obtained (Appendix C) from the organization were summarized in table 4.2. From Table, 4.2 it observed that the density of blended fuel (B15) and B15 with NPs are less than that of B100 at15℃. For biodiesel blended fuels calorific value (calculated) is higher than that of neat biodiesel. The addition of nanoparticles increased calorific value further. The Cloud point of B15 lower than neat biodiesel and the cloud point of blend with nanoparticles is further less. The kinematic viscosity was significantly reduced for both blended fuels B15 and B15C80A40M30 compared to B100. The total acidity of B15 is less than B100 and that of blend with nanoparticles is further less. Finally, the test result for three sample fuels showed that the properties of all sample fuels obey the international ASTM standards except the total acidity.

Table 4.2 Properties of pure biodiesel and its blended fuels

Properties	Test method ASTM	Biodiesel Limit	Test results		
			B100	B15	B15C80A40M30
Density@15℃(g/ml)	D4052	Report	0.8855	0.8452	0.8450
Density@20℃(g/ml)	D4052	Report	0.8821	0.8417	0.8415
Calorific value (BTU/LB)	Calculated		19200	19563	19565
Cloud point(℃)	D2500		+15	+9	+7
Kinematic viscosity @40℃(mm^2/s)	D445		6.0	3.0	3.0
Total acidity (mg KOH/g)	D974		1.137	0.413	0.386

4.4 Engine performance and exhaust emission characteristics

In this part of the study, the variations in engine performance parameters and tailpipe emission Vs change in engine speed were discussed. The three engine performance parameters against engine speed studied were BP, BT, and BSFC by using the formula given in the previous chapter three equation (3.3, 3.4, and 3.5). The emission analysis against engine speed was also done for four exhaust gases such as CO, CO_2, O_2 and HC emission. For engine performance, test, and exhaust gases emission test fuel samples prepared were B0, B15, B15C80A40M30, B15C80A20M50, B15C80A50M20. The test results determined were compared with baseline diesel fuel (B0).

4.4.1 Performance characteristics

Brake power (kW): The brake power (BP) can be calculated by using equation 3.3 and plotted against engine speeds. Table 4.3 shows the BP variation with engine speed obtained from the test stand for test fuels.

Table 4.3 The output brake power (BP) data recorded from the test stand

Engine Brake Power(kW)					
Engine Speed (rpm)	Fuel Samples				
	B0 (D100)	B15	B15C80A40M30	B15C80A20M50	B15C80A50M20
	Brake power (BP)				
2000	3	2.35	2.6	2.67	2.33
2200	3.11	2.59	2.48	2.65	2.49
2400	3.29	2.79	2.83	3.06	2.88
2600	3.34	3.1	3.31	3.18	3.32
2800	3.54	3.42	3.96	3.53	3.65
3000	3.99	3.86	4.39	3.94	4.07
3200	4.75	4.54	4.46	4.81	4.64
3400	4.86	5.2	4.85	5.12	4.96

The engine BP of test fuels at different engine speed at full load condition is shown in Figure. 4.1. It is realized from Figure 4.1 that the BP of test fuels gradually increased with an increase in engine speed. The maximum BP for B0 fuel was measured at an engine speed of 3400rpm 4.86 kW.

The average BP of B15, B15C80A40M30, B15C80A20M50, and B15C80A50M20 were 6.8%, 3.35%, 3.08%, and 5.15%, lower than B0 respectively. A lower amount of average BP (3.48 kW) was found with B15. The higher BP of B0 fuel is due to its low viscosity and high heating value. The combustion takes place more efficiently in the cylinder leading to rising in BP. When comparing the BP of modified fuels with NPs and biodiesel blends it was realized that the average BP of B15C80A40M30, B15C80A20M50, and B15C80A50M20 has 3.57%, 3. 08% and 1.76% more compared to B15, respectively. This could be due to the existence of metal oxide (aluminum, and magnesium) nanoparticles in test fuels(Gumus et al., 2016; Ranjan et al., 2018).

For blended fuel with NPs B15C80A40M30 and.B15C80A20M50 have better BP than B15C80A50M20. Increasing the dosage of magnesium oxide nanoparticles in blended fuels doesn't show a significant change in BP.

