ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Performance Testing of Castor Biodiesel with Additives in Diesel Engine

A Project Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of

Master of Science

In

Automotive Technology Teacher Education

By

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Department of Mechanical and Vehicle Engineering

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Adama

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CANDIDATE'S DECLARATION

We hereby declare that the work which is being presented in the this project ''***Performance Testing of Castor Biodiesel with Additive in Diesel Engine***" in partial fulfillment of the requirements for the award of the degree of master of science in automotive technology teacher education is an authentic record of our own work carried out from February 2015 to June 2015 under the supervision of N. Ramesh Babu, Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Ethiopia.

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

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

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ACRONYMS AND SYMBOLS

ASTM	American Society for Testing and Materials
ASTU	Adama science and technology university
B5	5% biodiesel and 95% diesel fuel
B6	6% biodiesel and 94% diesel fuel
B20	20% biodiesel and 80% diesel fuel
B100	100% biodiesel
BSFC	brake specific fuel consumption
CO_2	carbon dioxide
CP	cloud point
CH_3ONa	sodium acetate
CH_3OK	potassium acetate
COME	castor oil methyl ester
cc	cubic centimeter
CN	cetane number
DIN	measurement for photo graphic speed
DME	20 dimethyl ether
DMC	dimethyl carbonate
DTBP	di-t-butyl peroxide)
DEE	Diethyl ether
EHN	2- ethyl-hexyls nitrate
EN 14214,	United kingdom standard
FAME	Fatty Acid Methyl Ester
FFA	fatty acid methyl ester
gm	gram

H_2SO_4	sulpheric acid
JOME	jatropha oil methyl ester
kg	kilo gram
KOH	potassium hydro oxide
ml	mili liter
mn	
Nox	oxides of nitrogen
NaOH	Sodium hydro oxide
PP	pour point
PH	measure of acidity or alkalinity
RME	Rapeseed methyl ester
St	short ton
TVET	technical and vocational education and training
UV	ultra violate
VOC	volatile organic compounds
wt	weight
	Density
^0C	degree centi grade

Project Overview

*Our master's project title is ''**Performance Testing of Castor Biodiesel with Additive in Diesel Engine''** which will burst a new way in the production and usage of biodiesel with additives in order to minimize the amount of exhaust emission. The main focus of the project is in the reduction of* NO_x *on biodiesel blend from castor seed oil and diesel fuel. The driving force for large-scale use of biodiesel has been the need to reduce the harmful emissions that result from the burning of petroleum oil as well as our dependence on diminishing reserves of petroleum oil. The project has five parts. The first part deals with the background of the study, statement of the problem, objectives, scope and significance of the study. In part two related literature was reviewed. The third part deals with the laboratory work of the biodiesel production and blend formation. In addition to this performance test of the biodiesel was also performed. In this part oil from none edible plant feedstock has been obtained using oil extraction from castor seeds and blended with diesel fuel. The preliminary tests like the acid value, density and viscosity have been done to ascertain the quality of the oil. Transesterification was done using methanol and potassium hydroxide as a catalyst. The optimum conditions for transesterification were investigated. The engine test parameters was investigated; brake specific fuel consumption, thermal efficiency, brake horse power and exhaust temperature was compared to commercial diesel. In part four discussions about the previous part were done and at last conclusion and recommendation was done on the overall project work. The engine brake power, brake torque and brake specific fuel consumption (BSFC) were measured, and compared with that of the same engine working with petroleum diesel, B20 with and without additives. Performance of the engine was generally better with B20 with additives by 11% improvement than that of B20 blend without additives.*

Keywords: Castor Seed, Castor seed Oil, Biodiesel, Transesterification, and Blend

1. INTRODUCTION

1.1. Background

In today's competitive business environment transportation plays a great role. When transportation is taken as issue different types of transportation system is taken in to consideration. Amongst the transportation system dry land transportation takes most of the role play in this transportation sector. Different types of vehicle categories that use different types of fuels are in use nowadays. Among the types of fuels used today diesel fuel has greater percentage and most of vehicles from light duty to heavy duty are those which use this diesel fuel. Diesel fuels that are used for engine is produced from fossil fuel. As century passes this fossil fuel will be ended and the power source for engines becomes one of the global troubles.

Due to this scarce resource used for the vehicle as energy source, it should be a global issue to find other sources of energy for vehicles. One of the promising sources of vehicle fuel energy is bio degradable fuel. This is because bio fuel is one of the renewable sources of energy. In addition to this bio fuels are considered to be carbon–neutral. Its utilization can contribute to the carbon dioxide emissions reduction.

Nowadays biodiesel has received a great deal of attention because of the advantages associated with its biodegradability and its classification as a resource for renewable energy [1]. This biodiesel is composed of fatty acid methyl esters (FAME) and is synthesized usually via vegetable oils (triacylglycerols) transesterification with low-molecular-weight alcohols. The currently the use of biodiesel around the world are mostly based on a biodiesel–diesel blend. In addition to this use of additives in the biodiesel- diesel blend enhance performance of an engine and minimize exhaust emission. And it is believed that the additive is the most visible option to introduce the biodiesel as complete alternative fuel for mineral diesel [2].

The availability and sustainability of biodiesel feedstocks will be the crucial determinants in the popularization of biodiesel. From different literatures it has been found that feedstock alone represents 75%-80% of the overall biodiesel production cost. Therefore, selecting the high oil yield feedstock is vital to ensure low production cost of biodiesel [3]. Biodiesel (a mixture of mono-alkyl esters of saturated and unsaturated long-chain fatty acids) generally has a higher cloud and pour point (CP and PP), density, and kinematic viscosity as well as the acid value compared to diesel. The cold flow properties (CP and PP) are used to

characterize the cold flow operability of a fuel because the pour point of a fuel affects the utility of the fuel, especially in cold climate conditions [4].
Among the parameters of fuel used in the engine, density is important for various diesel engine performance aspects. The use of fuel with a high kinematic viscosity can lead to undesired consequences, such as poor fuel atomization during spraying, engine deposits, wear on fuel pump elements and injectors, and additional energy required to pump the fuel [5].

The fuel energy content has a direct influence on the engine power output. The biodiesel energy content is less than that of mineral diesel, therefore using of additive mostly influence the energy continent of the Castor Oil Methyl Ester fuel [6].

The development of biodiesel is a recent and at its initial stage in Ethiopia. Ethiopia has ample potential and opportunities for the production and utilization of biodiesel from castor oil, palm oil, and neem instead of petroleum. However, the country has not yet benefited from those biodiesel feedstocks because of educated human power and economical constraints. Among the potential biofuels, Castor bean is a non-edible biodiesel feedstock to substitute the consumption of fossil fuel. In addition, it is widely available and has no any other commercial purpose, has high oil content and yields per hector, grows in marginal land and has a resistance for variable climatic and soil conditions [7].

A result of transesterification experiments of castor oil with methanol has shown that the castor biodiesel has very interesting properties of fuel which is suitable to be used in diesel engine with additive. Biodiesel is currently undergoing a phase of attractive research by several universities and organizations [8].

1.2. Statement of the Problem

One of the major reasons hindering the use of biodiesel is its filter plugging temperature, which is higher than that of diesel. Cloud point (CP) and pour point (PP) temperatures have been shown to be well correlated with filter plugging point, which primarily determines the operability of a diesel engine in cold weather. Many biodiesel cold flow additives are available in the market that claims to reduce pour point. The additives in general worked better for ethyl esters than for methyl esters.

Today in the world, there is a growing increase in biofuels consumption, mainly ethanol and biodiesel as well as their blends with diesel that reduce the cost impact of biofuels while retaining some advantages of it. This increase is due to several factors like decreasing the dependence on imported petroleum; providing a market for the excess production of vegetable oils and animal fats; using renewable and biodegradable fuels; reducing global warming due to its closed carbon cycle by CO_2 recycling; increasing lubricity and reducing substantially the exhaust emissions of carbon monoxide, unburned hydrocarbons and particulate emissions from diesel engines. However, there are major drawbacks in the use of biofuels blends as NO_x tends to be higher, the intervals of engine fuel filters replacement is reduced and degradation by chronic exposure of varnish deposits in fuel tanks and fuel lines, paint, concrete, and paving occurs as some materials are incompatible. Here, fuel additives become indispensable (crucial) tools not only to decrease these drawbacks but also to produce specified products that meet international and regional standards like EN 14214, ASTM D 6751, and DIN EN 14214, allowing the fuels trade to take place. Additives improve ignition and combustion efficiency, stabilize fuel mixtures, protect the engine from abrasion and wax deposition and reduce pollutant emissions, among other features.

1.3. Objectives

1.3.1. General Objective

To test the performance of castor biodiesel with additives in pre heated diesel engine after burning of the fuel & reduce NO_x.

1.3.2. Specific Objectives

- To develop efficient methods for conversion (transesterification) of the castor oil into biodiesel (methyl esters).
- To prepare blends of biodiesel with commercial diesel and determine the biodiesel properties.
- To prepare the additives which reduce the NO_x
- To perform engine testing of the castor seed oil biodiesel with additives in diesel engine.

1.4. Significance of the study

The project indicates how and why the alternative fuel is used instead of using pure diesel fuel & show how to reduce NO_x which is produced in the presence of pre heating process. After the accomplishment and implementation of the project, it is expected to have the basic significances:

- Reduce the net emissions of greenhouse gases.
- It promotes the castor oil biodiesel by pre heating mechanism even if the viscosity of the Castor Oil Methyl Ester is high.
- Limit amount of high-octane additives.
- Biodiesel reduces the country's dependence on imported oil, lowering the trade deficit, and ensuring a dependable source of fuel.
- Farmers see an increased demand for production of castor seed grain which helps to produce biodiesel and stabilize expected fuel prices.
- The quantity of the environment pollution gases will be reduced.
- Blends of biodiesel reduce carbon monoxide better than any reformulated diesel fuel.

