ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Performance Evaluation of Biodiesel Produced from Avocado Seed in Diesel Engine

A thesis submitted in partial fulfillment of

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in

Automotive Engineering

By

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ADAMA

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this thesis entitled **"Performance evaluation of biodiesel produced from avocado seed in diesel engine"** in partial fulfillment of the requirements for the award of the degree of master of science in Automotive engineering is an authentic record of my own work carried out from October 2014 to October 2015 under the supervision of N.Ramesh Babu (Associate Professor) and Deresse Firew (Lecturer).

The matter embodied in this thesis has not been submitted by others for the award of any other degree or diploma. All relevant resources of information used in this thesis have been acknowledged.

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candidate	Signature	Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

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Performance evaluation of biodiesel produced from avocado seed in diesel engine

By

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Examiner (external)	Signature	Date

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ACRONYMS, SYMBOLS AND ABBREVIATION

A/F	Air Fuel ratio
AN	Acid Number
A_n	Injector orifice area
ASTM	American Standard of Testing Materials
AV	Acid Value
BPR	Boiling Point Range
BSFC	Brake Specific Fuel Consumption
Cc	Correction added to observed temperature
C_D	Discharge coefficient
CFPP	Cold Filter Plugging Point
CI	Cetane Index
CN	Cetane number
CO	Carbon monoxide
CO_2	Carbon dioxide
CP	Cloud Point
CSTR	Continuous Stirred Tank Reactor
Cv	Calorific value
EORC	Essential Oil Research Center
EPE	Ethiopian Petroleum Enterprise
F	Observed flash point
FA	Fatty Acid
FAME	Fatty Acid Methyl Ester
FBP	Final Boiling Point
Fc	Correction factor
FFA	Free Fatty Acid
FP	Flash Point
HC	Hydrocarbon

HHV	Higher Heating Value
IC	Internal Combustion Engine
IV	Iodine Value
KOH	Potassium Hydroxide
kPa	Kilopascal
kW	Kilowatt
kW/h	Kilowatt per hour
LHV	Lower Heating Value
ME	Methyl Ester
mg	milligram
ml	milliliter
mmHg	millimeter of mercury
NaOH	Sodium hydroxide
Nm	Newton meter
O_2	Oxygen
P_b	Brake power
Ppm	Parts per million
RPM	Revolution per minute
S.G	Specific Gravity
SV	Saponification Value
T_b	Brake torque
T_c	Observed temperature reading
ρa	Density of air

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ABSTRACT

Biodiesel is produced through a chemical process called transesterification, which refers to a catalyzed chemical reaction involving vegetable oil and alcohol to yield fatty acid alkyl esters (biodiesel) and glycerol as a byproduct. Biodiesel is petroleum substitution in which its quantity continually decreases due to increasing of demand. Plenty of plants could be used as raw material for biodiesel, for example is avocado (Persea gratissima) seed. The study was carried out to produce biodiesel through transesterification of waste avocado seed. The method involves solvent assisted alkali-catalyzed transesterification. Avocado seed (persea gratissima) is a waste that so many people throw them away after using the fruit flesh. This thesis focuses on the performance characteristics of diesel engine vehicle using biodiesel fuel mixture of avocado seed oil with diesel fuel. In this work, crude oil from waste avocado seed is obtained using chemical extraction method and the biodiesel is produced using a process called transesterfication. Performance analysis is done on chassis dynamometer on four stroke, four cylinder diesel engine vehicle. Brake power, brake torque and brake specific fuel consumption of biodiesel blends shows similar pattern with slight reduction of brake power and torque as the blend ratio increased as compared to that of diesel fuel on performance test result. Four selected important properties of the biodiesel were measured and all this properties are in the limits of the test standard for all blends of the biodiesel tested. The blends of the avocado seed biodiesel in this work uses a mixture of avocado seed oil biodiesel and diesel fuel with volumetric compositions of avocado seed oil biodiesel : diesel fuel were 10%: 90% (B10), and 20%: 80% (B20).

Keywords: Avocado seed oil biodiesel, brake power, brake torque, brake specific fuel consumption and transesterification.

1. INTRODUCTION

1.1. Background of the study

For more than two centuries, the world's energy supply has relied heavily on non-renewable crude oil derived liquid fuels.

The use of vegetable oils as a replacement as a diesel fuel in diesel engines is not a new concept. The idea was emerged during the innovation of diesel engine, by Mr. Rudolf Diesel. In 1900 Mr. Rudolf diesel tested vegetable oil as fuel for engine and in 1911 he stated "the diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it", (Shay, 1993). Despite the widespread use of fossil petroleum derived diesel fuels, interest in vegetable oils as fuels for internal combustion engines was reported in several countries during the 1920s and 1930s and later during World War II. Belgium, France, Italy, the United Kingdom, Portugal, Germany, Brazil, Argentina, Japan and China were reported to have tested and used vegetable oils as diesel fuels during this time. Some operational problems were reported due to the high viscosity of vegetable oils compared to petroleum diesel fuel, which results in poor atomization of the fuel in the fuel spray and often leads to deposits and coking of the injectors, combustion chamber and valves. Attempts which have done to overcome these problems are heating of the vegetable oil, blending it with petroleum-derived diesel fuel or ethanol, pyrolysis, cracking of the oils and transesterification.

It has been identified that the main cause of environmental pollution and its associated global warming is the exhaust emission from burning of petroleum products. Biodiesel is one of the alternative fuels that are environmentally friendly because biodiesel can reduce emissions of carbon monoxide (CO) of about 50%, carbon dioxide (CO_2) of about 78.45% and sulfur free. On the other hand it has been identified that the main cause of environmental pollution and its associated global warming is the exhaust emission from burning of petroleum products.

Nowadays, with the recent high and volatile prices of oil, different countries are being forced to develop innovative policies to mitigate the impact of these high prices on their economies. The

most effective policy in this respect is the diversification of energy supply sources in the transport sector, Biodiesel appear to offer the best opportunities. Now a days Ethiopia imports its entire petroleum fuel requirement and the demand for petroleum fuel is rising rapidly due to a growing economy and expanding infrastructure from year to year.

A clean alternative fuel is highly demanded, to cope up with increasing demand of global energy and to decrease environmental pollution. Because most alternative fuels are cleaner burning fuels and also is not a single source industry like the modern oil industry. One type of resource that can potentially be used for energy generation and transportation is oil derived biodiesel.

1.1.1. What is biodiesel

In the world, the diesel engine dominates the field of commercial transportation and agricultural machinery on account of its superior fuel efficiency.

According to the US Standard Specification for Biodiesel (ASTM 6751), Biodiesel is defined as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. In this context, it can be used in diesel engines and heating systems [20, 33].
Due to shortage of diesel fuel and its increasing cost, an alternate source of fuel for diesel is very much needed. It has been found that vegetable oil hold special promise in this regard [36]. Usage of Biodiesel will allow a balance to be sought between agriculture economic development and the environment [22]. The vegetable oils and their derivatives are suited as diesel fuel by their cetane number (CN), which generally are in the range suitable for or close to that of diesel fuel.
The heat contents of various vegetable oils are also nearly 90% that of diesel fuel.
The suitability of fats and oils as diesel fuel results from their molecular structure and high energy content. Unlike to petro diesel, Biodiesel is biodegradable and non-toxic and it significantly reduces toxic and other emissions when burned as a fuel [1].
Biodiesel is an ecologically friendly fuel because it has a lower emission profile than petrol-diesel and decreases the greenhouse gas emissions from combustion ignition engines [37]. In addition, bio-diesel is safer to handle (flash point above $110^{o}C$), contains little or no sulfur or carcinogenic poly aromatic components, and decreases soot emission considerably, which is

very advantageous in environmentally sensitive areas [18]. Furthermore, bio-diesel is a suitable outlet for the vegetable oil industry requiring little or no changes in current diesel engines when used in blends and increases engine life due to its superior lubricity over Petro-diesel [16, 29].

Chemically the oils/fats consist of triglyceride molecules of three long chain fatty acids that are ester bonded to a single glycerol molecule. These fatty acids (FA) differ by the length of carbon chains, the number, orientation and position of double bonds in these chains. Because different fatty acids have different physical and chemical properties, the fatty acid profile is probably the most important parameter influencing the corresponding properties of a vegetable oil or animal fat. Thus, bio-diesel refers to lower alkyl esters of long chain fatty acids, which are synthesized either by transeterification with lower alcohols or by esterification of fatty acids.

1.2.Statement of the problem

Today the price for using fossil fuels is increasing and also the environmental pollution due to burning of these fossil fuels is a major concern. In Ethiopia, importing of fuels for transportation and other industrial applications affects the economic, social and political stability in the country. Therefore it is important and a major issue to find other alternatives to mitigate the effect of importing this fuels. To meet these needs in the short to medium term future, search and find ways of using fuels that are preferably renewable and clean burning.

People's living in rural areas are highly dependent on energy sources from biomass resources (plants, animals…) which leads to deforestation and increase in environmental pollution.

Therefore, this research helps for the development of clean, new renewable energy and locally available, particularly bio-diesel extraction from avocado seed as an alternative energy solution to petroleum oil in response to the rise in oil price.

By producing oil from avocado seeds in large scale, Ethiopia may save its foreign expenditure, create job opportunities, establish local industrial base, increase its economic growth and participate in creating clean environment.

1.3.Objectives of the study

1.3.1. General objective

The general objective of this study is to evaluate the performance of biodiesel produced from avocado seed in diesel engine.

1.3.2. Specific objectives

The specific objectives of this study are:-

- To extract the oil from avocado seed.
- To produce biodiesel from avocado seed oil.
- To evaluate the performance of biodiesel blends in diesel engine at different engine speeds.
- To compare performance characteristics of biodiesel blends with diesel fuel.

1.4.Significant of the study

- Since avocado seeds are waste products that are thrown out after the flesh is taken, production of biodiesel from it helps in developing of waste management practices.
- This study will give a significant advantage in reducing the amount of money spending in importing of fuels by making different blends of biodiesel fuels.
- This study will have a great significance in reducing the amount of pollutant gases produced due to burning of fossil fuels so that providing environmental benefits.
- In general this study helps in further research to be conducted in producing of biodiesel from different sources.

1.5. Scope of the study

Because this thesis focuses on biodiesel production on small scale using the oil extracted from avocado seed, the performance characteristics is measured only for B10 and B20 blends at different engine speeds.

This work is based on the result of few parameters tested for short term only at different laboratories, which are not readily organized for this research and literature review on the area.

As a result, the outcome of this research shall not be considered as a comprehensive study on the biodiesel production and performance evaluation of crude avocado seed oil.

1.6. Limitations

The main objective of this thesis work is to evaluate the performance and emission analysis of avocado seed biodiesel on diesel engine, but because of the unavailability of engine dynamometer and exhaust analyzer, emission characteristics are not done and the performance characteristics (brake torque and power) are done on chassis dynamometer which will not give exact and more reliable result as compared to engine dynamometer.

After extraction of biodiesel using transisterfication process the properties (flash point, cetane number, acid value…) should be known this is because the biodiesel is to be used as a replacement of diesel fuel in CI engine, so to avoid possible drawbacks (poor fuel atomization, incomplete combustion, carbon deposition on the injector etc.) on the engine it's properties should be studied and must be on the limit's which is stated on ASTM standard for biodiesel fuels. But on this thesis work only four selected properties (flash point, density, viscosity and cloud point) are studied because of limited budget.

2. LITERATURE REVIEW

2.1. Vegetable oils and its blends

"Biodiesel is pure or 100%, Biodiesel fuel. It is referred to as B100 or "neat" fuel. A Biodiesel blend is pure Biodiesel blended with petro diesel. Biodiesel blends are referred to as Bxx. The xx indicates the amount of biodiesel in the blend, that is a B80 blend is 80% biodiesel and 20% petrodiesel by volume"[1].

Several vegetable oils have been tested as fuel components for diesel engines. Unlike diesel fuel, vegetable oils consist mostly of saturated hydrocarbons and these vegetable oils are triglycerides consisting of glycerol esters of fatty acids.

Vegetable oils have a different chemical structure. Up to 3 fatty acids are linked to a glycerin molecule with ester linkages. The fatty acids vary in their carbon chain length and in numbers of double bonds. Some fuel properties, e.g., oxidation resistance, are markedly affected by the fatty acid composition of vegetable oils. The large size of vegetable oil molecules (typically three or more times larger than hydrocarbon fuel molecules) and the presence of oxygen in the molecules suggest that some fuel properties of vegetable oils would differ markedly from those of hydrocarbon fuels. Because of the molecular weights, vegetable oils have low volatility. Because different fatty acids have different physical and chemical properties, the fatty acid profile is probably the most important parameter influencing the corresponding properties of a vegetable oil or animal fat. Thus, Biodiesel refers to lower alkyl esters of long chain fatty acids, which are synthesized either by transesterification with lower alcohols or by esterification of fatty acids [38]. Because of their instauration vegetable oils are inherently more reactive than are diesel fuels. Consequently, the much more susceptible to oxidative and thermal polymerization reactions, which interfere with combustion. Because of the above reasons neat vegetable oils cannot be used directly as a fuel. Gerhard Knothe et al reported that engines fueled with vegetable oil-diesel blend causes engine problems similar to those found with neat vegetable oils as fuels.