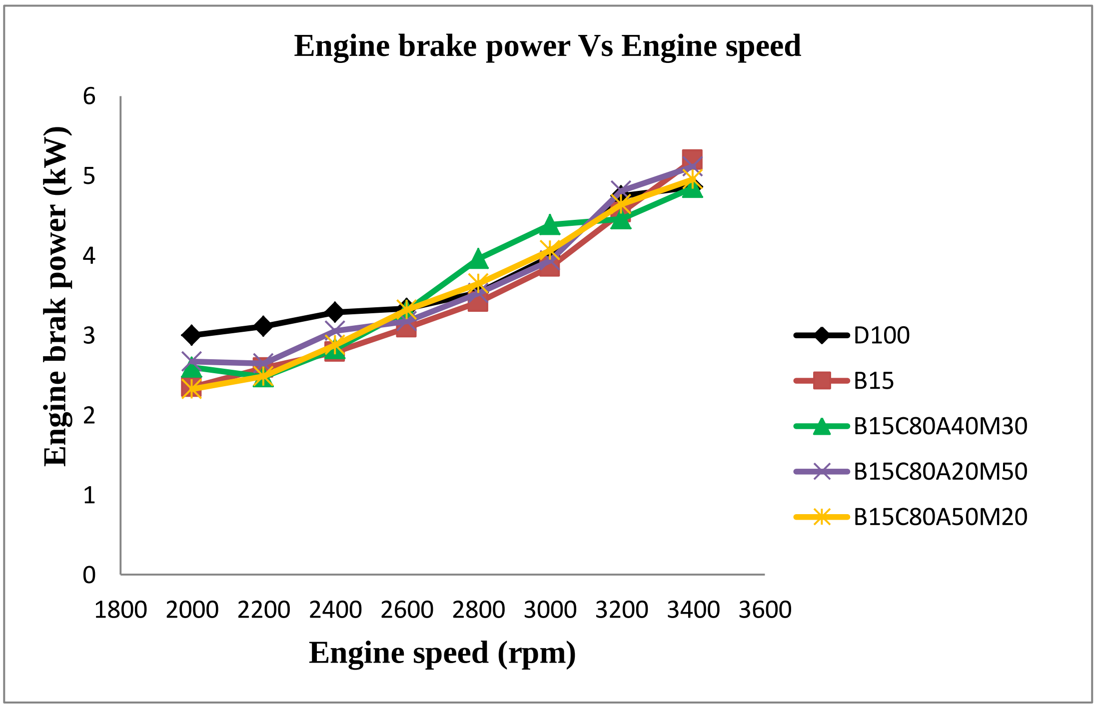


Figure 4.1 Variation of engine brake power with engine speed at full engine load

Engine brake torque (Nm): The engine brake torque (BT) was calculated based on equation 3.3 and plotted against engine speeds. Table 4.4 below shows the variation of BT with engine speed recorded from the test stand for test fuels. The brake torque trend at the full-load condition for test fuels slowly increased with an increase in engine speed, but further increases in engine speed reduce brake torque. The higher value of BT for baseline diesel fuel was measured 14.29Nm at an engine speed of 3400rpm. The BT of B0 fuels were slightly lower than B15C80A40M30 and B15C80A20M50, but slightly higher than B15 and B15C80A50M20. The average BT of B15 and B15C80A50M20 were.1.97% and 0.16% lower than B0 fuel respectively. The mean BT of B0 fuel was 2.5% and 0.7%, lower than B15C80A40M30 and B15C80A20M50 respectively. When comparing all test fuels with diesel B15C80A40M30 had improved BT. The enhancement in BT of test fuel was due to the optimum dosage of oxide of metals (oxide of cerium, and aluminum) NPs (Debas, 2019; Gumus et al., 2016). Fig 4.2 shown variation of BT with engine speed recorded from test stand for all test fuels.

Table 4.4 The output brake torque (BT) data recorded from the test stand

Engine Brake Torque(Nm)					
Engine Speed(rpm)	Fuel Samples				
	B0 (D100)	B15	B15C80A40M30	B15C80A20M50	B15C80A50M20
	BT				
2000	11.29	11.2	11	11.3	11.1
2200	11.34	11.21	11.27	11.5	10.83
2400	12	11.1	11.45	12.08	11.41
2600	11.85	11.37	12.14	11.66	12.14
2800	12.07	11.66	13.41	12.16	12.45
3000	12.68	12.27	13.95	12.58	12.86
3200	13.39	13.54	14.03	14.31	13.92
3400	14.29	14.61	14.14	14.39	14.04

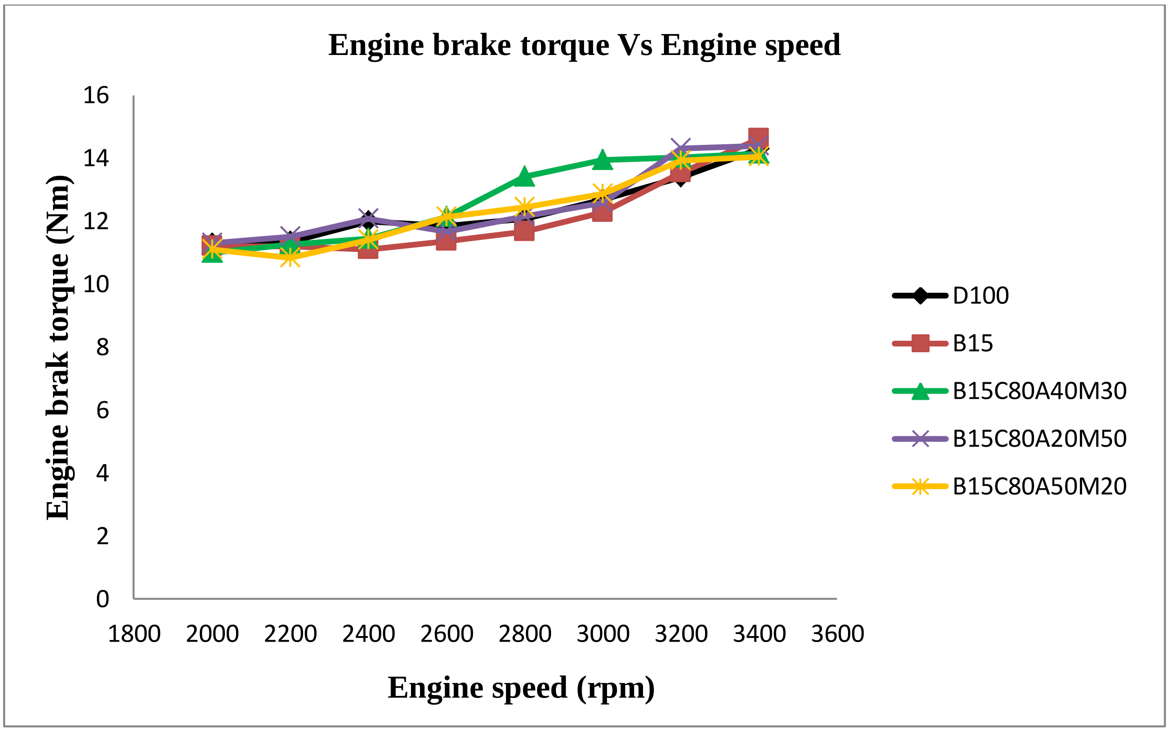


Figure 4.2 Variation of engine brake torque with engine speed at full engine condition

Brake specific fuel consumption (kg/kWh): The vital parameter to test engine performance is by the comparison of brake specific fuel consumption (BSFC) along with engine speed. BSFC of diesel engine mainly influenced by density, viscosity, the higher heating value of fuel, and volumetric fuel injection. Table 4.5 below shows that the output data for BSFC with engine speed obtained from the test stand. The BSFC of the engine at each engine speed was determined according to equation 3.4.

Table 4.5 The output BSFC data recorded from the test stand

Brake specific fuel consumption(kg/kWh)					
Engine Speed(rpm)	Fuel Samples				
	B0	B15	B15C80A40M30	B15C80A20M50	B15C80A50M20
	Brake specific fuel consumption (BSFC)				
2000	0.73	0.76	0.67	0.65	0.64
2200	0.72	0.74	0.65	0.62	0.63
2400	0.61	0.62	0.56	0.57	0.56
2600	0.62	0.62	0.55	0.54	0.52
2800	0.65	0.67	0.54	0.62	0.6
3000	0.81	0.83	0.74	0.75	0.7
3200	0.85	0.86	0.79	0.8	0.77
3400	0.87	0.89	0.83	0.82	0.83

The BSFC changes with engine speed as the engine speed increases the BSFC decreases simultaneously and reaches the minimum value, but further increases in engine speed resulted in a rise in BSFC at full load condition. Figure 4.3 shows the BSFC values of test fuels with a variation in engine speed.

