Experimental Investigation of Performance and Emission Characteristics of Diesel-Bio Diesel (CSOME) blend fuel With Nano Additive in CI Engine

by

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APPROVAL of BOARD of EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by **Debas Dessie Tariku** have read and evaluated his thesis entitled **"Experimental investigation on performance and emission characteristics of diesel-biodiesel (CSOME) blend fuel with nano additive in CI 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 masters of Science in Automotive Engineering. N. Ramesh Babu

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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.

Candidate	Signature	Date

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

Advisor	Signature	Date

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ABSTRACT

Diesel is a main source of fuel among petroleum products but ecological degradation and exhaust of petroleum reserves are matters of great concern around the world. Finding a suitable fuel alternative to diesel is an urgent need. In this perspective, biodiesel-diesel fuel blends are currently receiving renewed interest. For this context the use of nano particles like Aluminum oxide (Al_2O_3) and Cerium oxide (CeO_2) in combination with diesel and biodiesel is an effective measure to substitute renewable fuels and reduce emission for use in diesel engine. In this thesis an experimental investigation was conducted to evaluate the performance and emission characteristics of a single cylinder direct injection diesel engine with diesel (B0), diesel-biodiesel blend (B20), B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2 fuels. The Biodiesel was prepared from the cotton seed oil through transesterification process. Properties like density and kinematic viscosity were evaluated for these blends. Engine tests were conducted to get the comparative measures of performance like; Brake power (P_b), Brake torque (T_b) and brake specific fuel consumption (BSFC) and emissions such as CO, CO_2, HC, and oxygen concentration for all test fuels. From the experiment the brake power of the engine for the nanoparticles dispersed test fuels (B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppmAl_2O_3+50ppm CeO_2) significantly improved by 6.3%, 4.3%, 17.9% respectively. Similarly the engine brake torque of the engine was improved when using B20+50ppmAl_2O_3+50ppm CeO_2 fuel compared to diesel fuel. Furthermore the engine BSFC of B20 is higher than all the test fuels; however the addition of Aluminum oxide (Al_2O_3) and Cerium oxide (CeO_2) nanoparticles improved the BSFC of the engine. Moreover for B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2 fuels the emissions of carbon monoxide reduced by 6.7%, 11.2%, 9.7% and 23.2% and emissions of carbon dioxide reduced by 4.6%, 8.1%, 8.8% and 14.8% as compared with petro diesel (B0) fuel. Additionally HC emissions from all cotton seed biodiesel blended (B20, B20+50ppm Al_2O_3, B20 + 50ppm CeO_2, B20 + 50ppm Al_2O_3 + 50ppm CeO_2) fuels are lower than that of the diesel (B0) fuel. In general the experimental results showed that B20+50ppm Al_2O_3+50ppm CeO_2 test fuel has a better performance and emission improvements than the all other test fuels.

Keywords: *Biodiesel, Emission, Engine performance, Nano particle, Transesterification*

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LIST OF SYMBOLS & ABBREVIATIONS

ρ_f	Density of fuel
Al	Aluminum
Al_2O_3	Aluminum oxide
ASTM	American standards for testing and materials
B0	Pure diesel
B20	80%diesel and 20%biodiesel
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
CeO_2	Cerium oxide
CH_3OH	Methanol
CNT	Carbon nanotubes
CO	Carbon monoxide
CO_2	Carbon dioxide
CSOME	Cotton seed methyl ether
CTAB	Cetyle trimethyl ammonim
DI	Direct injection
EGR	Exhaust gas recirculation
EGT	Exhaust gas temperature
FFA	Free fatty acid
FAME	Fatty acid methyl ester
g/ml	Gram per mill litters
HC	Hydrogen carbide
Kg/kW.hr	Kilo gram per kilo watt per hour
KOH	Potassium hairdo oxide
kW	Kilo watt
m_f	Mass flow rate of fuel
Mg	Magnesium
MWCNT	Multiwall carbon nanotubes
N	Engine speed
N.m	Newton meter
NAOH	Sodium hydroxide
nm	Nanometers
NO_x	Nitrogen oxides
^oC	Degree celicious
P_b	Brake power

PM	Particulate mater
Ppm	Parts per million
SCADA	Supervisory control and data acquisition
T_b	Brake torque
v_f	Volume flow rate of fuel
W	Watt
W_L	Load

CHAPTER ONE

INTRODUCTION

1.1 Background

During the last years petroleum fuels are used to power automotive vehicles. Most of the petroleum fuels are derived from the fossil energy sources. In our global total petroleum fuel is decreasing day to day. The increasing consumption of petroleum fuels and the growing requirements for purity of engine exhaust gas motivates to take up research into alternative fuels or new combustion systems in the engine. Biofuels such as alcohol and biodiesel, could partly replace petroleum fuel, reduce toxic emission, and more important restrain the life-cycle emission of CO_2. Biodiesel has received wide attention as a replacement for diesel fuel because it is biodegradable, nontoxic, and can significantly reduce exhaust emissions and overall life cycle emission of carbon oxides, CO_2, from the engine. Biodiesel and ethanol can be produced from feedstock's that are generally considered to be renewable. Ethanol can be produced from agricultural products such as sugarcane, corn, sugar beet, molasses, cassava root, and barley by alcoholic fermentation process. Biodiesel fuel is produced by chemically reacting a vegetable oil or animal fat with an alcohol such as methanol or ethanol through the chemical reactions transesterification [51].

The exhaustion of fossil fuels increases the demands of the diesel and uncertainty of their availability has to be considered, which activates the importance for many initiatives to explore the alternative energy sources. Researchers are looking forward to new raw materials, low cost non-edible oil crops materials for biodiesel production. Physico-chemical properties of the cottonseed oil are similar to those of the major vegetable oil and also it contains heterogeneous triglycerides [5].

Many investigations have studied the impact of blending various additives with diesel or diesel-biodiesel blend fuel on engine performance and emission characteristics of diesel engine. The most investigated, in recent years, are alcohols such as ethanol and diethyl ether, metals and metallic oxide nano-additives. That the weight percent of oxygen content in the fuel is the most important factor for PM reduction, and it is more important than other properties such as chemical structure or volatility. Nano additives in biodiesel and diesel blends can increase the oxygen contents, which may further improve the PM emissions [54].

1.2 Biodiesel

Biodiesel is a liquid biofuel obtained by chemical processes from vegetable oils or animal fats and an alcohol that can be used in diesel engines, alone or blended with diesel fuel. It can be produced through transesterification, a process; in which heating of vegetable oils take place in the presence of a catalyst. Biodiesel helps to reduce pollution by lower exhaust emissions. It can be used pure or can be blended with petroleum diesel fuel in various proportions. It can be used in existing CI engines with practically no modifications [55].

1.2.1 Advantages of Biodiesel

Some of the advantages of using biodiesel are reducing dependency on petroleum, greenhouse gas emissions and air pollution, and it helps to provide fuel at cheaper rate.

Some of the advantages of using biodiesel as a fuel are [53];

- Renewable fuel, obtained from vegetable oils or animal fats.
- Low toxicity, in comparison with diesel fuel.
- Degrades more rapidly than diesel fuel, minimizing the environmental consequences of biofuel spills.
- Lower emissions of contaminants: carbon monoxide, particulate matter, polycyclic aromatic hydrocarbons, aldehydes.
- Lower health risk, due to reduced emissions of carcinogenic substances.
- No sulfur dioxide (SO_2) emissions.
- Higher flash point (100 ^{o}C minimum).
- It can be blended with diesel fuel.

1.2.2 Disadvantages of Biodiesel

There are certain disadvantages of using biodiesel as a fuel that must be taken into consideration [53]:

- Slightly higher fuel consumption due to the lower calorific value of biodiesel.

- Slightly higher nitrous oxide (NO_x) emissions than diesel fuel.
- Higher freezing point than diesel fuel. This may be inconvenient in cold climates.
- It is less stable than diesel fuel, and therefore long-term storage (more than six months) of biodiesel is not recommended.
- May degrade plastic and natural rubber gaskets and hoses when used in pure form, in which case replacement with Teflon components is recommended.
- It dissolves the deposits of sediments and other contaminants from diesel fuel in storage tanks and fuel lines, which then are flushed away by the biofuel into the engine, where they can cause problems in the valves and injection systems. In consequence, the cleaning of tanks prior to filling with biodiesel is recommended.

It must be noted that these disadvantages are significantly reduced when biodiesel is used in blends with diesel fuel.

1.2.3 Methods of Biodiesel Production

The biodiesel production process starts with collecting oil seeds from oil plants. The oil getting from oil seeds, which is raw oil, is converted in to biodiesel using Distillation, Pyrolysis, emulsification or transesterification processes [55].

1.2.3.1Transesterification process

The most common derivatives of agricultural oil for fuels are methyl esters. These are produced by means of transesterification of the oil with methanol in the presence of a catalyst to give methyl ester and glycerol. Sodium hydroxide (NaOH) is the most common catalyst, even though others along with potassium hydroxide (KOH) can also be used. The generation required for carrying out the transesterification technique is quite simple. In its crudest form, it can be in low volumes as a batch process. The methanol and NaOH are premixed and added to the oil, mixed for a few hours, and allowed to gravity settle for about 8 hours. The glycerin settles to the bottom, leaving Biodiesel on the top [53].

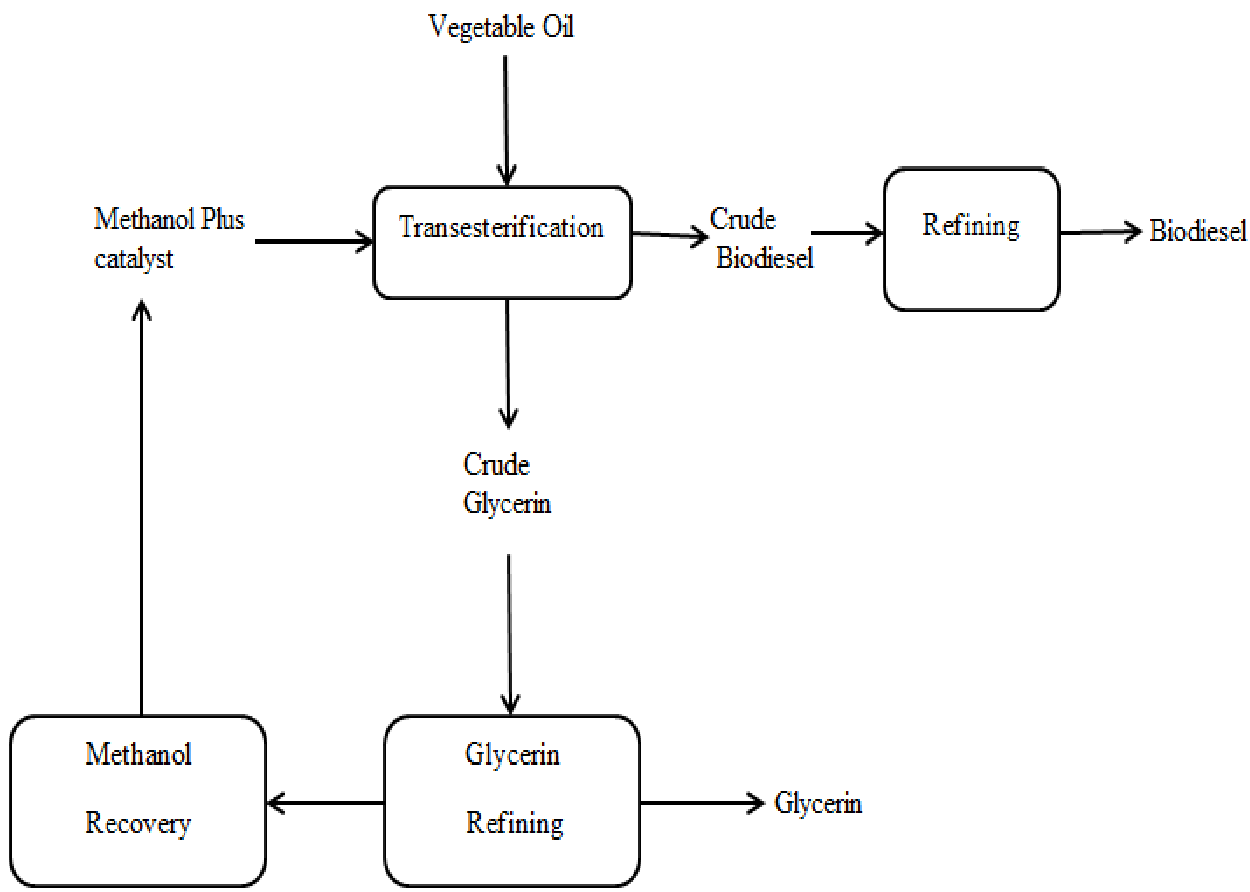


Figure1.1 Transesterification process [53]

1.3 Nanoparticles

Nano-additives are fuel-borne catalyst to improve the fuel properties, owing to their enhanced surface area/volume ratio, quick evaporation and shorter ignition delay characteristics. The size of nanoparticles varies from 1 to 100 nm. Following are the main requirements of naonoparticles as fuel additive [60]:

1. The nanoparticles act as catalyst should reduce exhaust emission as well as increase the oxidation intensity in the engine and in the particulates filters.

2. It should maintain the typical operational properties of engine.

3. The stability of additive in the fuel must be retained under all operational condition.

1.4 Statement of problem.

Now a days, the rapid growth in the transportation sector results a growing need of the fossil fuel and it need to be satisfied. But due to their limited resources and increased demands has made the fossil fuels are depleting at faster rate. In addition to fossil fuel depletion, this fossil fuel vehicle has led to increase the pollutants such as CO CO_2, NO_x, HC, and degrades the environment, thus there is a need to search for alternate fuels and the performance improvement methods. Biodiesel is one of the most potential renewable fuel to use in CI diesel engine. It is renewable, biodegradable and non-toxic fuel which can be easily produced through transesterification reaction. However, such biodiesel based fuel cannot directly use in diesel engine due to high ignition delay and low calorific value. The performance and emission characteristics of the diesel engine can be improved by addition of nanoparticles to the fuel.

1.5 Objectives

1.5.1 General objective

The main objective of this thesis work is to determine the engine performance and emissions characteristics of Direct Injection (DI) diesel engine using diesel- biodiesel (CSOME) blend fuel with aluminum oxide and cerium oxide nano additive.

1.5.2 Specific objectives

- ✓ To prepare biodiesel from cotton seed oil using transesterification process
- ✓ To prepare diesel-biodiesel blend fuel with aluminum oxide (Al_2O_3) and cerium oxide nano additives.
- ✓ To perform performance and emission characteristics test of CI engine using diesel-biodiesel blend fuel with aluminum oxide (Al_2O_3) and cerium oxide (CeO_2) nano additives.

1.6 Scope of the study

The scope of this research work is to investigate the performance and emission characteristics of DI engine using diesel, diesel-biodiesel blend and diesel-biodiesel with aluminum oxide (Al_2O_3) and cerium oxide nano particles blend as a fuel. The bio diesel was prepared from cotton seed oil.

1.7 Significance of the study

Now a day's the world is presently challenged with the twin crises of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground based carbon resources. The search for alternative fuels which promise a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced in the present context. The fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis.

This project will help for;

- ✓ To reduce emission
- ✓ To reduce fossil fuel consumption
- ✓ To encourage usage of biofuel

1.8 Limitation of the work

The challenges which were faced during this research work were:

- ➢ The engine test bench is not available in Adama Science and Technology University this was challenged to perform the experiment.
- ➢ Lack of nano particles in Ethiopia challenged the work; so it was purchased from India.
- ➢ Budget scarcity for all process and to conduct experiments.

1.9 Organization of the thesis

The thesis consists of five chapters. The first chapter is organize about background of study and introduction, problem statement, objectives, research scope, limitation of the work and the organization of the thesis. In the second chapter, it is explained about the literature review of some other researches about the performance and emission characteristics of diesel and diesel-biodiesel blend fuels with and without addition of nano additives. The research gap was also highlighted. Chapter three describes about materials and methodology of the work. Biofuel production, preparation of diesel-biodiesel fuel with addition of aluminum oxide (Al_2O_3) and cerium oxide (CeO_2) and characterization of the properties of fuels are discussed in Chapter four. Furthermore experimental test on performance and emission characteristics of DI engine also discussed in this chapter. Finally, Chapter five presents the results, conclusion and recommendations for the future works.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter discusses several literatures available on the current distinction of using biodiesel diesel blends with and without nano additives as alternate fuel for diesel engine. In this chapter, the review describes the use of biodiesel in CI engine and the production methods of biodiesel. Further the performance and emission characteristics, using the diesel-biodiesel blend fuel with and without nano additives will also be discussed**.**

2.2 Biodiesel in CI engine

Biodiesel can be produced from vegetable oils of edible and non-edible fedstokes, waste vegetable oils and from animal fats. Vegetable oil based ester fuels can be derived from a number of edible and nonedible fedstokes oil sources such as peanut, sunflower, palm, soybean, sesame, rape seed/canola, mustard, linseed, coconut, jatropha curcas, karanjia, cotton seed, mahua, neem, pine seeds, tung seeds, nagchampa, kusum etc. [62].

Yaliwala et al. [67] carried out an experiment using honge oil methyl ester producer gas in a dual fuel CI engine for the improvement of its fuel efficiency. Moreover, they have studied the effect of the compression ratio on the performance, combustion and exhaust emission characteristics of a single-cylinder, four-stroke, direct injection diesel engine operated using honge oil methyl ester and producer gas in a dual-fuel mode. Their results indicated that the honge oil methyl ester producer gas combination exhibited lower BTE and comparable emission levels with the diesel producer gas combination at different compression ratios. The comparative measures of BTE, peak pressure, pressure crank angle variation, heat release rate, smoke opacity and HC, CO and NOx emission levels were presented and analyzed.

Sahoo et al. [50] studied combustion analysis using biodiesel and their blends (B20 and B50) from Jatropha, Karanja and Polanga oil in a single cylinder air cooled diesel engine at varying loads (0, 50 and 100%). The ignition delays were found consistently shorter for the biodiesel when compared to the standard diesel.