1.5. Scope of the Project

This project included only testing of biodiesel produced from castor seed and diesel blends with diethyl ether additive. Exhaustive performance testing to see the detailed effect of the blends has not included in this project due to time constraint. Testing for the compatibility of the blends with hardware of the engine had included.

1.6. Limitation of the study

The result of this project is more fruit full if it had included many tests of diesel – biodiesel blend and addition of additives with many different ratios. However, due to time constraints, lack of experience and testing equipment limitation, we have been forced to limit the project only to comparison of the performance of biodiesel blend B20 with additive, B20 without additives and pure diesel fuel in four stroke diesel engines.

2.0. REVIEW OF LITERATURE

2.1. Introduction

In today's competitive business environment transportation plays a great role. When transportation is taken as issue different types of transportation system is taken in to consideration. Amongst the transportation system dry land transportation takes most of the role play in this transportation sector. Different types of vehicle categories that use different types of fuels are in use nowadays. Among the types of fuels used today diesel fuel has greater percentage and most of vehicles from light duty to heavy duty are those which use this diesel fuel. Diesel fuels that are used for engine is produced from fossil fuel. As century passes this fossil fuel will be ended and the power source for engines becomes one of the global troubles [1].

Due to this scarce resource used for the vehicle as energy source, it should be a global issue to find other sources of energy for vehicles. One of the promising sources of vehicle fuel energy is bio degradable fuel. This is because bio fuel is one of the renewable sources of energy. In addition to this bio fuels are considered to be carbon–neutral. Its utilization can contribute to the carbon dioxide emissions reduction. Even if biodiesel has environmentally friendly character it has low energy content than that of diesel fuel which directly influences the engine power. The blending of biodiesel with additive that have less energy continent usually causes the energy content of the fuel to decrease depending on the additive energy continent and portion [9].

2.2. Characteristics of castor seed oil and extraction methods

2.2.1. Toxicity of Castor seed and usage of castor oil

The seeds of Castorcurcas contain the highly poisonous toxalbumincurcin, a lectin dimer. It also contains carcinogenic phorbol. But this is being the fact at some places the seeds of carcass are sometimes eaten after roasting. Even if roasting reduces toxicity it is a skin irritant, and ingesting as few as three untreated seeds can be fatal to humans [10].

The castor plant that is generally cultivated for the purpose of extracting castor oil is Castorcurcas. The seeds are the primary source from which the oil is extracted. The major goal of castor cultivation, therefore, is performed for the sake of extracting castor oil. Analysis of Castorcurcas seed shows the following chemical compositions; Moisture: 6.20%; Protein: 18.00% , Fat: 38.00%, Carbohydrates: 17.00% , Fiber: 15.50%, Ash: 5.30% [10].

The oil content of castor seed is 25-30% in the seed. The oil contains 21% saturated fatty acids and 79% unsaturated fatty acids. The oil from the castor seed has very high saponification value and being extensively used for making soap in some countries. The castor seed oil is mainly used as fuel in place of, or along with kerosene stoves. Castor seed oil can be upgraded to higher grade fuel by transesterification process. It is significant to point out that, the non-edible vegetable oil of Castorcurcas has the requisite potential providing a promising and commercially viable alternative to diesel oil since it has desirable physical, chemical and performance characteristics comparable to diesel. Cars could be run with castorcurcas blend without requiring much change in design [10].

2.2.2. Variations in the Yield of Castor Oil

It is often considered that a more effective extraction technique would yield greater quantities of oil. This is partly inaccurate, since an effective extraction method would only yield the optimum quantity and not more than that. The optimum oil content in castor plants varies between species and genetic variants. Climatic and soil conditions generally affect the yield of the oil as well. However, improper processing techniques such as prolonged exposure of the harvested seeds to direct sunlight can impair the oil yield considerably. The maximum oil content that has been reported in Castorseed has been close to 47%. However, the accepted average is 40% [10].

2.2.3. Methods and Devices for Castor Oil Extraction

Castor seed oil can be extracted in many different ways. One of the methods is oil presses. This method has been used for the purpose of oil extraction as simple mechanical devices either powered or manually driven. Among the different oil presses that are used for castor oil extraction, the most commonly used presses include the Bielenberg ram press. The Bielenberg ram press involves the traditional press method to extract oil and prepares oil cakes as well as soaps. It is a simple device that yields around 3 liters of oil per 12 kg of seed input [11].

The other type of oil extraction method is by use of oil expellers. The most commonly used ones are the Sayari oil expeller and the Komet Expeller. The Sayari expeller is a diesel-operated oil extraction device [11].

As technology improves more and more things change. Methods like ultrasonication have been discovered to be effective in increasing the percentage of castor oil that can be extracted using chemical methods like aqueous enzymatic treatment. The optimum yield for such methods has been discovered to be around 74%. Castor oil extraction methods are still being researched. The goal of such research is to discover methods to extract a greater percentage of castor oil from the seeds than the current procedures allow [11].

2.3. General Overview of Biodiesel

Biodiesel is type of fuel which comprised of mono-alkyl esters of long chain fatty acids that are derived from vegetable oils, animal fats, and mixtures, and is produced by transesterification. It is also known as the product of the reaction of alcohol, such as methanol or ethanol with oil or fats. Biodiesel is a substitute of fossil fuel which is used for diesel engine. Biodiesel is biodegradable and deemed to be less toxic than petroleum diesel. Biodiesel a Fatty Acid Methyl Esters (FAME) is esterified oil produced from a variety of sources such as waste cooking oil, tallow, palm oil and canola oil. Biodiesel has slightly lower energy content than conventional diesel although this is not significant when operating vehicles on biodiesel blends. Blending biodiesel with diesel fuel offers improved lubricity and reduced emissions. Most diesel engine manufacturers warrant their engines for use with biodiesel blends up to 5% with conventional diesel (B5) as long as the resultant blend meets the diesel standard [11].

Biodiesel blends of up to B100 are currently used in fleet operations. Blends of biodiesel above B20 usually require engine modification and the fleet operator assumes legal responsibility for the impact of the use of the blend on the engine. Concerns about biodiesel raised by engine manufacturers in the World Wide Fuels Charter include; (a) biodiesel may be less stable, so precautions should be taken to prevent problems from fuel oxidation, (b) biodiesel requires special care at low temperatures to avoid viscosity problems and consequent risks of corrosion gum residue build-up may be higher than with conventional diesel and biodiesel produced from different feed stocks can have significantly different fuel quality characteristics including cold flow properties, density and oxidation stability [12].

2.4. Biodiesel Standards

For the biodiesel to be used as fuel in diesel engines it should be produced and handled in such a way that the variations in its properties and its performance characteristics will be less than or equal to what the consumer is used with diesel fuel [13].

For the standardized biodiesel a single, widely accepted standard for biodiesel is not available. Instead, the standard ASTM D6751 was developed for the United States, the CEN EN14214 Standard for the European Union (EU), and other regions also have established alternative standards [13].

2.5. Different ways how biodiesel can be used

Biodiesel has been approved by the US government to be used as a blend to petroleum diesel fuel in different concentrations. B5: is the blend of 5% biodiesel and 95% petroleum diesel. And this blend is used in pumps. B6-B20: These labels found on fuel pumps denote a fuel blend of 6-20% biodiesel to 94-80% petroleum diesel [14].

Based on ASTM D975 standard nearly every manufacturer approves the use of up to 5% biodiesel (B5) when blended with diesel fuel that meets its appropriate specifications. In most cases many industries believe that blends up to 20% (B20) causes not harmful to engine performance. Most US automobile engine and fuel injection equipment companies strongly discourage the use of blends over 20%, mainly due to the possible impacts of higher blends on equipment and fuel systems that have not been carefully tested [15].

Blending biodiesel with petroleum diesel compensates for many cold flow problems through dilution. Blending without additives bring to cold flow properties associated with a particular methyl ester is the result of its feed stock. In blending to levels of up to 20% (B20) the use of additives becomes more practical and more effective. In the course of blending biodiesel with diesel to warm up the biodiesel may be need needed. This is to ensure successful blending of the two fuels into a single mixture. The B100 biodiesel will let itself to easier mixing with diesel it is at temperatures of at least 25-30° F [15].

2.6. Properties of biodiesel

There are many properties of biodiesel that should be considered. One the property to be considered is cloud point. As far as cloud point is considered there are no minimum or maximum requirements for biodiesel to be reported. The Cloud Point is the most conservative temperature at which components begin to rush from the fuel that may cause operability issues. Cloud Point results will vary significantly depending upon the feedstock from which the methyl ester is made [15].

The parameter Cold Soak Filtration test is an industry agreed upon parameter but opposed to an ASTM specification. There may be many producers and marketers of biodiesel that do not perform this procedure. However, there is a growing belief that this may be one of the best performance-based predictors of operability [15].

The acid number is a relative indicator of the acidic impurities, degradation and oxidation of the fuel. Free fatty acids arise in part through the hydrolysis of the feedstock fats and oils. Improper processing may also lead to higher values. These oxidative products are associated with fuel system deposits and corrosion. In addition to this property Free Glycerin value records the level of by-product glycerin that remains in B100. The Total Glycerin result measures the amounts of unconverted and partially converted fats and oils. Excessive levels of these components may lead to storage tank and fuel system filter plugging, along with engine fouling.