A model on vegetable oil atomization showed that blends of diesel fuel with vegetable oil should contain from 0 to 34% vegetable oil if proper atomization was to be achieved.

Dilution of sunflower oil with diesel fuel provides a fuel with a viscosity of 4.88 mm^2/s at 40°C. Although greater than the maximum ASTM specification of 4.0 mm^2/s, the viscosity is markedly less than that of neat sunflower oil.

However, the blend could not be recommended for long-term use in the direct-injection diesel engine because of severe injector nozzle clogging and sticking.

2.2. Transesterification

It is the process of using an alcohol (e.g., methanol or ethanol) in the presence of a catalyst, such as sodium hydroxide (NaOH) or sodium methoxide (NaOMe), to chemically break the molecule of the raw vegetable oil into methyl or ethyl esters of the vegetable oil with glycerol as a by-product, which reduces the high viscosity of oils.

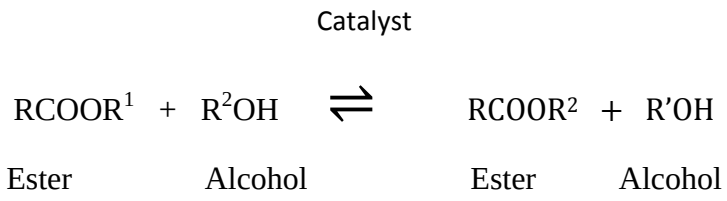
This method for reducing viscosity is the conversion of the triglyceride oils to simple esters, which, in effect, reduces the molecular weight of the original oil to 1/3 of its former value, reduces the viscosity by a factor of 8 and increases the volatility and cetane number to levels comparable to diesel fuel [38].

Initially, it was believed that vegetable oils could be used directly with minimal processing and preparation. However, extensive engine testing proved that while diesel engines operated satisfactorily on raw vegetable oils, combustion residues and deposits would quickly cause problems with fuel injectors, piston rings and oil stability. Blending of vegetable oil esters with diesel fuel would solve these problems. The most common blend is a mix of 20% biodiesel with 80% petroleum diesel, Blending in this way tends to reduce the emissions and smoke levels, though power output will still tend to be lower and separation of the blended constituents could occur in cold weather.

2.2.1. Transesterification process to produce biodiesel.

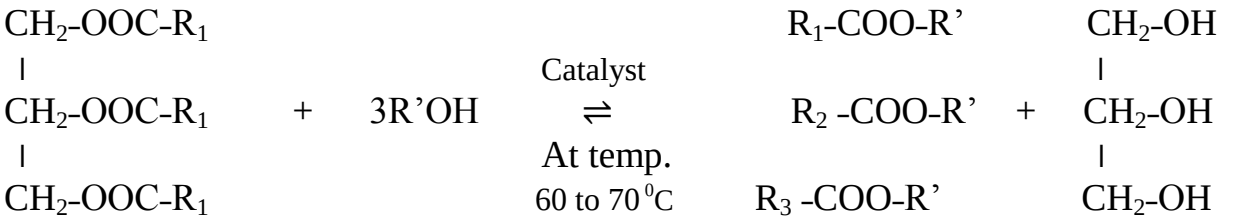
Transesterification is defined as a chemical process used to produce a fatty acid methyl ester or ethyl ester and glycerol a byproduct from the reaction of vegetable oils or animal fats with short chain alcohol in the presence of catalyst. Fatty acid methyl esters are conventionally produced by the transesterification of vegetable oils and fats using methanol in the presence of a suitable catalyst. Essentially, transesterification is the chemical reaction between triglycerides and

alcohol in the presence of a catalyst to produce monoesters. Both the straight and branched chain triglyceride molecules are transformed in this process to monoesters and glycerol.
The transesterification process can be done in a number of ways such as using an alkali catalyst, acid catalyst, biocatalyst or heterogeneous catalyst [2, 9]. The general reaction is shown as below



Transesterification of a vegetable oil was conducted as early as 1853 by scientists E. Duffy and J. Patrick, many years before the first diesel engine became functional. Rudolf Diesel's prime model, a single 10 ft (3 m) iron cylinder with a flywheel at its base, ran on its own power for the first time in Augsburg, Germany, on August 10, 1893 running on nothing but peanut oil. In remembrance of this event, August 10 has been declared "International Biodiesel Day"(From Wikipedia, the free encyclopedia)

The transesterification process actually consists of a sequence of three consecutive reversible reactions. That is, conversion of triglycerides to diglycerides, then the conversion of the diglycerides to monoglycerides. The monoglycerides are finally converted into monoesters and glycerol. Each step yields one molecule of the ester and its reaction is reversible. Alcohols are primary and secondary monohydric aliphatic alcohols having 1-8 carbon atoms. The overall reaction can be represented by the following scheme.



Triglyceride + Alcohol ⇌ Ester + Glycerol

Figure 1 Schematic representation of transesterfication process.

The efficiency and effectiveness of transesterification, and hence the quality of esters produced are highly dependent on the effects of moisture and free fatty acid content in the oil, alcohol to oil molar ratio, amount and type of catalyst, reaction time, reaction temperature, and the procedure followed [3]. It can be seen that for each molecule of triglyceride, three molecules of alcohol are required stochiometrically. In practice, a higher molar ratio is used in order to get higher ester production from this reversible reaction. Transesterification reactions can be catalyzed by both homogeneous and heterogeneous catalysts. The homogeneous catalysts include alkalis and acids. The most commonly used alkaline catalysts are the hydroxides and methoxides of sodium and potassium. Sulfuric acid, hydrochloric acid and Para-toluene sulfonic acid are the preferred acid catalysts [19].

Ramadhas et al., (2005) studied the production of biodiesel from high FFA rubber-seed oil by a two-step esterification (acid-alkaline catalysis) process. Their objective was primarily to reduce the free fatty acid content in the first reaction to a level that did not interfere with the alkali catalyzed second reaction. They found that for the esterification process, with the molar ratio of methanol to oil at 6:1 and with 0.5 % v/v of sulfuric acid, the maximum conversion efficiency was achieved. In a subsequent transesterification reaction, the maximum ester yield could be achieved with 9:1 molar ratio of methanol to oil and 0.5% w/w of NaOH.

2.2.1.1.Transesterification using basic catalyst:

Generally, this reaction is catalyzed by a basic catalyst. In the alkali or basic process sodium hydroxide (NaOH) or potassium hydroxide (KOH) is used as a catalyst along with methanol or ethanol. Initially, during the process, alcoxy is formed by reaction of the catalyst with alcohol and the alcoxy is then reacted with any vegetable oil to form biodiesel and glycerol. Glycerol being denser settles at the bottom and biodiesel can be decanted. This process is the most efficient and least corrosive of all the processes and the reaction rate is reasonably high even at a low temperature of 60-80^{o}C.There may be risk of free acid or water contamination and soap formation is likely to take place which makes the separation process difficult [9, 26].

Most studies of the basic-catalyzed transesterification of vegetable oils involve the calculations of the triglyceride conversion rate, the changes in product composition during reaction or some of the quality parameters of biodiesel. All of these aspects are related to the biodiesel purity, which means the methyl ester concentration in the biodiesel phase. Even though the biodiesel yield after the post-treatment stage is another relevant aspect of the process, it is considered less in the literature. The biodiesel yield could decrease due to the previously mentioned undesirable side-reactions like triglyceride saponification and free fatty acid neutralization and also to dissolution of the methyl ester in the glycerol phase. For an alkali-catalyzed transesterification, the glycerides and alcohol must be substantially anhydrous. Because water makes the reaction partially change to saponification, which produces soap. The soap lowers the yield of esters and renders the separation of ester and glycerol and the water washing difficult. Low free fatty acid content in triglycerides is required for alkali-catalyzed transesterification.

2.2.1.2.Transesterification using acidic catalyst:

The second conventional way of producing biodiesel is using an acid catalyst instead of a base. Any mineral acid can be used to catalyze the process; the most commonly used acids are sulfuric acid and sulfonic acid. Although yield is high, the acids, being corrosive, may cause damage to the equipment and the reaction rate was also observed to be low and needs very high temperature and pressure. Freedman et al [21] investigated the transesterification of soybean oil with methanol using 1 wt % concentrated sulfuric acid (based on oil). They found that at 65^{o}C and a molar ratio of 30:1 methanol to oil, it took 69 h to obtain more than 90% oil conversion of

methyl esters [21, 72]. If more water and free fatty acids are in the triglycerides, acid catalyzed transesterification can be used [36].

2.2.1.3.Transesterification using biocatalyst:

It has been recently found that enzymes such as lipase can be used to catalyze transesterification process by immobilizing them in a suitable support. The advantage of immobilization is that the enzyme can be reused without separation. Also, the operating temperature of the process is low (50^{o}C) compared to other techniques. Disadvantages include inhibition effects which were observed when methanol was used and the fact that enzymes are expensive [38].

Because of the high energy cost of the conventional chemical process and additional purification step of glycerol, application of lipase in the biodiesel industry has become more attractive .In several studies transesterification of vegetable oils and animal fats with primary and secondary alcohols and straight- and branched-chain alcohols in solvent or solvent-free medium using lipases as catalysts has been reported [38]. Because of the toxicity and flammability of organic solvents, and product recovery without further organic solvent evaporation, lipase-catalyzed transesterification in a solvent-free medium is important in industrial applications [9].

Alcoholysis of tallow with primary and secondary alcohols in solvent was investigated using lipase from Candida Antarctica (SP435) by Nelson [38] who reported that the lipase of C. Antarctica was most efficient for transesterifing triglycerides with secondary alcohols. The branched alkyl esters and methanolysis of oils occurred in a mixture with hexane even though three molar equivalents of methanol were present Shemada[37] investigated methanolysis of vegetable oil (a mixture of soybeans and rapeseed oils) by enzymatic transesterification reaction. They reported that immobilized C. Antarctica lipase was most effective for the methanolysis among lipases tested. But it was inactivated in the mixture containing more than 1.5 molar equivalents of methanol in oil conducted the reaction by adding methanol stepwise to avoid lipase inactivation and converted 98.4% of the oil to its corresponding methyl esters (ME) at 30^{o}C after 48 h total reaction time.

2.2.1.4.Transesterification using heterogeneous catalyst:

Heterogeneous catalysts such as amorphous zirconia, titanium-, aluminum-, and potassium-doped zirconias have also become popular for catalyzing the transesterification of vegetable oils. It has been reported that the conversion to methyl ester reaches 87% with the potassium-loaded alumina catalyst, when a mixture with a molar ratio of methanol to oil of 15:1 is refluxed for a reaction time 7 h. Besides these, there have been several other reports on heterogeneous catalysts [34]. However, the catalytic activities of most of them are not much greater than that of a homogeneous catalyst such as KOH. Furthermore, there is little information regarding their catalytic durability. Research is still in progress in order to solve the problem encountered in this process such as exhaustion of catalyst and to achieve higher conversions [27].

Of all the methods mentioned above for production of biodiesel, only the alkali process is carried out in an industrial scale. It is cost effective and highly efficient. However, problems arise in the downstream operations including separation of catalyst and unreacted methanol from biodiesel. The removal of the catalyst involves many complications and biodiesel requires repeated washing for attaining the necessary purity. The production of biodiesel using a biocatalyst eliminates the disadvantages of the alkali process by producing product of very high purity with less or no downstream operations [26]. Haas [29] also patented this method of production of biodiesel using a biocatalyst. But the process has not yet been implemented in an industrial scale due to certain constraints like enzyme inhibition by methanol, exhaustion of enzyme activity and high cost of enzymes.

2.2.2. Factors affecting transesterification process

2.2.2.1.The mechanism of kinetics

Transesterification consists of a number of consecutive, reversible reactions [21]. The triglyceride is converted stepwise to diglyceride, monoglyceride and finally glycerol.

A mole of ester is liberated at each step. The reactions are reversible, although theequilibrium lies towards the production of fatty acid esters and glycerol [14].

The reaction mechanism for alkali-catalyzed transesterification was formulated as three steps [18]. The first step is an attack on the carbonyl carbon atom of the triglyceride molecule by the anion of the alcohol (methoxide ion) to form a tetrahedral intermediate. In the second step, the tetrahedral intermediate reacts with an alcohol (methanol) to regenerate the anion of the alcohol (methoxide ion). In the last step, rearrangement of the tetrahedral intermediate results in the formation of a fatty acid ester and a diglyceride. When NaOH, KOH, K_2CO_3 or other similar catalysts were mixed with alcohol, the actual catalyst, alkoxide group is formed. A small amount of water, generated in the reaction, may cause soap formation during transesterification.

2.2.2.2. The effects of moisture and free fatty acids

The effects of moisture (water) and free fatty acids Wright [8] noted that the starting materials used for alkali-catalyzed transesterification of glycerides must meet certain specifications. The glyceride should have an acid value less than 1 and all materials should be substantially anhydrous. If the acid value was greater than 1, more NaOH was required to neutralize the free fatty acids. Water also caused soap formation, which consumed the catalyst and reduced catalyst efficiency. The resulting soaps caused an increase in viscosity, formation of gels and made the separation of glycerol difficult and therefore, water content should be less than 0.3%. Bradshaw et al[12]and Feuge et al[20] also stressed the importance of oils being dry and free (<0.5%) of free fatty acids. Freedman et al [23] stated that ester yields were significantly reduced if the reactants did not meet these requirements. Sodium hydroxide or sodium methoxide reacted with moisture and carbon dioxide in the air, which diminished their effectiveness. The effects of free fatty acids and water on transesterification of beef tallow with methanol were investigated [38]. The results showed that the water content of beef tallow should be kept below 0.06% w/w and free fatty acid content of beef tallow should be kept below 0.5%, w/w in order to get the best conversion. Water content was a more critical variable in the transesterification process than were free fatty acids.