Acharya et al. [1] studied the combustion and performance of diesel engine using rice bran oil methyl ether. Various parameters, such as BTE, BSFC, exhaust emissions of CO, CO_2, HC, and NO_x was analysed in a single cylinder, four stroke, constant speed, water cooled, direct injection diesel engine. While operating the engine performance was found to be very close to that of diesel for lower blend concentrations of rice bran oil methyl ether. The preheated oil performance was slightly lower in efficiency due to low heating value.

Deepanraj et al. [7] investigated Palm oil methyl ester blends with diesel in a direct injection diesel engine. The engine tests were performed at constant speed with net diesel fuel and several proportions of biodiesel blends. In this investigation exhaust emissions such as CO, HC and NO_x and the performance characteristics like BTE and SFC were analyzed. The differences in the measured emissions and performance of the biodiesel-diesel fuel blends from the baseline operation of the engine with standard diesel were determined and compared. Consequently it was observed that the lower blends of biodiesel increased the BTE and reduced the fuel consumption. The biodiesel blend produced lower engine emissions than that of the net diesel fuel. From the result, it was established that 20 to 40% of palm oil biodiesel can be used as a substitute for standard diesel without any engine modifications.

Paykani et al. [35] studied performance and emission characteristics of a diesel engine fueled with canola oil ethyl ether biodiesel and diesel fuel using exhaust gas recirculating (EGR). The experiments were conducted on a single cylinder, four-stroke, water cooled, indirect injection diesel engine at full load operation and constant engine speed of 730 rpm. The results gained with canola oil ethyl ester biodiesel were compared with the standard diesel fuel. The engine performance and efficiency obtained in the case of biodiesel were low, which could be attributed to lower calorific value of the biodiesel. The CO and UHC emissions for biodiesel were lower than that of the standard diesel. However, it was observed that NO_x emissions for biodiesel were higher than that of the standard diesel fuel. Moreover, they found out that the EGR was very effective technique to reduce the NO_x emissions in a diesel engine. In this study, the venturi type EGR system was used. When similar percentages (% by volume) of EGR were used in the case of standard diesel and canola oil ethyl ester, the NO_x emissions were considerably reduced to lower values.

Harinathareddy et al. [14] examined the performance of a diesel engine using diesel fuel, cotton seed oil methyl ether (CSOME) biodiesel and jatropha oil methyl ether. A single cylinder, 4-stroke vertical, water-cooled diesel engine was used for testing at full load conditions. The evaluation of theoretical data showed that the BTE of CSOME biodiesel was slightly higher than that of the diesel and jatropha oil methyl ether fuels. Moreover, the CSOME biodiesel improved the performance parameters of CI engine when compared to the diesel fuel.

Raheman H. and Phadatare [39] performed an experimental investigation to study the fuel properties of karanja methyl ester and its blend with diesel fuel from 20% to 80% by volume in a diesel engine. The engine tests were carried out to evaluate comparative measures of torque, power, SFC and emissions such as CO, smoke density and NO_x of diesel engine. The reduction in exhaust emissions, increase in torque, BP, BTE and reduction in BSFC were observed from the experiment using the blends of karanja methyl ester of B20 and B40.

Santos et al. [54] evaluated two diesel engines operated at 14.2 kW and 60 kW by using sunflower methyl ester and its blends with a diesel fuel. The results indicated that less power and torque were provided by both engines when ran on pure using sunflower methyl ester than on diesel fuel; However BSFC higher for pure SFME. The blends of SFME B5 and B20 with diesel fuel showed slight power loss and similar BSFC with that of diesel fuel. The higher concentrations of NO_x, CO_2 and HC in the exhaust emissions were observed for both the SFME and its blend performance.

Shanmugam et al. [57] used pungamia oil ethyl ester as an additive to prevent separation of bioethanol and diesel fuel. The stability, fuel properties, performance and emission characteristics of the blended fuels were investigated and compared with the diesel fuel. The result of the tests indicated that the BTE of the engine was almost equal to that of the diesel fuel. It was also observed that the exhaust gas temperature (EGT) and CO_2 emissions of the blended fuels were lower than those of the net diesel fuel. The NO_x and smoke emissions were decreased up to 15% and 12% respectively while increasing the bioethanol up to 25% in the blended fuels. However a slight increase in the HC and CO emissions was observed. This study concluded that the blend mixture E20P10D70 could be effectively used as a hybrid fuel in the existing compression ignition engine without any modifications.

Srivastava and Verma [59] carried out their experiments using (pongamia pinnata) oil methyl ester. The experimental results showed that the maximum thermal efficiency with methyl ester of karanja oil was about 24.9%, whereas that of the diesel was 30.6% at same power output. The authors concluded that the methyl ester of karanja oil is a suitable substitute for diesel.

Sureshkumar and Velraj [61] studied the performance characteristics of diesel engine with karanja oil methyl ester biodiesel. From the experiment the results indicated that the karanja oil methyl ester biodiesel-diesel blend fuel could replace the diesel fuel up to B40 for getting the expected power output with less emission. This is due to that biodiesel is a low carbon fuel and has a lesser elemental carbon to hydrogen ratio than diesel fuel.

Prabhakar et al. [37] investigated experiments with karanja oil methyl ester biodiesel in a single cylinder diesel engine. The results indicated that the brake thermal efficiency was decreased by 1.7% for blends compared with that of diesel fuel. The brake specific fuel consumptions were better for the biodiesel blends due to the low calorific value of biodiesel.

Forson et al. [10] investgated that jatropha oil methyl ester can be used in a diesel engine as a substitute of diesel fuel. The experimental result indicates that there is significant increase in brake thermal efficiency and reduction in the specific fuel consumption for jatropha oil and its blends with diesel. The authors recommended that introduction of jatropha oil into diesel engine appears to be effective in reducing the exhaust gas temperatures.

Rao et al. [46] performed an experimental investigation on a single cylinder diesel engine fuelled with biodiesel from karanja, jatropha and neem seed oils and their diesel blends. From the results it was reported that the properties of the different blends of biodiesel were very close to the diesel and the blend B20 fuel provided good results.

Tan et al. [63] conducted experiments on four cylinder diesel engine with jatropha biodiesel. From the results the NO_x emission of jatropha biodiesel was higher than that of diesel. This was due to the higher oxygen cotent in the combustion chamber helps to promote NO_x formation reactions.

Kumar and Kumar [20] performed the experimental investigation on CI engine with the biodiesel blends of cotton seed methyl esters and neem oil methyl esters. It was observed that the smoke and emissions from the blends of cottonseed and neem were less compared to pure diesel. The authors reported that the 20% cottonseed blend produced better performance and emission values than diesel.

Rakapoulos et al. [40] conducted experiments of diesel engine on the performance and emission characteristics using various biodiesel fuels such as cottonseed oil, rapeseed oil and sunflower oil. Cotton seed and sunflower biodiesel blends was slightly reduced NO_x emission with respect to that of the neat diesel fuel.

Rakopoulos et al. [41] assessed the use of sunflower and cottonseed oil methyl esters as supplements with diesel fuel. The smoke density and CO emission was reduced with the use of these biodiesel blends.

Aydin and Bayindir [4] evaluated the performance of diesel engine using cottonseed oil methyl ester and conventional diesel fuel blends. Results indicated that the torque was decreased possibly with the increase of cottonseed oil methyl ester in the blends, due to higher viscosity and lower heating value of the cottonseed oil methyl ester. Due to the inherent oxygen present in the cottonseed oil methyl ester the CO emissions decreased with biodiesel usage. The NO_x emission was also decreased in all the blends.

Kalam and Masjuki [15] investigated the effect of palm oil methyl ester diesel blend on engine performance and emissions. From the experiment it was indicated that the increase the palm oil biodiesel blend decreases the NO_x emission.

2.3 Biodiesel production process

There have been various production methods of biodiesel to develop and improve vegetable oil properties in order to approximate the properties of diesel fuels. The mostly associated problems with crude vegetable oils are high viscosity, low volatility and polyunsaturated characters. Generally there are four biodiesel production methods which can be overcome the above mentioned problems. These are pyrolysis, dilution with hydrocarbons blending, Microemulsion, and transesterification [3].

2.3.1 Pyrolysis (Thermal cracking)

Pyrolysis is the thermal decomposition of the organic matters in the absence of oxygen and with the presence of a catalyst. The feedstocks material for pyrolysis can be vegetable oils, animal fats, natural fatty acids or methyl esters of fatty acids. Thermal decomposition of triglycerides produces alkanes, alkenes, alkadines, aromatics and carboxylic acids. It has been observed that pyrolysis process is effective, simple, wasteless and pollution free [12]. Pyrolysis of the vegetable oil can produce a biodiesel that has high cetane number, low viscosity, acceptable amounts of sulfur, water and sediments contents, acceptable copper corrosion values. However, ash contents, carbon residues, and pour points were unacceptable.

2.3.2 Dilution

Vegetable oils are mostly diluted with diesel to reduce the viscosity and improve the performance of the engine. This method does not require any chemical process [3].

2.3.3Micro-emulsion

A micro-emulsion is a colloidal equilibrium dispersion of optically isotropic fluid microstructure with dimensions generally into 1–150 nm range formed spontaneously from two normally immiscible liquids and one and more ionic or more ionic amphiphiles. There are numerous solvents used in micro-emulsions such as methanol, ethanol, hexanol, butanol and 1-butanol. Micro-emulsion with these solvents has met the maximum viscosity requirement for diesel fuel [3].

$$\text{Triglycerides} + \text{ROH} \xrightarrow{\text{Catalyst}} \text{Diglyceride} + \text{FAME}$$

$$\text{Diglycerides} + \text{ROH} \xrightarrow{\text{Catalyst}} \text{Monoglyceride} + \text{FAME}$$

$$\text{Monoglycerides} + \text{ROH} \xrightarrow{\text{Catalyst}} \text{Glyceride} + \text{FAME}$$

Figure2.1 Equation of transesterification reaction [3]

2.3.4 Transesterification

Transesterification is the best method among other techniques due to its low cost and simplicity. Biodiesel is the main product of this process. Transesterification consists of a number of consecutive, reversible reactions. In these reactions, the triglycerides are converted step wise to diglycerides, monoglyceride and finally glycerol which sinks to the bottom and biodiesel which floats on top and can be siphoned off. Glycerol is an important by-product and can be burned for heat or be used as feedstock in the cosmetic industry. In this reaction, methanol and ethanol are the two main light alcohols used for transesterification process due to their relatively low cost. However, propanol, isopropanol, tert-butanol, branched alcohols and octanol and butanol can also be employed but the cost is much higher. Transesterification process contains two main processes; catalytic and non-catalytic method. A catalyst is used to initiate the reaction. The catalyst is vital as alcohol is barely soluble in oil or fat. The catalyst enhances the solubility of alcohol and thus increases the reaction rate. The most often used process is the catalytic transesterification process. The most common alkaline catalysts are NaOH, $NaOCH_3$, $KOCH_3$, KOH, NaMeO and K_2CO_3. Most of the biodiesel producers use sodium hydroxide or potassium hydroxide and there yield is better than all catalysts but they are costly, so they are not very frequently used. Alkaline catalytic method is the fastest and most economical catalyst than other catalysts. Moreover, this method can achieve high purity and yield of biodiesel product in a short time.

Therefore, it dominates the current biodiesel production methods. However, to use alkaline catalysts, free fatty acid (FFA) level should be below a desired limit (ranging from less than 0.5% to less than 3%). Beyond this limit the reaction will not take place and the product formed will be soap and water instead of esters and the yield of esters will be too less. In addition to, this reaction has several drawbacks; it is energy intensive; recovery of glycerol is difficult; the catalyst has to be removed from the product; alkaline wastewater requires treatment and the level of free fatty acids and water greatly interfere with the reaction. Acid catalysts include sulfuric, hydrochloric, ferric sulfate, phosphoric and organic sulfonic acid. Acid catalysts are more tolerant than alkaline catalysts for vegetable oils having high free fatty acids and water. Therefore, acid catalyst is used to reduce the free fatty acids contents to a level safe enough for alkaline transesterification which is preferred over the acid catalyst after the acid value is reduced to the desired limit. Acid-catalyzed reaction gives very high yield in esters. However, the reaction is slow. The homogeneous transesterification consumes large amount of water for wet washing to remove the salt produced from the neutralization process, and the residual acid or base catalyst. The catalytic transesterification has some problems such as: high time consumption, lag of reaction time caused by the extremely low solubility of the alcohol in the triglyceride phase and the need for separation of the catalyst and saponified impurities from biodiesel. These problems are not faced in the non-catalytic transesterification methods. For example, when comparing supercritical methanol system with catalytic transesterification it uses lower energy and completes in a very short compared of time. Further, since no catalyst is used, the purification of biodiesel and the recovery of glycerol are much easier, trouble free and environment friendly. However, due to high pressures and high temperatures the method has a high cost in reactor and operation and high methanol consumption [3].

Biodiesel can be produced through a chemical reaction known as transesterification process. The most commonly used alkali catalystsin thisproses ware Potassium hydroxide (KOH) and sodium hydroxide (NaOH) and alcohols which were used in transesterification process are methanol and ethanol. However, as compared to ethanol methanol was preferred for the biodiesel production due to its low price and higher reactivity [16, 31]. The main problem related to direct use of vegetable oils is their high viscosity and low volatility. Transesterification is one of the possible methods to reduce viscosity, which produces Biodiesel of respective oils. Biodiesel is a fatty acid alkyl ester, which can be derived from vegetable oil by transesterification [65].

Table2.1 Comparison of main biodiesel production technologies [22]

Techinologies	Advantages	Disadvantages
Dilution (direst blending or micro-emulsion)	• Simple process	• High viscosity, Bad volatility, Bad stability
Pyrolysis	• Simple process • No-polluting	•High temperature is required • Equipment is expensive • Low purity
Transesterification	• Fuel properties is closer to diesel • High conversion efficiency • Low cost • It is suitable for industrialized production	• Low free fatty acid and water content are required (for base catalyst) • Pollutants will be produced because products must be neutralized and washed •Accompanied by side reactions • Difficult reaction products separation

Mulimani et al. [31] stated that for producing the biodiesel from transestrification process free fatty acid, reaction temperature, reaction time, and the amount of catalyst, catalyst concentration and mixing rate were considered as the main factors of the process. During the esterification process, higher amount of FFA reacted with the catalyst to form soap and struggled to split the biodiesel from glycerol and reduced the yield. In transestrification process, methyl alcohol and catalyst, KOH were mixed and added oil in a flask. The mixture was stirred and heated up to 65–700C with the time of 1.5 h. Initially stirring speed range of 650–700 rpm and increase the temperature up to 70^{o}C, finally it was reduced to 450–500 rpm. After the time over, the mixture was transferred into a separating flask and allowed the time to settling for 12 hrs. And then two layers were formed into the flask. The Methyl ester was formed in the upper layer followed that glycerol in the lower layer of by-product of this process. The upper layer of methyl ester was again washed with hot water and contributes time to settling overnight. After those three layers were formed, i.e, upper layer methyl ester, middle layer glycerol and water in bottom layer. Finally, remove the middle and bottom layer, Methyl ester as a biodiesel was collected in a separate flask.

Yusup and Khan [68] studied the transesterification process of waste cooking palm oil with catalyst. They were using methanol to oil ratio of 6:1, 8:1 and 10:1, catalyst as KOH with 0.5, 1 and 2% of weight and the reaction temperature were 45, 55 and 65^{0}C respectively. The optimum conditions of this process were 3hr reaction time, 55^{0}Creaction temperature, 2wt% catalysts, methanol to oil ratio is 8:1.Through this process, the yield of biodiesel is 96%.

Kumar et al. [21] showed that Jatropha oil can directly be used in diesel engines, as they have calorific value very close to diesel. The high viscosity and low volatility of vegetable oils lead to difficulty in atomizing the fuel. Transesterification of vegetable oil provides a significant reduction in viscosity, compared to other process, thereby enhancing the physical properties.

Agarwal et al. [2] discovered that the process of transesterification is found to be an effective method for reducing the viscosity of vegetable oils.

Wang et al. [66] reported that the vegetable oils possess almost the same heat values as that of diesel fuel. The authors stated that the engine power output and the fuel consumption of the engine are the closest compared with that of pure diesel.

Lin et al. [23] stated that transesterification is a simple and an efficient method for biodiesel production process. The authors showed that the rice bran biodiesel can be used instead of diesel fuel with or without blending to the diesel fuel to be used as fuels in diesel engines.

2.4 Effect of different fuel additives on performance and emission characteristics of CI engine

Additives are organic based or metal based substances which are easily soluble in fuel and its main purpose is to improve, maintain and provide beneficial characteristics to the fuel without affecting the performance and combustion parameters.

2.4.1 Metal based nano additives

The burning characteristics of the fuel can also be improved by the addition of metals and metal oxides to the fuel in the range of micro or nano sizes through ppm or percentage by weight ratios. Metals like iron (Fe), aluminum (Al), magnesium (Mg), manganese (Mn), silver (Ag), gold (Au), copper (Cu), boron (B), graphene, silica (Si), etc. and metal oxides like aluminum oxide (Al_2O_3), cobalt oxide (Co_3O_4), cerium oxide (CeO_2), titanium oxide (TiO_2), zinc oxide (ZnO), copper oxide (CuO) etc., are used as additives to improve the fuel physio-chemical properties [65].

Alloys of metals like magnalium (Mg-Al), Carbon nano tubes (CNT) are also used as metal based additive which improves the performance of fuels by changing its physiochemical properties. Researchers have found that the modification of fuel with respect to its physio-chemical properties yields better results in enhancing the engine performance and controlling the exhaust emissions rather than carrying out engine modifications.

Rakhi et al. [28] investigated burning characteristics, engine performance and emission parameters of a single cylinder CI engine using nanofuels which were formulated by adding nanoparticles of aluminium (Al), iron (Fe) and boron (B) in base diesel. These fuels showed reduced ignition delay and improved combustion rates. The brake thermal efficiency increased by 9%, 4% and 2% for Al, Fe and B respectively as compared to diesel at maximum loading conditions. At higher load the SFC reduced by 7% when engine fuelled with Al as compared to diesel, while SFC for Fe and B was almost same to that of diesel. Volumetric reduction of 25-40% in CO emission, 8% and 4% in hydrocarbon emission was observed when engine fuelled with A1 and F1 respectively as compared to diesel. The NO_x emission marginally increased compare to pure diesel because of increase in burning temperature in the combustion chamber.