The mean BSFC of baseline diesel fuel (B0) was 2.21% lower than B15. For other biodiesel blended fuels with NPs average BSFC of B15C80A40M30, B15C80A20M50, and B15C80A50M20 were 9.04%, 8.36%, and 10.4% lower than B0 respectively. On average BSFC of B15C80A50M20 was about 10.4% lower than B0 this occurs because of the addition of oxide of cerium and aluminum NPs. The BSFC was reduced due to the positive effect of two NPs resulted in the oxidizing of carbon deposit and donating of oxygen leads to complete combustion results in reduced fuel economy (Aalam et al., 2015; Babu & V.Pandurangadu, 2018; El-Seesy et al., 2018)

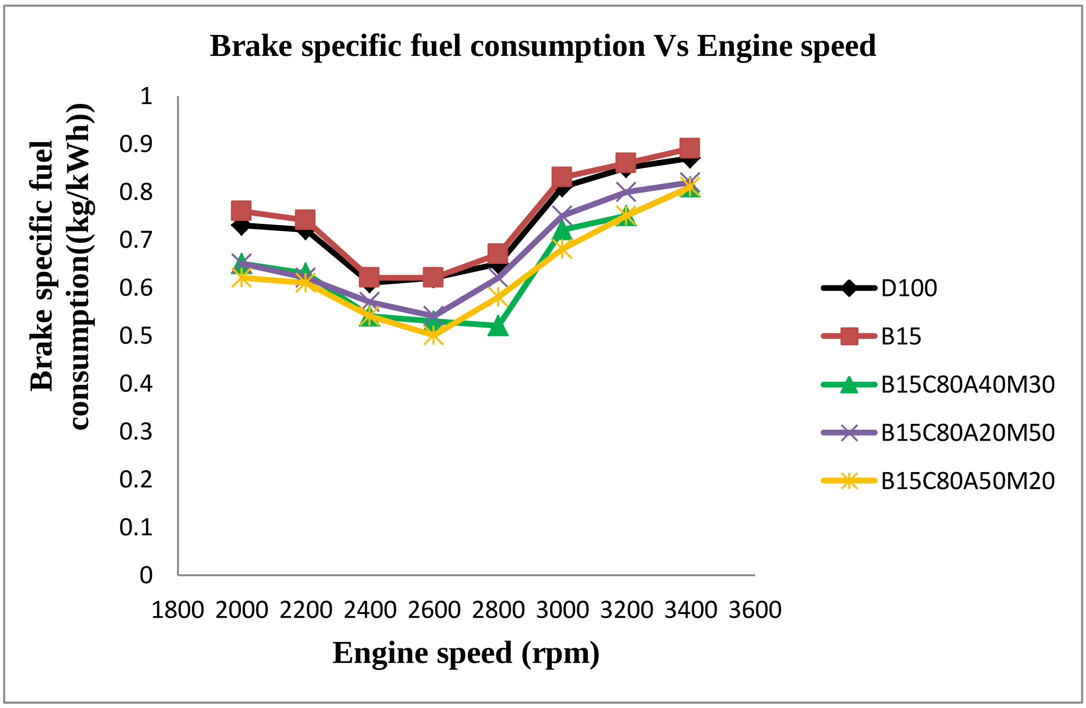


Figure 4.3 Variation of BSFC with engine speed at full engine load

4.4.2 Exhaust emission characteristics

In this part of the study, the variation in the exhaust emissions with engine speed is discussed. The different exhaust parameters studied are carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon emission (HC), and oxygen emission (O_2).

Carbon monoxide emission (CO): Incomplete combustion of test fuels leads to an increase in CO emission. For complete combustion of fuel, the basic requirements are excess oxygen supply, good air-fuel mixture blending, enough time, and oxygen concentration are needed to avoid incomplete combustion. Table 4.6 below shows that the output data of CO (%) emission obtained from the test stand.

Table 4.6 Carbon monoxide emission (%) data recorded from the test stand

Carbon monoxide emission (%)					
Engine Speed(rpm)	Fuel Samples				
	B0	sB15	B15C80A40M30	B15C80A20M50	B15C80A50M20
	Carbon monoxide emission(CO)				
2200	0.075	0.062	0.048	0.05	0.054
2400	0.064	0.056	0.045	0.045	0.049
2600	0.063	0.055	0.052	0.047	0.049
2800	0.069	0.059	0.046	0.046	0.052
3000	0.076	0.065	0.057	0.063	0.062
3200	0.089	0.076	0.067	0.065	0.071
3400	0.097	0.089	0.081	0.08	0.082

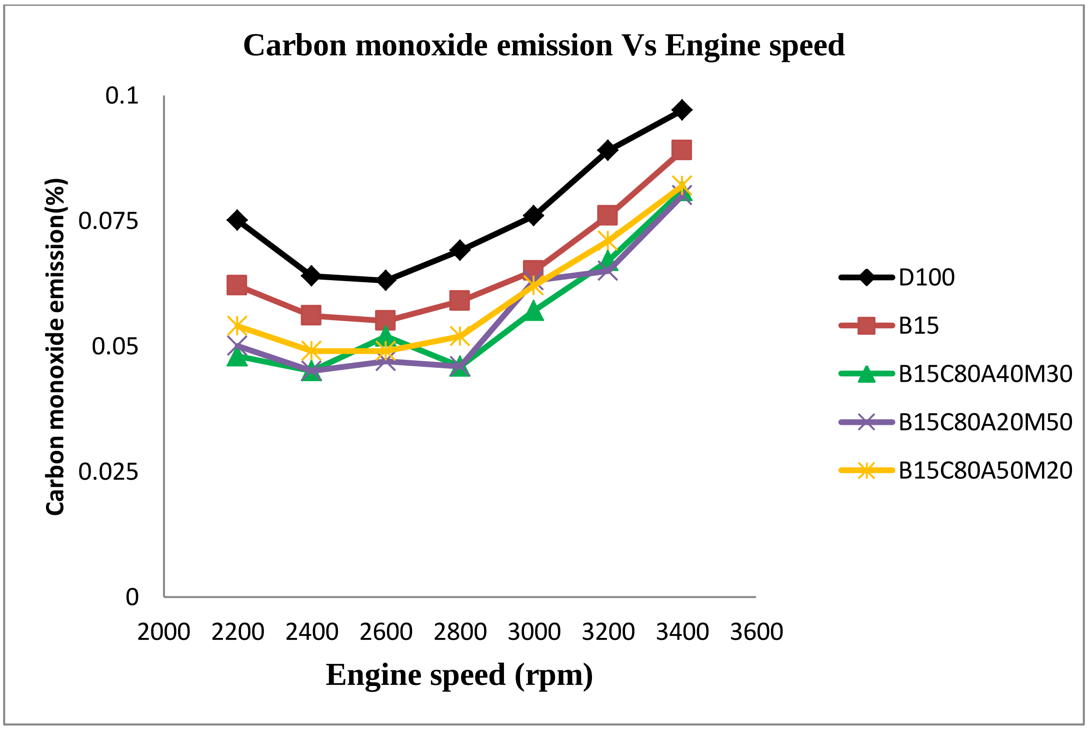


Figure 4.4 Variation of carbon monoxide emission with engine speed at full engine load

The variation of CO emission with an engine speed for test fuels at full load conditions is shown in Fig. 4.4. The higher value CO emission was measured for B0 than other test fuels. In average CO emission of B0 fuels were 13.32%, 25.7%, 25.7%, and 21.39% higher than B15, B15C80A40M30, B15C80A20M50, and B15C80A50M20 respectively. Two biodiesel blended fuels with NPs B15C80A40M30 and B15C80A20M50 had nearly similar less CO emission than other test fuels because aluminum oxide NPs acts as a O_2 donating catalyst and provide oxygen for the oxidation of UHC and CO (Aalam & Saravanan, 2015b). Also, magnesium oxide improves the oxygen content of fuels which facilitates complete combustion of the air-fuel mixture. The other reason is biodiesel blended fuels have better oxygen content than B0.