2.6.1. Combustion characteristics of biodiesel

Cetane Number is one of the parameter which shows rough equivalent to Octane Rating of gasoline. This value provides a measure of the ignition characteristics of the fuel in compression ignition engines. As combustion character flash Point is used in shipping and safety regulations to define flammable and combustible materials. The Flash Point is also used to ensure the residual methanol left in the fuel after biodiesel processing will not negatively affect combustion and other fuel system components [15].

2.7. Problems by using biodiesel fuel blends

There are some common problems that have been experienced when using biodiesel fuel includes which includes: Fuel line/filter clogging due, Degradation of the vessel's rubber fuel lines and gaskets and voided engine warranties for use of biodiesel blends above what the manufacturer recommends [14].

Although biodiesel can be used in most diesel engines with no modifications to the engine system, it is highly recommended that checking the engine manufacturer before using it. Some problems have been associated with its use in the environment, and your engine manufacturer can give you further guidance as to what biodiesel blends are acceptable for use and how to mitigate potential problems [16].

2.8. Performance Parameter of Engine Operation Using Biodiesel

2.8.1. Engine Performance

Biodiesel is known for its lower power and torque. It could produces about 3-5% less engine power and torque due to its lower value energy when compared to diesel. It is expressed in terms of kWh/liter of fuel or as Brake specific fuel consumption (BSFC) in gm/kWh [13].

2.8.2. Deposit and Clogging

Deposits and clogging problems are widely reported and are generally attributed to sub standard quality of biodiesel or due to its less oxidation stability and therefore engine wear is relatively more when run on biodiesel [13].

2.8.3. Pollution from engine exhaust

One of the advantages of biodiesel is its less air pollution due to its higher oxygen content and absence of "aromatic compounds" and sulphur. But the NO_x tends to be slightly higher compared to biodiesel which can be minimized by proper engine timing [13].

2.8.4. Cold-weather performance

Diesel engines that are operated in cold weather experience the problems of clogging of the filters and choking of the injectors. The use of flow improving additives of biodiesel and kerosene has been proved effective in the operating range of climate temperatures B100 tends to operate well at temperatures down to about 5°C. Additives reduce the range by about 5-8^0C [13].

2.9. Environmental benefits of biodiesel

The property of the biodiesel makes it a good alternative fuel to petroleum-based diesel oil. Biodiesel has many other environmental benefits, such as it is biodegradable, non-toxic, and has a low emission profile. Among the properties of biodiesel greenhouse effect is the one. Biodiesel on its one full life cycle basis for B100 with reductions in greenhouse gas emissions of 90% and B5 greenhouse emissions are 2 per cent lower than petroleum-derived diesel. In addition to this on a full life cycle basis B100 has significantly lower emissions of carbon monoxide (26–46%) and VOCs (22 –46%) compared to petroleum-derived diesel. B5 has a reduction in carbon monoxide emissions of almost 12% and a reduction in VOCs of 5 %. Particulate emissions from vehicles using B100 are reduced by 11–14% compared to petroleum-derived diesel. NO_X emissions from B100 are 16–30% higher than from petroleum-derived diesel. B5 has around an 11% increase in NO_X emissions [17].

2.10. Transesterification Reaction of biodiesel

Transesterification is the chemical conversion of the oil into its corresponding fatty ester. It's one of the most common methods used to reduce oil viscosity in the biodiesel industry. Catalysts are usually used to improve the reaction rate and yield. Because the reaction is reversible, excess alcohol is needed to be used to shift the equilibrium to the product side [18].

2.10.1. Homogeneous base and acid catalyzed transesterification

This type of transesterification reaction commonly uses alkali catalysts such as NaOH, CH_3ONa, CH_3OK and KOH. In the transesterification method the catalyst is dissolved into methanol by vigorous stirring in a small reactor. The oil is transferred into a biodiesel reactor and then the catalyst mixture is pumped into the oil. A successful transesterification reaction produces two liquid phases: ester and crude glycerol. The alkaline-catalyzed transesterification process is not suitable to produce esters from unrefined oils. For the purpose of saponification prevention during the reaction, FFA and water content of the feed must be below 2 wt. % and 0.05 wt. %, respectively. [19].

2.10.2. Heterogeneous acid and base catalyzed transesterification

Homogeneous catalysts showed greater performance toward transesterification to obtain biodiesel. Heterogeneous catalysts can be separated more easily from reaction products. Undesired saponification reactions can be avoided by using heterogeneous catalysts. They can enable the transesterification of vegetable oils or animal fats with high contents of FFAs [18].

2.10.3. Two-step acid - base catalyzed transesterification

This process involves a two-step process for the production of biodiesel from oils having high FFA. Initially, the acid catalyzed esterification reaction takes place to convert the FFAs present in the oil to esters. After the reduction of FFA, transesterification reaction was carried out, in which the pre-treated oil reacts with methanol using conventional base catalysts. This method of biodiesel production alleviates the draw backs of the esterification process requires longer time reaction to come to completion and transesterification problem of soap formation process [20].

2.10.4. Pre-treatment of acidic feed stocks

Many pretreatment methods have been proposed for reducing the high free fatty acid content of the oils, including steam distillation, extraction by alcohol, and esterification by acid catalysis. However steam distillation for reducing high free fatty acids requires a high temperature and has low efficiency. Because of the limited solubility of free fatty acids in alcohol, extraction by alcohol method needs a large amount of solvent and the process is complicated. Esterification by acid-catalysis makes the best use of the free fatty acids in the oil and transforms it into biodiesel. The catalysts used can be homogeneous acid-catalysts. An alternative approach to reduce the FFA is to use iodine as a catalyst to convert free fatty acids into biodiesel [21].

There are three categories of catalysts used for biodiesel production: alkalis, acids, and enzymes. Enzyme catalysts have become more attractive recently since it can avoid soap formation and the purification process is simple. Compared with enzyme catalysts, the alkali and acid catalysts are more commonly used in biodiesel production. The alkali and acid catalysts include homogeneous and heterogeneous catalysts. Due to the low cost of raw materials, sodium hydroxide and potassium hydroxide are usually commercially used as alkali homogeneous catalysts. These materials are the most economic because the alkali-catalyzed transesterification process is carried out under a low temperature and pressure environment, and the conversion rate is high with no intermediate steps [22].

2.10.5. Mixing and neutralization

The purpose of mixing methanol with the catalyst is to produce methoxide which reacts with the base oils. Most of the catalysts are in solid form and do not readily dissolve into methanol and needs to be stirred. Once the catalyst completely dissolves in the methanol, the methoxide is ready to be added to the oil. Once the methoxide is added into the oil, a neutralization reaction will immediately start. More catalyst is needed to be added to complete the reaction [19].

2.10.6. Transesterification and separation

When the catalyst and oil are mixed and agitated in a reaction vessel, a transesterification reaction will start. A stirred reactor is usually used as the reaction vessel for continuous alkali-catalyzed biodiesel production. If the free fatty acid level or water level is too high, it may cause problems downstream with the saponification and the separation of the glycerol by-product. Therefore, the amount of water and free fatty acids in the feedstock oil should be monitored during the reaction. Once the transesterification reaction is completed, two major products exist: esters and glycerol. The glycerol phase is much denser than the biodiesel phase and settles at the bottom of the reaction vessel. The reaction mixture is allowed to settle in the reaction vessel in order to allow the initial separation of biodiesel and glycerol, or the mixture is pumped into a settling vessel [19].

Both the biodiesel and glycerol are contaminated with an unreacted catalyst, alcohol, and oil during the transesterification step. Soap that may be generated during the process also contaminates the biodiesel and glycerol phase. It is suggested that although the glycerol phase tends to contain a higher percentage of contaminants than the biodiesel, a significant amount of contaminants is present in the biodiesel. Therefore, crude biodiesel needs to be purified before use [19].

2.10.7. Refining crude glycerol

Even if the biodiesel is the desired product from the transesterification reactions, the refining of glycerol is also important due to its numerous applications in different industrial products such as moisturizers, soaps, cosmetics, medicines, and other glycerol products. It is one of the few products that has a good reactivity on sump oil, and is extremely effective for washing shearing shed floor, so it can be used as a heavy duty detergent and degreaser [23].

The unused alkali catalyst is usually neutralized by an acid. In more sophisticated operations, the glycerol is distilled to 99% or higher purity and sold in different markets. After the re-neutralization step, the alcohol in the glycerol phase can be removed through a vacuum flash process. The alcohol vapor is condensed back into liquid and reused in the process [21].

2.10.8. Purification of crude biodiesel

The next step after separation from the glycerol phase is crude biodiesel. Biodiesel is could be mainly contaminated with residual catalyst, water, unreacted alcohol, free glycerol, and soaps that were generated during the transesterification reaction. So it the biodiesel goes to the neutralization step and then passes through an alcohol stripper before the washing step. In some cases, acid is added to crude biodiesel to neutralize any remaining catalyst and to split any soap. Soaps react with the acid to form water soluble salts and free fatty acids. Neutralization before the washing reduces the materials required for the washing step and minimizes the potential for emulsions being formed during the washing step. The purpose of this step is to wash out the remnants of the catalyst, soaps, salts, residual alcohol, and free glycerol from the crude biodiesel. Generally, three main approaches are adopted for purifying biodiesel: water washing, dry washing, and membrane extraction [24].

Water washing is one of the purifying biodiesel. In water washing since both glycerol and alcohol are highly soluble in water the method is very effective for removing both contaminants. It also can remove any residual sodium salts and soaps. Water washing starts from the usage of warm distilled water. Warm water prevents the precipitation of saturated fatty acid esters and retards the formation of emulsions with the use of a gentle washing action. After washing several times, the water phase becomes clear and the biodiesel and water phases are separated by a separation funnel or centrifuge. The remaining water can be removed from the biodiesel by heating the biodiesel [25].