Ganesh et al. [12] studed the effect of Nano-fuel additives; Magnalium (Al-Mg) and cobalt oxide (CO_3O_4) on the performance and emission characteristics of Jatropha biodiesel (B100) in a single cylinder, air cooled, direct injection diesel engine. The addition of cobalt oxide (CO_3O_4) nanoparticle resulted in maximum reduction of about 60% in unburnt hydrocarbon and 50% reduction in carbon monoxide at full load and 75% load respectively for neat biodiesel operation. The results showedthat NO_x emission were higher at neat biodiesel operation compared with neat diesel operation and it was countered by introduction of Nano-fuel additive which resulted in 45% reduction in NO_x emission at the same biodiesel operation. Magnalium particles are highly energetic materials and it reduces the energy consumption and improves the thermal efficiency, the reason is that, the additive releases energy during combustion, in addition to the liquid fuel. Magnalium improves the atomisation by means of micro explosion phenomena and hence it reduces the pollution formation. The addition of Magnalium (Al-Mg) resulted in 70% reduction in HC emission and 41 % reduction in CO emission for B100 with additive at part load and full load conditions respectively. It was also noticed that, additive act as a heat sink and reduces the in-cylinder temperature.

Patil et al. [34] studied the Experimental investigation of effect of cerium oxide nanoparticles as a fuel additive in cottonseed biodiesel blends. In the experimentation Cerium Oxide Nanoparticles in 50 ppm concentration was used in cottonseed biodiesel blends $10BCeO_250$ and $20BCeO_250$. The experiments were carried out on single cylinder D.I. diesel engine. Results show the significant improvement in performance parameters and reduction in NOx emissions.

Syed Sameer et al. [62] studied the Effects of CeO_2 and Al_2O_3 nanoparticles added to diesel in a four stroke single cylinder CI engine. The result showed that addition of nanoparticle to diesel blend reduces the carbon monoxide, HC and smoke emission. The NO_x emission showed an increase because nanoparticles act as an oxygen providing catalyst and it increases the in-cylinder temperature at both fragment load and complete load conditions.

Sathiyamoorthi et al [54] carried out an experimental study to evaluate the performance, emission and combustion characteristics of single cylinder direct injection diesel engine fuelled with neem oil-biodiesel with CeO_2 nano-additive. The properties of BN20 with and without nano additive were compared with standard diesel fuel. The addition of nano additive has resulted higher BSFC and BTE when compared to standard diesel fuel. In the case of emission, NO_x, Smoke, HC and CO emissions reduced considerably by the addition of nano additive in the BN20 fuel blend. It is also observed that higher cylinder pressure and heat release during the cerium oxide blended BN20 fuel mode.

Somasekar Babu and Pandurangadu [33] investigated the effect of cerium oxide and diethyl ether in the mango seed oil methyl ester biodiesel on engine performance, combustion and emission characteristics of four stroke direct injection diesel engine. It is concluded that BTHE and ME is improved, BSFC and EGT is reduced by adding diethyl ether and cerium oxide nano particles. There is considerable reduction in the HC, CO, CO_2, and NO_x emissions.

Rao et al. [44] evaluated the effect of cerium oxide nano particles addition in diesel and bio diesel on the performance and emission analysis of ci engine. An experimental investigation was carried out to evaluate the performance and emission characteristics of a compression ignition engine while using cerium oxide nanoparticles as additive in neat diesel and diesel-biodiesel. The cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NO_x. The activation energy of cerium oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and prevents the deposition of non-polar compounds on the cylinder wall resulted reduction in HC emissions. The tests revealed that cerium oxide nanoparticles can be used as additive in diesel and diesel-biodiesel to improve complete combustion of the fuel and reduce the exhaust emissions significantly.

Sajeevan and Sajith [51] conducted an experimental investigation diesel engine emission reduction using cerium oxide nanoparticle. The influence of cerium oxide nanoparticle on various physicochemical properties of diesel fuel has also been investigated through extensive experimentation by means of ASTM standard testing methods. The results the test show that a reduction of HC and NO_x emissions respectively, especially at higher load.

Rao et al. [45] analyzed the performance of di diesel engine fuelled with diesel with cerium oxide and zinc oxide nanoadditives. An experimental investigation was carried out to study the performance of a compression ignition engine fuelled with diesel with nanoparticles as an additive. Various blends were prepared by varying the nanoparticles i.e. cerium oxide and zinc oxide to study its operating characteristics of a single cylinder constant speed CI engine. The engine test results showed that addition of nanoparticles i.e. cerium oxide and zinc oxide leads to an improvement in thermal efficiency compare to diesel operation at full load. However, the brake specific fuel consumption of zinc oxide 250ppm blend was nearly same as cerium oxide 40ppm and also zinc oxide 500ppm blend was nearly same as cerium oxide 80ppm at higher loads, and all the nanoparticle added blends ware having less exhaust temperature than the diesel values at higher load. The smoke was decreased with the addition nano additives and also 40ppm of CeO_2 as given the lowest rate of smoke.

Slvan et al. [55] studied on effects of cerium oxide nanoparticle addition in diesel and diesel-biodiesel-ethanol blends on the performance and emission characteristics of a CI engine. The Biodiesel was prepared from the castor oil through transesterification process. Performance characteristics were studied using the blend fuel in a single cylinder four stroke CI engine coupled with an eddy current dynamometer and a data acquisition system. The cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NOx. The activation energy of cerium oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and prevents the deposition of non-polar compounds on the cylinder wall results reduction in HC emissions. The tests revealed that cerium oxide nanoparticles can be used as additive in diesel and diesel-biodiesel-ethanol blend to improve complete combustion of the fuel and reduce the exhaust emissions significantly.

Ramarao et al. [42] determine the engine performance and emissions of a single cylinder direct injection (DI) diesel engine using diesel-biodiesel blends with Cerium Oxide (CeO_2) nano additive.in the study Blends of diesel-biodiesel of different proportions ware prepared to which Nano additive Cerium Oxide (CeO_2) is added. Properties like Flash point, Fire poin tand Calorific values were evaluated for the blends. The fuel was used in single cylinder direct injection four stroke diesel engine and performance and emission was recorded. In the investigation cotton seed oil methyl ether was taken as biodiesel and Cerium Oxide (CeO_2) as Nano additive. By using different blends of cotton seed oil methyl esters for which Cerium Oxide (CeO_2) Nano additives was added in different proportions with neat diesel fuel. The experiments were conducted on a single cylinder direct injection four stroke diesel engine, and observed the variation of Specific Fuel Consumption (SFC), Brake Thermal Efficiency, Air-Fuel ratio, Exhaust Gas Temperature (EGT), NO_x emissions, Carbon Monoxide (CO), and Hydro Carbons (HC) emissions. The results have shown lower fuel consumption, better performance, and lower emissions of Carbon Monoxide (CO), Hydro Carbons (HC) but higher emissions of (NO_x), in comparison to neat diesel fuel.

Samuel et al. [52] carried out an experiment to establish the performance and emission characteristics of a compression ignition engine while using cerium oxide nanoparticles as additive with neat diesel. In the study two experiments were conducted. In the first phase pure diesel was tested in a CI engine. Then in the second phase performance characteristics are studied using the fuel added with nanoparticle in a four cylinder four stroke engine. The cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NO_x. The results from the experiment showed that the performance of engine increases with the addition of nanoparticle to the fuel and there was a significant improvement in the exhaust emissions while using diesel mixed with cerium oxide nanoparticle.

Dhahad et al. [8] studied the effect of Aluminum Oxide nanoparticle additive on the performance and emission characteristics of diesel engine. Diesel fuel was mixed with the Al_2O_3 nanoparticle by using ultrasonicator. The result was compared with the normal diesel fuel. Measurements indicated that there is improvement in the thermal efficiency and the brake specific fuel consumption with Al_2O_3 nanoparticles in the blended fuel. The emission results at all loads showed that NO_x and smoke produced by Al_2O_3 blended fuels were less than those produced by diesel fuel. Diesel fuel produced CO and HC more than Al_2O_3 blended fuels at high load and less at low load.

Mendonca et al. [29] Studied the influence of aluminium oxide nanoparticles blend biodiesel fuel on the performance and emission distinctiveness of a compression ignition engine. The biodiesel was formed from Simarouba oil methyl ether by transesterification method and blended with Aluminium oxide nanoparticle. The analysis was carried out in invariable speed CI engines with four phase’s pure diesel, diesel- Aluminium oxide nanoparticles, blended biodiesel B20 and B20-Aluminium oxide nanoparticle. The outcome revealed a significant improvement in brake thermal efficiency and reduction in brake specific fuel consumption, carbon monoxide (CO), unburnt Hydrocarbons (HC). But there was small percentage increase in oxides of nitrogen emissions.

Rani et al. [43] evaluated the performance and emission characteristics of four stroke, single cylinder diesel engine using aluminium oxide nano particles as additive in diesel ethanol blends compared with neat diesel. N-butanol is used to prevent the phase separation between diesel and ethanol. 30nm sized aluminium oxide nano particle additives are used in diesel and ethanol blends in the mass fraction of 50ppm.Final results are showing that the brake thermal efficiencies of the engine using diesel ethanol with nano additive blends are increased at higher loads compared to neat diesel and diesel-ethanol blends. Specific fuel consumption was slightly increased in diesel–ethanol blends compared to neat diesel due to lower heating value of ethanol. Emissions also controlled by using diesel, ethanol with nano additive blends compared to diesel-ethanol blends.

El-Seesy et al. [9] conducted an experimental investigation on the effect of Aluminum oxide nanoparticles addition with jojoba methyl ester-diesel fuel blend on a diesel engine performance, combustion and emission characteristics. The results of the study revealed that JB20D slightly reduced the engine performance and increased emission characteristics at all engine tested operating conditions as compared to pure diesel oil. Utilizing of Al_2O_3 additives was found to improve all engine performance characteristics. However, the best emission characteristics were obtained at the dose level of 20 mg/l, where remarkable emissions reduction were observed; NOx by 70%, CO by 80%, UHC by 60%, and Smoke opacity by 35%.

Razek et al. [47] examined the effect of aluminum oxide nano-particle in jatropha biodiesel on performance, emissions and combustion characteristics of DI diesel Engine. The results were compared with neat diesel and B20 as base fuels. As the result shows the overall BSFC was, and exhaust gas temperature was, unburned hydrocarbon, carbon monoxide and nitrogen oxides reduced compared with the corresponding values obtained when only a blended fuel of 20% biodiesel is used. However engine thermal efficiency was increased. Such type of biofuel based Nano fluids having improved performance characteristics can be utilized directly as an alternate fuel for diesel engines.

Krishna et al. [18] executed an experiment on performance and emissions characteristics of Palm stearin methyl ester bio-diesel with alumina blended palm blend fuel on direct injection diesel engine. The author performed the test on a Kirsloskar DI diesel engine at constant speed of 1500 rpm using different Nano Biodiesel Fuel blends (PB50 ppm, PB150 ppm and PB200 ppm) and results were compared with those of neat conventional diesel and Palm Stearin Methyl Ester Bio diesel. It was observed that for Nano Biodiesel Fuel blend PB50ppm) there is an significant reduction in carbon monoxide emissions and NO_x emissions compared to diesel and the brake thermal efficiency for (PSME50ppm) was almost same as diesel.

Surendra et al. [60] investigated an experimental on performance and emissions characteristics of direct injection diesel engine using diesel-ethanol blend fuel with Al_2O_3nano particle additive. The authors accomplished the experiment on four stroke single cylinder direct injection diesel engine using three different proportions of alternative blends and alumina nano particle additives. These three different proportions ware 20%, 40% and 50% ethanol mixed with diesel by using magnetic stirrer and to estimate the performance, combustion and emissions. Also adding with 30nm sized alumina nano particles (each proportions 50 ppm quantity) ware mixed with diesel-ethanol blends and also find out the combustion, performance and emissions. Final results were observed that the brake thermal efficiency of the given engine increases with increasing load for diesel and bio fuel blends with nano particle additives and fuel consumption decreases with increasing the loads. CO and HC emissions ware less at lower loads for different proportions compared to diesel fuel. However; NO_x emissions of the fuel blends were higher with increase of load compared with diesel fuel.

Ghogare et al. [13] determined the performance, emission and combustion characteristics of single cylinder diesel engine fuelled with Soya Bean Methyl Ester biodiesel blends with the Alumunia (Al_2O_3) nano Additives. The fuel used by the authors for the study were neat diesel, diesel with biodiesel blended fuel along with aluminum oxide nanoparticles that are; B20, B30, B20$Al_2O_3$50ppm, B20$Al_2O_3$100, B30$Al_2O_3$50, B30$Al_2O_3$100. The authors were carried out experimental setup on a single cylinder 4 stroke diesel engine. From the results observed that Brake Thermal Efficiency of B20 is slightly less than that of B30 but there is considerable increase in volumetric efficiency with the B20 blend; hence out of these combinations B20 can be considered as the best combination with diesel. Other parameters like Brake Specific Fuel

Consumption and Air fuel Ratio also yielded good result with B20 combinations. It is observed that smoke reduces in all blends as compared to the neat diesel.

Zinabu [70] studied the performance characteristics diesel engine using cotton seed oil biodiesel with ethanol additive. The test was conducted for B20, B20E5, B20E10 and B20 E15 fuels. The results indicate that the power and torque decreases as the percentage of additive increases and specific fuel consumption increases as the amount of ethanol additive increases. The experimental result showed that the power and torque of diesel fuel was also higher than that of B20 with ethanol additive and its brake specific consumption was lower.

Marta [24] evaluated the exhaust gas analysis and performance parameters of cotton seed oil biodiesel in diesel engine using diesel, B10, B20 and B30 fuels. The results showed that the blends of cotton seed oil biodiesel (B10, B20 and B30) reduced brake torque by 5% , 7% & 12%, brake power reduced by 6%, 8% and 11% and the fuel consumption was increased by 4%, 8% & 20% respectively. From the emission results there was a significant reduction on CO, CO2 and HC emissions however NOx and O2 were increased as compared to diesel fuel.

Megersa [25] investigated the performance and emission characteristics of single cylinder four stroke diesel engine using cotton seed oil biodiesel and diesel blended fuel with cerium oxide nano particle additive. The performance and emission characteristics were tested on, pure diesel (B0), B10, B20, B25, B20+ 50ppm CeO2 and B20+ 100ppm fuels. The results shows that the engine brake power and brake torque of B20+ 50ppm CeO2 and B20+ 100ppm fuels were higher than that of B10, B20and B25. Moreover the brake specific fuel consumption was increased as the percentage of the biodiesel blend was increased. The emission results shows that the biodiesel blend and biodiesel blend with nano additives with cerium oxide nano particle produce lower CO, CO2, HC while there is increment in CO2 as compared to pure diesel fuel.

2.4.2 Mixed nano additives

Mortaza et al. [30] examined effects of adding hybrid nanocatalyst (CeO_2+Multi walled carbon nanotube) in diesel and biodiesel blends (B5 and B20) on performance and emission characteristics of diesel engine. The hybrid nanocatalyst was added in dosing level of 30, 60 and 90 ppm. The engine torque and power increased by adding hybrid nanocatalyst compare to pure blend. Interestingly, a remarkable reduction in emissions was obtained by incorporating the soluble catalyst nanoparticles to the diesel/biodiesel blends Because of unique oxygen absorption and donation properties of CeO_2 nanoadditive the emission of CO, HC, NO_x and soot reduced. The MWCNT acts as support for CeO_2. MWCNT acts as catalyst to accelerate burning rate which result in decreased ignition delay. The CeO_2 nanoparticles act as oxygen donating catalyst which oxidize CO into CO_2 and absorb oxygen for reduction of NO_x into nitrogen. The activation energy of CeO_2 burn off carbon deposits within the combustion chamber and hence lower HC and soot emission.

Selvan et al. [56] studied performance and emission characteristics of VCR engine at optimum compression ratio of 19:1 using diesterol (diesel-castor oil biodiesel – ethanol blend) with CeO_2 and CNT blends. They used CeO_2 and CNT of each 25, 50 and 100 ppm of concentrations added with diesterol blends. The addition of nanoparticles in diesterol blends increased thermal efficiency by 7.5%, reduced HC and smoke emission by 7.2% and 47.6% respectively compare to diesterol blends without nanoparticles.

2.5 Research gap

Based on the review, it is understood that the addition of nanoparticles plays a major role in improving the fuel properties and enhancing the performance of CI engine as well as reducing the exhaust emissions. Nanoparticles like Al_2O_3, CeO_2 and shows good results as additives with diesel and biodiesel blends in all aspects. The performance enhancement cannot be achieved with every amount of nanoparticle addition. Therefore, selecting optimal range of nanoparticle addition is a key to get good results on enhanced performance and reduced emission in a CI engine. Some nanoparticles gives good results with every base fuel with which it is added, but in some cases it fails to improve neither performance nor emissions. Therefore, selecting the nanoparticles based on the properties of the fuel to be improved will help to attain better results and lot of researches should be done on this area to select the suitable nano-metal additive based for the fuel. Most researchers are investigated the effect of single nano additives in CI engine. Therefore based on the literature survey the present work was performed with an objective to investigate the effect of mixed (aluminum oxide and cerium oxide) nanoparticles in diesel-CSOME biodiesel blend fuel to observe the performance and emission characteristics of diesel engine. Moreover, experimental tests were conducted on performance and emissions characteristics of Direct Injection diesel engine fuelled with diesel-biodiesel blends with and without nano-additives.

CHAPTER THREE

METHODOLGY

The vegetable oil methyl ether for biodiesel, the equipment used and nano additive selection for the diesel-biodiesel blends fuel discussed in detail. In addition, production requirements, production method adopted, production procedures, sample preparation and experimental setup are also presented in this chapter. Further, the steps follow during performance and emission tests of diesel engine using the developed diesel-biodiesel blend fuels with and without nano additives also discussed. Fig.3.1 shows general procedure of this research work.