2.2.2.3. The effect of molar ratio

One of the most important variables affecting the yield of ester is the molar ratio of alcohol to triglyceride. The stoichiometric ratio for transesterification requires three moles of alcohol and one mole of glyceride to yield three moles of fatty acid ester and one mole of glycerol. The molar ratio is associated with the type of catalyst used. An acid catalyzed reaction needed a 30:1 ratio of BuOH to soybean oil, while an alkali-catalyzed reaction required only a 6:1 ratio to achieve the same ester yield for a given reaction time [21] Bradshaw et al stated[12] that the practical range of molar ratio was from 3.3 to 5.25:1 methanol to vegetable oil. The ratio of 4.8:1 was used in some examples, with a yield of 97-98%, depending upon the quality of the oils. If a three step transesterification process was used, the ratio was reduced to 3.3:1. Methanol present in amounts of above 1.75 equivalents tended to prevent the gravity separation of the glycerol, thus adding more cost to the process.

Higher molar ratios result in greater ester conversion in a shorter time. In the ethanolysis of peanut oil, a 6:1 molar ratio liberated significantly more glycerine than did a 3:1 molar ratio [20]. Rapeseed oil was methanolyzed using 1% NaOH or KOH. They found that the molar ratio of 6:1 of methanol to oil gave the best conversion. When a large amount of free fatty acids was present in the oil, a molar ratio as high as 15:1 was needed under acid catalysis.Freedman et al.,[21] studied the effect of molar ratio (from 1:1 to 6:1) on ester conversion with vegetable oils. Soybean, sunflower, peanut and cotton seed oils behaved similarly and achieved highest conversions (93-98%) at a 6:1 molar ratio. Tanaka et al [16]in his novel two-step transesterification of oils and fats such as tallow, coconut oil and palm oil, used 6:1-30:1 molar ratios with alkali catalysis to achieve a conversion of 99.5%.[7].A molar ratio of 6:1 was used for beef tallow transesterification with methanol [1]. Zhang [36] reported 80% by tallow weight of esters was recovered in the laboratory.

2.2.2.4.The effect of catalyst

Catalysts are classified as alkali, acid, or enzyme. Alkali-catalyzed transesterification is much faster than acid-catalyzed [21]. However if a glyceride has a higher free fatty acid content and more water, acid-catalyzed transesterification is suitable [21]. The acids could be sulfuric acid,

phosphoric acid, hydrochloric acid or organic sulfonic acid. Alkalis include sodium hydroxide, sodium methoxide, potassium hydroxide, potassium methoxide, sodium amide, sodium hydride, and potassium amide and potassium hydride [17]. Sodium methoxide was more effective than sodium hydroxide [21,30] Because of the hydroxide group is responsible for the formation of soaps by the side-reaction of saponification of the triglycerides and they contain only a minor amount of the hydroxide group as impurity and due to the assumption that a small amount of water was produced upon mixing NaOH and MeOH. Ma et al, observed the opposite result NaOH and NaOCH3 reached their maximum activities at 0.3 and 0.5% w/w of beef tallow, respectively. Sodium hydroxide was also chosen to catalyze the transesterification because it is cheaper. Ester conversions at the 6:1 ratio for 1% NaOH and 0.5% NaOCH3 were almost the same after 60 min [21]. Sodium hydroxide, however, is cheaper and used widely in large-scale processing. The transesterification of soybean oil with methanol, ethanol and butanol, using 1% concentrated sulfuric acid, was Unsatisfactory when

the molar ratios were 6:1 and 20:1 [21]. A 30:1 ratio resulted in a high conversion to methyl ester. More recently, an immobilized lipase was employed to catalyze the methanolysis of corn oil in flowing supercritical carbon dioxide with an ester conversion of >98% [33].

2.2.2.5.The effect of reaction time

The conversion rate increases with reaction time. Freedman et al[21] transesterified peanut, cottonseed, sunflower and soybean oils under the condition of methanol to oil ratio of 6:1, 0.5% sodium methoxide catalyst and 60°C. An approximate yield of 80% was observed after 1 min for soybean and sunflower oils. After 1 h, the conversions were almost the same for all four oils (93-98%). Ma et al standard the effect of reaction time on transesterification of beef tallow with methanol. The reaction was very slow during the first minute due to the mixing and dispersion of methanol into beef tallow. From one to five min, the reaction proceeded very fast. The apparent yield of beef tallow methyl esters surged from 1 to 38. The production of beef tallow slowed down and reached the maximum value at about 15 min. The di- and monoglycerides increased at the beginning and then decreased. At the end, the amount of monoglycerides was higher than that of diglycerides [4].

2.2.2.6.The effect of reaction temperature

Transesterification can occur at different temperatures, depending on the oil used. In methanolysis of castor oil to methyl ricinoleate, the reaction proceeded most satisfactorily at 20-35°C with a molar ratio of 6:1-12:1 and 0.005-0.35% (by weight of oil) of NaOH catalyst [33]. For the transesterification of refined soybean oil with methanol (6:1) using 1% NaOH, three different temperatures were used [21]. After 0.1 h, ester yields were 94, 87 and 64% for 60, 45 and 32°C, respectively. After 1 h, ester formation was identical for the 60 and 45°C runs and only slightly lower for the 32°C run. Temperature clearly influenced the reaction rate and yield of esters [9].

Batch Processing;-The simplest method for producing alcohol esters is to use a batch, stirred tank reactor. Alcohol to triglyceride ratios from 4:1 to 20:1 (mole: mole) have been reported, with a 6:1 ratio most common. The reactor may be sealed or equipped with a reflux condenser. The operating temperature is usually about 65°C, although temperatures from 25°C to 85°C have been reported. The most commonly used catalyst is sodium hydroxide, with potassium hydroxide also used. Typical catalyst loadings range from 0.3 % to about 1.5%. Thorough mixing is necessary at the beginning of the reaction to bring the oil, catalyst and alcohol into intimate contact. Towards the end of the reaction, less mixing can help increase the extent of reaction by allowing the inhibitory product, glycerol, to phase separate from the ester oil phase, Completions of 85% to 94 % are reported.

Antolin et al.; (2002) studied the effect of the amount of catalyst, the amount of alcohol, and temperature on the purity of ester obtained from the transesterification of sunflower oil in a batch stirred tank reactor. They found that when 3 times the stoichiometric amount of ethyl alcohol and 0.28% by weight of KOH were used with a reaction temperature of 60^0C, ester could be obtained at a purity of 96% w/w. D. Darnoko1; M. Cheryan (2000) studied the Kinetics of Palm Oil transesterification in a Batch Reactor. Methyl esters were produced by transesterification of palm oil with methanol in the presence of a catalyst (KOH). The rate of transesterification in a batch reactor increased with temperature up to 60^0C.

Continuous Process Systems: - figure 2 shows Continuous Heterogeneous Catalytic Process for Biodiesel Production. A popular variation of the continuous process is the use of continuous stirred tank reactor (CSTR) in series. The CSTR can be varied in volume to allow for a longer residence time in CSTR 1 to achieve a greater extent of reaction. After the initial product glycerol is decanted, the reaction in CSTR 2 is rather rapid, with 98% completion. An essential element in the design of a CSTR is sufficient mixing input to ensure that the composition throughout the reactor is essentially constant. This has the effect of increasing the dispersion of the glycerol product in the ester phase. The result is that the time required for phase separation is extended.

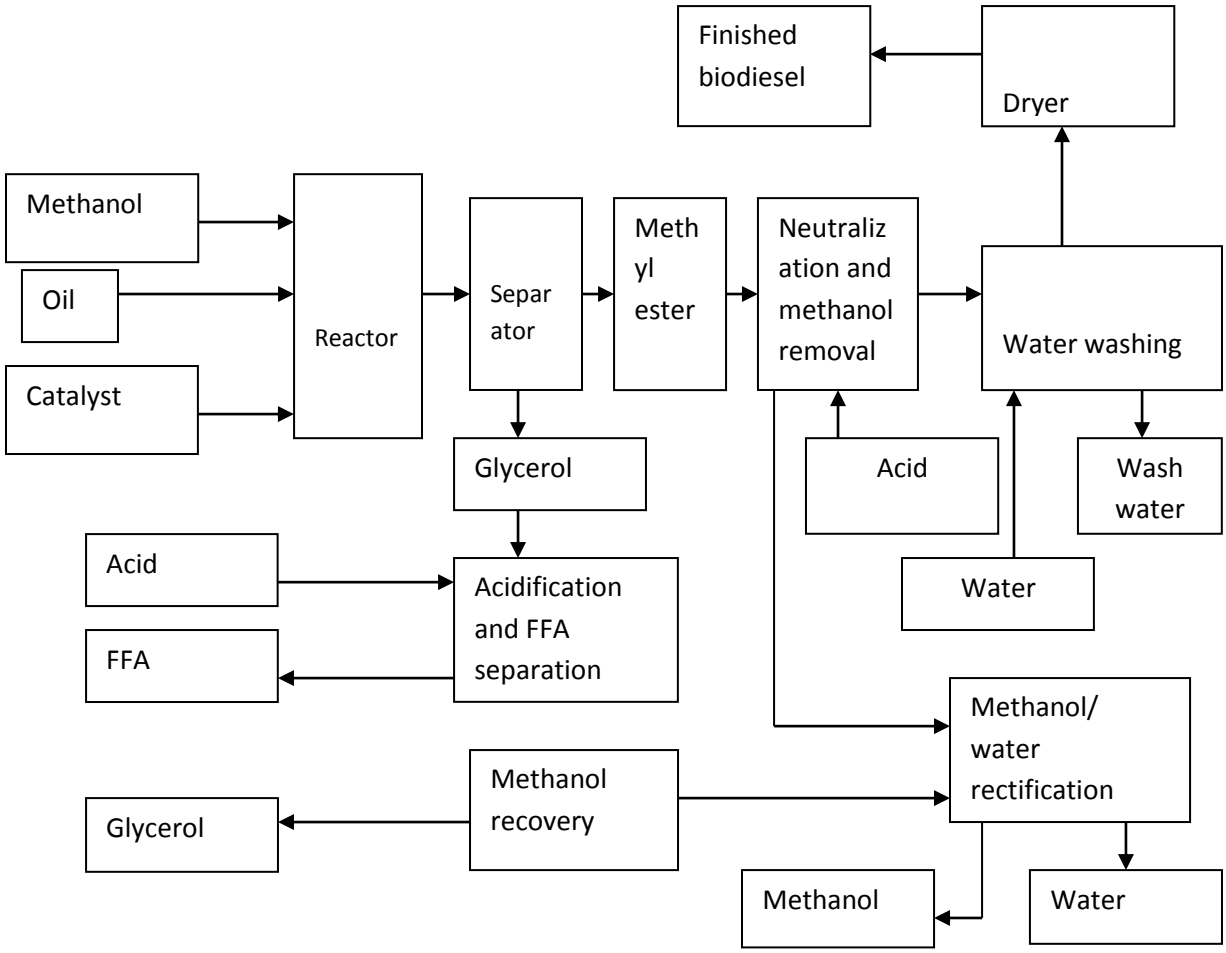


Figure 2 Scheme for Continuous Heterogeneous Catalytic Process for Biodiesel Production.

Many low cost feed stocks are available for biodiesel production. Unfortunately, many of these feed stocks contain large amounts of free fatty acids (FFA). As discussed elsewhere, these free fatty acids will react with alkali catalysts to produce soaps that inhibit the reaction.

When working with feed stocks that contain 5-30% FFA or even higher, it is important to convert the FFA to biodiesel unless the process yield will be low. In the production of palm oil, there are two crude oil products extracted, one is crude oil from palm fruit fiber and the other is oil from palm fruit kernel. Free fatty acids from these two kinds of oil are normally controlled at 5 % w/w but for small palm oil extracting industries, palm oil from the whole fruit is extracted (kernel and fiber). Because palm fruit in this process has to be toasted before extraction takes place, the free fatty acid of the oil produced is usually quite high (typically greater than 10 %w/w). It is difficult to utilize this kind of crude palm oil (which may be called mixed crude palm oil) for making biodiesel by the alkaline transesterification process because the free fatty acid content is too high. There are at least four techniques for converting the FFA to biodiesel:

Enzymatic methods: - these methods require expensive enzymes but seem to be less affected by water. [27, 28] At the present time, no one is using these methods on a commercial scale.

Glycerolysis: - this technique involves adding glycerol to the feedstock and heating it to high temperature (200ºC), usually with a catalyst such as zinc chloride. The glycerol reacts with the FFA to form mono and diglycerides. This technique produces a low FFA feed that can be processed using traditional alkali catalyzed techniques.