Dry washing is another method for purifying the biodiesel. In this method ion exchange resin or a magnesium silicate powder are used in order to remove impurities. These two dry washing methods can bring the free glycerol level down and is reasonably effective for removing soaps. Both process have the advantage of being waterless and thus eliminate many of the problems related with water [25].

2.11. Characterization of biodiesel fuels

The produced biodiesel should be analyzed using sophisticated analytical equipment to ensure whether it has met standard or not. Even though a few specifications have been set, the ASTM D6751 and EN14214 standards are the most commonly used standards in the characterization of the biodiesel. Some properties in the standard can reflect the properties of the chemical compounds that make up the biodiesel, and other properties provide an indication of the quality of the production process. Biodiesel standards identify the parameters that pure biodiesel must meet before being used as a pure fuel or being blended with distillate fuels [26].

The most important aspects of the biodiesel product are the completion of the reaction, the removal of the free glycerol, residual catalyst and alcohol, and the absence of free fatty acid. If the transesterification reaction is not complete then triglycerides, diglycerides, or monoglycerides may be left in the final product. Fuel with excessive free glycerol may plug the fuel filter sand cause combustion problems in the diesel engine. The ASTM standard requires the total glycerol to be <0.24% of the final biodiesel product [25].

Also EN 14214 standards is used to limit the amount of alcohol. Residual methanol of little amount (1%) can lower the flashpoint of the final biodiesel product from 170^0C to <40^0C. Specific value for the residual catalyst is limited by the specification on levels of sulfated ash [27].

2.12. Storage of Biodiesel Product

Long time storage of biodiesel should be settled. Biodiesel is safe to store and the properties of biodiesel should conform to respective standards after it has been stored for a longtime. Factors to be considered in the storage of the biodiesel include exposure temperature, oxidative stability, fuel solvency, and material compatibility. The temperature of stored biodiesel should be controlled so as to avoid the formation of crystals. The storage temperature of most pure biodiesel is generally kept between 7 and 10^0C [21].

When biodiesel should be stored for long period of time, stability of biodiesel is an important property. Poor stability can lead to an increased acid value and fuel viscosity and to the formation of gums and sediments. For this reason if the duration of storing biodiesel or biodiesel blends is more than 6 months, it should be treated with an additive [28].

2.13. Recent improvements in biodiesel fuel

In today's technological condition pure biodiesel (RME) such as B100 cannot be used for passenger cars due to the problem of engine oil dilution. Another favorable modification that can be performed on fats and oils to be used as fuel additives is ozonization. Ozonization of fats and oils is a known process. Furthermore the addition of ozonized oils affects the thermodynamics and kinetics of biodiesel crystal formation. [29].

The advanced automobile technology demands the necessity for further chemical modification of present day biodiesel (FAME) in order to withstand future demands. The drastic increase in the production of biodiesel in the past few years has changed the glycerol markets, and it also created a necessity to find value added outlets for the over-produced glycerol [29].

2.14. Physicochemical properties of biodiesel

The physical and chemical properties of biodiesel such as: viscosity, density, bulk modulus of compressibility, sound velocity, cetane number, iodine value, surface tension, thermal conductivity, chain length, heat capacity and fuel composition etc have a significant effect on NO_x emissions. Fuel viscosity has significant effect on NO_x emissions. Nox formation is a function of viscosity and increase in NO_x with increasing viscosity at low temperatures. The kinematic viscosity of biodiesel is greater than that of diesel fuel and reduces fuel leakage during injection and leads to increased pressure as well as advanced injection timing. The advance in injection timing facilitates increased fuel mass injected which in turn results in increased NO_x emissions [30].

Blend of 60 vol % biodiesel and paraffinic solvent (Norpar-13) displays the same bulk modulus of compressibility as a diesel fuel. So one method for straggling the "biodiesel NO_x effect" is to use highly paraffinic diesel fuels, such as F–T diesel as the diesel base stock. The higher cetane number of biodiesel implies shorter ignition delay which reduces the combustion temperature as well as residence time, consequently less NO_x formation. It is suggested that high CN of biodiesel tend to increase peak pressure and temperature due to shortened ignition delay which leads to enhanced NO_x formation [31].

2.15. Main Factors Affecting the Yield of Biodiesel

2.15.1. Alcohol quantity

Amongst the many of the factors that affect biodiesel yield molar mass ratio of alcohol to triglyceride. The ratio for transesterification reaction in most cases requires 3 mol of alcohol for 1 mol of triglyceride to produce 3 mol of fatty acid ester and 1mol of glycerol. In order to change oil completely to ester excess of alcohol is used in biodiesel production. The yield of biodiesel is increased when the alcohol to triglyceride ratio is raised beyond 3 and reaches a maximum. But further increasing the amount of the alcohol beyond the optimal ratio will not increase the yield rather it will increase cost for alcohol recovery. In most investigations is 6:1, with the use of an alkali catalyst. When the percentage of free fatty acids in the oils or fats is high a molar ratio as high as 15:1 is needed when using acid-catalyzed transesterification [32].

2.15.2. Reaction time

It was also investigated that in the conversion process of oil to ester conversion rate of fatty acid esters increases with reaction time. At the starting time the reaction is slow due to the mixing and spreading of alcohol into the oil but as reaction time increase, the reaction proceeds very fast. The yield of the reaction reaches a maximum at a reaction time of less than 90 minute and then remains relatively constant with a further increase in the reaction time. In addition to this excess reaction time will lead to a reduction in the product yield due to the backward reaction of transesterification, resulting in a loss of esters and causing more fatty acids to form soaps [30].

2.15.3. Reaction temperature

Another factor of production yield of the biodiesel is temperature. It influences the reaction and yield of the biodiesel product. A higher reaction temperature can decrease the viscosities of oils and result in an increased reaction rate, and a shortened reaction time. When the reaction temperature increases beyond the optimal level, yield of the biodiesel product decreases because of saponification reaction of triglycerides. The reaction temperature must be less than the boiling point of alcohol in order to ensure that the alcohol will not leak out through vaporization [33].

2.15.4. Catalyst

Catalysts play a great role in the product yield of biodiesel. The type of catalyst concentration affects the yield of the biodiesel product. The most commonly used catalyst for the reaction is sodium hydroxide [34]. However sodium methoxide was identified to be more effective than sodium hydroxide because upon mixing sodium hydroxide with methanol a small amount of water will be produced, which will affect the product yield because of the hydrolysis reaction. This is the reason why the catalyst should be added into the methanol first and then mixed with the oil [35].

An increase in the concentration of the catalyst increases the conversion of triglyceride and the yield of biodiesel increase. This is because an insufficient amount of catalysts result in an incomplete conversion of the triglycerides into the fatty acid esters. The yield of the biodiesel reaches an optimal value when the catalyst (NaOH) concentration reaches 1.5 wt. % and then decreases a little with a further increase in catalyst concentration. The reduction of the yield of the biodiesel is due to the addition of excessive alkali catalyst causing more triglycerides to react with the alkali catalyst and form more soap [31].

2.16. Reduction of the NO_x emissions

Diesel engines emissions are considered as one of the major sources of environmental air pollution. These pollutants cause impacts the ecological systems, lead to environmental problems, and carry carcinogenic components that significantly endanger the health of human beings. It is commonly accepted that clean combustion of diesel engines can be fulfilled only if engine development is coupled with diesel fuel additive introduction. Additives are used to boost the combustion hence improves fuel economy at lower emission rates from the engine [36].

These NO_x emissions include high-pressure injection, turbo charging, and exhaust after treatments or the use of fuel additives which is believed to be one of the most attractive solutions [17].

2.17. Use of different additives

In the course of using biodiesel different types of additives such as metal-based, oxygenated fuel (diethyl ether, ethanol, and methanol), diesel–vegetable oil blends, antioxidant, cetane number improver etc. are generally used to reduce the NO_x emissions from biodiesel combustion product. By using ethanol into biodiesel as an additives reduces the NO_x emissions because of its having lower heating value [37].

The cetane number improver is used to reduce the biodiesel NO_x emissions by decreasing engine ignition delay and premixed combustion phase which implies to burn less fuel during the premixed combustion phase. The maximum combustion temperature would be decreased, which suppresses the NOx formation. Some effective cetane improvers such as 2- ethyl-hexyls nitrate (EHN), di-t-butyl peroxide (DTBP) are mostly used in biodiesel to reduce the NO_x emissions [37].

2.18. Types of Additives

2.18.1. Metal-Based Additives

Some metal-based additives are effective in lowering diesel emissions. They reduce diesel emissions by two ways. Firstly the metals react directly with carbon atoms thereby lowering the oxidation temperature. The additive is added as a metal-organic compound, and it is emitted in the particulate phase as oxide, on soot particles or forming new nanometer-sized particles by homogeneous nucleation of the additive [38].

2.18.2. Oxygenated Additives

Amongst the additives used in biodiesel or its blend, Diethyl ether (DEE) can be added to biodiesel fuels to suppress the NO_x emission. DEE is an excellent ignition enhancer and has a low auto ignition temperature. It is an aid for cold starting and ignition improver for diesel water emulsion. As to the experiment done by Iranmanesh 5% of DEE with diesel blend was the most effective combination based on performance and emission characteristics [39].

The additive 15% DEE is found to be the optimum blend with Jatropha oil methyl ester (JOME) on the basis of performance and emission characteristics. However that of 20% of DEE addition was more beneficial in reducing NO_x compared to other combination when using Pongamia biodiesel and diethyl ether as a fuel [40].