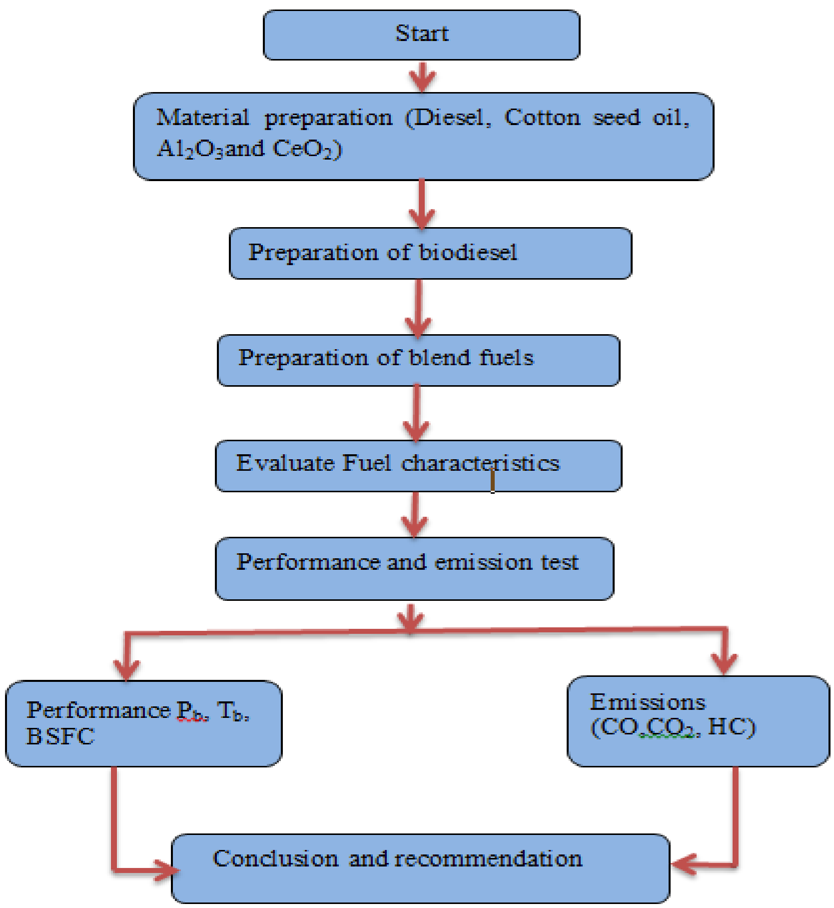


Figure3.1 General Procedure of the research work

3.1Materials

The cotton seed oil was purchased from Addis Mojo oil factory and diesel fuel was obtained from Oil Libya Adama, Ethiopia. The nano particles (Aluminum Oxide and Cerium Oxide) were purchased from India. Methanol potassium hydroxide and distilled water were obtained from chemical supplier companies in Ethiopia (C-lab Trading PLC, Addis Ababa) for laboratory scale amount. Furthermore separator funnels, volumetric flask, beakers, measuring cylinder, protecting equipment, thermometer, hotplate with magnetic stirrer, digital balance, ultrasonicator, single cylinder four stroke diesel engine, dynamometer and exhaust gas analyzer were used for this thesis work. The materials and equipment required for this thesis work are listed in table 3.1 and table 3.2 given below.

Table3.1 The materials required

No	Item	Quantity
1	Diesel fuel	20 liter
2	Cotton seed oil	10 Liter
3	Aluminia (Al_2O_3)	10gm
4	Cerium Oxide (Ce_2O_4)	10gm
5	Methanol	200ml
6	NaOH	500gm
7	Distilled water	30 liter

Table3.2 Required equipment

No	Equipment	Quantity
1	Thermometer	1
2	Separator Funnels	5
3	Beakers	8
4	Ultrasonicater	1
5	Hot plate with magnetic stirrer	1
6	Diesel engine	1
7	Exhaust gas analyzer	1
8	Viscometer	1

3.1.1 Cotton Seed Oil

Cotton (Gossypium arboreum L.), belongs to the Malvaceae family. It is an important crop that yields the natural fibers used by the textile industry. Cottonseed oil is extracted from the seeds of the cotton plant after the removal of cotton lint. Cottonseed oil is one of the oldest vegetable oils used in the industries like soap and glycol lubricants besides the usage as edible oil. Compared with the other oils like soybean oil and palm oil cotton seed oil is a suitable raw material for biodiesel production [6].

3.1.2 Nano additives

3.1.2.1 Aluminum oxide (Al_2O_3)

Aluminum oxide nanoparticle has the ability to increase the power output of engines as a result of its high combustion energy. Incorporating aluminum oxide ($Al_2 O_3$) nanoparticle into diesel-biodiesel blend fuel significantly improved engine performance while simultaneously reducing the NOx emissions carbon monoxide (CO) emissions and smoke opacity [58].

3.1.2.2 Cerium oxide (CeO_2)

Cerium oxide has the ability to catalyze combustion reactions by donating oxygen atoms from its lattice structure. Adding cerium oxide nanoparticles to fuel can help assist in the decomposition of unburnt hydrocarbons and soot, thereby reducing the emission of these pollutants from the exhaust while simultaneously reducing the amount of fuel used. It has also been shown that cerium oxide decreases the pressure in the combustion chamber, which reduces the production of NO_x and makes combustion reactions more efficient. Cerium oxide nanoparticles can also be used as a short term treatment for particulate filters in diesel engines. Cerium oxide nanoadditive also significantly reduce particulate size number distribution, lowered particle size surface area distribution and reduce total particulate number concentration as compared to diesel fuel emission characteristics [58].

Table3.3 Specification of nanoparticles

Item	Specification	
Manufacturer	NRL , USA	NRL, USA
Chemical Name	Alumina (Al_2O_3)	Cerium Oxide (CeO_2)
Purity	99.9%	Purity 99.9%
Average particle size	30-50 nm	20-30nm
Specific surface area (SSA)	130-140 m^2/g	40-45 m^2/g
Color	White	light yellow
Density	3.97 g/cm^3	6.5 g/cm^3

3.2 Methods

3.2.1 Determination of acid number

In order to determine the percent of FFA in the oil and to determine the amount of catalyst needed to neutralize the fatty acids in the cottonseed oil, a process called titration is used. The cotton seed oil is first mixed with methanol. Next, a mixture of Sodium Hydroxide (NaOH) and distilled water is added until the color of the solution is changed in to pink. The following items are needed to perform an accurate titration.

Materials used for titration;

-Beakers - Sodium hydroxide NaOH

- 500mL conical flasks -Cotton seed oil

-Electro balance -Distilled water

-100 ml Burette - Phenoptaline pH indicator

The process for titration is as follows:

1. Measure 1gram of NaOH.

2. Measure 100 milliliter of distilled water.

3. Pour the 1gram of NaOH into the beaker containing 100 milliliter of distilled water

Figure3. 2 a) Measuring of NaOH   b) Measure of distilled water   c) NaOH solution

4. Pour 15 ml of distilled water and sodium hydroxide mixture solution in to a 100 ml burette.

5. Measure 20% per one liter of cotton seed of methanol (1 ml) into a 500 ml conical flask.

6. Dissolve 5 ml of cotton seed oil into the methanol

7. Label this beaker as “oil/alcohol solution”

Figure3.3 Oil / Alcohol mixed solution

8. Add phenylphethalin indicator solution drop by drop (2 or 3 drops) in to the oil/alcohol solution.

9. Pour the NaOH/water solution into the oil/alcohol solution drop by drop using a burette

10. Swirl the vegetable solution as the NaOH/ distilled water is added and watch carefully for a color change.

11. Continue to add NaOH until the color changes to pink

12. Record the quantity of NaOH/water solution you add until the color of the oil/alcohol changes pink

13. Calculate the amount of FFA found in the cotton seed oil and amount of catalyst used in the transesterfication reaction by using the following equation

Figure3.4 Titration when pink color was found

$$\text{Acid number} = \frac{39.997\text{xVxN}}{\text{weigt of the sample in gm}}$$

$$\text{Acid number} = \frac{39.997x2.5x0.1}{5.8} = 1.72$$

The acid value is less than two so the methyl ester can be produced using transesterification process without pretreatment of the cotton seed oil.

$\text{FFA} = \frac{1.72}{2} = 0.86$ Where, V = Volume of NaOH consumed, N= Normality of NaOH = 0.1

3.2.2 Biodiesel production process

The biodiesel was produced from cotton seed oil using trasesterfication process. The production of the biodiesel was performed in Adama Science and Technology University chemistry department laboratory. Fig.3.5 shows the general procedure of biodiesel production from cotton seed oil.

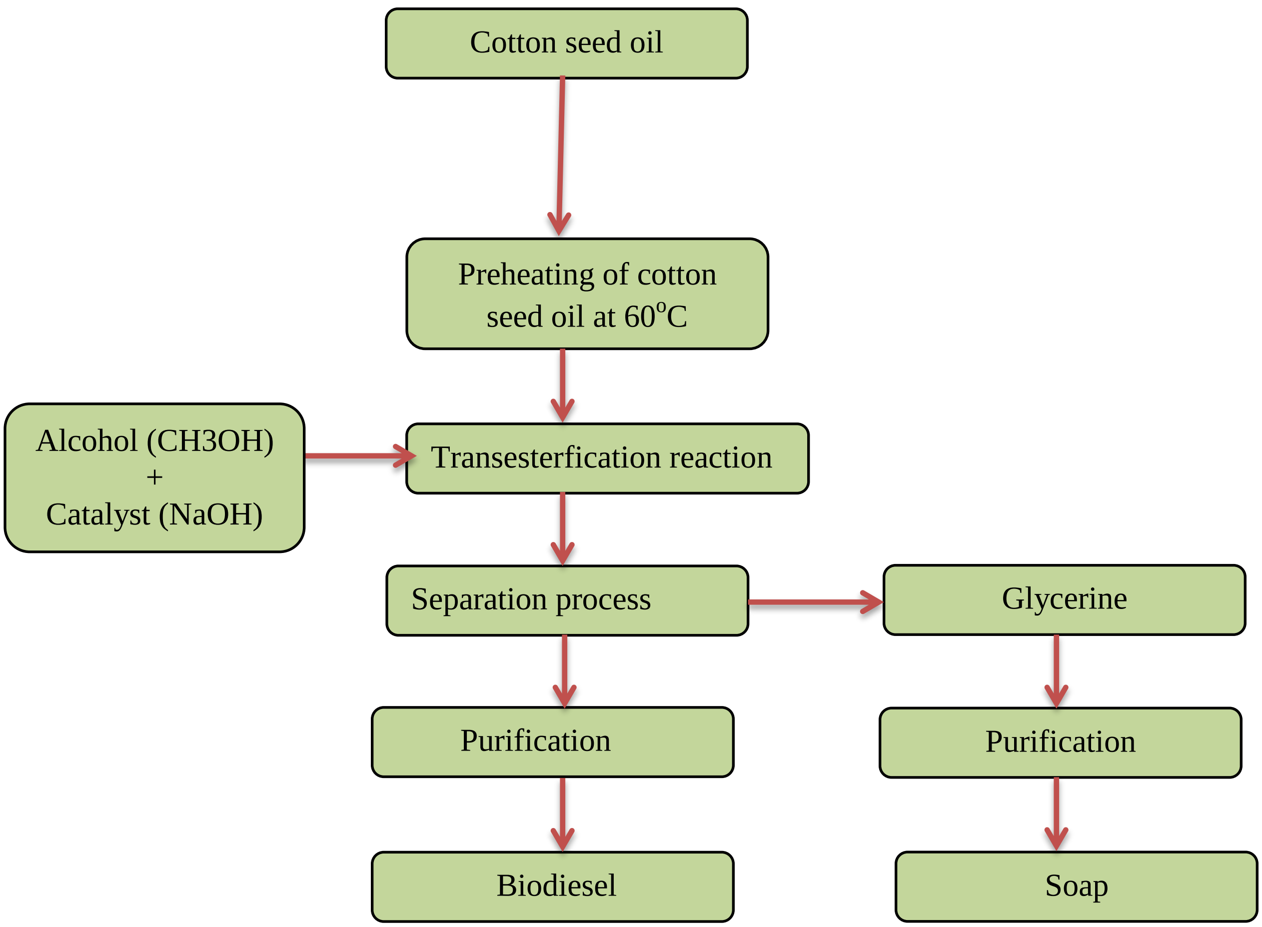


Figure 3. 5 Flow chart of Biodiesel production

Biodiesel was produced from vegetable oils or animal fats and an alcohol, through a transesterification reaction [2, 21, 23, 31, 68 , 66]. This chemical reaction converts an ester into a mixture of esters of the fatty acids that makes up the oil. The process consist conversion of the cotton seed oil to Biodiesel. Biodiesel was obtained from the purifications of the mixture of fatty acid methyl esters (FAME). A catalyst was used to accelerate the reaction. A general transesterification reaction was presented in Equation given below:

$$RCOO' + R''\mathrm{OH} \xrightarrow{\text{catalyst}} \mathrm{R'}OH \; + RCOOR''$$

RCOOR’ indicates an ester, R”OH an alcohol, R’OH another alcohol (glycerol), RCOOR” an ester mixture and cat a catalyst.

$$\begin{array}{lcccl} H_2C-OCOR_1 & & H_2C-OH & & CH_3-OCOR_1 \\ \quad | & & \quad | & & \\ HC-OCOR_2 & +3\,CH_3OH \xrightarrow{\text{KOH}} & HC-OH & + & CH_3-OCOR_2 \\ \quad | & & \quad | & & \\ H_2C-OCOR_3 & & H_2C-OH & & CH_3-OCOR_3 \end{array}$$

Figure 3.6 Transesterification reactions with methanol [6]

When methanol was used in the transesterification process, the product of the reaction would be a mixture of methyl esters. In this process glycerin will be the co-product of the reaction. This is shown schematically in Fig. 3.6. After the chemical reaction was completed and mix of esters and glycerin were separated, the mix of methyl esters must be purified to reduce the concentration of contaminants to acceptable levels. These include remnants of catalyst, water and methanol. In the following sections the steps of the production process was described in detail. There are five main Stages of Biodiesel Production Process. Those are;

- Pre-heating of the oil
- Alcohol-catalyst mixing
- Chemical reaction
- Separation of the reaction products
- Purification of the reaction products

3.2.2.1Pre-heating of the cotton seed oil

First the 10 Liters of cotton seed oil was prepared for the biodiesel production. Measure 500 ml cotton seed oil and poured in to the beaker and preheating to 60^{o}C for 60 minutes.

Figure 3.7 Preheating of cotton seed oil

3.2.2.2 Alcohol-Catalyst Mixing

The transesterification process is performed in the presence of NaOH (catalyst) and methanol (solvent). The alcohol (methanol) used for biodiesel production must be mixed with the catalyst (NaOH) before adding the oil. The Sodium Methoxide solution required during the transesterification process is prepared by mixing of 10gm (1%) of Sodium Hydroxide (NaOH) with 200 ml (20%) of Methanol for one liter of cotton seed oil. That mixture of Methanol and

Sodium Hydroxide is prepared as shown in Fig-3.8. The mixture was stirred until the catalyst was completely dissolved in the alcohol for minimum of 15 minutes.

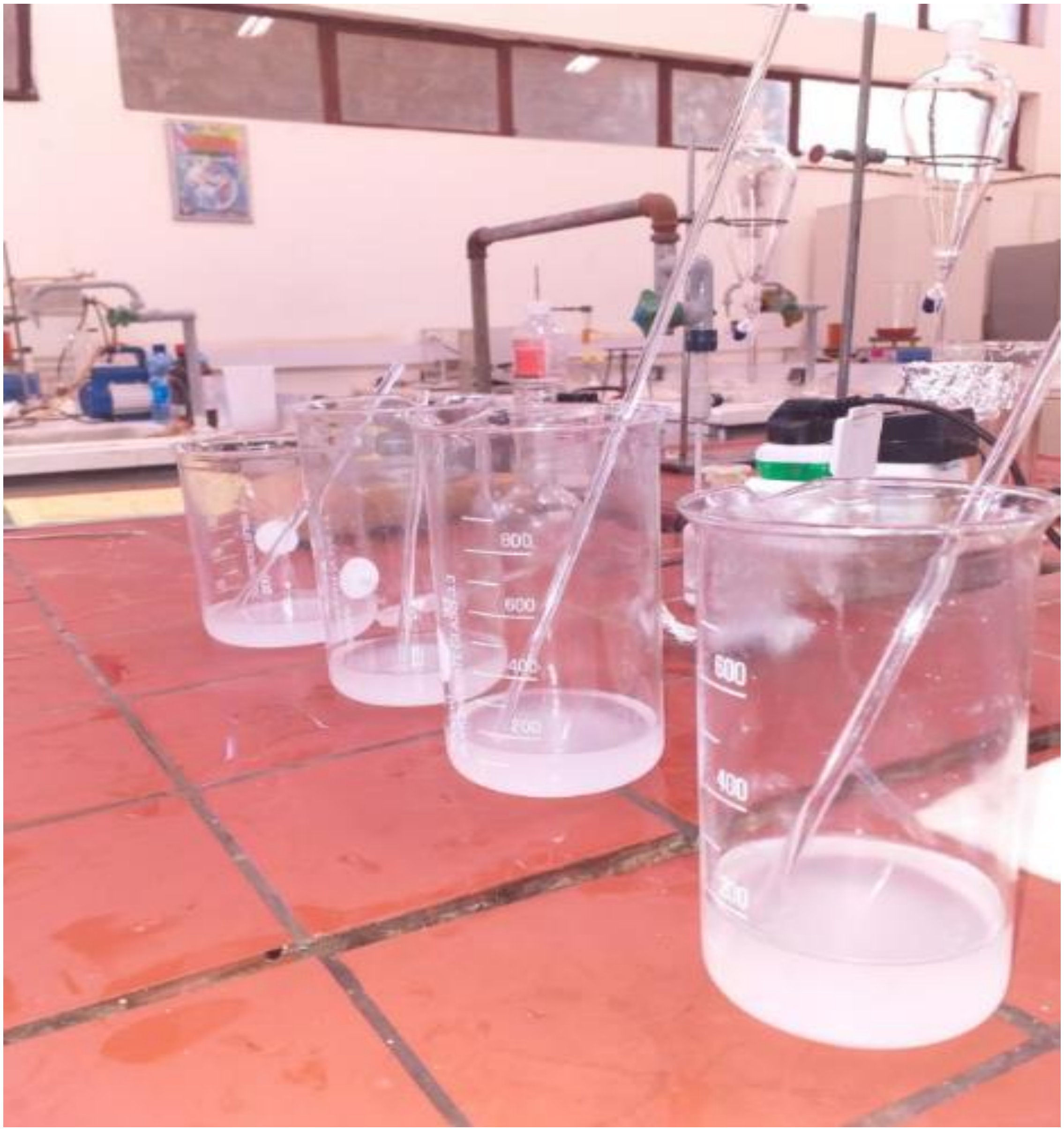


Figure3. 8 Preparation of Sodium-Methoxide

3.2.1.3 Chemical Reaction

The chemical reaction takes place when the heated cotton seed oil was mixed with the sodium-methoxide (alcohol–catalyst mix) solution. During chemical reaction Shield the beaker using the aluminum foil. Since alcohols and oils do not mix at room temperature, the chemical reaction is carried out at high temperature ($60^{o}C$) and under continuous stirring at speed of 1000 rpm for 60 minutes using magnetic stirrer hot plate, to increase the mass transfer between the phases.