Acid Catalysis: - This technique uses a strong acid such as sulfuric acid to catalyze the esterification of the FFA and the transesterification of the triglycerides. The reaction does not produce soaps because no alkali metals are present. The esterification reaction of the FFA to alcohol esters is relatively fast, proceeding substantially to completion in one hour at 60ºC. However, the transesterification of the triglycerides is very slow, taking several days to complete.

Acid catalysis followed by alkali catalysis: - this approach solves the reaction rate problem by using each technique to accomplish the process for which it is best suited. Since acid catalysis is relatively fast for converting the FFA to methyl esters, it is used as a pretreatment for the high FFA feed tocks. Then, when the FFA level has been reduced to 0.5%, or lower, an alkali catalyst is added to convert the triglycerides to methyl esters. This process can convert high free fatty acid feedstock quickly and effectively. Water formation is still a problem during the

pretreatment phase. One approach is to simply add so much excess methanol during the pretreatment that the water produced is diluted to the level where it does not limit the reaction. Molar ratio of alcohol to FFA is as high as 40:1 may be needed. The disadvantage of this approach is that more energy is required to recover the excess methanol.

Methyl ester production from high free fatty acid mixed crude palm oil by two stage esterification-transesterification process has been investigated. Methyl esters were prepared from mixed crude palm oil containing high free fatty acid content by using a two-stage process. Sulfuric acid was used as the catalyst in an esterification reaction which was then followed by a transesterification reaction using sodium hydroxide as the catalyst. The products of the reaction at various time intervals were sampled to determine the percentage of tri, di, and monoglycerides, free fatty acid and methyl ester present. Analysis was performed by a thin layer chromatographic technique. A factorial experiment was carried out using 8, 10 and 12% by volume of methanol and 1, 3 and 5 % w/w of sulfuric acid in the acid catalyzed esterification process. Similarly, 16, 20 and 24% v/v methanol and 2, 3 and 4 % w/w of sodium hydroxide were used in the alkaline catalyzed transesterification process. Results from the analyses showed that with 3 and 5 % w/w of sulfuric acid, the free fatty acid of the oil could be significantly decreased in less than one hour at 60^0C. However, the amount of methanol used had a negligible effect on the reduction of the free fatty acid content. The subsequent transesterification process using sodium hydroxide as catalyst and 20-24 % v/v of methanol produced an ester having 99 % w/w methyl ester [G. Prateepchaikul, et al., 2007].

2.3. Important properties of biodiesel

The fuel properties of biodiesels are characterized by determining their viscosity, density, cetane number, cloud and pour points, distillation range, flash point, ash content, sulfur content, carbon residue, acid value, copper corrosion, and higher heating value.

2.3.1. Cetane Number (CN)

The cetane rating of a diesel fuel is a measure of its ability to autoignite quickly when it is injected into the compressed and heated air in the engine. Though ignition delay is affected by several engine design parameters such as compression ratio, injection rate, injection time, inlet

air temperature etc., it is also dependent on hydrocarbon composition of the fuel and to some extent on its volatility characteristic. The cetane number is a numerical measure of the influence the diesel fuel has in determining the ignition delay. The numerical value of the cetane number indicates the ignitability of a fuel by the ratio of the mixture of reference fuels (cetane ($C_{16}H_{34}$) and alpha-methyl naphthalene ($C_{11}H_{10}$). Cetane's ignitability is assigned the cetane number 100, and alpha-methyl naphthalene, with poorer ignitability, is assigned the number 0. The volume of cetane contained in the reference fuel is represented by percentage. For example the diesel fuel of ignitability, which is assigned the cetane number 45, is consists of 45% cetane and 55% methyl naphthalene. Because a fuel with a low cetane number has a poorer ignitability, it has a longer ignition delay, which makes the engine susceptible to diesel knocks.

The higher the cetane rating of the fuel, lesser is the tendency for diesel knock [35].

2.3.2. Iodine Values (IV)

Iodine values (IV) are useful for determination of the overall degree of saturation of the oil, which is important for viscosity, cloud point, and reactivity characteristics. At lower temperatures the oil becomes solid when saturated, but remains liquid with higher degrees of unsaturation. This is important for biodiesel characteristics where ideally the fuel will remain more liquid at lower temperatures, but remains somewhat stable from oxidation or hydrogenation reactions.

Iodine is introduced and reacts with the double bonds within the fatty acid structure, thus saturating the oil with iodine only at the double-bond sites. The amount of iodine absorbed in grams per 100 ml of oil determines the iodine value.

High degrees of unsaturation are generally not desirable for fuels because their oxidation reactions generally found at high temperatures during combustion may result in irreversible polymerization to plastic-like substances. Iodine values greater than 50 may result in decreased engine life, but give better viscosity characteristics in cooler conditions. The increase in the iodine value (IV) (*i.e.*, carbon–carbon double bond, −C=C−, content) results in a decrease in the heat content of an oil [21, 22].

2.3.3. Saponification Value (SV)

The saponification value is defined as the amount of potassium hydroxide (KOH) in milligrams required to saponify one gram of fat or oil. Based on the length of the fatty acids present in the triglycerol molecule, the weight of the triglycerol molecule changes which in turn affects the amount of KOH required to saponify the molecule. Hence, saponification value is a measure of the average molecular weight or the chain length of the fatty acids present. The SV of an oil decreases with increase of its molecular weight. The percentages of Carbon and Hydrogen in an oil decrease with an increase in molecular weight. The increase in SV results in a decrease in the heat content of an oil [23, 25].

2.3.4. Heat of Combustion

The heat of combustion measures the energy content in a fuel. This property is also referred to as the calorific value or heating value. Although the cetane number determines the combustion performance, it is the heating value along with thermodynamic criteria that sets the maximum possible output of power.

The higher heating values (HHVs) of oil samples are measured in a bomb calorimeter according to the ASTM D2015 standard method.

The ultimate analysis of a vegetable oil provides the weight percentages of carbon, hydrogen, and oxygen. The carbon, hydrogen, and oxygen contents of various common vegetable oils are 74.5–78.4, 10.6–12.4, and 10.8–12.0 wt%, respectively.

The HHV of vegetable oils ranges from 37.27– 40.48 MJ/kg. The HHVs of different vegetable oils vary by <9%.

The saponification value (SV) of an oil decreases with increase of its molecular weight. The percentages of Carbon and Hydrogen in an oil decrease with increase in molecular weight. The increase in SV results in a decrease in the heat content of an oil. The increase in iodine value (IV) (*i.e.*, carbon–carbon double bond, –C=C–, content of oil) results in a decrease in the heat content of an oil. The heat contents of the oil depend on the saponification and iodine values. Therefore, for calculation of the HHVs (MJ/kg) of oil samples, the following empirical relation was suggested (24).

$$HHV = 49.43 – 0.041\ (SV) – 0.015\ (IV)$$

Thus the heating values of the vegetable oils can be calculated by using their SVs and IVs obtained from simple chemical analyses without using a calorimeter [21].

2.3.5. Acid number

It is the quantity of base, expressed as milligrams of potassium hydroxide per Gram of sample, required to titrate a sample to a specified end point. Acid number for biodiesel is primarily an indicator of free fatty acids (natural degradation products of fats and oils) and can be elevated if a fuel is not properly manufactured or has undergone oxidative degradation. New and used petroleum products may contain acidic constituents that are present as additives or as degradation products formed during service, such as oxidation products. The relative amount of these materials can be determined by titrating with base. The acid number is a measure of this amount of acidic substance, in the oil. The acid number is used as a guide in the quality control of lubricating oil formulations. It is also sometimes used as a measure of lubricating degradation in service. Acid numbers higher than 0.80 have been associated with fuel system deposits and reduced life of fuel pumps and filters [23].

2.3.6. Cloud and pour points

Two important parameters for low temperature applications of a fuel are the cloud point (CP) and the pour point (PP).

Cloud Point is the temperature at which a cloud of crystals first appears as the fuel is cooled.

The cloud point of biodiesel varies significantly with feedstock. The fatty acid distribution of the feedstock has an effect on the cloud point. Biodiesel made from feedstocks such as stillingia, tung, perilla, hemp, evening primrose, linseed, corn, borage, and soybean have a cloud point below or close to 0ºC because of the lower fraction of saturated fatty acids like palmitic and stearic. Biodiesel made from feedstocks such as beef tallow, yellow grease, and poultry fat, have a higher fraction of saturated fatty acids and therefore have higher cloud points. Biodiesel made from Lesquerella and castor oil has cloud points of -11.6ºC and -13.4ºC, which may be due to the low amount of saturated fatty acids

Pour Point is the temperature at which the amount of wax out of the solution is sufficient to gel the fuel; thus it is the lowest temperature at which the fuel can flow. PP is the lowest

temperature at which the oil specimen can still be moved. These two properties are used to specify the cold temperature usability of a fuel [26].

2.3.7. Cold filter plugging point (CFPP)

Cold filter plugging point refers to the temperature at which the test filter starts to plug due to fuel components that have started to gel or crystallize. The CFPP is a commonly used indicator of low temperature operability of fuels. As with other low temperature properties, the CFPP of biodiesel also depends on the feedstock used for production of methyl esters. ASTM D6751 does not include the CFPP test as a standard. Similar to cloud point, the CFPP of biodiesel also varies with the fatty acid distribution; with a lower fraction of saturated fatty acids resulting in a lower CFPP, and a higher fraction of saturated fatty acids resulting in a higher CFPP [27].

2.3.8. Kinematic viscosity

Viscosity is a measure of the internal fluid friction or resistance of oil to flow, which tends to oppose any dynamic change in the fluid motion. As the temperature of oil is increased its viscosity decreases and it is therefore able to flow more readily. It is also important for flow of oil through pipelines, injector nozzles and orifices. The lower the viscosity of the oil, the easier it is to pump and atomize and achieve finer droplets.

Viscosity is the most important property of biofuel since it affects the operation of fuel injection equipment, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel.

Biodiesel has viscosity close to diesel fuels. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors [21].

2.3.9. Flash point

The flash point temperature of diesel fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source. Flash point varies inversely with the fuel's volatility. Minimum flash point temperatures are required for proper safety and handling of diesel fuel. Biodiesel and diesel have a common boiling point, but biodiesel has a higher flash

point because biodiesel has a high number of Fatty Acid of Methyl ester's (FAMEs) which are generally not volatile. Thus, biodiesel is safer to handle at higher temperatures than diesel.

2.3.10. Relative density

Relative density is the density of the component compared to the density of water. Relative density is a measure of weight per unit volume. The relative density of biodiesel is needed to make mass to volume conversions, calculate flow and viscosity properties, and is used to judge the homogeneity of biodiesel tanks [28].

2.3.11. Distillation range

The distillation range of a fuel affects its performance and safety. It is an important criterion for an engine's start and warm-up. It is also needed in the estimation of the cetane index (CI). The distillation range of the liquid product is determined by a test method (ASTM D2887-97) that covers the determination of the boiling range distribution of liquid fuels [29]. Biodiesel is fundamentally different from petroleum based diesel, and it is especially evident with distillation. Biodiesel has a fairly homogenous consistency of straight chain hydrocarbons, all with 16 to 18 carbons. Consequently it exhibits a boiling point rather than a distillation curve [10].

The degree of saturation of the fatty acids attached to the glycerol backbone determines the boiling point of the triglyceride. Generally, the FAMEs, which are mainly comprised of carbon chain lengths from 16 to 18, have boiling points in the range of 330–357 ^{0}C [30].

2.3.12. Carbon residue

The carbon residue test indicates the extent of deposits that result from the combustion of a fuel. Carbon residue which is formed by decomposition and subsequent pyrolysis of the fuel components can clog the fuel injectors. ASTM D6751 includes carbon residue as a standard for biodiesel. The maximum allowable carbon residue for biodiesel is 0.050 % by mass [31].

2.3.13. Copper corrosion

The copper strip corrosion test indicates potential compatibility problems with fuel system components made of copper alloys such as brass and bronze. The presence of acids or sulfur in the fuel can tarnish copper. It is well known that a double bond in the fatty acid structure

increases copper corrosion because it causes inner oxidation or peroxidation during combustion. Therefore double bonds decrease quality.

This test method is suitable for setting specifications, for use as an internal quality control tool, and for use in development or research work on industrial aromatic hydrocarbons and related materials. It also gives an indication of the presence of certain corrosive substances which may corrode equipment, such as acidic compounds or sulfur compounds [25].

2.4. Engine test with biodiesel as fuel

In an internal combustion engine the heat energy is released by burning fuel in the engine cylinder. The chemical reaction which permits the release of heat energy is quit fast but the time taken in preparing a proper mixture of fuel and air depends mainly up on the nature of fuel, and the method of introducing it in to combustion chamber. Thus the fuels used in IC engines are designed to satisfy the performance requirements of the IC engine system. Fuel derived from petroleum reservoirs has been used for many years in IC engines for energy generation and transportation. The two popularly used IC engines in this industry are SI engines and CI engines. Among the two popular types of IC engines CI engine, which run by diesel fuel has been widely used as power of engineering machinery, automobile, and shipping equipment for its excellent drivability and thermal efficiency.