Carbon dioxide emission (CO_2): Complete combustion of the air-fuel mixture is described by a higher measurement of CO_2 in the emission. The higher percentage of CO_2 emission is due to complete combustion and excess O_2 content in blended fuels results in the conversion of CO to CO_2. The output data of CO_2 emission is given in table 4.7

Table 4.7 Carbon dioxide emission (%) data recorded from the test stand

Carbon dioxide emission (%)					
Engine Speed(rpm)	Fuel Samples				
	B0	B15	B15C80A40M30	B15C80A20M50	B15C80A50M20
	Carbon dioxide emission (CO_2)				
2200	2.23	2.17	2.09	2.14	1.94
2400	2.18	2.16	2.14	2.1	2.01
2600	2.42	2.35	2.28	2.25	2.09
2800	2.49	2.45	2.34	2.33	2.31
3000	2.66	2.53	2.51	2.48	2.4
3200	2.7	2.59	2.55	2.6	2.5
3400	2.85	2.8	2.73	2.85	2.63

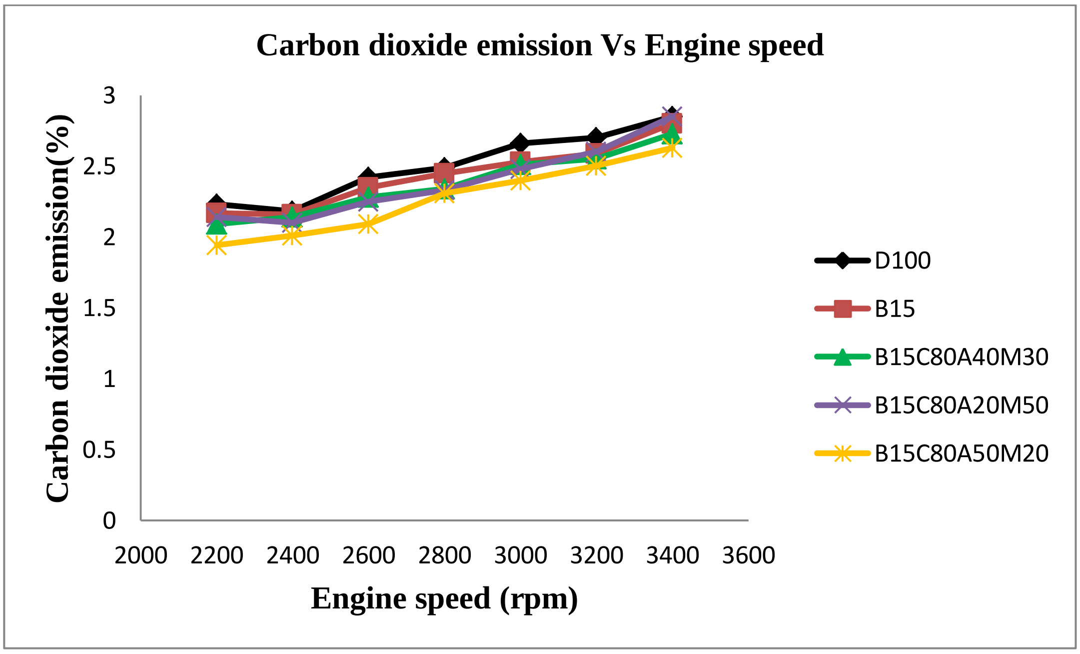


Figure 4.5 Variation of carbon dioxide emission with engine speed at full engine load

Fig. 4.5 shows that the variation of CO_2.emission with an engine speed for test fuels at full load condition. From the plot, it is observed that as the engine speed increases the CO_2.emission increasing.

The mean CO_2 emitted by B0 was 2.73%, 5.08%, 4.45%, and 9.41% higher when compared to B15, B15C80A40M30, B15C80A20M50, and B15C80A50M2B20 respectively. From all nanoparticles blended fuels B15C80A50M20 was better in the reduction of CO_2 emission. This reduction may be due to fact that biodiesel has lower elemental carbon to hydrogen ratio than diesel fuel. The burning of blend fuels with air will therefore form lower emissions than diesel fuel. This reduction in CO_2 emission was due to the addition of metal oxide nanoparticles (oxide of cerium and aluminum) (Babu & V.Pandurangadu, 2018; Debas, 2019; Prakash et al., 2019).

Hydrocarbon emission (HC): HC is produced due to incomplete combustion of test fuels inside a cylinder. HC emissions are influenced by parameters like the composition of test fuels, operating conditions of an engine. The recorded data of HC emission is given in Table 4.8.

Table 4.8 Hydrocarbon emission (ppm) data recorded from the test stand

Hydrocarbon emission (ppm)					
Engine Speed(rpm)	Fuel Samples				
	B0	B15	B15C80A40M30	B15C80A20M50	B15C80A50M20
	Hydrocarbon emission (HC)				
2200	14	13	11	12	11
2400	13	12	11	11	10
2600	13	11	10	10	10
2800	13	11	10	11	10
3000	14	12	11	11	11
3200	15	14	13	12	13
3400	17	15	13	14	14

Figure 4.6 shows the change in HC emission of test fuels under various engine speeds. From the plot, it is observed that as the engine speed increases the HC emission increases for B0 as well as for blends at full engine load. Average HC emissions were determined to be 12.57, 11.28, 11.57, 11.29, and 14.14 respectively for B15, B15C80A40M30, B15C80A20M50, B15C80A50M20, and B0. For B15 and its blends with NPs, the HC emissions were lesser than that of B0 and this might be the presence of oxygen in blended fuels and due to which resulted in complete combustion.

In average HC emission of B15, B15C80A40M30, B15C80A20M50, and B15C80A50M20 were 11.11%, 20.18%, 18.18%, and 20.2% less emission as compared to B0. From the above analysis, it’s found that B15C80A40M30 and B15C80A50M20 were better than both B15 and B0 in the reduction of HC emission. The addition of more aluminum oxide promotes complete combustions which act as oxygen donating catalysts and also magnesium oxide enhances the oxygen content of fuels (Gumus et al., 2016; Sachuthananthan et al., 2019).