Figure 3.9 Chemical reaction of transesterification process

3.2.1.4 Separation of the Reaction Products

The separation of reaction products takes place by decantation. The mixture of fatty acids methyl esters (FAME) separates from glycerin forming two phases, since they have different densities; the two phases begin to form immediately after the stirring of the mixture is stopped.

Figure3.10 Before separation of glycerol and FAME

It must be noted that if decantation takes place due to the action of gravity, it takes 24 hours to complete. Hence the mixture was allowed to settle for 24 hours using a separating funnel to separate the glycerol from the FAME. Due to their different chemical affinities, the glycerol and soap was settled at bottom, while the biodiesel was found on the top. Once the interphase is clearly and completely defined, the two phases were physically separated. The biodiesel then poured in to a separating beaker whereas the glycerol and soap were collected from the bottom of the separating funnel.

Figure3.11 After separation of glycerol and soap from COME

3.2.1.5 Purification of the Reaction Products

After the separation of glycerin, the FAME mixture contains impurities such as remnants of methanol, NaOH and glycerine. These impurities confer undesirable characteristics to FAME for instance increased cloud point and pour point, lower flash point, etc. In consequence a purification process was necessary for the final product to comply with standards.

The mixture of fatty acids methyl esters (FAME) obtained from the transesterification reaction must be purified in order to comply with established quality standards for biodiesel. Therefore, FAME must be washed, neutralized and dried.

Successive washing steps with water remove the remains of methanol, catalyst and glycerin, since these contaminants were water soluble. Care must be taken to avoid the formation of emulsions during the washing steps, since they would reduce the efficiency of the process.

Washing of biodiesel was performed under the following procedure;

1. Distilled water was heated at 60^oC

2. The CSOME was poured in to a separating funnel

3. Add half amount of heated distilled water to wash the ester

4. The water and soap settled down and separated by opening the valve of the separating funnel

5. Repeat the washing process at list six times until the water mostly clear

For proper washing of the ester keep the water temperature 60^oC and the washing takes place for 24 hrs to saturate the water with contaminates.During the first wash of cotton seed oil methyl ester a high amount of soap and contaminates were seen at the bottom of the separator funnels.

Figur3.12 First stage of washing of COME

At the second washing of the methyl ester of cotton seed oil the reduction of soap and contaminates were seen.

Figure3.13 Second washing step of COME

After the third washing stage of the COME clear water was starts seen at the bottom of the separator funnels.

Figure3.14 Third and fourth stage of washing COME

Figure3.15 Fifth and sixth step washing of COME

6. Finally the traces of water must be eliminated by a drying step. During drying the COME was heated at 130^{o}C to remove water and contaminates from the methyl ester. After drying, the purified product was ready for characterization as biodiesel according to international standards.

Figure3.16 Drying of biodiesel

3.3 Preparation of diesel- biodiesel blends and nano particles

Biodiesel and petro diesel were mixed in some specific proportions (v/v) to obtain the blends. The B20 blend of COME was prepared by mixing 20% cotton seed oil biodiesel with 80% diesel and nanoparticles using with an aid of magnetic stirrer and ultrasonic cleaner.

The nano blends were prepared by using B20 obtained from COME with the nanoparticles Al_2O_3 and CeO_2, B20 blend fuel, at a dosage of 50ppm with an aid of ultrasonic cleaner. The ultrasonication method is the best suitable method to disperse the nanoparticles in a base fuel, as it facilitates potential intermix nanoparticles. The nanoparticles are weighed to a mass fraction of 50 ppm and dispersed in biodiesel blended (B20) fuel by ultrasonic cleaner set at a power and frequency of 120 W and 40 kHz, respectively for 40 minutes, to make the nanoparticles blended biodiesel fuel. The produced blended fuels for this experiment were diesel (B0), B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2 blended fuels.

The required Required equipment's and materials used for fuel blending and nano particle preparation are; Beakers, Ultrasonic cleaner, Digital balance, Hot plate with magnetic stirrer, Cerium oxide nano particle, Aluminum oxide nano particle, Cetyle trimethyl ammonium bromide (CTAB), petro Diesel and the prepared cotton seed oil biodiesel.

a) Ultrasonic cleaner b) Digital balance c) Hot plate with magnetic stirrer

Figure3.17 Equipment's used during blending of diesel-biodiesel and nano particles

a) CTAB b) Aluminum oxide nanoparticle c) Cerium oxide nanoparticle

Figure3.18 Materials used during blending of diesel-biodiesel and nano particles

3.3.1. Procedure of preparation of fuel samples

Step 1: blending diesel and biodiesel fuels

First of all the diesel-biodiesel blend (B20) fuel was prepared. The blending was performed using following procedure.

- Measure 800ml of diesel using 1000ml beaker.
- Measure 160ml (20% of petro diesel by volume) of biodiesel using a 500ml beaker.
- Pour the 800 ml diesel in to 1 liter bottle.
- Then the 160 ml biodiesel was poured in to the 1 liter bottle and shake it at least for 2 minutes.

Step 2: preparation of nano particles

- Measure 100ml diesel-biodiesel (B20) blend fuel and poured in to the 500ml beaker.
- Measure 0.05g of Al_2O_3 plus 0.05g of CTAB and 0.05g of CeO_2 plus 0.05g of CTAB for each sample of the blend fuel.
- The measured nano particles and CTAB were poured in to the 100ml diesel-biodiesel (B20) blend fuel containing beaker and stirred at least for 15 minutes.

a) 0.05g of Al_2O_3 plus 0.05g of CTAB for B20+ $Al_2O_3$50ppm
b) 0.05g of CeO_2 plus 0.05g for B20+ CeO_2 50ppm

c) 0.05g of Al_2O_3 plus 0.05g of CTAB and 0.05g of CeO_2 plus 0.05g for B20+ $Al_2O_3$50ppm + CeO_2 50ppm

- Finally the 100ml nano particle dispersed diesel-biodiesel blend fuel solution was poured in to the 900ml diesel- biodiesel (B20) containing bottle

Step 3: Ultrasonic cleaning

Figure3.19 Ultrasonic cleaning process

First of all the recommended diesel-biodiesel blend fuels (B20, B20+ $Al_2O_3$50ppm, B20+ CeO_2 50ppm and B20+ $Al_2O_3$50ppm + CeO_2 50ppm) was prepared

Fill the cleaning tank with water at least half full

Connect the ultrasonic cleaner to the power supply and press the "power on key" on the top of the ultrasonic cleaner

Set the cleaning time and temperature using time and temperature adjustment keys

Start cleaning by pressing the "cleaner on" key. the remaining cleaning time and temperature were seen on time and temperature displays respectively on the top of the ultrasonic cleaner

Clean the prepared samples at 40 kHz for 40 minutes then after finishing the seated time the ultrasonic cleaner was stop cleaning automatically

After finishing the cleaning process switch of the ultrasonic cleaner using the “power on/off” key and disconnect the power supply.

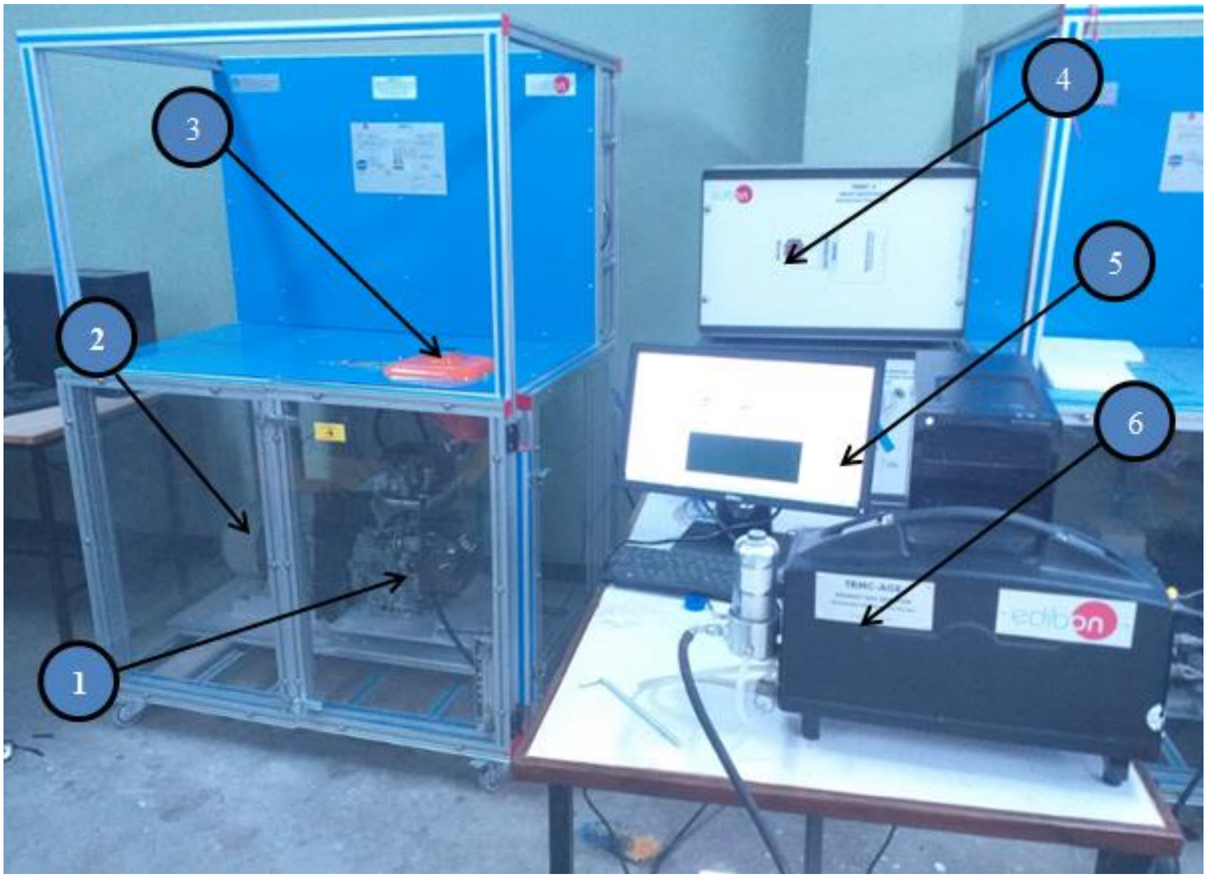
Figure3.20 Prepared fuels samples for the test

3.4 Evaluation of properties of the fuels

Several important fuel properties ware evaluated using the appropriate ASTM test methods. The properties such as density and viscosity for the test blend fuels were evaluated and given in appendix table B.3.

3.5 Experimental set up and procedure

In the experiment analyzed performance characteristics and emission of exhaust gases of direct injection diesel engine. The test was conducted in Addis Ababa Science and Technology University on TBMC3-02 Computer Controlled Test bench for single cylinder diesel engine. An exhaust gas analyzer is installed during experimentation. This test bench measures the power output of internal combustion engines delivering up to 4.2HP/3.13kW. The complete test stand consists of four main elements; Asynchronous motor, an air cooled diesel engine (TBMC3-02), SCANDA software control system and exhaust gas analyzer (TBMC_AGE).



1 Diesel engine, 2 Asynchronous motor, 3 fuel tank, 4 SCADA control system,

5 Computer, 6 Exhaust gas analyzer

Figure3.21Experimental setup of TBM3-02 test bench for single-cylinder diesel engine

Cottonseed oil methyl ether was taken as biodiesel and diesel-biodiesel blend is used for finding out the performance of the direct injection diesel engine. In this investigation, aluminum oxide (Al_2O_3) and cerium oxide (CeO_2) nano additive was taken as an additive to the diesel-biodiesel blend and performance and emission tests were conducted on the same engine. After checking engine condition along with lubricating oil level fuel is supplied to the engine on its start and engine is run and the experiments will be conducted. Fig. 3.21 shows the experimental setup for the thesis work.

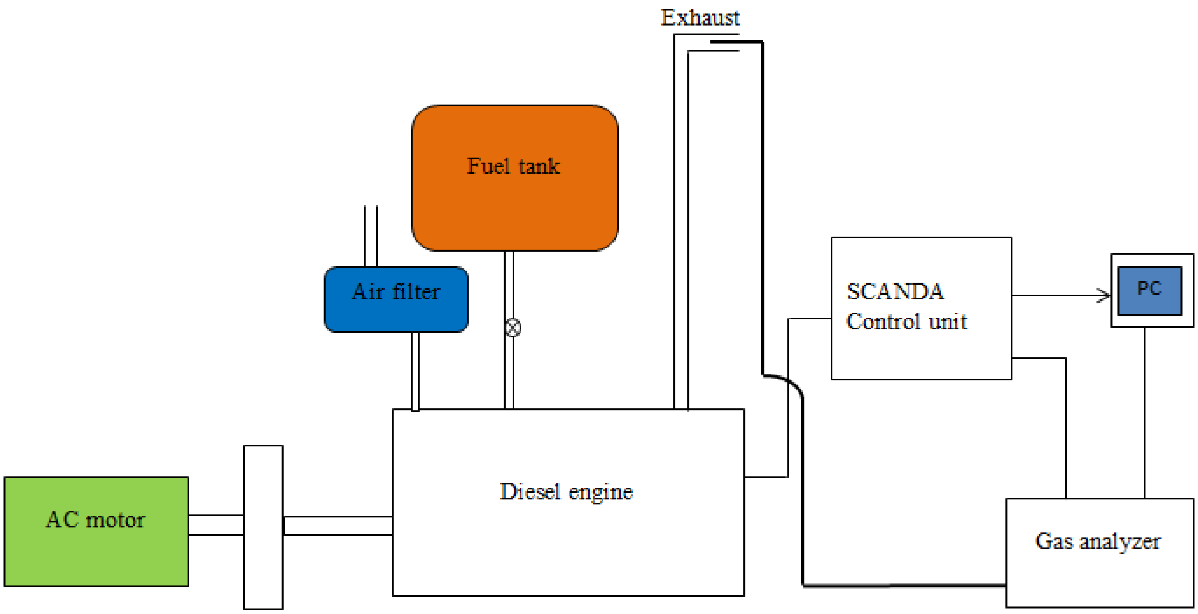
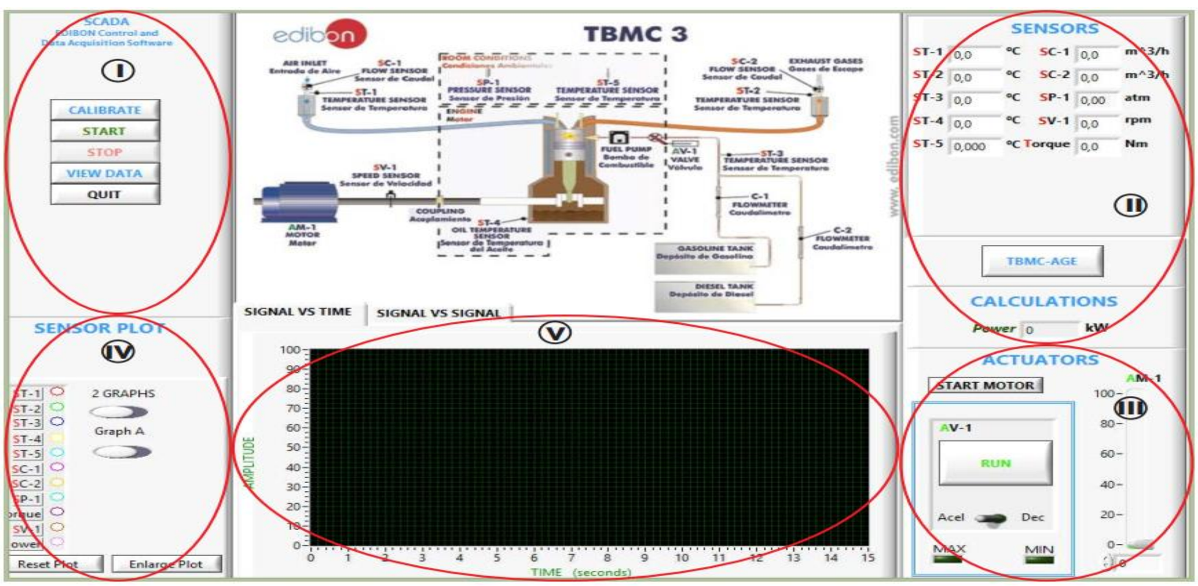


Figure3.22 Diagrammatical experimental setup

The engine analyses are conducted to find out its performance parameters and emission characteristics in the TBMC3-02 engine test bench for all test fuel samples.



I. Main software operations, II. Sensor displays, III. Actuator controls, IV. Channel selection and other plot parameters, V. Real time graphics display

Figure3.23 SCADA main screen

3.5.1Major equipment used

3.5.1.1 Diesel engine

During the experiment the four stroke diesel engine was used for performance characteristics and emission measurements. The engine used here was an air cooled single cylinder four stroke diesel engines with direct injection. The engine was computer controlled and started by software an electric motor mounted in the TBM3-02 unit.