Diesel engines usually exhaust higher amounts of particulate matter (PM) than spark ignition engines. Many alternative diesel fuels have been shown to have better exhaust emissions than traditional diesel fuel. Alkyl esters of vegetable oils and animal fats, called biodiesel, hold promise as fuel alternatives for diesel engines. Ramadhas at al. (2004) suggested that biodiesel has fuel properties and provides engine performance that is very similar to diesel fuel. The primary incentive for using biodiesel is that it is a nontoxic, biodegradable, and renewable fuel. Further advantages over petroleum based diesel fuel include a high cetane number, low sulfur, low aromatics, low volatility and the presence of oxygen atoms in the fuel molecule. These features of biodiesel lead to its greatest advantage, which is its potential for emission reduction including CO, HC, solid carbon particles and PM. But making petro diesel standard biodiesel is not simple. Hence making your own fuel (biodiesel) should start with experiment to find

suitable fuel, because the fuel quality depends on the fatty acid composition of oil, method of oil extraction, careful transesterification, safety handling and storage.

The result of Comprehensive analysis on performance, combustion and emission characteristics fueled by various blends of corn oil, palm oil and cotton seed oil biodiesel in a CI engine is studied [39]. Engine Brake thermal efficiency of B20 blends is comparable to that of B100 at almost all the loads. Brake specific fuel consumption is higher for B20 than diesel by 3.3% at maximum load. The maximum deviation of peak pressure for B20 is 3.9% lesser than pure diesel. It is observed that when engine is fueled with biofuels, the combustion starts earlier under all operating conditions and also biofuels have shown shorter ignition delay compared to diesel. At the maximum load, the exhaust gas temperature of B20 (cotton seed oil) deviation is observed to be 10.82% higher than that of B100.

2.4.1. Biodiesel performance characteristics

Engine test will be carried out for engine performance, efficiency and exhaust emission. Engine manufactures always wary about their customer (market) and legislation. Customers firstly, look for an engine with good output and less fuel consumption. The engine performance characteristics are highly dependent on engine design parameters and operating variables. For a given engine by fixing all operating conditions constant, how two fuels with different chemical structure and from different sources but relatively similar properties will affect engine performance is essential to consider. The heating value of vegetable oils are similar to that of diesel fuel. However, their use in direct injection diesel engines is restricted by some unfavorable physical properties, particularly viscosity, which is approximately ten times higher than the diesel fuel [5]. Therefore, use of vegetable oil in direct injection diesel engines creates poor fuel atomization, incomplete combustion, carbon deposition on the injector, and fuel guild up in the lubricant oils resulting in serious engine fouling.

S. Darren et al., (2005) suggested that the engine exhibited a decrease in output power while running with B100 biodiesel fuel. The tests with B20 exhibited a 9% increase in fuel flow rate and a 6.8% increase in specific fuel consumption.

The lower specific fuel consumption occurs partially because there is no associated loss in power with B20, only an increase in fuel flow rate.

2.4.1.1. Brake torque and power

Engine performance is more precisely defined by the maximum power (or the maximum torque) available at each speed with in the useful engine operating range. Or the range of power and speed over which engine operation is satisfactory. Engine torque is normally measured with a dynamometer. The engine is clamped on a test bed and the shaft is connected to the dynamometer rotor.

Figure 3 illustrates the operating principle of a dynamometer. The rotor is coupled electromagnetically, hydraulically, or by mechanical friction to a stator, which is supported in low friction bearings. The stator is balanced with the rotor stationary. The torque exerted on the stator with the rotor turning is measured by balancing the stator with weights, springs, or pneumatic means.

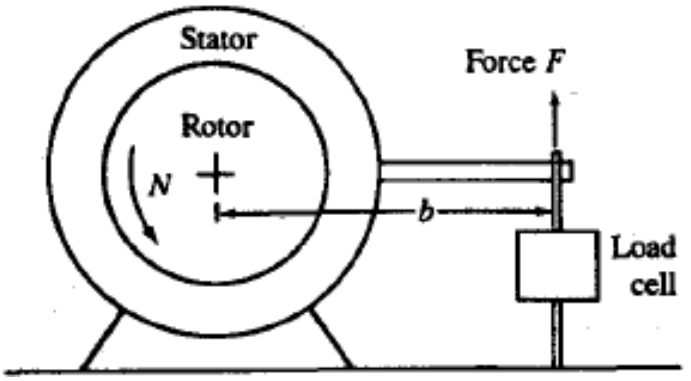


Figure 3 Schematic diagram for engine dynamometer

Using the notation in Fig.3, if the torque exerted by the engine is T:

$$T = Fb$$

Where, T in Nm

The brake power 'P_b' delivered by the engine and absorbed by the dynamometer is the product of torque and angular speed:

$P_b = 2\pi NT/60$

Where, P_b in kW

N crankshaft rotational speed in minute and

T torque in Nm.

The performance of the engine is highly dependent on engine design and operating parameters. The importance of the parameters to engine performance becomes evident when power and torque are expressed in terms of these parameters. For four-stroke cycle engine,

O. J. ALAMU et al. (2009) investigated Power and Torque Characteristics of Diesel Engine Fuelled by Palm-Kernel Oil Biodiesel. Short-term engine performance tests were carried out on test diesel engine fuelled with Palm kernel oil (PKO) biodiesel. The diesel engine was attached to a general electric dynamometer. Torque and power delivered by the engine were monitored throughout the 24hour test duration at 1300, 1500, 1700, 2000, 2250 and 2500 rpm. At all engine speeds tested, results showed that torque and power outputs for PKO biodiesel were generally lower than those for petroleum diesel. Also, Peak torque for PKO biodiesel occurred at a lower engine speed compared to diesel.

2.4.1.2. Brake specific fuel consumption and efficiency

In engine tests, the fuel consumption is measured as a flow rate, mass flow per unit time**.** A more useful parameter is the specific fuel consumption (sfc) the fuel flow rate per unit power output. It measures how efficiently an engine is using the fuel supplied to produce work:

$$\mathrm{BSFC} = \frac{\text{Fuel flow (Kg/h)}}{\text{Brake power (kW)}} \qquad [\mathrm{Kg/kWh}]$$

The specific fuel consumption has units. A dimensionless fuel conversion efficiency that relates the desired engine output (work per cycle or power) to the necessary input (fuel flow) would have more fundamental value. It is the ratio of the work produced per cycle to the amount of fuel energy supplied per cycle that can be released in the combustion process. The fuel energy supplied which can be released by combustion is given by the mass of the fuel supplied to the engine per cycle times the heating value of the fuel.

$$\eta_f = \frac{1}{sfc * Q_{HV}}$$

Where, $\eta_f =$ Fuel conversion efficiency

$Q_{HV} =$ Fuel heating value

In engine tests, the fuel consumption can be measured in different manner. One method is measuring the mass of the fuel in the fuel tank before and after the engine test has been commenced. The difference of the two masses is the total mass of the fuel consumed during the test period. In this measurement test duration will recorded and the difference will divided to the test duration to obtain fuel consumption rate on the basis of mass [40]. The second approach is to measure fuel flow rate by using fuel flow meter. The meter is connected in fuel line between the fuel tank and fuel injection unit and continuously monitors the fuel flow rate at any time for various engine load and operating conditions. This measurement technique is more accurate and enables one to measure the fuel consumed for specific output at any given time. The third approach is mathematically approximate estimation of the injection rate through the injection nozzle. If the pressure upstream of the injector nozzle can be estimated or measured, and assuming the flow through each nozzle is quasi steady, incompressible, and one dimensional, the mass flow rate of fuel injected through the nozzle can approximated by the following equation.

$$\dot{m}_f = C_D A_n \sqrt{2\rho_f \Delta p}$$

Where, $C_D =$ Discharge coefficient

$A_n =$ Injector orifice area

$\rho_f =$ Density of the fuel

Dr. J.G. Suryawanshi (2009) in his paper "Palm Oil Methyl Ester: A New Fuel for CI Engines," the variation of brake thermal efficiency with load for various blends of Palm oil methyl ester has shown. The brake thermal efficiency is improved as compared to diesel at part and full load for various blends of palm oil methyl ester. The brake thermal efficiency is increased by 11% at

full load for POME (B100) than diesel. This may be attributed to sharp premixed portion of the heat release which is a desirable feature for thermal efficiency and complete combustion because of oxygenated fuel. Maximum cylinder pressure is lower with blends of bio diesel as diesel. There is a difference of about 0.55 MPa between the peak pressures with the POME (B_{100}) and diesel at full load. This difference decreases for lower blends of POME. The maximum cylinder gas pressure depends on the combustion rate in the initial stages, which in turn is influenced by the amount of fuel taking part in the uncontrolled combustion phase. The delay period govern the uncontrolled or the premixed combustion phase. The lower delay period is responsible for lower trend of peak pressure. Exhaust gas temperature is slightly higher with blends of biodiesel as diesel due to better combustion. The brake specific energy consumption is the product of brake specific fuel consumption and calorific value of fuel. The brake specific energy consumption is lower as compared to diesel at all loads. This may be due to complete combustion because of oxygenated fuel.

2.4.1.3. Biodiesel exhaust emissions characteristics

Diesel emission contains carcinogenic components, such as carbonyl compound (formaldehyde), light aromatic hydrocarbon (benzene). Although diesel engine produces lesser amount of CO and total hydrocarbon compounds (THC) than spark ignition (SI) engine, it forms large quantities of fine particulate matter (PM). Diesel particles the emissions of concern are unburned hydrocarbons (HC), carbon monoxide (CO), carbon dioxide, (CO_2), oxygen (O_2) Oxides of nitrogen (NO_X) and particulate matter (PM).

A number of research studies have proved the positive benefits of biodiesel on diesel engine emissions. The severe emission regulations in the world have placed design limitations on heavy duty diesel engines. The trend towards cleaner burning fuel is growing worldwide. The cetane number, aromatic content and type, sulfur content, distillation temperature, and density are important factors for emission control. Reduction in the aromatic content and/or the removal of heavy fractions or the use of lighter fuel is considered to be effective for this purpose [41].

A change of trend in the design of internal combustion engines is currently taking place owing to the increasing market of diesel engine vehicles. This technological turn is also related to the appearance of new environmental policies, user requirements and technical advances. In spite of

this progress, the search for a compromise between engine performance (efficiency and effective power) and emission is still going on. In particular the particulate and nitrogen oxide emissions have attracted much attention, since their stringent legal limitations greatly affect the engine design. The results obtained so far show that the biofuel has good overall behavior, with performance and emission levels comparable to diesel fuel. Severe engine deposits, injector coking and ring sticking have been detected in long term usage when neat vegetable oil was used.

Comprehensive analysis on performance, combustion and emission characteristics fueled by various blends of corn oil, palm oil and cotton seed oil bio diesel in a CI engine has been done. At the maximum load, B_{20} of palm and cotton seed oil has the carbon dioxide content of 11.5% lower than that of diesel. At the peak load, B20 (corn and cotton seed oil) has the hydrocarbon content of 18.75% higher than that of B100. NO_X content is 8.9% higher than B100 at maximum load. The smoke intensity B20 (cotton) is 2.3 times higher than diesel [39].

A. Azhar Abdul et al., (2007) suggested the Effects of cotton seed methyl esters on performance and emission of a direct injection diesel engine. The use of cotton seed oil based biodiesels has been proposed as an alternative fuel for diesel engines in Malaysia. The purpose of this study is to investigate the performance and exhaust emissions of various blends of neutralized cotton seed oil methyl ester in a small-unmodified direct-injection diesel engine and to compare them with that of a reference diesel fuel (D2). It has been blended together with D_2 in several percentages (10%, 20% and 50%) and known as B10, B20 and B50. The acquisition of operating parameters such as performances, emission concentrations, cylinder pressure and fuel line pressure were performed as a function of engine loads, at the engine speed of 1500 rpm. The effect of engine load and blend percentages on brake specific fuel consumption (bsfc), brake thermal efficiency, heat release, cylinder pressure, ignition delay, carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbon (HC), nitrogen oxide (NO_x) and exhaust smoke were carried out in this study. As a whole it was found that the palm oil-based alternatives behaved comparably well to the D_2 in terms of performance (fuel consumption and thermal efficiency). Smoke density readings show improvements as compared to that emitted by the diesel fuel in which operating under similar conditions. The emissions of CO, CO_2 and HC were reduced by using biodiesel fuels, while NO_x emissions for biodiesels were slightly higher.

3. MATERIALS AND METHODS

Experimentation is the only method used in this research paper.

The procedures used to enhance the experimental work are the following:-

1. Sample collection,
2. Extraction of oil,
3. Transesterification,
4. Characterization of Avocado seed derived biodiesel using different parameters,
5. Testing the performance of the produced biodiesel in a four stroke diesel engine.

3.1. Sample collection

Fig. 4 shows sample collection, cutting into smaller size and drying and crushing of avocado seed. Sample of waste avocado seed were collected from juice houses in Adama town and conventional No. 2 diesel fuel (petrodiesel) was purchased from fuel station in Addis Ababa, for comparative analysis with the biodiesels.

Figure 4 Sample collection, drying and crushing waste avocado seed.

3.2. Extraction of oil

Fig. 5 shows the hexane solvent and mixing the solvent with the crushed seed in a container. Oil was extracted from waste avocado seed by using solvent extraction method with n-hexane.

Solvent extraction was chosen because it can produce oil content higher than as compared with mechanical extraction using screw press which resulted no oil.

Oil extraction was done in wondogenet agricultural research center and chemical engineering department (ASTU). The crushed avocado seed is mixed with hexane and allowed to settle for 2 days and the oil and hexane solution were separated by Rotavapour. In chemical extraction method from 1000 grams of seed around 125 ml of oil was extracted.