Another group of fuel additives is oxygenated compounds. Some oxygenate compounds used are ethanol,2,21-23 acetoacetic esters and dicarboxylic acid esters,24 ethylene glycol monoacetate,25 2-hydroxy-ethyl esters,26 diethylene glycol dimethyl ether, sorbitan monooleate and polyoxyethylene sorbitan monooleate,27 dibutyl maleate and tripropylene glycol monomethyl ether,28 ethanol and dimethyl ether,20 dimethyl ether (DME), dimethyl carbonate (DMC) and dimethoxy methane,3 1-octylamino-3 octyloxy-2-propanol and N-octyl nitramine,21 dimethoxy propane and dimethoxy ethane,29 biodiesel,22,30,31 and a mixture of methanol and ethanol [40].

Oxygenated additives have been considered for reducing the ignition temperature of particulates. However, the reduction of particulate emissions through the introduction of oxygenated compounds depends on the molecular structure and oxygen content of the fuel and also depends on the local oxygen concentration in the fuel plume. The composition of diesel and the use of additives directly affect properties such as density, viscosity, volatility, behavior at low temperatures, and the cetane number [41].

DME is a potential ultraclean diesel fuel. It burns without producing the smoke associated with diesel combustion. However, DME has a low viscosity compared to diesel fuel and has insufficient lubricity to prevent excessive wear in fuel injection systems. A better strategy in order to obtain cleaner-burning fuels with satisfactory properties is the use of diesel-DME blends. DMC is usually used as an oxygenated additive to improve combustion and reduce emissions of diesel engines [42].

Dimethyl carbonate presents good blend fuel properties and reduces smoke almost linearly with its concentration. The addition of 10% dimethyl carbonate in the fuel promotes a smoke reduction of 35-50%, and also apparent reductions of hydrocarbons and carbon monoxide densities were attained with a slight increase in NO_x emissions [43].

3. MATERIALS AND METHODS

3.1. Materials

The materials used in the process of transesterification are mentioned in the table 3.1. Laboratory materials and equipments that are used in the lab work are mentioned in the table 3.2. And the equipments and machines used in the engine testing are mentioned in the table 3.3.

Table 3.1. Materials used in the laboratory for transesterification process

No.	Item
1	Caster bean oil
2	Flask of different sizes
3	Heater with magnetic stirrer
4	Digital Balance
5	Thermometer
6	KOH
7	Methanol
8	Decanter

Table 3.2. Materials used in the laboratory for characterization

No	Item
1	PH tester
2	Automatic viscometer
3	UV tester
4	Flask
5	Digital balance

Table 3.3. Materials used in the automotive work shop for performance testing

No	Item
1	Diesel engine
2	Chassis Dynamometer
3	Blended fuel
4	Diesel fuel
5	Additive diethyl ether

3.2. Extraction of Castor seed oil

Castor bean was purchased from local market. The castor oil was extracted by mechanical pressing (in the Bedada Edible oil production and sale plc). After the extraction of castor oil, the debris was settled, oil was filtered.

Figure 3.1. Castor bean seed crushing operation

3.3. Production of biodiesel (transesterification)

Most researchers have found that transesterification is the most effective way to reduce the viscosity of vegetable oils to be used in the diesel engine blended with diesel fuel.

Transesterification of the biodiesel was conducted in chemistry laboratory of Adama Science and Technology University. The crude oil sample was tried for transesterification and by taking 100ml of the oil with twenty five percent of methanol and two and half grams of potassium hydroxide.

The process, transesterification, is used to produce the biodiesel. By the process, ester reacts with alcohol to form another ester and another alcohol. The catalyst for this reaction can be KOH or NaOH. In our project work we have used KOH for transesterification because of its availability. In the transesterification process three moles methanol react with one mole triglyceride and produces mixture of fatty esters and glycerin.

As shown in the reaction equation (eq. 1), three moles of methanol react with one mole of triglyceride. In practice, most producers use at least 100% excess methanol to force the reaction equilibrium towards a complete conversion of the oil to biodiesel. It can become unavailable for the reaction without agitation since the catalyst tends to concentrate in the glycerin.

The reactions are given below:

Soap + Hydrochloric Acid $\longrightarrow$ Fatty acid + Salt ……………….. (eq. 1)

Fatty acid + NaOH $\rightarrow$ COME ester + Soap + Water …………….(eq. 2)

After the biodiesel is separated from the glycerol, it contains 3% to 6% methanol and usually some soap. If the soap level is low enough (300 to 500 ppm), the methanol can be removed by vaporization and this methanol will usually be dry enough to directly recycle back to the reaction. After the methanol has been removed, the biodiesel needs to be washed to remove residual free glycerin, methanol, soaps, and catalyst. This is most frequently done using liquid-liquid extraction by mixing water with the biodiesel and gently agitating them to promote the transfer of the contaminants to the water without creating an emulsion that might be difficult to break.

The washing process is usually done multiple times until the wash water no longer picks up soap. Although the gray water from later washes can be used as the supply water for the earlier wash steps, the total amount of water will typically be one to two times the volume flow rate of the biodiesel.

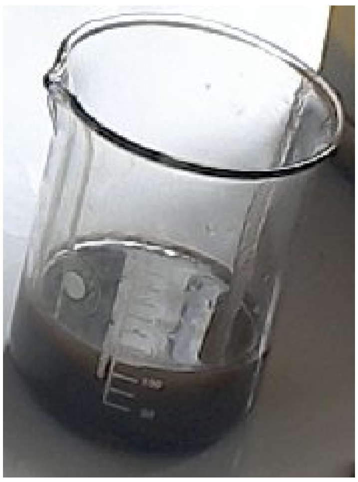


Figure.3.2 Crude Castor oil

After washing, the biodiesel is frequently cloudy due to small water droplets suspended in the fuel. While these droplets will eventually settle out, it is much faster to use a flash evaporator to remove the residual water from the fuel.

The glycerin that is separated from the biodiesel will contain a substantial amount of methanol, most of the catalyst, soaps that have been formed during the reaction and many of the polar contaminants that were originally present in the oil. These contaminants contribute to a dark brown or black color for the glycerin in spite of it being clear when present as a pure compound. The raw glycerin has very little value and must be upgrade to raise its purity before it can be sold. The usual practice is to add strong hydrochloric acid to the glycerin to neutralize the catalyst and split the soap.

The soaps split into free fatty acids (FFAs) and salt, as shown in the reaction equation. The FFAs are not soluble in the glycerin and can be separated with a centrifuge. The methanol can be removed by vaporization leaving a crude glycerol that is 80% to 90% pure. The fatty acids are not soluble in the glycerin and can be separated with a centrifuge. These high free fatty acid oils present special challenges when used for biodiesel production. When an alkali catalyst is added to these feed stocks, the free fatty acid reacts with the catalyst to form soap and water as shown in the above reaction. This reaction makes the catalyst unavailable for catalyzing the reaction and if enough soap is produced, it can inhibit the separation of the methyl esters and glycerin.

When oils and fats with high free fatty acids are to be used for biodiesel production, an acid catalyst such as sulfuric acid can be used to transesterify the free fatty acids to methyl esters as shown in the reaction below

$$\text{Fatty acid + Methanol} \xrightarrow[H_2SO_4]{} \text{Methyl ester + Water} \;\ldots\ldots\ldots\ldots\ldots\; \text{(eq. 3)}$$

Then, the Methanol with the FFAs converted to methyl esters, a conventional alkali-catalyzed process can be used to transesterify the triglycerides in the feedstock. While acids can be used to catalyze the transesterification reaction, the reaction is very slow at 50 to 60^0C reaction temperature the two-step approach of acid-catalyzed esterification followed by base-catalyzed transesterification gives a complete reaction at moderate temperatures.

A problem with this approach is that the water produced by the esterification reaction should be removed before the base-catalyzed process begins so that soap formation is not excessive. This can be done by settling or centrifuging the methanol-water-acid layer that separates after the esterification has reached equilibrium. The additional equipment required for the acid-catalyzed pretreatment raises the processing cost, but this approach allows the use of feed stocks containing up to 100% FFA.

Finally after drying the found methyl ester is converted to the required biodiesel.