Table3.4Specification of Test engine

Engine Manufacture	Edibon
Type of engine	Compression ignition
Fuel	Diesel
Number of cylinders	1
Number of strokes	Four
Type of air intake	naturally aspirated
Type of cooling	Air
Start	Computer controlled / manual
Compression ratio	21:1
Maximum power	4.2HP/3.13kw @ 3600 rpm
Cylinder bore	69mm
Stroke	60mm

3.5.1.2 Dynamometer

A dynamometer is a device which is used for measuring force, torque or power produced by the engine. It can also be used to apply load or torque on the engine. The dynamometer used in this study was an asynchronous motor. The advantage of asynchronous motor of is that they have no inertia and don’t need brushes. Velocity is controlled by regulating the frequency, what implies the use of power electronic equipment. It can be used to brake, or start the engine.

3.5.1.3 Exhaust Gas analyzer

The exhaust gas analyzer was used to measure the exhaust emissions of the engine. In conjunction with for TBMC3-02 engine test bench the TMC-AGE is used to measure the exhaust gas emissions of the engine such as Carbon monoxide CO (%), Carbon dioxide CO_2 (%), unbent hydrocarbons (HC) and Oxygen O_2 (%).

3.5.2 Test procedure

Primarily the experiments were carried out on the engine with diesel fuel to develop optimum cooling rate and by maintaining this optimum rate of engine cooling all the experiments were conducted on the engine. The performance and emission test was conducted using diesel-biodiesel blend with nano additive as fuel. The following step by step procedure was implemented for the test.

1. Provide the necessary electrical connections to the panel.

2. Check the lubricating oil level in the engine

3. Supply the tank with the fuel

5. Start the SCANDA TBMC3-02 software on the computer

6. Press "**start"** in the screen to be able to control the unit

7. Allow the engine to run under idling condition (no load) for 10 minutes to ensure warm and steady operating conditions.

8. Next brake the engine little by little and record the performance and emission parameters. When more brake was applied on the engine it was observed that the speed reduced.

8. Repeat the experiment for different speeds and note down the readings.

9. After the completion release the load to zero and then switch of the engine.

The performance and emission tests were conducted using diesel and diesel biodiesel (CSOME) blend with and without nano additive petro diesel (B0), B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppmAl_2O_3+50ppm CeO_2 on the engine and comparing the results.

3.5.2.1 Engine performance characteristics test

The performance of the diesel engine is evaluated with petro diesel B0), B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2 fuels. The performances of test fuels were analyzed in a TBMC3 computer controlled test bench for single cylinder four-stroke diesel engine coupled with asynchronies motor (AM-1). Experiments were conducted with varying engine speed. The parameters such as brake power, brake torque, brake thermal efficiency and brake specific fuel consumption were evaluated for different engine speed.

3.5.2.1.1Brake power (B.P)

Brake power is the power available at the delivery point, at the engine crank shaft. The brake power was usually measured by attaching a power absorption device to the drive shaft of the engine. The brake power of the engine at different operating conditions was determined using the following equation:

$$P_b = W_L x 2\pi N \ (kW) \quad (3.1)$$

Where, P_b = Brake power in kW

W_L = Load applied in kg

N = Engine speed in RPM

3.5.2.1.2 Brake Torque

It is the torque available at the flywheel. The brake power was recorded for each test fuels at various engine speeds from the TBMC-3 test bench from which the brake torque with respect to engine speed can be drawn.

$$T_b = \frac{60P_b}{2\pi N} \ (N.m) \quad (3.2)$$

Where;

T_b is engine brake torque in N.m

P_b= engine brake power in kW

N is engine speed in rpm

3.5.2.1.3 Mass of fuel consumed (m_f)

The fuel consumption of an engine was measured by determining the time required for consumption of a given volume of fuel. The mass of fuel consumed can be determined by multiplication of the volumetric fuel consumption to its density. The mass of fuel consumed by the engine at different operating conditions was determined using the equation given below:

$$m_f = v_f \times \rho_f \ \text{g/sec} \quad (3.3)$$

Where,

v_f is the volume flow rate of the fuel in ml/min

ρ_f is density of fuel in g/ml

3.5.2.1.4 Brake specific fuel consumption (BSFC)

The brake specific fuel consumption of the engine is the ratio between the fuel consumed per hour to the brake power. The brake specific fuel consumption of the engine at different operating conditions was determined using the equation as given below.

$$\text{BSFC} = \frac{m_f * 3600}{P_b} \text{kg/kW.hr} \quad (3.4)$$

Where,

m_f is mass of fuel consumed in kg/sec

BP is brake power in kW

3.5.3 Emission Characteristics test

The emission characteristics of the diesel and diesel-biodiesel blend fuel with and without nano additive (B0, B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2) are measured using exhaust gas analyzer at the engine steady state condition. The exhaust gas analyzer is used to measure the carbon monoxide (CO), carbon dioxide (CO2), unburnt hydrocarbon emission (HC) and oxiygen (O_2).

CHAPTER FOUR

RESULT AND DISCUSSION

In the present research, several experiments were conducted to study the effect of aluminum oxide and cerium oxide nano-additives on the engine performance characteristics and emissions. Engine performance and emission characteristics results are analyzed for diesel (B0), B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2 and B20+50ppmAl_2O_3+50ppm CeO_2 test fuels and are discussed in the following section. The engine performance parameters such as brake power (BP), brake torque (BT), brake specific fuel consumption (BSFC) and emissions such as CO, CO_2, O_2 and HC were discussed in this chapter.

4.1 Biodiesel production

The solvent methanol and catalyst NaOH (sodium-methoxide) were mixed with cotton seed oil at constant temperature of 60^0C and reaction time 60 minutes using hot plat magnetic stirrer. COME and glycerin were separated in separator funnel after 24 hour of interval time. The free fatty acids and glycerin were removed from the flask. Water washing was used to remove the remaining fatty acids glycerin and other remnants from the COME. The purified COME then collected from the separator funnel and then heated up to 130^oC, the water content in the methyl ester was evaporated and pure biodiesel was obtained. The optimum reaction conditions of biodiesel production are tabulated in Table 4.1.

Table4.1 Reaction condition of biodiesel production

Name of Oil	Quantity of oil (ml)	Name of solvent	Quantity of solvent (ml)	Name of catalyst	Quantity of catalyst (gm)	Reaction time (min)	Yield (%)
Cotton seed oil	500	Methanol	100	NaOH	5	60	82

4.2 Determination of fuel properties

Fuel properties were analyzed to know the fuel quality and suitability of fuel used in the engine. The fuel properties like density and viscosity for prepared fuel samples (B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppmAl_2O_3+50ppm CeO_2) were tested in Adama Scince and

Techinology Universty Material Scince department laboratory. The properties of fuel were tested as per ASTM standards procedure and tabulated in Table 4.2.

Table4.2 properties of prepared fuels

No	Property	Test method	ASTM D6751 limits	Test Results				
				B100	B20	B20+ 50ppm Al_2O_3	B20+ 50ppm CeO_2	B20+50ppm Al_2O_3+ 50ppmCeO_2
1	density@20 ^oC (g/ml)	D4052	0.820 - 0.890	0.8523	0.8435	0.8442	0.8445	0.8447
2	Kinematic viscosity @40^oC (cst)	D562	1.9-6 mm^2/s	4.564	4.428	4.216	3.890	4.009

4.3 Performance characteristics

4.3.1 Brake power

The net power available at the shaft is known as brake power. The results of the calculated (see Eq.3.6) engine brake power for all test fuels are presented in table 4.3.

Table4.3 Engine brake power at different engine speed

No	Engine speed (rpm)	Engine break power (kW)				
		B0	B20	B20 + 50ppmAl_2O_3	B20 + 50ppmCeO_2	B20 + 50ppmAl_2O + 50ppmCeO_2
1	1154	0.21	0.32	0.32	0.28	0.31
2	1250	1.19	1.15	1.18	1.16	1.08
3	1500	1.62	1.83	1.62	1.72	1.68
4	2000	2.14	2.21	2.23	2.24	2.35
5	2400	2.72	2.34	2.71	2.85	2.91
6	3000	2.98	2.53	2.92	3.15	3.15
7	3600	3.01	2.89	3.21	3.35	3.56
8	3840	2.87	2.66	3.13	3.22	3.43

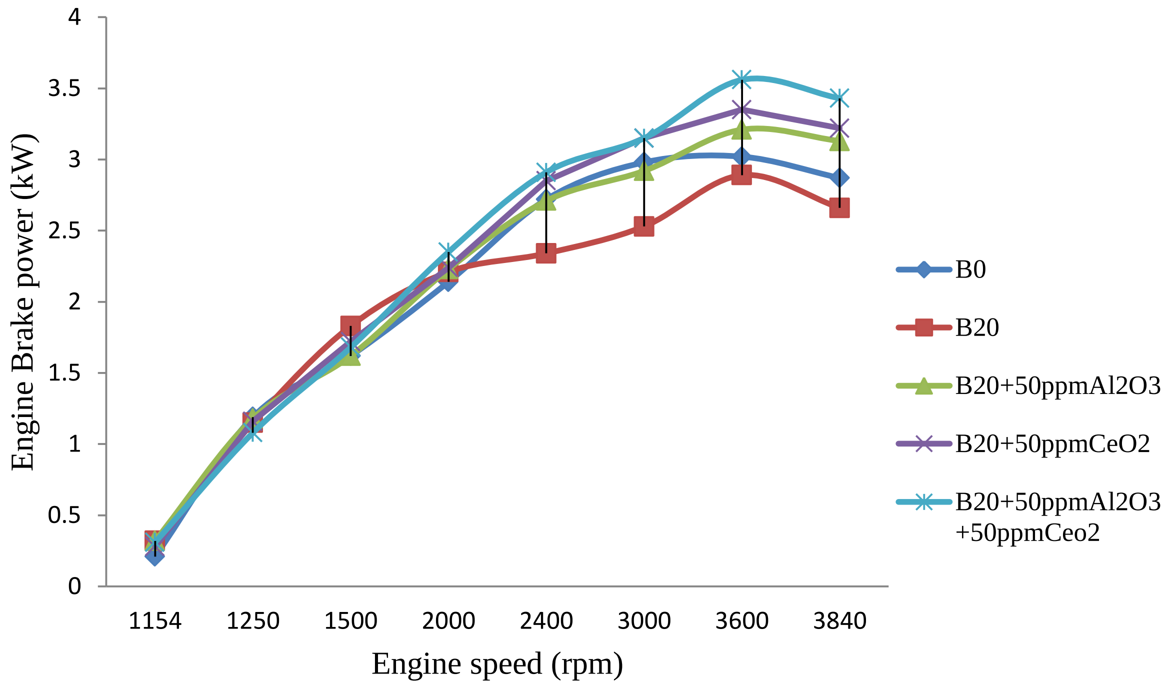


Figure 4.1 Brake power at different engine speeds

The test was conducted for petro diesel and for different blends of biodiesel (B0, B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2) at different engine speeds. It was observed that from fig.4.1 the brake power increases when the engine speed increased for all test fuel samples until it reaches the maximum limiting engine speed which is 3600rpm and then brake power starts to decrease after this engine speed. The higher values of brake power for diesel (B0), B20, at the engine speed of 3600 rpm were 3.01.kW, 2.89kW, 3.21kW, 3.35kW and 3.56kW respectively. It was observed from the Fig. 4.1 that the increase in brake power of nanoparticles dispersed test fuels were 6.6%, 11.3% and 18.3% for B20+50ppm Al_2O_3 B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2 respectively compared with petro diesel fuel at 3600rpm engine speed . This is due to the higher combustion energy of nanoparticles [58]. The B20+50ppmAl_2O_3+50ppm CeO_2 test fuel shows improved brake power over other test fuels this is due to the combined effect of CeO_2 and Al_2O_3 nanoparticles on the combustion property of the fuel.

4.3.2 Brake Torque

The engine brake torque for various engine speeds for various test fuels was shown in fig 4.2 (equ.3.2) as recorded from TBMC-3 engine test bench. At low speed, torque increases as the engine speed increases, reaching a maximum (2400 rpm) and then, as the engine speed increases further, the torque decreases for all types of test fuels. Experimental test results indicated the fact that adding nanoparticles (Aluminum oxide and cerium oxide) to diesel-biodiesel (B20) blended fuel increased engine torque output, as illustrated in Fig.4.2. This is due to that the addition of metallic nanoparticles (Aluminum oxide and cerium oxide) promotes the complete combustion, higher combustion energy and thus higher torque [33].

Table4.4 Engine brake torque at different engine speeds

No	Engine speed (rpm)	Brake Torque (N.m)				
		B0	B20	B20 + 50ppm Al_2O_3	B20 + 50ppm CeO_2	B20 + 50ppm Al_2O_3 + 50ppm CeO_2
1	1154	2.7	2.1	2.6	2.2	2.5
2	1250	7.8	6.7	6.8	6.6	6.5
3	1500	8.0	7.5	7.8	7.7	7.4
4	2000	8.2	8.0	8.1	8.2	8.3
5	2400	8.5	8.1	8.2	8.4	8.6
6	3000	8.2	7.9	7.9	8.3	8.2
7	3600	8.1	7.6	7.8	8.2	8.0
8	3840	7.7	7.2	7.5	7.9	7..7

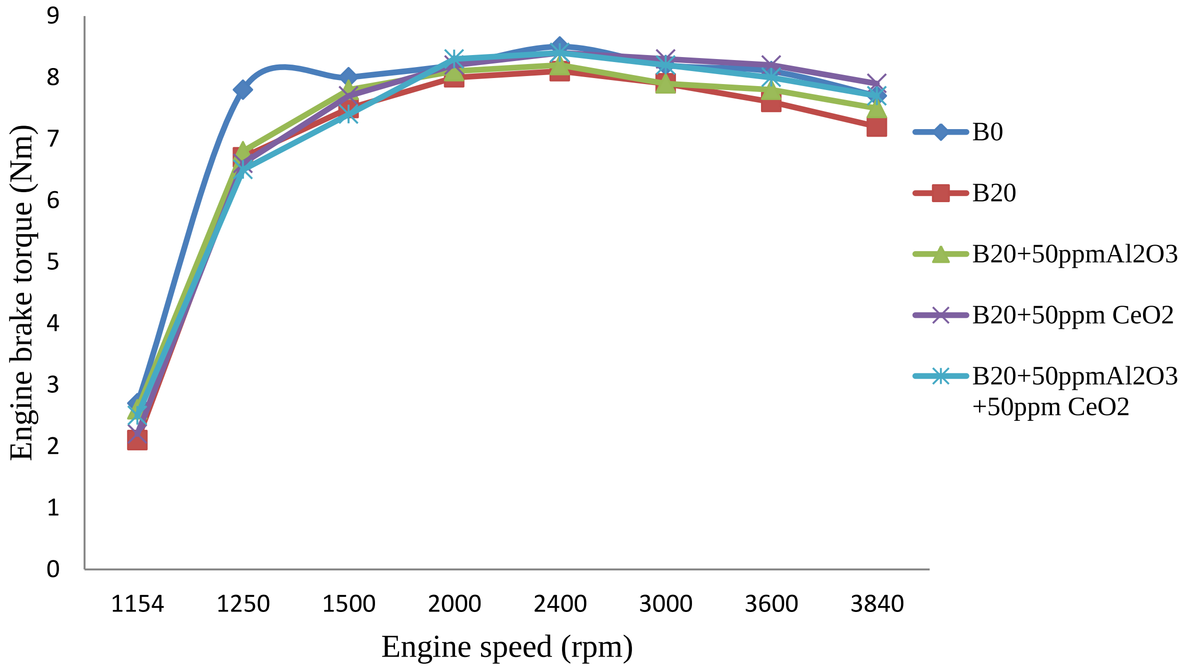


Figure 4.2 Variation of brake torque with Engine speed

The nano particles dispersed diesel-biodiesel (B20) blended fuels has higher brake engine torque while compared to the B20 fuel. The maximum recorded brake engine torque was produced by B20+50ppm Al_2O_3+50ppm CeO_2 test fuel which was about 8.6 Nm at the engine speed 2400 rpm and. The higher value of engine brake torque is occurred at this engine speed for all test fuels which were 8.5,8.1, 8.2 and 8.4 N.m for B0, B20, B20+50ppm Al_2O_3 and B20 +50ppm CeO_2 respectively.

4.3.3 Break specific fuel consumption (BSFC)

The brake specific fuel consumption is the fuel consumed by the engine in kg per kW per hour. Table 4.5 shows the recorded data (equ.3.4) of BSFC with engine speed for petro diesel and cotton seed oil biodiesel blended (B0, B20, B20+50ppm $Al_2O_3$50, B20+50ppm CeO_2 and B20+50ppm $A_2O_3$50+50ppm CeO_2) test fuels.