Figure 5 Extraction of oil

3.3. Transesterification

There are several important factors that influence transesterification reaction, such as temperature and molar ratio of oil to alcohol (methanol) [4].

Fig. 6 shows the transesterfication process, washing and drying process of biodiesel. Ester formation occurs at 45-60°C after 1 hour. That temperature appropriate with the properties of methanol whose boiling point is 64.7°C. Higher temperature refers to methanol loss because of vaporization and also result fewer methyl ester content. Transesterification is an exothermic reaction; rise in temperature will push equilibrium into reactant side [5].

The most common way to produce biodiesel is by transesterification, which refers to a catalyzed chemical reaction involving vegetable oil and an alcohol to yield fatty acid alkyl esters (i.e., biodiesel) and glycerol.

Free fatty acid (FFA) level of avocado seed oil is just 1.55% (less than 2%), so it needs no esterification process to convert FFA into methyl ester. The oil can be processed by transesterification directly.

Next stage react oil with methanol using potassium hydroxide (KOH) as base catalyst, called transesterification. The reaction results crude fatty acid methyl ester (crude biodiesel), containing glycerol and other impurities. So biodiesel must be washed first in order to get higher methyl ester content.

In this thesis work of the transesterfication process methyl alcohol (99.95%) (CH_3OH) and a basic catalyst potassium hydroxide (KOH) are used. The transesterification process is done in Essential Oils Producers laboratory of the Wondogenet Agricultural Research Center.

Generally the procedure followed in the transesterification of avocado oil to its corresponding methyl ester (CME) is as follows:

1. Two grams of potassium hydroxide pellets is used for each 100ml of methyl alcohol.
2. In the above ratio the two are mixed and dissolved.
3. For each 25 ml of the above solution 100 ml of avocado seed oil is prepared (1:4 ratios).
4. Using a beaker the oil is heated to a temperature of 50^0C.
5. Keeping the oil temperature to 50^0C, methyl alcohol and potassium hydroxide solution were added in to the heated oil and stirred manually vigorously for not less than 30 minutes using a hot plate with magnetic stirrer. Two phases were obtained at the end of the reaction: ester and crude glycerol. A successful reaction produces two liquid phases: ester and crude glycerol.
6. The mixture is then poured to a separation flask for easy separation. The entire mixture then settles and glycerol is left on the bottom and a methyl ester (biodiesel) is left on top. Crude glycerol, the heavier liquid, was collected at the bottom. Phase separation can be observed within 10 min and can be complete within 2 hrs. After stirring has stopped. Complete settling can take as long as 20 hrs. after settling is complete.

7. The glycerol is then carefully drained from the bottom by opening the drain valve of the separation flask.

8. The next step after drainage of glycerol is biodiesel washing. Washing the biodiesel is necessary to remove excess catalyst, glycerol, and glycerides not fully reacted that would be detrimental to an engine.

   Most impurities settle out into the glycerol layer including unfiltered particulates, methanol, and glycerin. Some sources encourage using unwashed biodiesel, because washing biodiesel is a time- consuming process. However, some alcohol, sodium hydroxide, and soap remain suspended throughout the biodiesel after the transesterification is complete. Water in biodiesel can lead to biological growth as the fuel degrades. Unreacted methanol in the biodiesel fuel can result in fire or explosion and can corrode engine components. The catalyst, sodium hydroxide, can also attack other engine components. Since the methanol and sodium hydroxide are chemical bases, unwashed biodiesel is caustic and may damage diesel engine components. Soap is not a fuel and will reduce fuel lubricity and cause injector coking and other deposits.

   Washing the methyl ester is a process which is carried out with extreme care. Warm water (up to 50^0C) at the rate of 30% by volume of oil (biodiesel) is added to the methyl ester and gently agitated. The solution is then hanged for 24 hours and the soup like solution is drained from the bottom. This step is performed for two times (Biodiesel is washed 2 times).
9. The last step is drying the biodiesel. This is because after washing the biodiesel the remain water is removed by drying process. This can be done by letting the biodiesel sit (covered) in a sunny location for a few days, or it may be heated to about 120°F for a few hours. Reacted, washed, and dried biodiesel may be used in any diesel engine. It should have a pH of close to 7 or chemically neutral and it should have no methanol left in it.

Figure 6 Transesterification and washing process

3.4. Characterization of Avocado seed derived biodiesel

Characterization is the process of determining the physiochemical properties of petroleum products or mixture of petroleum and non-petroleum products like biodiesel blends. Before testing the performance of the produced fuel in diesel engines, it is very important to know its physiochemical properties. Some of the properties of the fuel studied in this thesis work include viscosity, density, cloud point and flash point.

Fig. 7 shows blended (biodiesel and diesel) fuel B10 and B20 for testing their properties. Characterization of the fuel to be tested in this research project is done in the laboratory of Ethiopian Petroleum Enterprise (EPE) following the procedures given in the book of ASTM D 6751- 2011. In this thesis work the fuel properties of B100 (neat biodiesel), B20, B10, and petrodiesel (B0) are studied. The first procedure was preparing the blends.

Figure 7 Preparing blends of biodiesel

Then the physiochemical properties of each blend including B100 (neat biodiesel) and B0 (petrodiesel) are studied following the procedure for each property given in the ASTM book.

3.4.1. Determination of density, ASTM (D1298)

Fig. 8 shows density measurement using a hydrometer. Density of each sample is measured using hydrometer. The sample fuel was filled into graduated cylinder (250 ml) and its temperature was recorded. Hydrometer was inserted in to the fuel to measure the SG of the fuels specified. Then, temperature correction factors (according to tables from (ASTM D 1250-80, 1980; Petroleum Measurement Tables, 1963)) were applied to convert the measured specific gravities to the reference temperature of $60/60^0$F and densities were taken at temperatures of 15 ^{0}C and 20 ^{0}C.

The API gravity is obtained from the relation:-

API gravity = 141 /Specific gravity -131.5

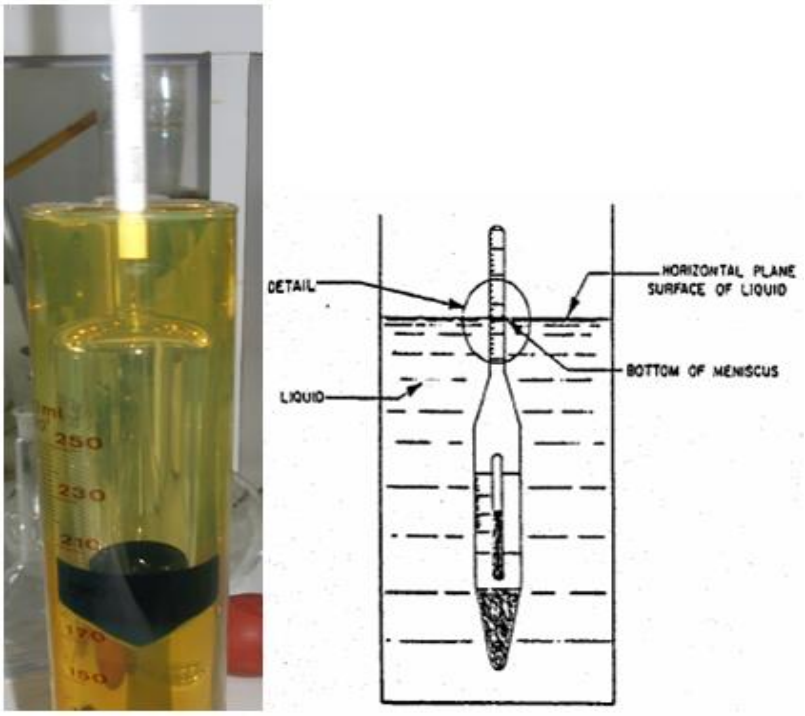


Figure 8 Measuring SG and Density

3.4.2. Determination of flash point (FP) (ASTM D93)

The flash point is the lowest temperature at which fuel emits enough vapors to ignite. Biodiesel has a high flash point, usually more than 150°C, while conventional diesel fuel has a flash point of 55-66°C. If methanol, with its flash point of 12°C is present in the biodiesel the flash point can be lowered considerably. To ensure that the methanol has been adequately stripped from the biodiesel, the Pensky-Martens closed cup flash point test was adopted.

The flash points were measured with a Pensky-Martens closed cup tester using ASTM D93, Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester as shown in the figure bollow. The apparatus and method consist of the controlled heating of the biodiesel sample in a closed cup, introducing an ignition source, and observing if the heated biodiesel flashes. The temperature at which the biodiesel flashes is recorded as the flash point. For biodiesel, a flash point of below 93°C is considered to be out of specification. If the biodiesel has not flashed at 160°C, the test is finished and the result is reported as >160°C [23, 35].

Correction of flash point:

By recording the ambient barometric pressure at the time of test,

Corrected flash point (CFP) = T + 0.25 (101.3 –K)

Corrected flash point (CFP) = T + 0.033 (760-P)

Corrected flash point (CFP) = F + 0.06 (760 –P)

Where, T = Observed Flash Point Temperature (^{0}C)

K = ambient barometric pressure (kPa)

P = Ambient pressure (mmHg)

F = observed flash point (^{0}F)

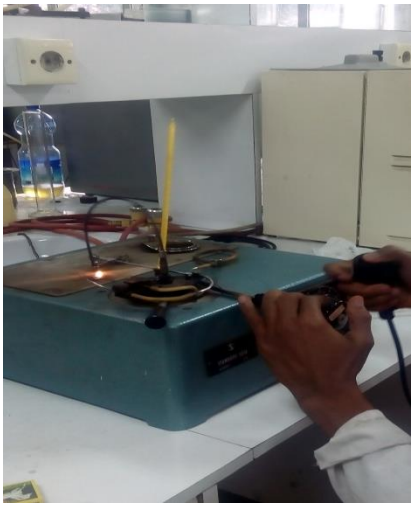


Figure 9 Pensky-Martens closed cup tester

3.4.3. Determination of cloud point (CP) (ASTM D 2500)

The cloud point of petroleum product is an index of the lowest temperature of its utility of certain applications and it is measured as shown in the fig. 10 using ice pack. Mixtures commonly used for temperature reduction are the following:-

1. Ice and water up to 10^{0}C.
2. Crushed ice and sodium chloride crystals, up to – 12^{0}C.
3. Crushed ice and calcium chloride crystals up to – 26^{0}C.

4. Acetone, Methyl or Ethyl chloride or petroleum naphtha chilled up to - 57^0C [27].

Cloud point was determined using ASTM D2500, Standard Test Method for Cloud Point of Petroleum Products. The cloud point was determined by visually inspecting for a haze in the normally clear fuel, while the fuel was cooled under carefully controlled conditions. The sample was continuously monitored and the temperature (^{0}C) that corresponds to the first formation of a cloud in the fuel was recorded.

Figure 10 Cloud point measuring apparatus

3.4.4. Determination of kinematic viscosity (ASTM D 445)

Kinematic viscosity in biodiesel was determined using ASTM D445, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids. Cannon-Fenske glass capillary Viscometer Tube was used in a SETA KV-8 viscometer bath (fig. 11). Sample fuel is filled in the capillary viscometer tube and kept for 30 minutes to maintain an equilibrium temperature of 40 ^{0}C. The time (t) is recorded for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer. Kinematic viscosity is then calculated as the product of this time (t) in seconds and the calibration constant (K) of the viscometer tube.

Kinematic Viscosity = K* t

Where, K = Calibration constant for the viscometer in (mm^2/s^2)

t = Time in (s) [46]

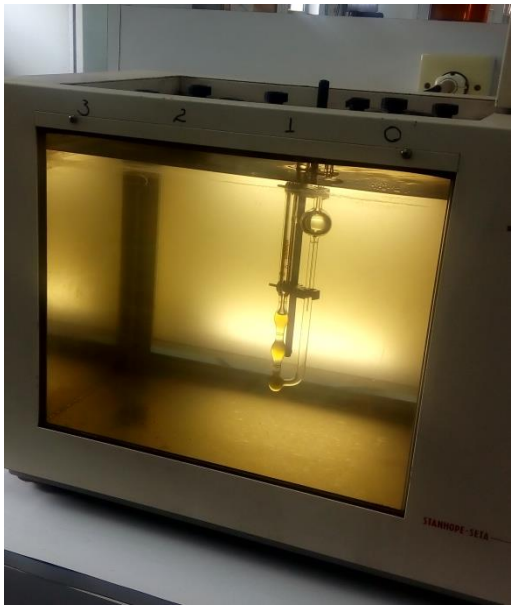


Figure 11 Determination of Kinematic Viscosity apparatus

3.5. Performance Test

The experimental work was carried out using a chassis dynamometer and the performance of diesel vehicle equipped with 4 cylinder,4 stroke diesel engine with B0,B10 and B20 as fuels was tested in Adama science and technology university in mechanical and vehicle engineering department workshop. Performance was measured in terms of wheel force and wheel power. Rear wheel drive vehicle is allowed to run on the chassis dynamometer and wheel power and force readings are taken from the gauge.

3.5.1. Pre-test procedures

Before testing, a variety of checks and tasks have been carried out. The engine was inspected visually for any problems, the engine coolant was filled to the optimum level in the expansion tank, the air intake system and test area were cleaned properly.