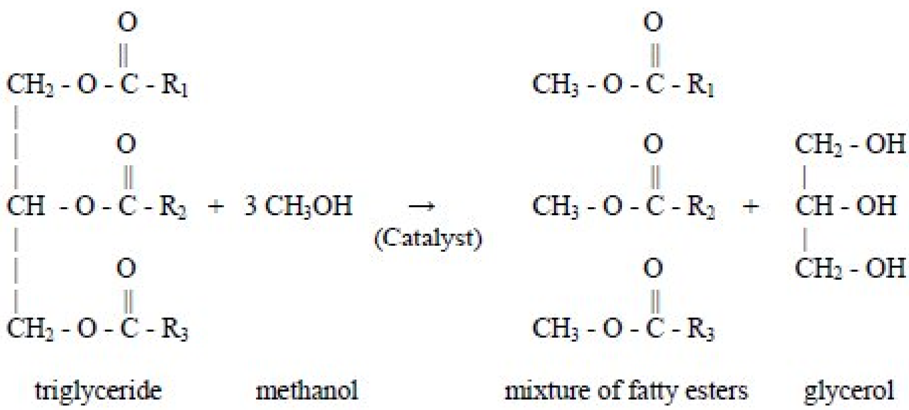
3.4. Transesterification phase

3.4.1. Procedures for preparation of catalyst and transesterification process and heating of crude oil

- At first two (2gms) of potassium hydroxides pellets were measured. Twenty five milliliter of methanol was measured (25ml) in a graduated cylinder. The potassium hydroxide pellets are dissolved in methanol. The crude oil (150ml) was heated to 60^0C to 70^0C in oil bath by hot plate and catalyst was added while stirring by the magnetic stir. The catalyst and the oil were stirred for 40 to 45 minutes until a clear solution was observed. But the expected clear solution was not observed. So the other trail was done.
- At second trial two point five (2.5gms) of potassium hydroxides pellets were measured. Twenty five milliliter of methanol was measured (25ml) in a graduated cylinder. The potassium hydroxide pellets are dissolved in methanol. The crude oil (100ml) was heated to 60^0C to 70^0C in oil bath by hot plate and catalyst was added while stirring by the magnetic stir. The catalyst and the oil were stirred for 40 to 45 minutes until a clear solution was observed. But the expected clear solution was not observed. So the other trail was done.
- At third trial three (3gms) of potassium hydroxides pellets were measured. Twenty milliliter of methanol was measured (20ml) in a graduated cylinder. The potassium hydroxide pellets are dissolved in methanol. The crude oil (100ml) was heated to 60^0C to 70^0C in oil bath by hot plate and catalyst was added while stirring by the magnetic stir. The catalyst and the oil were stirred for 40 to 45 minutes until a clear solution was observed. But the expected clear solution was not observed. So the other trail was done.

Figure 3.3. Heating of crude oil

Triglyceride + Methanol $\xrightarrow{\text{potassium hydroxide}}$ Methyl ester + Glycerin
(Castor seed oil) (biodiesel)



3.4.2. Decantation of biodiesel

- After the castor oil is heated up to 65^0C the solution of ethanol and KOH is added with oil while stirring.
- Glycerine started to separate and started settling at the bottoms.

Figure 3.4. Glycerin settled at the bottom

- After a clear solution was observed, heating of the biodiesel was stopped
- The oil was poured into a decanter and the glycerine was separated after 24 hrs
- By opening the decanters valve, the glycerine was separated and collected into a glass
- The wasted oil with glycerine was collected by a pipette
- In such procedure the biodiesel was collected.

3.4.3. Washing the biodiesel

After the glycerol was collected from the decanter the biodiesel was washed by the water which heated up to 50°C. The washing process was done as follows.

- Water was heated at 50 °C
- One third by volume of the water was taken and filled to a spray gun after heating
- The biodiesel was filled in a decanter and hung on stand
- By using the spray gun, the water was sprayed to the oil slowly

Figure 3.5. Water washing of the biodiesel

- The oil was left for 30 minutes hang on a decanter
- The water and soap settled at the bottom and was separated by opening the valve of the decanter

3.4.4. Drying of the biodiesel

- The biodiesel was collected and heated on the heater for an hour at a temperature of 100^0c up to 120^0C to evaporate the residual water left during washing process.

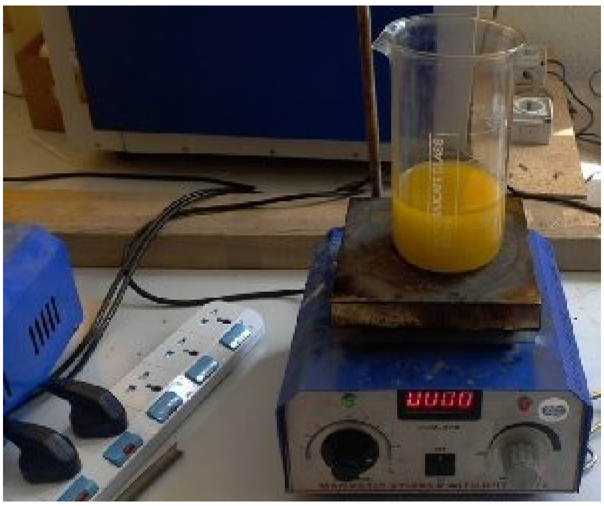


Figure 3.6. Heating biodiesel in a heater

- Finally, pure biodiesel was collected

Figure 3.7. Heating after washing process

3.5. Blending of the biodiesel with diesel fuel and adding of additive

In the blending process of the biodiesel with diesel fuel 780ml of diesel was mixed with 200ml of castor biodiesel and 20 milliliter of diethyl ether was added on it as an additive. The mixture was allowed to settle for about 2 hours for miscibility and consistency.
For the purpose of testing five different types of blends were prepared as shown below:

Table 3.4. Blending ratio of test fuels with biodiesel and additive

Fuel type	Petro diesel	Castor biodiesel	Additive di-ethyl ether	Total
B0	1000ml	-	-	1000ml
B20	800ml	200ml	-	1000ml
B20	8000ml	200ml	20ml	1020ml

3.6. Characterization of biodiesel

The produced biodiesel has been characterized for many of the characteristics of its diesel property. These are mentioned as follows:

3.6.1. Test for UV test

The biodiesel was tested for its range to be in the biodiesel in the chemistry laboratory by ultra violet spectrometer. From the test the biodiesel is found in the range of the biodiesel. The standard for biodiesel is 220 to 240 wavelengths. The tested biodiesel fuel has the pick reading of 230 wave length. So it is within the biodiesel range as it is shown in the picture below.

Figure 3.8. The UV test of the biodiesel

3.6.2. The PH value of the biodiesel

The PH value of the biodiesel was measured in the chemical engineering laboratory by using PH testing machine. The PH value of the biodiesel was found to be 8.68.

Figure 3.9. The PH value of the biodiesel

3.6.3. Density of the biodiesel

The density of the biodiesel is measured in such a way that by measuring the volume of 48ml of biodiesel its mass and it becomes 43 gram. So from the calculation of mass divided by volume the density has been determined.

Density = mass ÷ volume:

$$= \quad \div \; :$$

$$= 43 \quad \div 48$$

$$= 0.8958 \quad /$$

Figure 3.10. Measurement of density

3.6.4. Viscosity of the biodiesel

The viscosity of the biodiesel is measured in the material engineering laboratory by using rotary viscometer. In the process of viscosity measurement stirring time was 5 seconds in which the machine is automatic viscosity measuring tool. The measuring time was 20 seconds. And the viscosity of the biodiesel becomes 91 centi poise as it is shown bellow.

Figure 11. The viscometer set up

Table 3.5. ASTM Standard and the biodiesel characterization

Test items	Unit	ASTM standard	Character of Biodiesel when compared to standard
UV test	Mn	220-240mn	230 mn
PH value	St	6.3-8.8st	8.76
Density	g/ml	0.957-0.96	0.897g/ml
Viscosity	Centi poise	--	91 centi poise
Flash point	^{0}C	--	83
Cloud point	^{0}C	+5	+5
Acidic value	mg KOH/gm	0.5	0.24

3.7. Experimental setup for measuring engine performance testing

The main objective of the test was to observe the variation in the performance of engine with varying proportion of biodiesel as blend with addition of 2% of additive which was diethyl ether. The test was conducted using engine testing with dynamometer available in the automotive shop of the automotive and vehicle engineering department. The specification of the test engine is given in the table below.

Table 3.6. Test engine specification

Engine model	Toyota pickup, LN 106L – PRMRS
Engine type	3L
Engine capacity	2779cc
Fuel system	Diesel
No. of cylinder	4
Frame Number	LN106 – 0136567
Color	Trim GVM (KG)
Maximum speed	160km/h

4. RESULTS AND DISCUSSION

4.1. About castor seed Oil Extraction

The extraction of the oil is done by local food oil mills (named as: Bedada Food oil production and sale house) that is located in Adama town Kebele 13 in a special place called Amede near east Shoa zone agriculture office. It has been possible to extract 6 liters of oil from 20 kg of castor seed which was purchased from Amhara zone Bahirdar town. The percentage yield of oil from the castor seed which was purchased from local market was 30%.

4.2. Yield of biodiesel and other products

The biodiesel was produced by transesterification reaction process using methanol alcohol and KOH catalyst. In the production of this biodiesel about 156ml of glycerol was produced in the process of decantation from the transesterified crude oil of 500ml. After the biodiesel was washed by warm distilled water about 50^0C six times about 175ml of soap was gained from 500ml of biodiesel.

4.3. Characterization of the biodiesel

After the production of the biodiesel four tests of the biodiesel characterization was done in chemistry, chemical and mechanical engineering laboratories by those people who work in their respective workshops.

4.3.1. Test check of the biodiesel

Those chemistry people have helped us in the testing of the biodiesel for the biodiesel to be in the biodiesel range. According to the measurement done by the UV SIV tester and the biodiesel was found in the biodiesel range which was 230 pick reading, the standard being 220-240 wavelengths.

4.3.2. PH value test of the biodiesel

The PH value test was done in the chemical engineering department laboratory by the chemical engineering people. The PH value was measured by the PH tester and it was found to be 8.67.

4.3.3. Density test

The density of the biodiesel was measured in such a way that by measuring the weight of 48ml of biodiesel which became 43g. By calculating the density by using the formula density = mass ÷ volume. And it was found to be 0.8958g/ml.

4.3.4. Measurement of viscosity of the biodiesel

The measurement of viscosity was done in material engineering department. Peoples who works in the material engineering was willing to help us on measuring the viscosity of the biodiesel. Viscosity was measured by automatic viscometer. The measurement was found to be 91 centi poise. The stirring time for the measurement was 5 seconds while the measuring time was 20 seconds.

4.4. Engine Performance Test of the blends of the biodiesel with additive diethyl ether of 2%

The Performance test was done on 3L Toyota engine which was found in the department of Mechanical and Vehicle Engineering of Adama Science and Technology University. The test results are shown below in tables and graphs.