Table4.5 Break specific fuel consumption at various engine speeds

No	Engine speed (rpm)	Break specific fuel consumption (kg/kW.hr)				
		B0	B20	B20 + 50ppm Al_2O_3	B20 + 50ppm CeO_2	B20 + 50ppm Al_2O_3 + 50ppm CeO_2
1	1154	0.427	0.441	0.414	0.421	0.441
2	1250	0.348	0.362	0.343	0.346	0.339
3	1500	0.333	0.353	0.332	0.322	0.317
4	2000	0.321	0.343	0.313	0.309	0.305
5	2400	0.302	0.324	0.298	0.287	0.389
6	3000	0.301	0.317	0.296	0.283	0.277
7	3600	0.298	0.312	0.295	0.278	0.273
8	3840	0.281	0.301	0.288	0.267	0.258

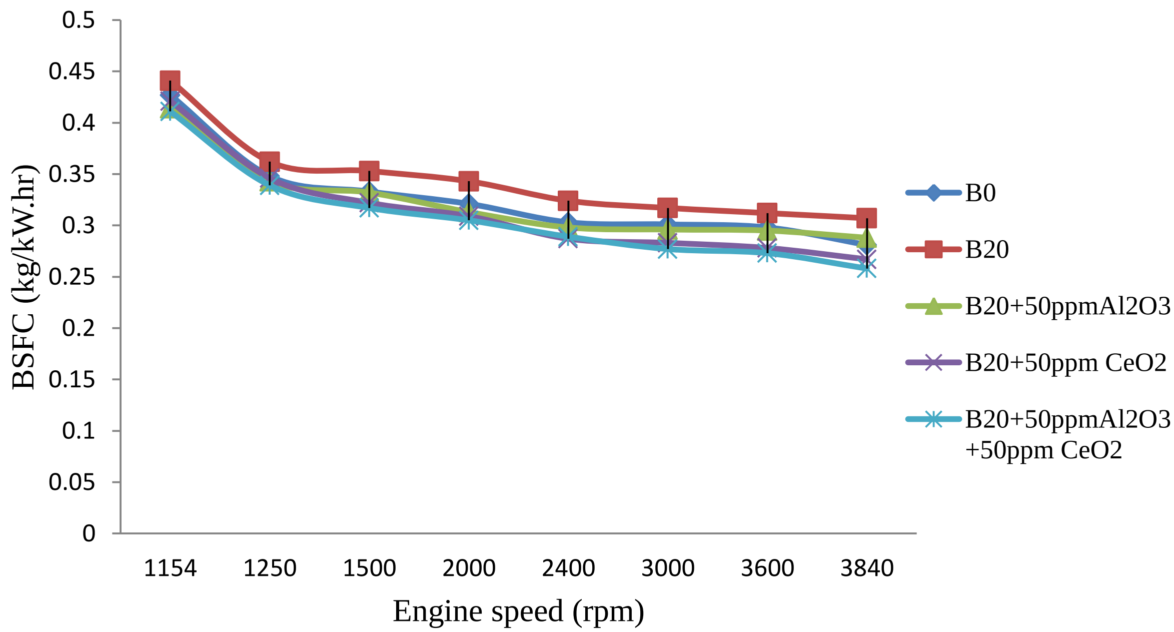


Figure 4.3 The variation of brake specific fuel consumption with respect to engine speed

Fig.4.3 shows the brake specific fuel consumption for different blends of cotton seed oil biodiesel and the diesel fuel at different speed. The test was conducted for petro diesel and for different blends of COME (B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppmAl_2O_3+50ppm CeO_2) samples at various engine speeds. It was observed from the experiment that the brake specific fuel consumption decreases when the engine speed was increased for all test fuel samples. The reason for decrease in Brake specific fuel consumption is the increase in brake power more rapidly than fuel consumption. The higher brake specific fuel consumption was observed for B20 among all the test fuels. This is due to the lower calorific value and higher density of cotton seed oil biodiesel [36]. But the improvement was observed with the addition of nano particle, due to the enhanced surface area to volume ratio of the nano particle favoring better combustion [38]. The lowest specific fuel consumption was observed for B20 + 50ppm Al_2O_3 + 50ppm CeO_2 fuel than other test fuels.

4.4 Emission characteristics

4.4.1 CO emission

Figure4.4 shows CO emission for diesel and cotton seed biodiesel blended (B20) fuel with aluminum oxide and cerium oxide nano particles. It can be seen that the CO emission of cotton blended (B20) fuel is less than that of petro diesel. Predominantly, lack of oxygen and incomplete combustion is the reason for CO formation. Since biodiesel was an oxygenated fuel, it leads to better combustion of fuel resulting in the decrease in CO emission [19].

Further the addition of nanoparticles to diesel-biodiesel blended (B20) fuel further decreases the CO emission when compared to petro diesel (B0) and diesel-biodiesel blend (B20) fuels. This is due to oxidation takes place between the Nano additive (Aluminum oxide and cerium oxide) which converts CO to CO_2 [62]. The least CO emission is observed for the B20+50ppmAl_2O_3+50ppm CeO_2 test fuel. The average percentage reduction in CO emission values for B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2 test fuels are 6.7%, 11.2%, 9.7%, 23.2% respectively.

Table4.6 CO (%) Emissions at various engine speeds

No	Engine speed (rpm)	CO (%) emission				
		B0	B20	B20+ 50ppm Al_2O_3	B20+ 50ppm CeO_2	B20+ 50ppm Al_2O_3 + 50ppm CeO_2
1	1154	0.072	0.062	0.061	0.062	0.056
2	1250	0.061	0.057	0.057	0.055	0.047
3	1500	0.064	0.061	0.059	0.059	0.051
4	2000	0.067	0.063	0.059	0.062	0.054
5	2400	0.073	0.069	0.064	0.066	0.059
6	3000	0.077	0.074	0.069	0.071	0.063
7	3600	0.081	0.078	0.073	0.073	0.066
8	3840	0.094	0.086	0.081	0.084	0.075

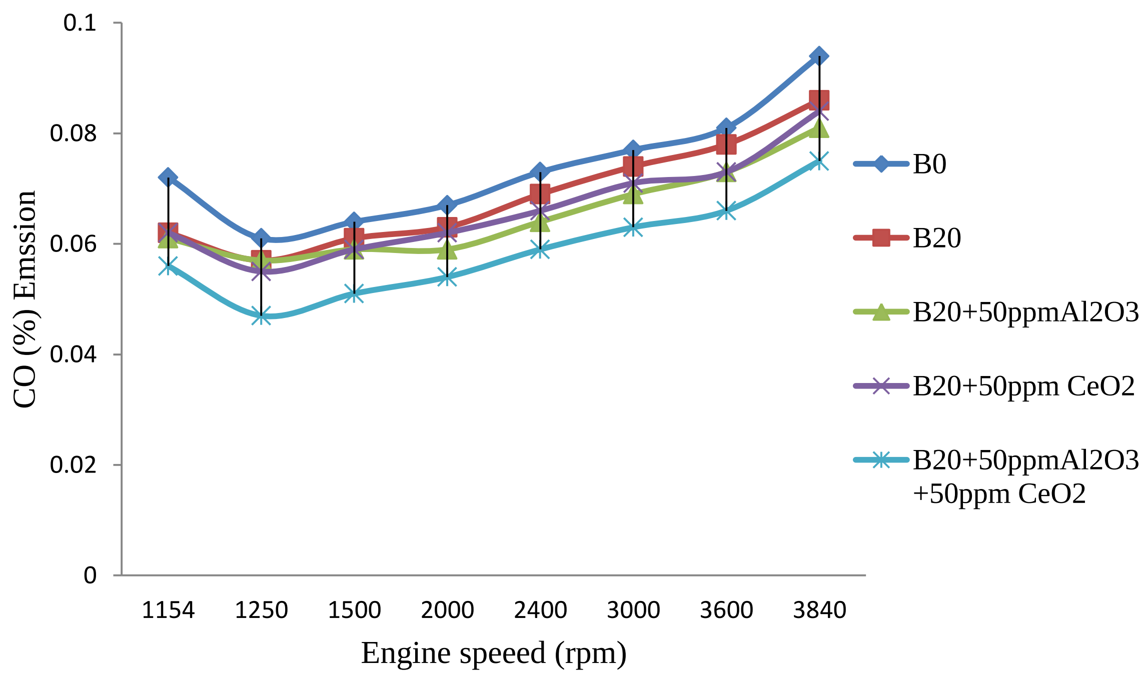


Figure 4.4 Carbon monoxide (CO) emissions at different engine speed

4.4.2 CO_2 Emission

Experimental CO_2emission results obtained from the tests on TBMC-3 CI engine test bench fuelled with petro diesel and various blends of cotton seed oil biodiesel(B20) and nanoparticles (Al_2O_3 and CeO_2) blends running at a range of engine speeds in conjunction with TBMC-AGE are shown in table 4.7.

Figure 4.5 shows that the CO_2 emissions of CI engine over a range of engine speeds. It can be seen that the CO_2 emissions increased significantly with increases in the engine speeds. Further the CO_2 emission of biodiesel blended fuels has lower value than the petro diesel (B0) fuel; due to the lower carbon to hydrogen ratio of biodiesel [64]. The CO_2 emission observed from the test at 1554 rpm for all types of fuels were 2.51%, 2.64%, 2.72%, and 2.87% for pure petro diesel (B0), B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2 and B20+50ppmAl_2O_3+50ppm CeO_2 respectively.

Table4.7 Carbon dioxide (CO_2%) emission at various speeds

No	Engine speed (rpm)	CO_2 (%) Emission				
		B0	B20	B20 + 50ppm Al_2O_3	B20 + 50ppm CeO_2	B20+ 50ppm Al_2O_3+ 50ppm CeO_2
1	1154	2.37	2.24	2.11	2.13	2.04
2	1250	2.42	2.31	2.32	2.34	2.09
3	1500	2.44	2.44	2.37	2.35	2.18
4	2000	2.63	2.52	2.46	2.49	2.27
5	2400	2.76	2.58	2.51	2.51	2.35
6	3000	2.83	2.71	2.58	2.53	2.39
7	3600	2.91	2.79	2.65	2.58	2.44
8	3840	2.96	2.87	2.72	2.64	2.51

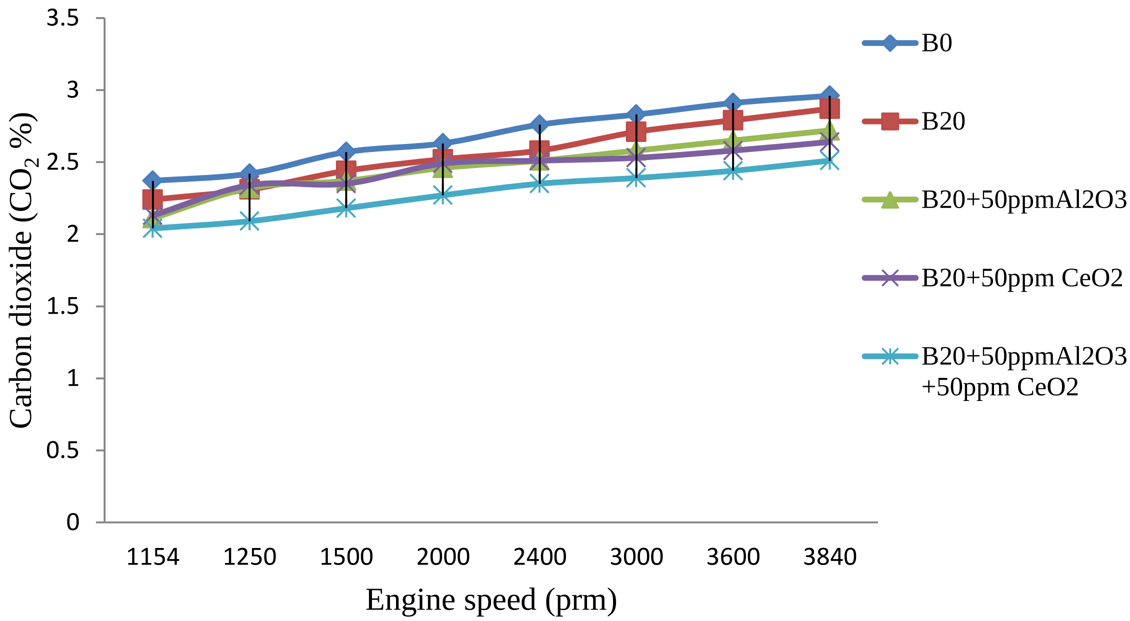


Figure 4.5 Variation of Carbon dioxide (CO_2 %) emissions with engine speed

The CO_2 emissions corresponding to petro diesel and various biodiesel blends (B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2) have been compared and resulted in a reduction change in CO_2 emission as shown in Fig. 4.5. From the experimental results the average CO_2emission reduction of B20, B20 + 50ppm Al_2O_3, B20 + 50ppm CeO_2, and B20 + 50ppm Al_2O_3 + 50ppm CeO_2 as compared to petro diesel (BO0 fuel were 4.6%, 8.1%, 8.8% and 14.8% respectively. The CO_2 emission of B20+50ppmAl_2O_3+50ppm CeO_2 shows the lowest reduction from all test fuels.

4.4.3 Hydrocarbons emission (HC) emission

Fig. 4.6 shows the variation of hydrocarbon emission with engine speed for all tested fuels. Higher HC emissions were formed during combustion of fuel, due to the deficiency of oxygen molecule in the fuel rich region and due to incomplete combustion [62]. From the experimental results, the HC emissions from all cotton seed biodiesel blended (B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2, B20+50ppmAl_2O_3+50ppm CeO_2) fuels are lower than that of the diesel (B0) fuel emissions.

Table 4.8 Hydro carbons emission at various engine speeds

No	Engine speed (rpm)	HC emission (ppm)				
		B0	B20	B20+ 50ppm Al_2O_3	B20+ 50ppm CeO_2	B20+ 50ppm Al_2O_3+ 50ppm CeO_2
1	1154	16	15	14	14	14
2	1250	15	14	12	13	13
3	1500	14	13	12	12	12
4	2000	14	13	12	12	12
5	2400	15	14	13	13	14
6	3000	17	16	14	14	15
7	3600	18	17	15	15	16
8	3840	19	18	16	17	15

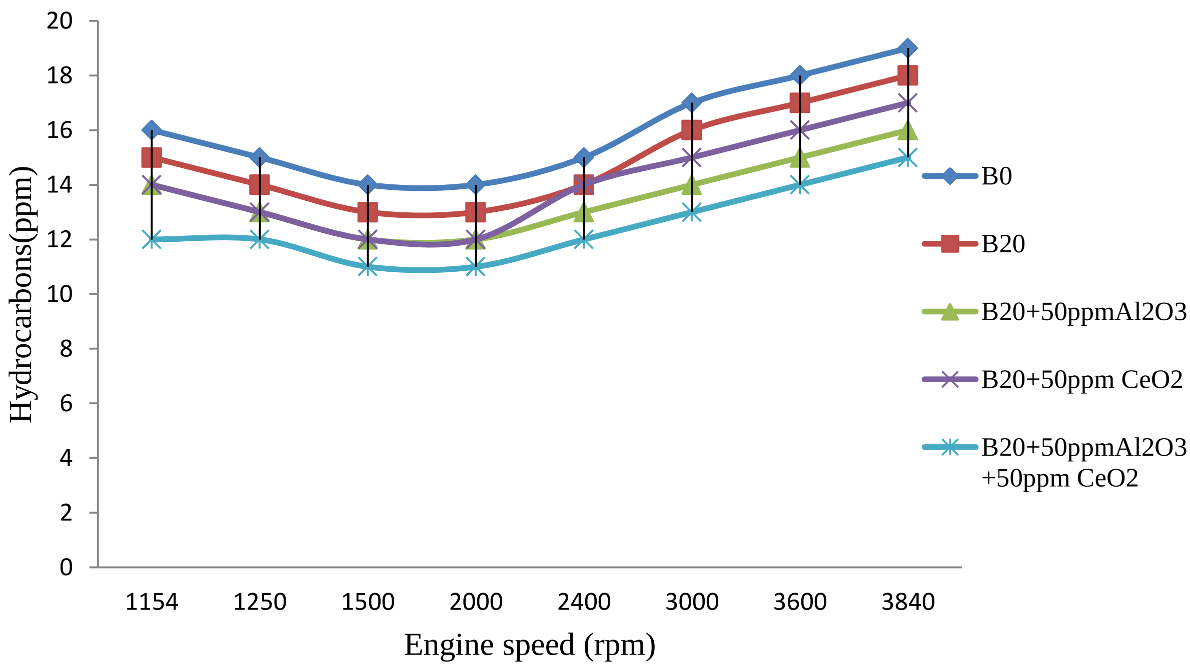


Figure 4.6 Variation of hydrocarbons emission with respect to engine speed

The addition of aluminum oxide and cerium oxide nanoparticles on diesel-biodiesel blend (B20) reduces the HC emission when compared to petro diesel and B20 fuels. The addition of aluminum oxide and cerium oxide nanoparticles promote the complete combustion and can help assist in the decomposition of unburnt hydrocarbons thus reducing the HC emission [62]. Therefore a significant reduction in the values of HC emission was observed for nanoparticles dispersed test fuels. From all test fuels the lower value of HC emission was observed for B20+50ppm Al_2O_3+50ppm CeO_2 test fuel.

4.4.4 Oxygen (O_2 %) Emission

The O_2 emission of various fuels from the diesel engine is shown in Figure 4.7. At 1554 rpm the O_2 concentration recorded was 16.51%, 17.63%, 17.74%, 17.83% and 17.97 for petro diesel (B0), B20, B20+50ppm $Al_2O_3$50, B20+50ppm CeO_2 and B20 + 50ppm Al_2O_3+ 50ppm CeO_2 respectively.B20, B20 + 50ppm Al_2O_3 B20 + 50ppm CeO_2 and B20 + 50ppm Al_2O_3+ 50ppm CeO_2 showed higher O_2 concentrations because the biodiesel and nanoparticle blended fuels contain higher amounts of O_2 than pure petro diesel.