Additionally, the engine was properly warmed up prior to tests for two reasons. First, the engine can be damaged if run under high loads before reaching proper operating temperature. Second, torque, power, fuel flow and many other types of readings tend to fluctuate depending on engine temperature. Once the engine reaches operating temperature (in this case 75^0C cooling water temperature), the readings will be reliable.

3.5.2. Post-test procedures

After full load testing, the engine was idled down for at least five minutes in order to stabilize the internal engine temperature for all types of fuel test. When switching from one fuel test to the next, the engine was allowed to operate at least for 10 minutes before starting the test in order to ensure the complete consumption of leftover primarily tested fuel in the fuel system and its smoother operation with the new fuel.

3.5.3. Data analysis

From the experiment wheel power, wheel force and fuel consumption rate data were collected. These data were tabulated in accordance with specified respective vehicle speed. The bsfc was calculated manually from the gram of fuel consumed at a given duration of time and engine brake power.

From this data graphs which indicate performance characteristics were plotted, by using computer program (XL). Finally the comparison of overall performance characteristics was done with specific standard value of diesel fuel on a given test engine.

4. RESULTS AND DICUSSION

4.1. Important properties of avocado seed oil biodiesel and tested diesel fuel

The extraction process was done by solvent method. In this process, dried avocado seeds were crushed and soaked with hexane. The mixture was stirred repeatedly and settled after 24hrs.The filtered oil solution was fractionally distillated by the apparatus, Rota vapor and the hexane solvent was separated and collected. This crude oil sample was tried for transisterfcation. By taking 100 ml of the oil, the exact and appropriate reaction temperature was reached after three trials of each 100 ml oil sample.

The fuel characterization result shown in table 1 indicates that there is small deviation in most properties for avocado seed oil derived biodiesel from that of tested diesel fuel. The most important biodiesel property that depends on type of feed stock and appropriate transesterification process is viscosity. This property could affect the fuel flow in fuel lines, the droplet formation and atomization which are directly related to complete combustion and utilization of fuel energy.

The result of the experimentation as shown in the table below all the parameters are tested as to the test method indicated and all have satisfied the above requirement except the cloud point and all the parameters are obtained in the accepted range as shown below when compared to the values of ASTM standard test method.

Table 1 Important properties of tested neat diesel fuel and blended avocado seed biodiesel

SN.	Property	Test Method ASTM	Limits	Test result			
				Parent Diesel used for blending	Biodiesel from avocado seed	B-10	B-20
1.	Density @20^{0}C @15^{0}C (g/ml)	D1298	Report	0.8443 0.8477	0.8850 0.8884	0.8478 0.8512	0.8528 0.8562
2.	Flash point (PMCC), ,min (^{0}C)	D93	93	90	175	93	94
3.	Cloud point,max (^{0}C)	D2500	+5	2.5	+9	+4	+5
4.	Kinematic viscosity @40 (mm^2/s)	D445	1.9-6.0	–	–	–	4.0

4.2. Performance Characteristics

Fig. 12 shows the chassis dynamometer gauge and diesel vehicle (engine model 3L Toyota 2779cc) for performance testing. The engine performance test results using conventional diesel fuel and blends are presented in the figure below. The power and torque curves pattern of the fuel blends against the speed seems to be similar to the conventional diesel fuel. The slight reduction in power and torque is due to the lower calorific value of the biodiesel. Other researchers believed that, using additives may optimize the combustion behavior and improve the engine performance.

Figure 12 Chassis dynamometer for vehicle (engine) performance testing

The following data shows the measured wheel force and power for blended biodiesel (B10 & B20) and pure diesel fuel at 4^{th} gear.

Table 2 wheel force at 4th gear (kN)

Speed (km/h)	B0	B10	B20
30	1.4	1.35	1.3
35	1.35	1.3	1.5
40	2	1.25	1.5
45	1.1	1.6	1
50	0.9	0.68	0.6
55	0.84	0.7	0.55

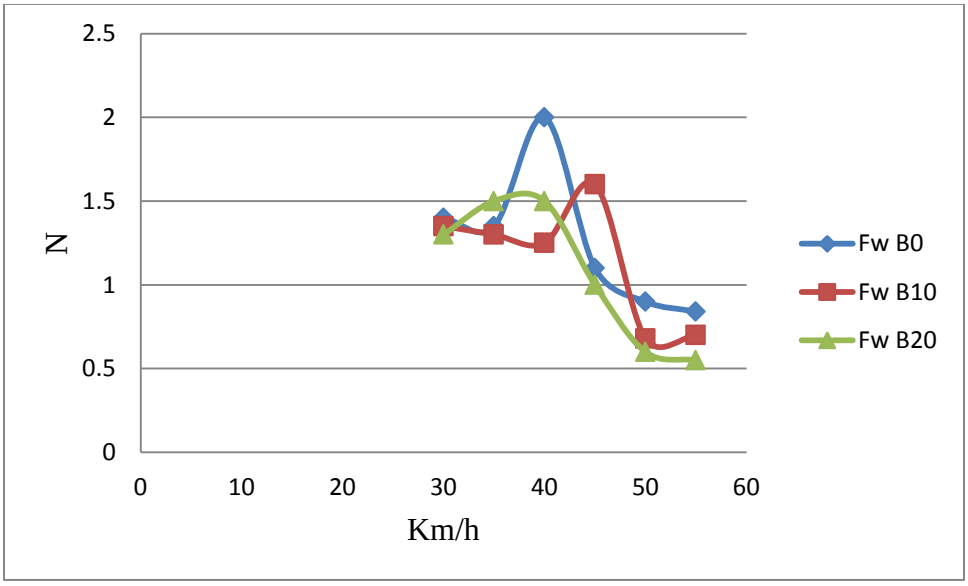


Figure 13 wheel force characteristics at 4th gear

Table 3 wheel power at 4th gear (kW)

Speed (km/h)	B0	B10	B20
30	11.5	9.5	8
35	14.5	12	11.5
40	17	14.5	15.5
45	9.5	16	6.5
50	8	10	7.5
55	5	7	3.5

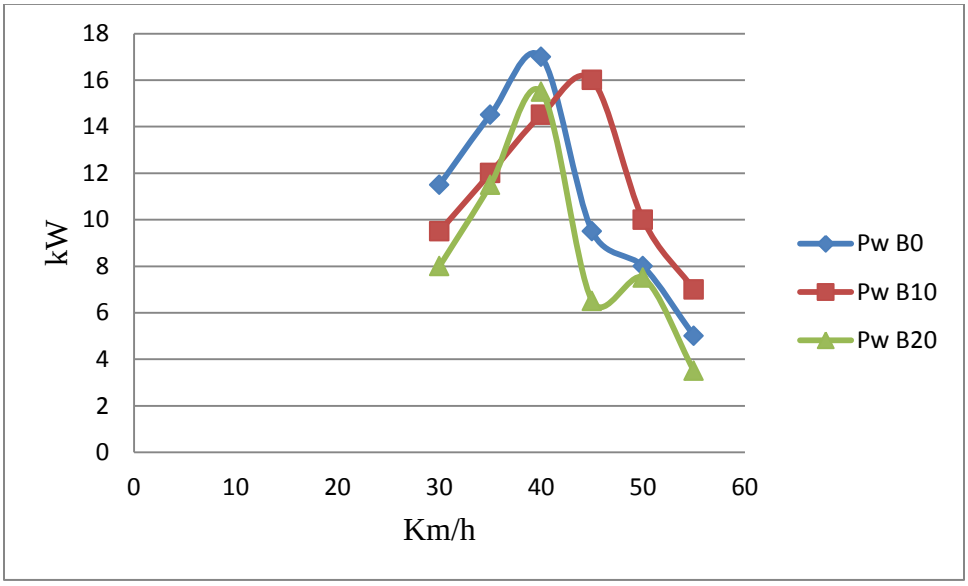


Figure 14 Wheel power characteristics at 4th gear

Generally fig. 13 and 14 shows the performance (wheel force and wheel power) results from table 2 and 3 for four stroke four cylinder diesel engine vehicle tested on chassis dynamometer for B0, B10 and B20 fuels. As shown in the figures B0 is the maximum from other fuels (B10 and B20). This is because diesel fuel has higher energy content or heating value than biodiesel and due to poor atomization of the fuel for blended biodiesel and diesel fuels due to higher viscosity of the biodiesel fuel. And the difference is more as the blending ratio is more.

$$N = 2.65 \times \frac{GR_t}{r_w} \times V$$

Where, N Engine speed in 'rpm'

V Vehicle speed in 'Km/h'

r_w Radius of wheel in 'm'

GR_t Total gear ratio and it is given by:

$$GR_t = GR_i \times GR_f$$

Where, GR_i Specified gear ratio, i = 1, 2, 3…

GR_f Final drive gear ratio

$$N_1 = 2.65 \times \frac{GR_i \times GR_f}{r_w} \times V_1$$

$$= 2.65 \times \frac{1 \times 4.3}{0.3} \times 30 = 1140 \text{ rpm}$$

Using the above equation we can find all engine rpm's (N2, N3…) from the corresponding vehicle speed, so finally we will get:

Table 4 Engine speed in RPM

SNo.	1	2	3	4	5	6
V in Km/h	30	35	40	45	50	55
N in rpm	1140	1329	1519	1709	1899	2089

Table 4 shows the converted vehicle speed in Km/h to engine speed in rpm.

$$P_b = \frac{P_w}{\eta_t}$$

Where, P_b Engine brake power in 'kW'

P_w Wheel power

η_t Total gear efficiency, $\eta_t = \eta_i \times \eta_{fd}$

η_i , Efficiency of specified gear

η_{fd} , Efficiency of final drive

$$P_{b1} = \frac{P_{w1}}{\eta_t} = \frac{11.5}{0.875 \times 0.92} = 14.3 \text{ kW}$$

In the same way we can find $P_{b2}, P_{b3}, \ldots and\ P_{b6}$ finally we will get:

Table 5 Engine brake power for B0

SNo.	1	2	3	4	5	6
N in rpm	1140	1329	1519	1709	1899	2089
P_b in kW	14.3	18	21.12	12	10	6.2

Table 6 Engine brake power for B10

SNo.	1	2	3	4	5	6
N in rpm	1140	1329	1519	1709	1899	2089
P_b in kW	12	15	18	20	12.4	8.6

Table 7 Engine brake power for B20

SNo.	1	2	3	4	5	6
N in rpm	1140	1329	1519	1709	1899	2089
P_b in kW	10	14.3	19.3	8	9.3	4.3

Generally from table 5 to7 shows the calculated engine brake power for all tested fuels (B0, B10, and B20) at different engine speed.

$$T_b = \frac{P_b}{w_w}$$

Where, T_b Engine brake torque

w_w Angular velocity of wheel, $w_w = \frac{2\pi N}{60}$

$T_b = \frac{60 \times P_b \times 1000}{2\pi N}$, T_b in 'Nm'

$$T_{b1} = \frac{60 \times P_{b1} \times 1000}{2\pi N1} = \frac{60 \times 15 \times 1000}{2\pi \times 1140} = 125.64 \text{ Nm}$$

Table 8 Engine brake torque for B0

SNo.	1	2	3	4	5	6
N in rpm	1140	1329	1519	1709	1899	2089
T_b in Nm	119.78	129.3	132.77	67	50.3	28.34

Table 9 Engine brake torque for B10

SNo.	1	2	3	4	5	6
N in rpm	1140	1329	1519	1709	1899	2089
T_b in Nm	117.3	115	112	106	99.56	89

Table10 Engine brake torque for B20

SNo.	1	2	3	4	5	6
N in rpm	1140	1329	1519	1709	1899	2089
T_b in Nm	83.76	102.75	121.33	44.7	46.76	19.65

From table 5 to7 shows the calculated engine brake torque for all tested fuels (B0, B10, and B20) at different engine speed.

$$\text{BSFC} = \frac{\text{Amount of fuel consumed (g)}}{\text{Brake power (kW)} \times \text{Duration of time(h)}} \qquad [\text{g/kWh}]$$

$$\text{BSFC}_{1\ \text{B0}} = \frac{240}{14.3 \times 0.1667} = 100.7\text{g/kWh}$$

In the same way we can find BSFC for all blends at the specified engine speed as shown in the tables 11, 12 and 13 bellow.

Note: duration of time for BSFC test for respective engine speed for all blends is 10 minute.