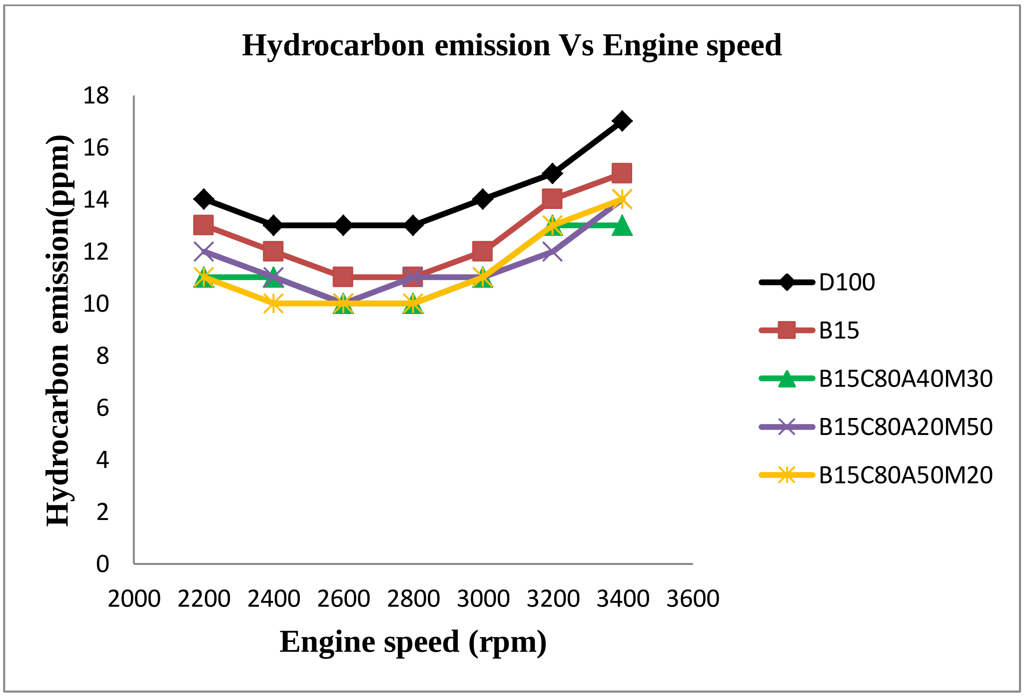


Figure 4.6 Variation of hydrocarbon emission with engine speed at full engine load

Oxygen emission (O_2): Oxygen emissions occur due to the presence of higher oxygen molecules in the biodiesel up to 11% or blended fuels with or without nanoparticles (NPs) than baseline diesel fuel. The higher O_2 emission is an indication of complete combustion of the air-fuel mixture in the combustion chamber. Table 4.8 below gives the output data of O_2 emission recorded from the test stand. As the engine speed was increased from O_2 emissions decreased. This may be due to the reduction of oxygen content. The average O_2 emissions of B0 were, 1.4%, 1.93%, 1.95%, and 1.62% lower than those of B15, B15C80A40M30, B15C80A20M50, B15C80A50M20, respectively. Biofuel has high oxygen content than baseline diesel fuel. The addition of magnesium oxide NPs results in higher oxygen content of the fuel (Ranjan et al., 2018). The addition of oxide of cerium and aluminum nanoparticles also have a positive effect on O_2 emission (Debas, 2018). From the above analysis, it’s realized that B15C80A40M30 and B15C80A20M50 are better than both B15 and B0 to higher O_2 emission. Oxygen emission Vs engine speed shown in Figure 4.7

Table 4.8 Oxygen emission (%) data recorded from the test stand

Engine Speed(rpm)	Oxygen emission (%)				
	B0	B15	B15C80A40M30	B15C80A20M50	B15C80A50M20
2200	17.3	17.55	17.58	17.63	17.54
2400	17.28	17.45	17.54	17.59	17.52
2600	17.03	17.36	17.39	17.47	17.35
2800	16.96	17.23	17.28	17.24	17.29
3000	16.76	17.07	17.17	17.17	17.11
3200	16.68	16.86	16.98	16.93	16.89
3400	16.47	16.61	16.83	16.76	16.7

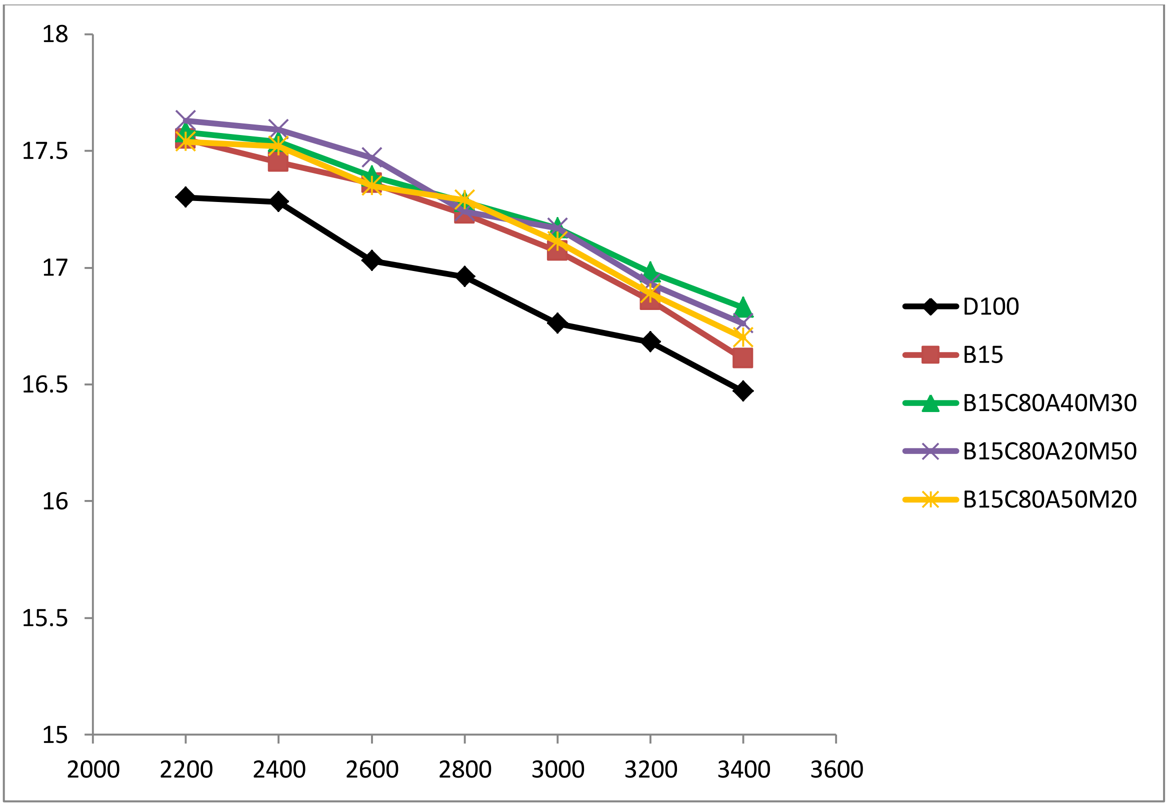


Figure 4.7 Variation of oxygen emission with engine speed at full engine load

Based on the evaluation of engine performance and exhaust gas emission experiment for all test fuels the following discussion was drawn.