Due to high viscosity and the favorable property of the fuel, the torque recorded by B0 was the lowest of all the test fuels.

- Measured data for performance characteristics of diesel fuel and biodiesel B20

Measured data of wheel power of diesel fuel and biodiesel fuel performance during experimentation and the graphic representation is indicated below.

Table 4.1. Wheel power (Pw) of diesel and biodiesel

Speed	Power at different Gears									
	1st Dl	1st Bdl	2nd Dl	2nd Bdl	3rd Dl	3rd Bdl	4th Dl	4th Bdl	5th Dl	5th Bdl
15	6	8								
30			15.50	17.5						
45			18.92	20.98	21.89	22.98	27.78	29.50		
60			21.89	23.70	25.80	27.50	29.90	30.97	32.23	34.25
75					27.06	28.95	32.23	34.20	37.4	38.90
90							37.4	38.90	42.57	44.40
105							42.57	44.60	47.74	48.65
120							46.74	48.90	50.90	51.98
135									52.91	53.80
160									53.80	55.70

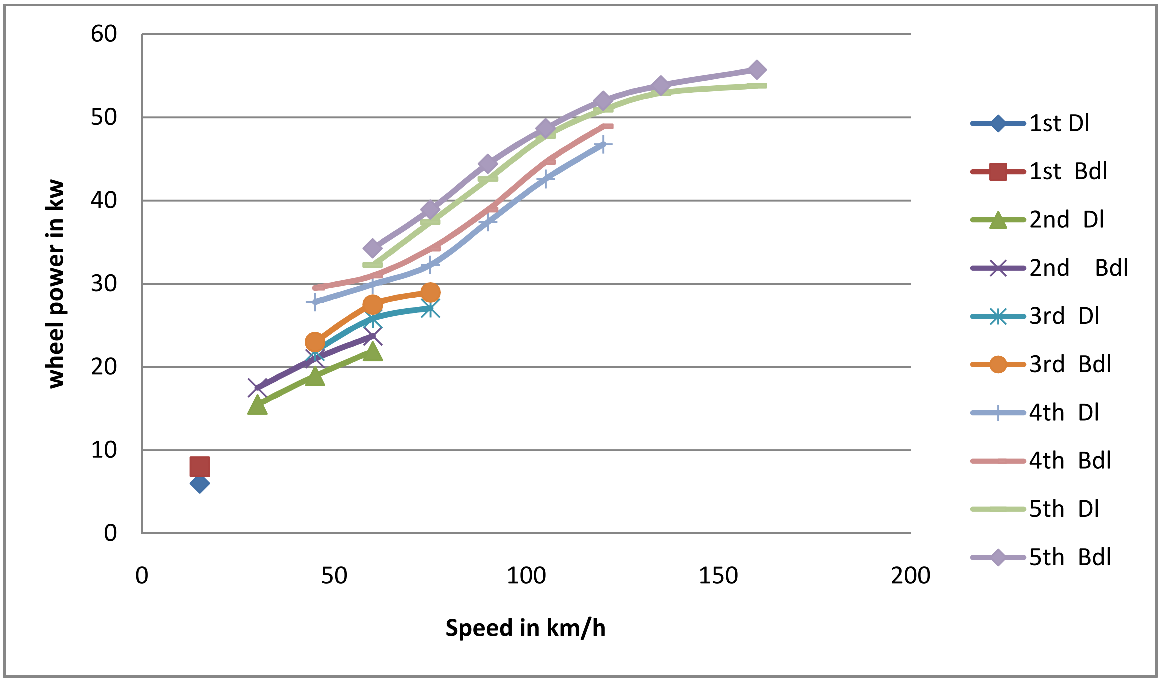


Figure 4.1. Comparison of wheel power of diesel and biodiesel

As it is seen from the above figure the wheel power of the diesel fuel shows better wheel power than biodiesel.

Measured data of wheel power of diesel fuel and biodiesel fuel performance during experimentation and the graphic representation is indicated below.

Table 4.2. Traction force when diesel fuel and biodiesel

Speed	Power at different Gears									
	1^{st} Dl	1^{st} Bdl	2^{nd} Dl	2^{nd} Bdl	3^{rd} Dl	3^{rd} Bdl	4^{th} Dl	4^{th} Bdl	5^{th} Dl	5^{th} Bdl
15	3	2.6	3	2.6	2.1	1.3				
30			2.75	1.4	1.1	1.0	1.8	1.5		
45			0.75	0.8	0.6	0.5	1.6	1.45		
60					0.5	0.4	1.5	1.4	1.6	1.5
75							1.0	0.9	1.4	1.3
90							0.5	0.45	1.3	1.25
105									1.0	0.9
120									0.8	0.7
135									0.5	0.4
160									0.4	0.3

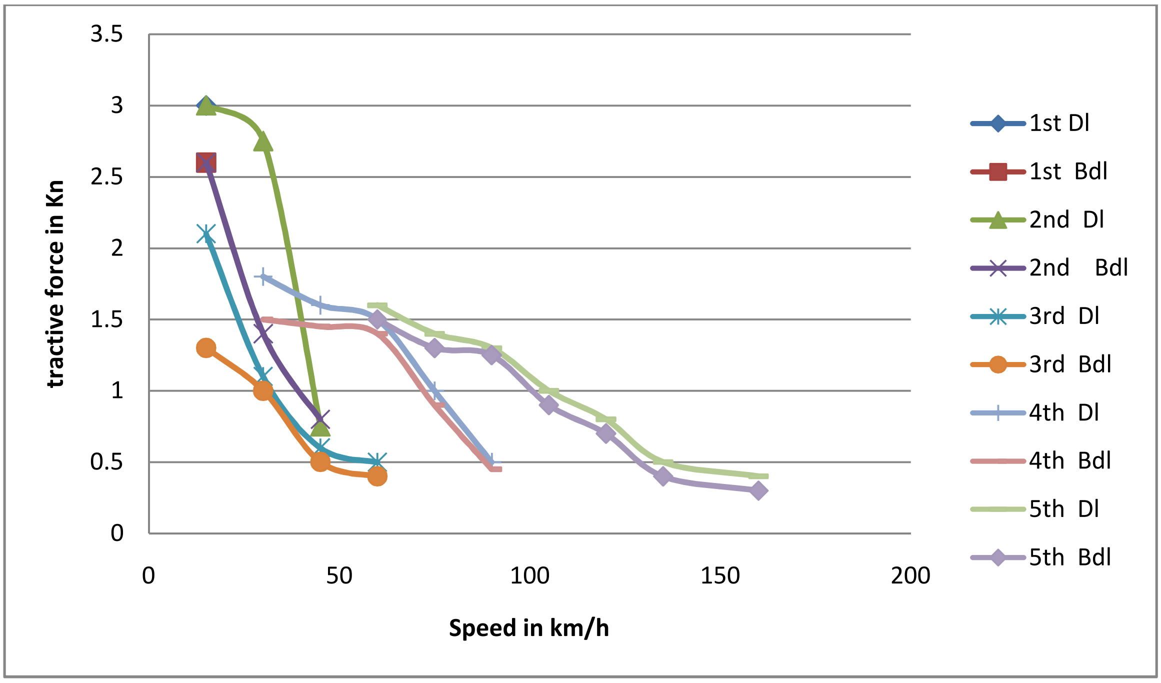


Figure 4.2. Performance curve of tractive force of diesel Fuel and biodiesel

As we can see it from the performance curve on figure 4.3 and 4.4 the performance of diesel fuel is better than that of biodiesel fuel. So the biodiesel blend needs more modification to initiate better performance than diesel fuel.

Measured data of wheel power of diesel fuel and biodiesel fuel performance during experimentation and the graphic representation is indicated below.

Table 4.3. Wheel torque when diesel fuel and biodiesel used respectively

Speed	Power at different Gears									
	1st Dl	1st Bdl	2nd Dl	2nd Bdl	3rd Dl	3rd Bdl	4th Dl	4th Bdl	5th Dl	5th Bdl
15	1.083	0.9386	1.083	0.9386	0.7581	0.4693				
30			0.99275	0.505	0.3971	0.361	0.6498	0.5415		
45			0.271	0.289	0.2166	0.1805	0.5776	0.5235		
60					0.1805	0.1444	0.5415	0.5054	0.5776	0.5415
75							0.361	0.3249	0.5054	0.4693
90							0.1805	0.1624	0.4693	0.4513
105									0.361	0.3249
120									0.289	0.2527
135									0.1805	0.1444
160									0.1624	0.1083