Table 11 BSFC data for B0

SNo.	1	2	3	4	5	6
N (rpm)	1140	1329	1519	1709	1899	2089
Gram (g)	240	228	224	210	179	168
BSFC in g/kwh	100.7	76	63.6	105	107.4	162.6

Table 12 BSFC data for B10

SNo.	1	2	3	4	5	6
N (rpm)	1140	1329	1519	1709	1899	2089
Gram (g)	300	320	318	286	306	305
BSFC in g/kwh	128.5	120	107	90.3	92.7	93.8

Table 13 BSFC data for B20

SNo.	1	2	3	4	5	6
N (rpm)	1140	1329	1519	1709	1899	2089
Gram (g)	335	296	278	223	245	232
BSFC in g/kwh	146.7	112.6	95.3	71.74	76.36	73.26

Table 14 Combined data for engine brake power, torque and BSFC

SNo.	N(rpm)	B0			B10			B20		
		P_b	T_b	BSFC	P_b	T_b	BSFC	P_b	T_b	BSFC
1	1140	14.3	119.78	100.7	12	100.5	130	10	83.76	138.6
2	1329	18	129.3	76	15	107.78	112	14.3	102.75	110.35
3	1519	21.12	132.77	63.6	18	113.2	90	19.3	121.33	86
4	1709	12	67	105	20	111.7	78	8	44.7	139.5
5	1899	10	50.3	107.4	12.4	62.35	101.6	9.3	46.76	119.35
6	2089	6.2	28.34	162.6	8.6	39.3	128	4.3	19.65	191

4.2.1. Power characteristics

Figure 15 which is potted from results stated from table 5 to 7 illustrates the engine brake power output at low to high engine rpm. B20 is minimum brake power output at low and high engine speed from all fuels. B0 also minimum brake power output at low engine speed and maximum at 1519rpm engine speed. Results in brake power output increases as engine speed increasing to some extent and then reduces as the speed increase more during the test.

A close resemblance occurred at low speed indicating little difference in output between the fuels. However, at higher speed, a clear gap appeared between the alternatives and reference fuel.

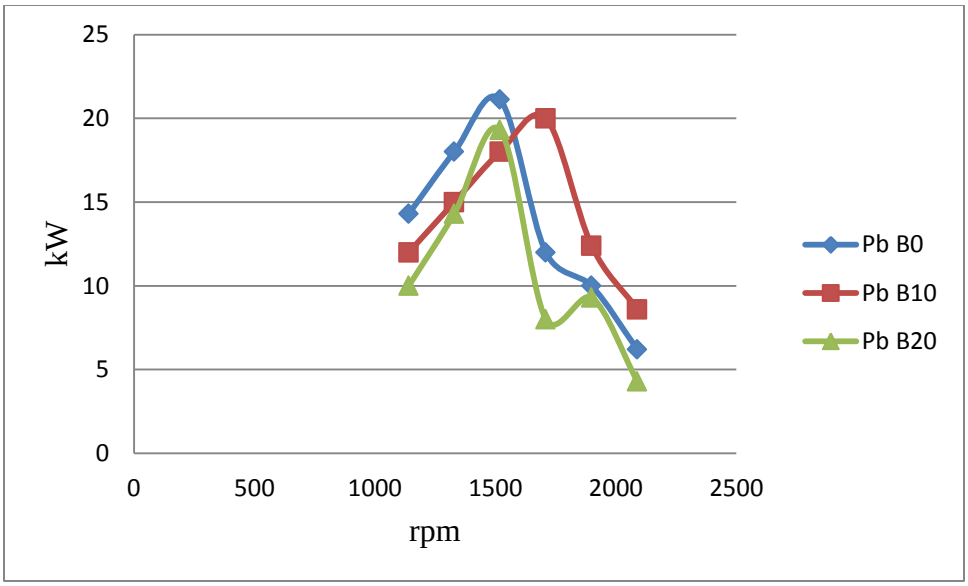


Fig. 15 power output characteristics

The brake power reduction was 16% at lower engine speed for B10 and 7% at 1899rpm (higher engine speed) for B20 by taking B0 (diesel fuel) as a reference fuel.

The overall brake power reduction for blends was expected because neat avocado biodiesel has got higher viscosity, poor atomization and lower heating value than neat diesel fuel. As fuel viscosity increases it requires higher injection pressures to break fuel drops in to very fine droplets, conventional diesel engine fuel system is designed for lower viscous diesel fuel and it is not exactly fit for higher viscous fuels. Hence larger the original drop size emitted by the injector, the quicker and more efficient atomization process will not occur. If the atomization is not efficient as required, the small droplets of liquid fuel evaporate to vapor slowly as compared to low viscous fuel. Due to this the fuel vapor mixing with in the combustible A/F ratio will be delayed and associated self-ignition to provide complete combustion will be less efficient, thus comparatively lower fuel conversion efficiency can be achieved.

4.2.2. Torque characteristics

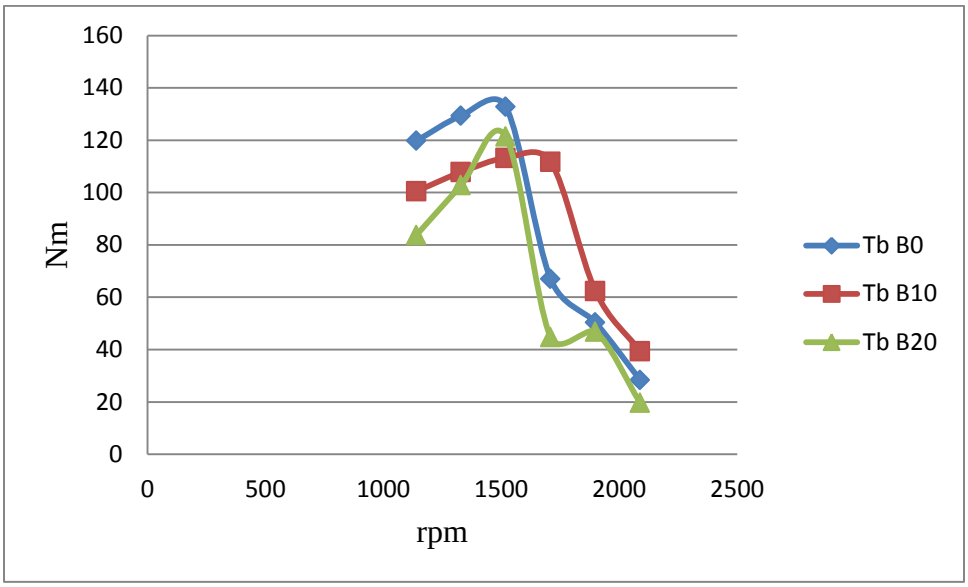


Figure 16 Torque output characteristics

As Figure 16 illustrates similar variation to power characteristics were observed, except that maximum torque for all type fuels was obtained at lower rpm around 1519rpm. However, the torque variation among diesel fuel and various blends was slightly higher at low to medium speed and closer pattern was observed at maximum rpm operations.

The brake torque reduction from 16% for B10 up to 30% for B20 at 1140rpm was observed. From the experimental test using the base fuel and the alternative fuels as engine speed is increasing from 1519rpm to 2089rpm the brake torque output is continuously decreasing as engine speed increasing.

However, the brake torque variations among diesel fuel and various blends was slightly Similar from the lower to the higher engine speed and a closer pattern was observed at higher rpm (1899 to 2089rpm) operations.

4.2.3. Brake Specific fuel consumption

The fuel consumption is determined by measuring the amount of gram consumed by the engine for the given time (10min.) and brake power.

In this study, the brake specific fuel consumption (BSFC) was taken as a performance indicator to compare the fuels. Figure 17 shows the BSFC plots with engine speed for the fuels. Diesel had the lowest BSFC throughout the test. The BSFC for blends and neat diesel fuel was higher at lower speeds and slightly lower consumption was observed at higher engine rpms.

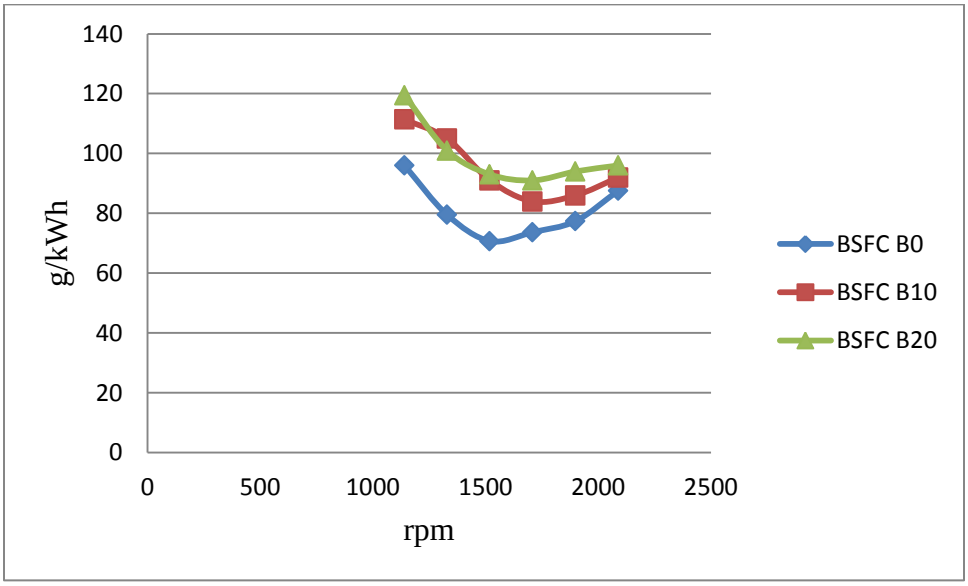


Figure 17 BSFC characteristics

The fuel consumption had increased as blends percentage increased up to 1519 engine rpm and lower after 1519 rpm of engine speed.

The curves showed that the specific fuel consumption at low speeds is high. According to the researcher's believe the major portion of the fuel is consumed to overcome the engine friction. It is possible to see that the trend of the curves for all blends is similar and comparable with that of the petrodiesel. But the BSFC increases as the percentage of the biodiesel increase in the blends.This may be is due to that biodiese is an oxyginated fuel. The higher fuel viscosity may also reduce the quality of fuel atomization, and could result in higher gas emission and fuel consumption. The increase in BSFC for biodiesel blends was understandable as the bio diesels

have less energy than the diesel. The higher the avocado oil contents in the biodiesel, the lower their heating values, resulting in higher BSFC.

5. SUMMARY, CONCULUSIONS AND RECOMMENDATIONS

The main aspiration of the research is to produce and compare the performance characteristic of biodiesel produced from avocado seed with that of petro diesel in the existing four stroke cycle diesel engine without doing modifications. The results from the research are illustrated as follows.

5.1. SUMMARY

Avocado seed are waste materials that are thrown away after the flesh is taken and it is available in juice house in large amount as a waste, so using the seed for biodiesel production gives two advantages that is for waste management and production of alternative fuel.

The performance test results depict the tested blends (B5, B10, B20, and B40) perform almost similar when compared with the performance of petro diesel. The torque and power performances get reduced and fuel consumption increase as the percentage of biodiesel in the blends increase. This is because of the fact that biodiesels are oxygenated fuels and hence has less energy content compared to petro diesel. But this little reduction in performance can be compensated with a lot of advantages of biodiesel like its better lubricity, renewability, degradability, very less contribution to global warming,

The flash point of avocado seed biodiesel is 175^0Cwhich is higher than that of pure petro diesel which is 90^0C. Therefore biodiesel is safer to fire hazard during storage and custody transfer of fuel and the cloud point, the lowest temperature at which the biodiesel starts to form haze or cluster of wax is 9^0Cwhich is higher than pure diesel fuel with a cloud point of 2.5^0C. Hence the biodiesel produced from avocado seed has to be used in a climate with a temperature above 9^0C without any modification of the fuel system components and without additives which lowers the freezing point of the fuel.

The brake power decreased when the percentage of the biodiesel in the blend increased due to its lower calorific value of the biodiesel.

5.2.Conclusions

- In thesis work crude avocado seed oil extracted on small scale was selected for biodiesel production. It was produced by means of transesterification process, which can be described as a renewable energy sources.
- Biodiesel characterization was done in national petroleum fuels organization, and the result of all important properties in the range of ASTM D 6751 and EN 14214 biodiesel specifications. Neat avocado seed biodiesel has got slightly higher kinematic viscosity, flash point and density.
- The engine test was carried out on a chassis dynamometer on 4 stroke diesel engine with neat diesel to take base line, and with B_{10} and B_{20} to evaluate the performance characteristics of bio-diesel blend. Performance parameters of the engine with two different bio-diesel blends were investigated and compared with that of diesel fuel. The brake power was generally lower throughout the engine speed range due to the lower calorific values of the blended fuels. The reduction in brake power is more at higher engine speeds.
- BSFC for the biodiesel fuels were slightly higher over the entire engine speed. This is probably because of lower calorific values of biodiesel.

5.3. Recommendations

- Biodiesel washing is a very important step in the production process of the biofuel in order to remove excess catalyst, glycerol, and glycerides not fully reacted that would increase the viscosity of the fuel and detrimental to an engine. The biodiesel in this research is washed only two times which I feel is not enough. Hence I recommend the biodiesels to be washed more than two times.
- Important properties of biodiesel are dependent not only on the type of feed stock also on accuracy and control of production process. Before starting the ester production process the crude oil must be free from water and impurities, so that adequate purification and water evaporation is needed.

- During reaction controlling molar ratio of reactants reaction time, temperature, catalysts are very essential. Therefore computer monitored control of overall production process and sample characterization is recommendable before usage and Water and impurity free storage and safety handling system is essential.
- The performance test is done on a chassis dynamometer which will not give more reliable result than engine dynamometer and limited blending ratios. With this test only it is difficult to exactly conclude the final result. Hence I recommend the research has to be done with engine dynamometer and different blending ratios in order to get better result.
- Lastly, I recommend the Department of Mechanical and Vehicle Engineering of Adama science and technology university to Set–up engine dynamometer which is very important to make a research work on renewable energy sources like bioethanol ,biodiesel from different feed stocks so that more reliable result on performance and emission analysis will be obtained.

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