Related to engine performance

- The average brake power (BP) of B0 fuel was 3.35%, 3.08% higher than B15C80A40M30, B15C80A20M50
- The average brake torque (BT) of B0 fuel was 2.5% lower than B15C80A40M30.
- The average brake specific fuel consumption (BSFC) of B15C80A50M20 fuel was about 10.4% lower than B0.

Related to exhaust gases emission

- In average CO emission of B0, fuels were 25.7% and 25.7%s, higher than B15C80A20M50 and B15C80A40M30, respectively.
- The mean CO_2 emitted by B0 were 9.04% higher than B15C80A50M20.
- On average HC emission of B15C80A40M30 and B15C80A50M20 were 20.18% and 20.2% less emission as compared to B0.
- The average O_2 emissions of B0 were 1.93% and 1.95% lower than those of B15C80A40M30 and B15C80A20M50.

From the above analysis, it was concluded that biodiesel blended fuel with NPs B15C80A40M30 (better in BP, BT, O_2 and lower in CO, HC), B15C80A50M20 (lower in BSFC, CO_2, HC), and B15C80A20M50 (better in BP, O_2 and lower in CO) in engine performance and exhaust emissions, respectively.

4.5 Comparison of each nanoparticle with three combined nanoparticles

Comparison of brake specific fuel consumption (kg/kW-hr)

Table 4.9 gives a comparison of the results obtained for BSFC in this work with previews work B15C80A40M30 is compared with B20C80, B20A40, B20M30, and B15C80A50M20 is compared with B20C80 and B20A50, and B15C80A20M50 is compared with B20C80 and B20A20. Table 4.9 shows the brake specific fuel consumption obtained in this work and previous works at full load condition. In comparison, the brake specific fuel consumption of the current study (B15C80A40M30, B15C80A50M20, and B15C80A20M50) shown better improvement than (B20C80, B20A40, and B20M30), (B20C80 and B20A50), and (B20C80 and B20A20), respectively.

Table 4.9 Comparison of brake specific fuel consumption with previous research works

Comparison of brake specific fuel consumption (BSFC or SFC) of B0 with modified fuels at full load condition (↑↓)			
Current work	Previous works		
	Ramarao et al., 2015	Razek et al., 2017	Ganesan et al., 2020
B15C80A40M30 BSFC↓9.04%,	B20C80 (SFC↑1%)	B20A40 (BSFC↑13.35%)	B20M30 (SFC near B0)
B15C80A20M50 BSFC ↓8.36%,	B20C80 (SFC↑1%)	(Razek et al., 2017)	-
		B20A20 (BSFC↑5%)	B20M50
B15C80A50M20 BSFC ↓10.4%	B20C80 (SFC↑1%)	(Aalam & Saravanan, 2017)	-
		B20A50 (SFC ↑8.3%)	B20M20

Comparison of carbon monoxide emission (%)

Table 4.10 Comparison of carbon monoxide emission with the previous research work

Comparison of Carbon monoxide (CO) emission of B0 with modified fuels at full load condition (↑↓)			
Current work	Previous works		
	Ramarao et al., 2015	Razek et al., 2017	Ganesan et al., 2020
B15C80A40M30 ↓25.7%,	B20C80 (↓7.7%)	B20A40 (↓32%)	B20M30 (↓13%)
B15C80A20M50 ↓25.7%,	B20C80 (↓7.7%)	(Razek et al., 2017)	-
		B20A20 (↓22%)	B20M50
B15C80A50M20 ↓21.39%	B20C80 (↓7.7%)	(Aalam & Saravanan, 2017)	-
		B20A50 (↓14%)	B20M20

From Table 4.10 on a comparison of current works with previous works for carbon monoxide emission. Table 4.10 shows the carbon monoxide emission at full load condition of the current works and previous work. In comparison, CO emission of B15C80A40M30 shown better reduction than (B20C80 and B20M30), B15C80A20M50 shown better reduction than B20C80 and B20A20, and B15C80A50M20 shown better reduction than (B20C80 and B20A50), respectively

Comparison of hydrocarbon emission (ppm)

Table 4.11 Comparison of hydrocarbon emission with the previous research work

Comparison of hydrocarbon (HC) emission of B0 with modified fuels at full load condition (↑↓)			
Current work	Previous works		
	Ramarao et al., 2015	Razek et al., 2017	Ganesan et al., 2020
B15C80A40M30 ↓20.18%,	B20C80 (↓38.1%)	B20A40 (↓12%)	B20M30 (↓53%)
B15C80A20M50 ↓18.18%,	B20C80 (↓38.1%)	(Razek et al., 2017)	-
		B20A20 (↓7.5%)	B20M50
B15C80A50M20 HC↓20.2%	B20C80 (↓38.1%)	(Aalam & Saravanan, 2017)	-
		B20A50 (↓31%)	B20M20

Table 4.11 gives a comparison of the present work with previous work for HC emission. Table 4.11 shows that the HC emission of the current work is found between previous works. In comparison, the HC emission of B15C80A40M30 shown better reduction than B20A40, B15C80A20M50 shown better reduction than B20A20, but B15C80A50M20 shown less reduction than B20C80 & B20A50, respectively. Based on the above comparison it was realized that the combined effect of nano additives was better in the improvement of performance (i.e brake specific fuel consumption) and exhaust gas emission (i.e carbon monoxide) and also individual nanoparticles showed a better reduction in hydrocarbon emission.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Summery of finding

This part shows the results of the significant findings from this thesis work and summarized as follows. The used cooking oil was collected from the student cafeteria Ethiopia Adama ASTU. The sample oil contains impurities were removed by decantation and filtering. Finally, from 8 liters of collected oil sample, 7.8 liters of filtered sample oil was obtained.