Table4.9 Oxygen (O_2 %) emission at various engine speeds

No	Engine speed (rpm)	Oxygen (O_2%) emission				
		B0	B20	B20+ 50ppm Al_2O_3	B20+ 50ppm CeO_2	B20+ 50ppm Al_2O_3+ 50ppm CeO_2
1	1154	16.51	17.63	17.74	17.83	17.97
2	1250	15.53	16.34	16.75	16.97	17.56
3	1500	14.65	15.59	14.42	16.63	17.28
4	2000	14.42	15.25	15.65	15.72	16.77
5	2400	13.52	14.23	15.34	15.58	16.43
6	3000	12.13	13.68	14.82	14.93	15.69
7	3600	11.24	13.26	13.73	13.66	14.12
8	3840	10.4	12.35	12.72	12.93	13.57

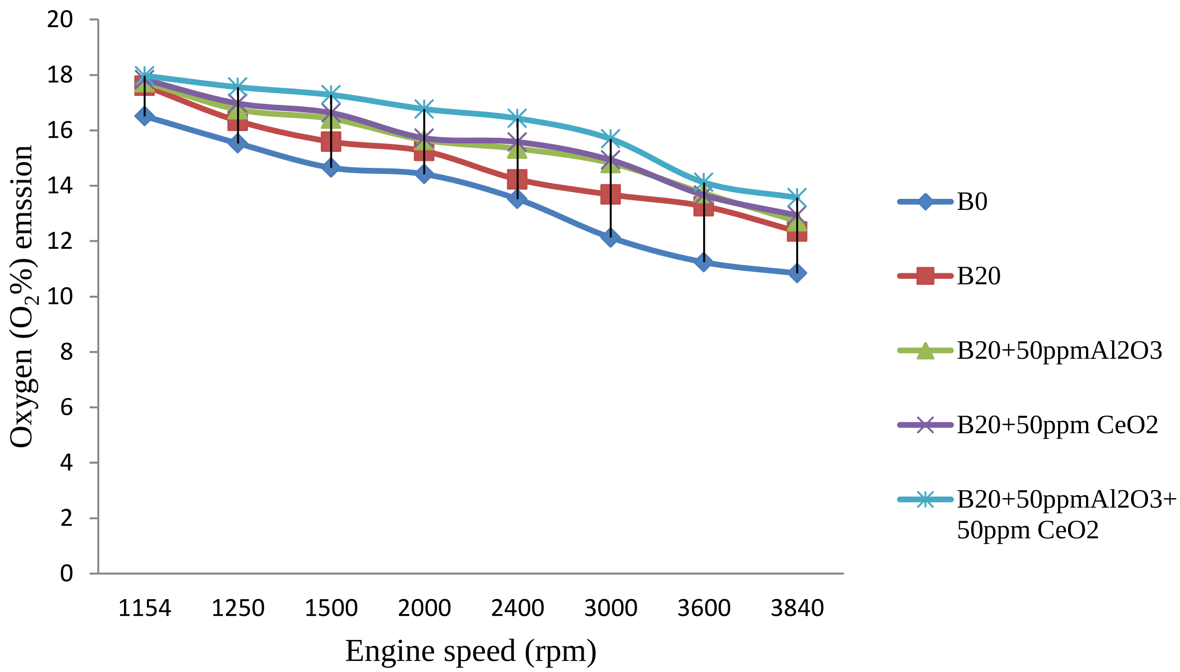


Figure4.7 Variation of oxygen (O_2 %) emission with engine speed

The emission analyses of the CI engine running with biodiesel blended fuel has significantly higher in O_2 emission under working engine operation conditions. This emission increment is most likely a result of the oxygen content in biodiesel and the low carbon hydrogen ratio. Furthermore the addition of aluminum oxide and cerium oxide nanoparticles on diesel blends increases the oxygen (O_2) emission when compared with neat diesel. This is due to the increase amount of oxygen in the combustion process by donating oxygen atom from there structure. The usage of nanoparticles (oxygenated additives) also promotes the complete combustion [62].

CHAPTER FIVE

CONCLUSION AND RCOMMENDATION

5.1 CONCLUSION

In this study the experimental investigation was performed to evaluate the performance and emission of CI engine on diesel and cotton seed oil biodiesel with aluminum oxide and cerium oxide nanoparticles. The biodiesels of cotton seed oils was prepared by transesterification process and blended with diesel and also with aluminum oxide and cerium oxide nanoparticles. Properties of these blends were tested. Performance and emission characteristics of single cylinder four stroke CI engine was tested using diesel (B0), B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2 as fuel. Based on the experiments performance analysis shows that brake power of the engine when fuelled with diesel- cotton seed oil biodiesel (B20) blend lower (2.89kW) than that of petro diesel (B0) 3.02kW fuel. But because of higher combustion energy of the aluminum oxide and cerium oxide nano particles; nanoparticle blended (B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2) fuels have higher brake power than that of B0 and B20 fuels which were 3.21kW, 3.35kW and 3.56kW respectively. Similarly it was concluded from the experiment an improved engine brake torque was realized for nanoparticles added fuels compared with B0 and B20. The engine brake torque for B0, B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2 were 8.5Nm, 8.1Nm, 8.2Nm, 8.4Nm and 8.6Nm respectively. Furthermore the BSFC of B20 has higher than all the test fuels this is due to the lower calorific value of cotton seed oil biodiesel but B20+50ppmAl_2O_3+50ppmCeO_2 has the lowest BSFC. From all test fuels B20+50ppmAl_2O_3+50ppmCeO_2 has a better performance results. This is due to the combined effect of aluminum oxide and cerium oxide nano particles on the combustion property of the fuel.

Emission results showed that for B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2, the emissions of carbon monoxide reduces by 6.7%, 11.2%, 9.7% and 23.2% and emissions of carbon dioxide reduces by 4.6%, 8.1%, 8.8% and 14.8% as compared with petro diesel (B0) fuel. Additionally HC emissions from all cotton seed biodiesel blended (B20, B20+50ppm Al_2O_3, B20 + 50ppm CeO_2, B20 + 50ppm Al_2O_3 + 50ppm CeO_2) fuels are lower than that of the diesel (B0) fuel. Moreover the oxygen concentrations of all cotton seed blended fuels were higher than that of diesel fuel.

Altogether, the performance and emission characteristics of a DI diesel engine are improved by incorporation of alumina and cerium oxide nanoparticles as additive in biodiesel-diesel blend without any engine modification.

5.2 Recommendations

Based on the above conclusions, the following recommendations have been made:

- B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2 blends can be recommended as fuel for diesel engine because of their performance and emission characteristic were found to be significantly better than pure diesel characteristics.
- The engine brake torque of B20+50ppm Al2O3+50ppm CeO2 was found to be very close to pure diesel characteristics.
- Among the all fuel blends B20+50ppm Al_2O_3+50ppm CeO_2 has better performance and emission characteristics, therefore, it can be strongly recommended.

5.3 FUTURE WORK

Based on the present work the future investigations will be made on the following aspects:

- The present research conducted on a single cylinder DI diesel engine can be investigated for multi cylinder engine.
- In the future research can be test other fuel properties like flash point, calorific value, cloud point, total acidity, et.c.
- Concentration of nano particles in the fuel blends can be varied at different ppm in order to extensively study its effects.
- The research could be extended to investigate performance and emission characteristics of diesel engine using different nanoparticles.
- Experiments can be conducted for NO_x emission reduction techniques
- Performance and emission characteristics of engine testing can be extended to various proportions of biodiesel blending.

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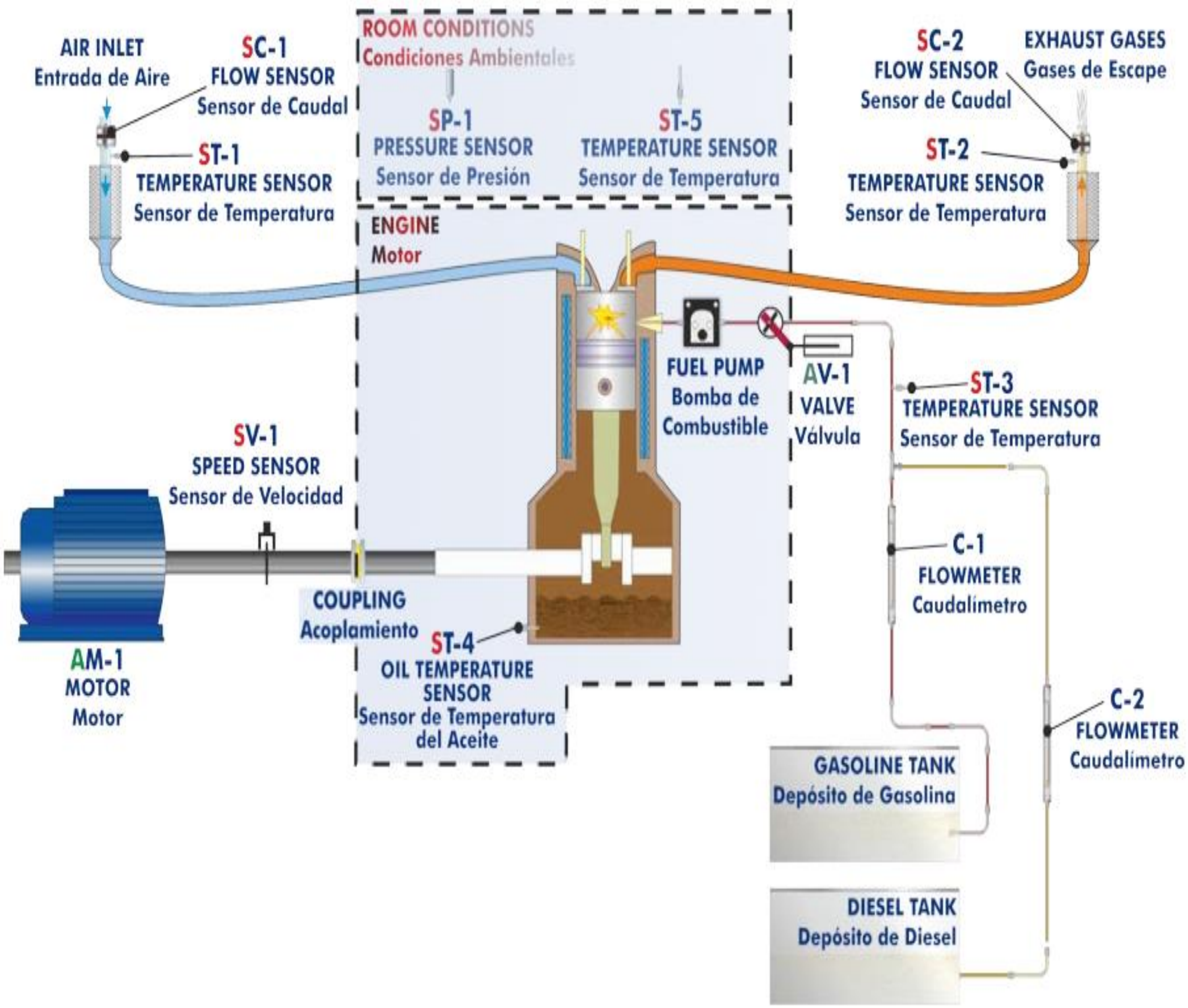
APPENDICES

APPENDIX-A

Process diagram and unit elements allocation of TBM3-02computer controlled test bench for single-cylinder diesel engine.



APPENDIX-B

Table B.1 Specification of nanoparticles

Item	Specification	
Manufacturer	NRL , USA	NRL, USA
Chemical Name	Alumina (Al_2O_3)	Cerium Oxide (CeO_2)
Purity	99.9%	Purity 99.9%
Average particle size	30-50 nm	20-30nm
Specific surface area (SSA)	130-140 m^2/g	40-45 m^2/g
Color	White	light yellow
Density	3.97 g/cm^3	6.5 g/cm^3

Table B.2 Specification of TBMC3-02 computer controlled single cylinder diesel engine test bench

Engine Manufacture	Edibon
Type of engine	Compression ignition
Fuel	Diesel
Number of cylinders	One
Number of strokes	Four
Type of air intake	naturally aspirated
Type of cooling	Air
Start	Computer controlled / manual
Compression ratio	21:1
Maximum power	4.2HP/3.13kw @3600 rpm
Cylinder bore	69mm
Stroke	60mm

Table B.3 Fuel properties

No	Property	Test method	ASTM D6751 limits	Test Results				
				B100	B20	B20+ 50ppm Al_2O_3	B20+ 50ppm CeO_2	B20+50ppm Al_2O_3+ 50ppmCeO_2
1	density@20 ^oC (g/ml)	D4052	0.820 – 0.890	0.8523	0.8435	0.8442	0.8445	0.8447
2	Kinematic viscosity @40^oC (cst)	D562	1.9-6 mm^2/s	4.564	4.428	4.216	3.890	4.009

APPENDIX-C

Basic equations for engine performance analysis

1. Engine brake power (kW):

$$P_b = W_L x 2\pi N \ (kW \tag{1}$$

Where, P_b = Brake power in kW

W_L = Load applied in kg

N = Engine speed in RPM

2. Engine brake torque (N.m)

$$T_b = \frac{60P_b}{2\pi N} \ (N.m) \tag{2}$$

Where;

T_b is engine brake torque in N.m

P_b= engine brake power in kW

N is engine speed in rpm

3. Mass flow rate (g/s)

$$m_f = v_f \text{ x } \rho_f \ g/sec \tag{3}$$

Where,

v_f is the volume flow rate of the fuel in ml/min

ρ_f is density of fuel in g/mil

4. Brake specific fuel consumption (kg/kW.hr)

$$BSFC = \frac{m_f * 3600}{P_b} kg/kW.hr \tag{4}$$

Where, m_f is mass of fuel consumed in kg/sec, BP is brake power in kW

APPENDIX-D

አዲስ ሞጆ የምግብ ዘይት ኮምፕሌክስ አ.ማ.

ADDIS MODJO EDIBLE OIL COMPLEX S.C.

ISOQAR

ቁጥር Ref No. ZR/1614/2011

ቀን Date 05/10/2011

ለአዳማ ሣይንስና ቴክኖሎጂ ዩኒቨርስቲ

<u>አዳማ</u>

ጉዳዩ፡ <u>የጥጥፍሬ ዘይት ሽያጭን በተመለከተ</u>

በቁጥር 7/2-4/7m80/10929/11 ግንቦት 29 ቀን 2011 ዓ.ም በተጻፈ ደብዳቤ አቶ ደበሳ ደሴ በዩኒቨርስቲው ተማሪ መሆኑን እና የምርምር ጽሁፉን በመስራት ላይ እንደሆነ በመግለጽ የጥጥፍሬ ዘይት በሽያጭ ትብብር እንድናደርግለት ጠይቃችሁናል፡፡

ስለሆነም በጠየቃችሁት መሠረት የድርጅታችን ምርት የሆነውን 10 (አሥር) ሊትር የጥጥፍሬ ዘይት በሽያጭ የሰጠናቸው መሆኑን እናስታውቃለን፡፡

አዲስ ሞጆ የምግብ ዘይት ኮምፕሌክስ አ.ማ
Addis Modjo Edible Oil Complex S Co

ከሠላምታ ጋር

ጥላሁን ነጋሽ

የሽያጭ መምሪያ ዳይሬክተር

ዋና ዋና ምርቶቻችን
Main Products

1. የተጣራ የምግብ ዘይት
   Refined Edible oil
2. ማርጋሪን
   Margarine
3. የአትክልት ቅቤ
   Vegetable Ghee
4. የከብት መኖ
   Extracted Meal
5. ከብት ማድለብ
   Cattle fating
6. ፋቲ አሲድ
   Fatty-Acid

ማዞሪያ 442 04 33 PBX 442 04 81 | ሽያጭ ዘርፍ 0114 43 16 90 Sales 0967 52 82 30 | ዋና ሥራ አስኪያጅ ጽ/ቤት G/Manager 442 12 73 | E-mail Addis mod@ethionet.et | ፋክስ Fax 442 12 74 | 1175 | አዲስ አበባ Addis Ababa

APPENDIX-E

አዳማሣይንስናቴክኖሎጂዩኒቨርሲቲ

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Adama Eihopia አዳማኢትዮጵያ

ቀን:16/12/2011

ለ:መካኒካል ት/ት ክፍል

አ.ሳ.ቴ.ዩ

ቁጥር; አ.ኬ.ዲ./713/2011

አፕላይድ ኬሚስትሪ ት/ት ክፍል ኃላፊ
ፈድሉከድር (ዶ.ር)

ጉዳዩ:-<u>መረጃ መስጠትን ይመለከታል</u>

በአዳማ ሳይንስና ቴክኖሎጂ ዩኒቨርስቲ በመካኒካል ፣ ኬሚካል ት/ት ክፍል እና በመካኒካል ስስተም ቬህከል ኢንጂነሪንግ ዲፓርትመንት ተማሪ የሆኑት አቶ ደባስ ደሴ የ2ኛ ዲግሪ የሁለተኛ አመት የአውቶሞቲቨ ኢንጅነሪንግ ተማሪ ሲሆን በኬሚስተሪ ት/ክፍል ለ3 ሳምንት በ Old Lab የ መመረ ቂ ያ ምር ምራ ቸ ውን መስ ራ ታ ቸ ውን እ ን ግ ል ፃ ለ ን ፡ ፡

ከሠላምታጋር

ዶ/ር ፈድሉ ከድር ሳቢር
Fedlu Kedir Sabir (PhD)

የአፕላይድ ኬሚስትሪ ትምህርት
ክፍል ኃላፊ
Applied Chemistry
Department Head

አፕላይድ ኬሚስትሪ ትምህርት ክፍል
Applied Chemistry
Department
School of Applied Natural Science

APPENDIX-F

አዲስ አበባ ሳይንስና ቴክኖሎጂ ዩኒቨርሲቲ
የኤሌክትሪካል እና ሜካኒካል ምህንድስና ኮሌጅ
የሜካኒካል ምህንድስና ት/ት ክፍል

Addis Ababa Science and Technology University
College of Electrical and Mechanical Engineering
Department of Mechanical Engineering

Date: 28/12/2011

ለአ.ሳ.ቴ.ዩ
ለመካኒካል ሲስተምስና ቬህክል ኢንጂነሪንግ ዲፓርትመንት፣
አዳማ

ጉዳዩ፡<u>የባዮዲዝልሳብሙከራመስራቱንይመለከታል</u>፡-

ከ[illegible]ከረውበተፃፈልንየትብብርደብዳቤመሰረትበመካኒካል፣ኬሚካልና ማቴሪያልስ ኢንጂነሪንግ ት/ት ክፍል፣ በመካኒካል ሲስተምስና ቬህክል ኢንጂነሪንግ ዲፓርትመንት፣ የአውቶሞቲቭ ኢንጂነሪንግ የሁለተኛ ድግሪተማሪ የሆነው ተማሪ ደባስ ደሴ ታሪኩ በመካኒካል ዲፓርትመንት የባዮዲዝል ሙከራ (test) በ TBMC3-02 computer controlled diesel engine test bench ላይመስራቱንእናሳውቃለን።

ኤሊያስ ገብረሚካኤል ሀብቱ
የሜካኒካል ምህንድስና
ት/ክፍል ሃላፊ

አዲስ አበባ ሳይንስና ቴክኖሎጂ ዩኒቨርሲቲ
የኤሌክትሪካል እና ሜካኒካል ምህንድስና ኮሌጅ
College of Electrical & Mechanical Engineering
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