In this thesis work, to obtain better yield and quality of biodiesel, starting from cleaning UCO, pretreatment of sample oil, determination of acid value, transesterification reaction, and purification process must be included. Before the transesterification reaction determined acid value of sample oil was 1%. This produced biodiesel blended with diesel and metal oxide NPs in presence of CTAB by using Ultrasonicator cleaner. Addition of nano additives in sample fuels shown improvement in test fuel properties (i.e. cloud point, total acidity, calorific value), engine performance (i.e. BP, BT, BSFC), and exhaust gases emission (i.e. CO, HC, CO_2, and O_2).

5.2 Conclusion

This thesis work was based collection of sample oil, biodiesel production, characterization, preparation of blended fuel, performance, and emission test were done. The characterization of modified fuels was carried out at Ethiopian Petroleum Supply Enterprise. CT 100.32 a single-cylinder, four-stroke, air-cooled diesel engine with a direct injection system, and Infralyt smart exhaust gas analyzer was used to test performance and exhaust emission at Ethiopia Dilla DU, respectively. Based of these outcomes, the following conclusion has been drawn.

- The impurities from sample oil were distant by decantation and filtering. Lastly, 7.8 liters of cleaned sample oil was collected
- The transesterification reaction method was used to synthesis biodiesel and glycerol from sample oil.
- The yield of the ester obtained from a batch chemical reaction was 88.46% by weight from 390g of sample oil 345g of pure biodiesel was obtained. The glycerol was removed as a byproduct which is used mostly in the production of cosmetics.

- Ultrasonicator cleaner was used to prepare biodiesel-diesel blend with metal oxide NPs in presence of CTAB. The prepared test fuels were B100, B15, and B15 with NPs.
- The characterization results of biodiesel and modified fuels near the ASTM D-6751 standard. The addition of NPs in blended fuels shows enhancement in properties (i.e reduction of cloud point, total acidity and increases calorific value) as compared to B100 and B15.

Based on the experimental results of the performance and exhaust emission test of B15 and B15 with NPs, it can be realized that modified fuels can be used in a diesel engine without any modification.

- In comparison modified fuels B15C80A20M50 and B15C80A40M30 fuels have better BP and BT than B15 and near diesel respectively. The modified fuel B15C80A50M20 has a lower BSFC than B15 and B0.
- Related to emission B15C80A40M30 (lower in CO, HC emission and higher in O_2 emission), B15C80A50M20 (lower inCO_2, HC emission), and B15C80A20M50 (lower in CO emission and higher in O_2 emission).
- Modified fuels have shown a reduction in exhaust gases emission such as CO, CO_2, HC and increases in O_2 emissions in contrast with B15 and B0. The increase in O_2 emission was due to higher oxygens content in the biodiesel molecules and the addition of NPs.
- Modified fuel B15C80A50M20 was lower in BSFC, HC and CO_2 emission. Sample fuel B15C80A20M50 was higher in BP, lower CO emission, and increases in O_2 emissions. Test fuel B15C80A40M30 was higher in BT, BP, lower in HC, CO emission, and increase in O_2 emissions.
- As a result of the study, it can be concluded that modified fuels with NPs better in performance and emission were B15C80A40M30, B15C80A50M20, and B15C80A20M50 than B0 and B15 were used in diesel engines without any modification.

5.3 Recommendation

In this study work, properties of sample fuels, engine performance, and exhaust emission test were done for some fuel properties and engine parameters. To obtain better similarity related to modified fuels characterization, performance, and exhaust emission tests should be done for all engine parameters and fuel properties.

After the production of biodiesel, the byproduct (glycerol) was removed as waste. It is recommended that use this byproduct as feedstocks for the production of cosmetics and soap. The modified fuels is better in engine performance and lower in exhaust emission to reduce air pollution the government has to support the use of modified fuels.

Currently, Adama Science and Technology University (ASTU), Department of Mechanical and Vehicle engineering doesn't give experimental engine testing services so for future research work in biofuels it must establish the service. ASTU should establish a linkage with industries in the area of biodiesel production in our country Ethiopia.

5.3 Future work

Based on this thesis work, performance evaluation and emission analysis were carried distinctly for B15 with NPs. The future experimental investigation will take by B15 blended fuels with only optimum dosage of metal oxide with metal-based NPs (i.e Fe, Al, Mn, and Ti, etc). The future research work should also include neural network and error analysis for modified fuels.

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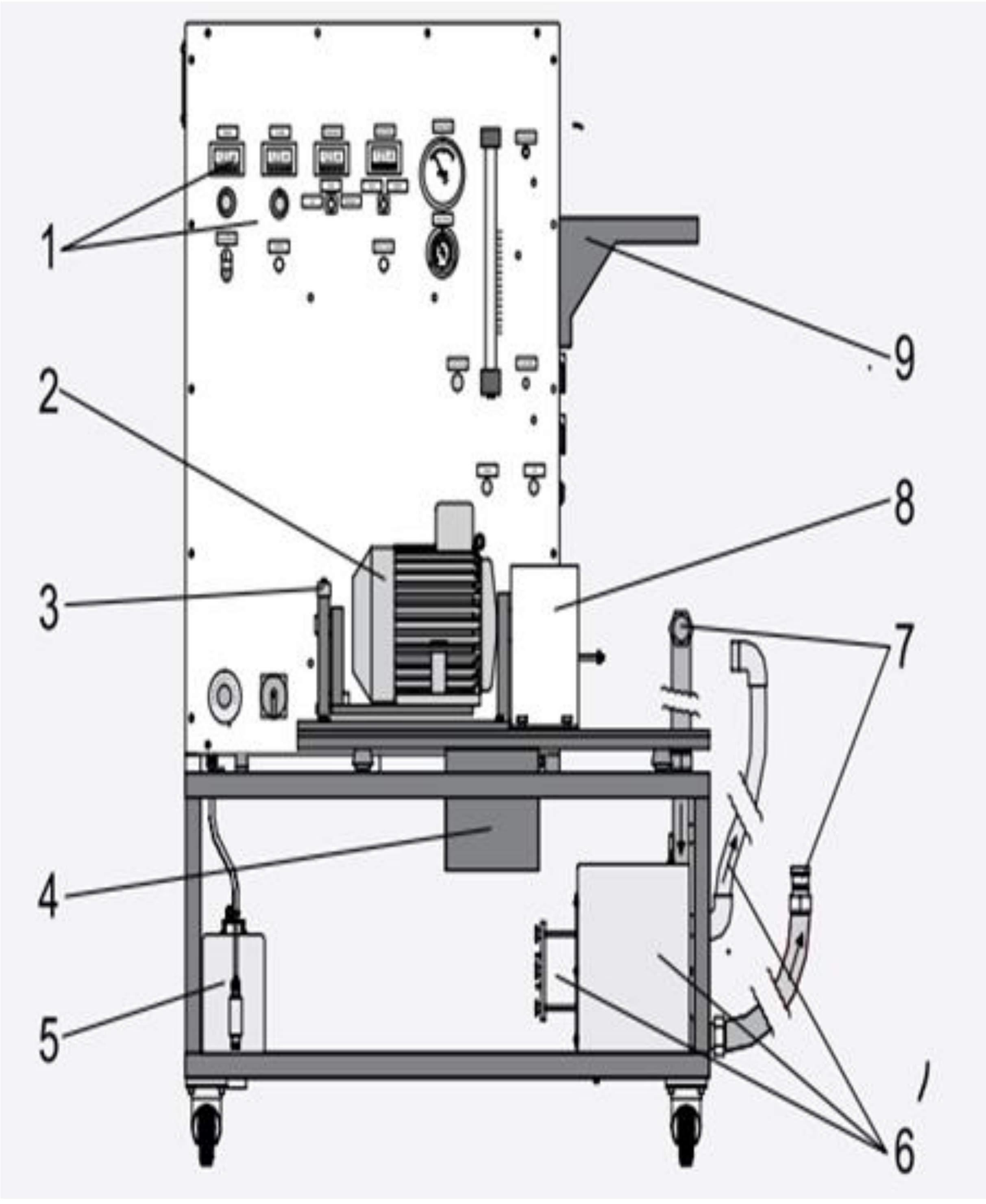
APPENDICES

APPENDIX-A



1 display and control panel, 2 asynchronous motors, 3 force sensor (torque), 4 base plate,

5 fuel tank with pump, 6 quietening vessels with air filter and air hose, 7 exhaust gas connections, 8 coupling cover, 9 shelf.

APPENDIX-B

Test stand set at engine speed 3000rpm and full load set near 10

APPENDIX-C

Exhaust gases analyzer

APPENDIX-D

ዲላ ዩኒቨርሲቲ
ኢንጂኔሪንግና ቴክኖሎጂ ኮሌጅ
ምር/ቴክ/ሽግ/ም/ዳ/ጽ/ቤት

DILLA UNIVERSITY
COLLEGE OF ENGINEERING AND TECHNOLOGY
RESEARCH & TECHNOLOGY TRANSFER V/DIRECTOR OFFICE

ቁጥርኢ/ቴ/ኮ/ቴ/ሽ/ም/ዳ/33/12

ቀን፡10/10/2012 ዓ.ም

ለአ.ሳ.ቴ.ዩ

ጉዳዩ፡- የባዮ ዲዝል ቤተሙከራ መስራትን ይመለከታል

ከላይ በርዕሱ ለመጥቀስ እነደተሞከረው ከዚህ በፊት በተጻፈልን የድጋፍ ደብባቤ መሰረት የሜካኒካል ሲስተም ኤንድ ሞቶር ቬሂክል ኢንጅነሪንግ የሁለተኛ ዲግሪ ተማሪ የሆነው ተማሪ ታምሩ ሀይለማርያም የባዮ ዲዝል ቴስት በሜካኒካልና አውቶሞቲብ ኢንጅነሪንግ ቤተ ሙከራ በCT100.32 Diesel Engine ላይ መስራቱን እንገልጻለን።

ከሰልምታ ጋር!!!

ዘውዴ አለማየሁ ሙላት
Zewdie Almayehu Mulat
የኢንጅነሪንግና ቴክ/ኮ/ምርምርና
ቴክ/ሽግግር ም/ዳይሬክተር
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መልሱን ሲጽፉልን የእኛን ቁጥር ይጥቀሱ
In Replying, Please Quote our Ref. Number

APPENDIX-E

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251- (0)11- 551 79 56
251- (0)11- 554 19 05
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Direct: (251) - 011-551 00 45,
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Addis Ababa - Ethiopia

የ ኢ ት ዮ ጵ ያ ነ ዳ ጅ አ ቅ ራ ቢ ድ ር ጅ ት
ETHIOPIAN PETROLEUM SUPPLY ENTERPRISE

Ref. No 6898/6-1-3-4-4/2012
27. ግንቦት 2012

የአዳማ ሳይንስና ቴክኖሎጂ ዩኒቨርስቲ
ለሜካኒካል፤ኬሚካል እና ማቴሪያልስ ኢንጂነሪንግ ት/ቤት
አዳማ

ጉዳዩ፡- የነዳጅ ምርመራ ውጤት ስለማሳወቅ

በቀን መጋቢት 02/2012 ዓ.ም በቁጥር 7/2.1.3//7m80/8908/12 በተጻፈ ደብዳቤ በተማሪ ታምሩ ኃ/ማሪያም የተዘጋጀ ሶስት (03) የባዮዲዝል ናሙና እንዲፈተሽላችሁ በጠየቃችሁት መሠረት የናሙናው ፍተሻ ውጤት በዚህ ሸኝ ደብዳቤ በ 01 ገጽ አባሪ በማድረግ የላክን መሆኑን በአክብሮት እንገልፃለን፡፡

ከሠላምታ ጋር

ስዩም አራጋው
የነዳጅ ጥራት ማረጋገጫ
አገልግሎት ኃላፊ

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

APPENDIX-F

	Company Name: የኢትዮጵያ ነዳጅ አቅራቢ ድርጅት ETHIOPIAN PETROLEUM SUPPLY ENTERPRISE	Document number: OF/EPSE/QAS/110
		Page --- of ---
TITLE:	CERTIFICATE OF TEST REPORT	
Issue No.: 2	Date of Issue: July 17, 2019	
Prepared by: QM		Approved by: Tadesse H/Mariam

Sample Originator: ASTU
Sample Type: BIODIESEL
Sample Number: 03
Lab. Number: 2020- ADO - EXT-11
Sample Submitted By: CUSTOMER
Test date: 03/06/2020
Customer Address: - ADAMA

Request No: 7/2-1-3/7M80/8908/12
Analytical Method: ASTM /IP/ISO
Analytical Result: Interpreted with Stds.
Report No: QA/0015/2020
Date Submitted: 01/06/2020
Issued Date: 04/06/2020
Telephone. +251 951 01 04 59

	Property	Test method ASTM	BD Limits	Test results		
				B100	B15	B15+NP
1.	Density@15°C, g/mL	D4052	Report	0.8855	0.8452	0.8450
	Density@20°C, g/mL	D4052	Report	0.8821	0.8417	0.8415
2.	Calorific value, calc, BTU/LB	Calculated		19200	19563	19565
3.	Cloud point, ^{O}C	D 2500		+15	+9	+7
4.	Kinematic viscosity @ 40 ^{O}c	D 445		6.0	3.0	3.0
5.	Total acidity, mg KOH/g	D974		1.137	0.413	0.386

Lab. expert
Name: Alemneh M.
Signature

Senior expert
Name: Addisu Ayza
Signature

Quality Control Head
Name: Seyoum A
Signature

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