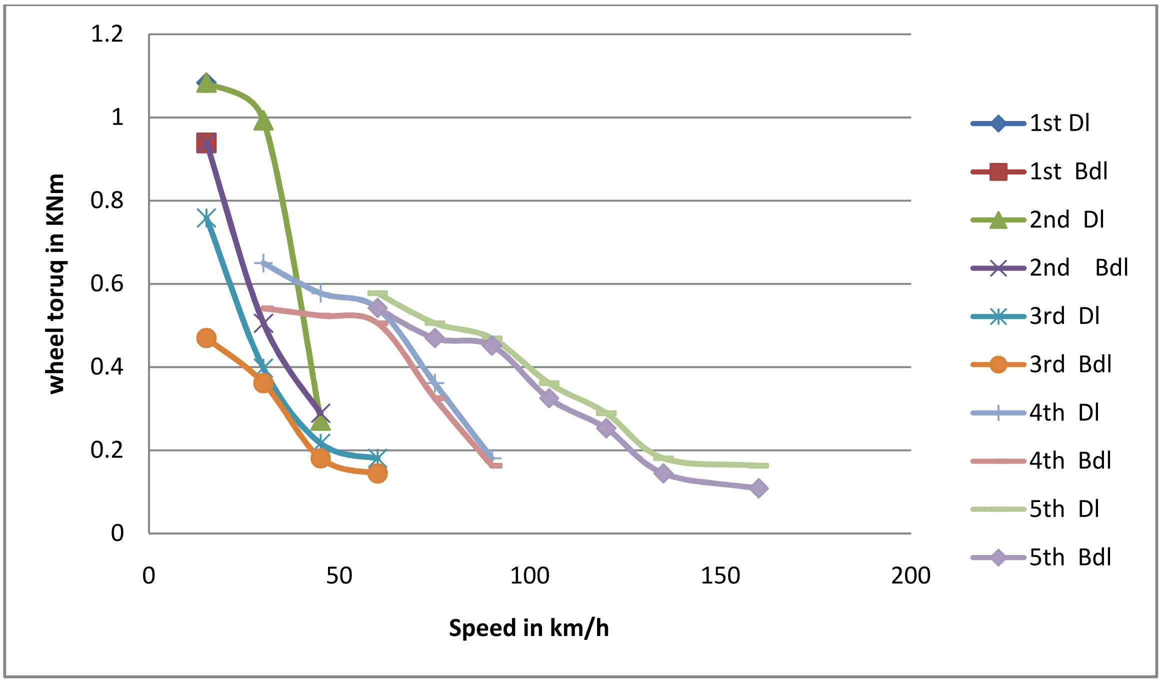


Figure 4.3. Performance curve of wheel torque of diesel Fuel and biodiesel respectively

As it is seen from the figure diesel fuel as sown better performance than biodiesel in most of the engine operation, but at 4th gear it as sown slightly better performance up to 50km/h speed of the vehicle.

Measured data of wheel power of diesel fuel and biodiesel fuel performance during experimentation and the graphic representation is indicated below.

Table 4.4. Brake torque when diesel fuel and biodiesel respectively

Speed	Power at different Gears									
	1st Dl	1st Bdl	2nd Dl	2nd Bdl	3rd Dl	3rd Bdl	4th Dl	4th Bdl	5th Dl	5th Bdl
15	6	8								
30			15.50	17.5						
45			18.92	20.98	21.89	22.98	27.78	29.50		
60			21.89	23.70	25.80	27.50	29.90	30.97	32.23	34.25
75					27.06	28.95	32.23	34.20	37.4	38.90
90							37.4	38.90	42.57	44.40
105							42.57	44.60	47.74	48.65
120							46.74	48.90	50.90	51.98
135									52.91	53.80
160									53.80	55.70

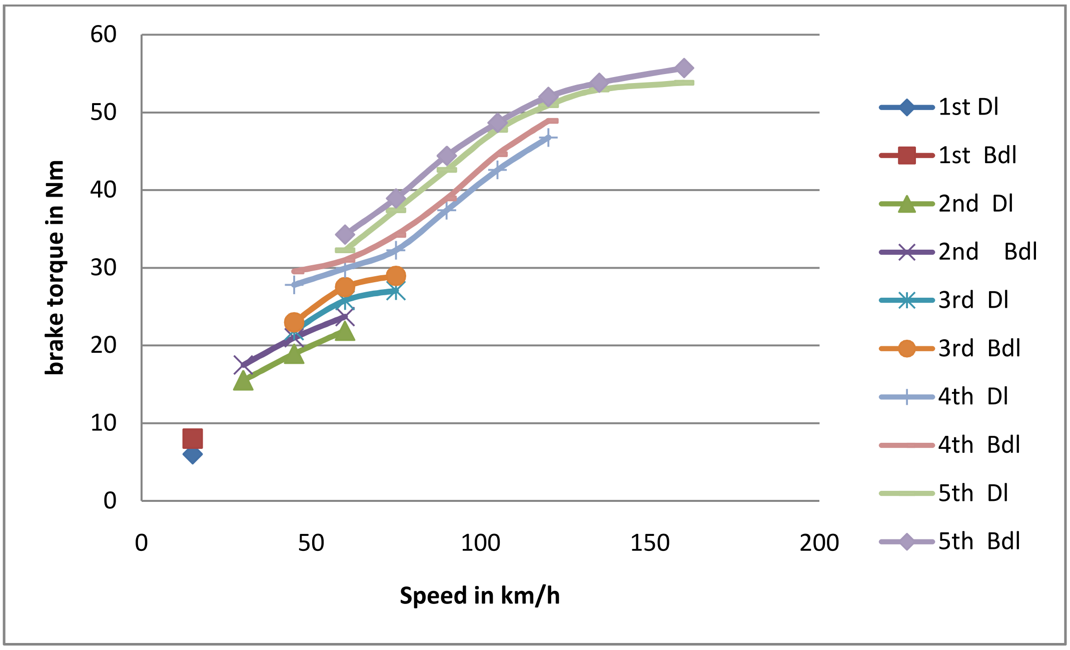


Figure 4.4. Performance curve of diesel biodiesel brake torque

As it is seen from the figure the brake torque of diesel has better performance than that of biodiesel fuel.

Measured data of wheel power of diesel fuel and biodiesel fuel performance during experimentation and the graphic representation is indicated below.

Table 4.5. Brake power when diesel fuel and biodiesel are used respectively

Speed	Power at different Gears									
	1st Dl	1st Bdl	2nd Dl	2nd Bdl	3rd Dl	3rd Bdl	4th Dl	4th Bdl	5th Dl	5th Bdl
15	8.15	10.87								
30			20.42	23.06						
45			24.93	27.64	28.11	29.39	34.71	36.86		
60			28.84	31.23	32.99	35.17	37.36	38.69	38.08	40.47
75					34.60	37.02	40.27	42.73	44.19	45.72
90							46.73	48.60	50.30	52.46
105							53.19	55.72	56.40	57.48
120							58.40	61.09	60.14	61.41
135									62.51	63.56
160									63.56	65.81

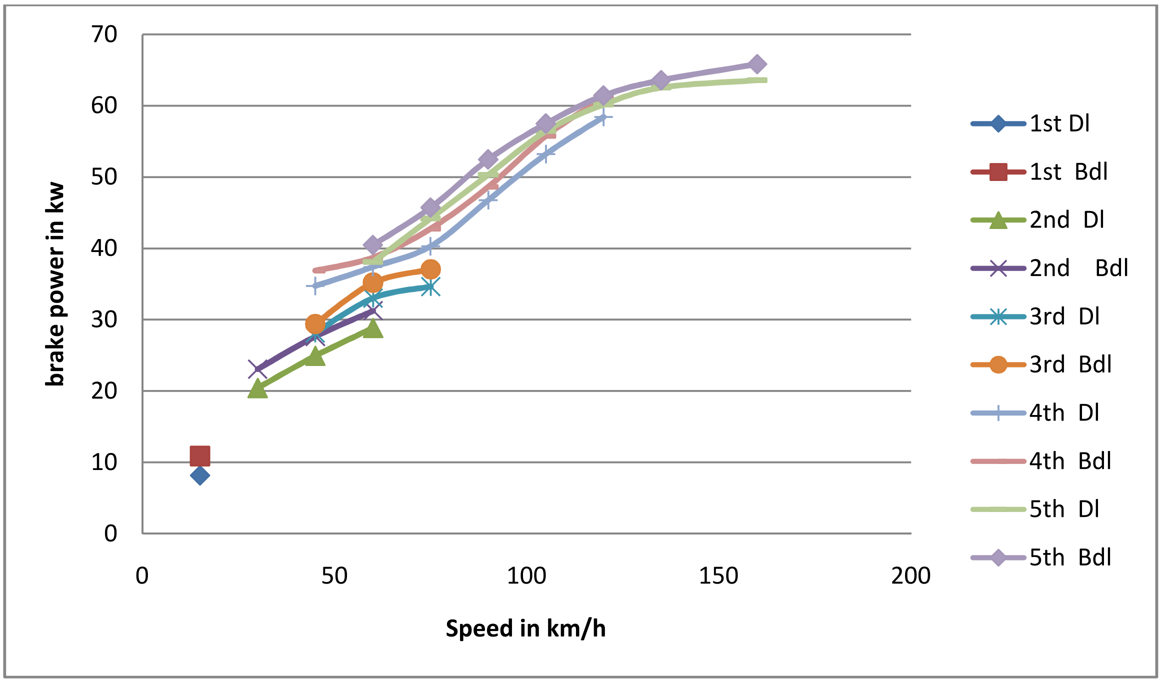


Figure 4.5. Performance curve of diesel Fuel and biodiesel brake power respectively

As it is seen from the figure the brake power of diesel much better than that of biodiesel fuel.

Measured data of wheel power of diesel fuel and biodiesel fuel performance during experimentation and the graphic representation is indicated below.

Table 4.6. BSFC when diesel and biodiesel fuels are used respectively

Speed	Power at different Gears (ratio used 1:10)									
	1st BDl	1st dl	2nd BDl	2nd dl	3rd BDl	3rd dl	4th BDl	4th dl	5th Dl	5th Bdl
15	72.4	49.6								
30			29.4	23.4						
45			23.7	19.5	21.0	20.4	20.4	17.9		
60			20.5	17.3	17.9	17.1	19.0	17.1	20.7	20.1
75					17.1	16.2	17.6	16.9	19.7	18.7
90							17.7	17.3	19.4	18.8
105							17.8	18.3	20.9	19.9
120							20.2	18.7	22.5	21.6
135									23.6	22.7
160									24.6	24.1

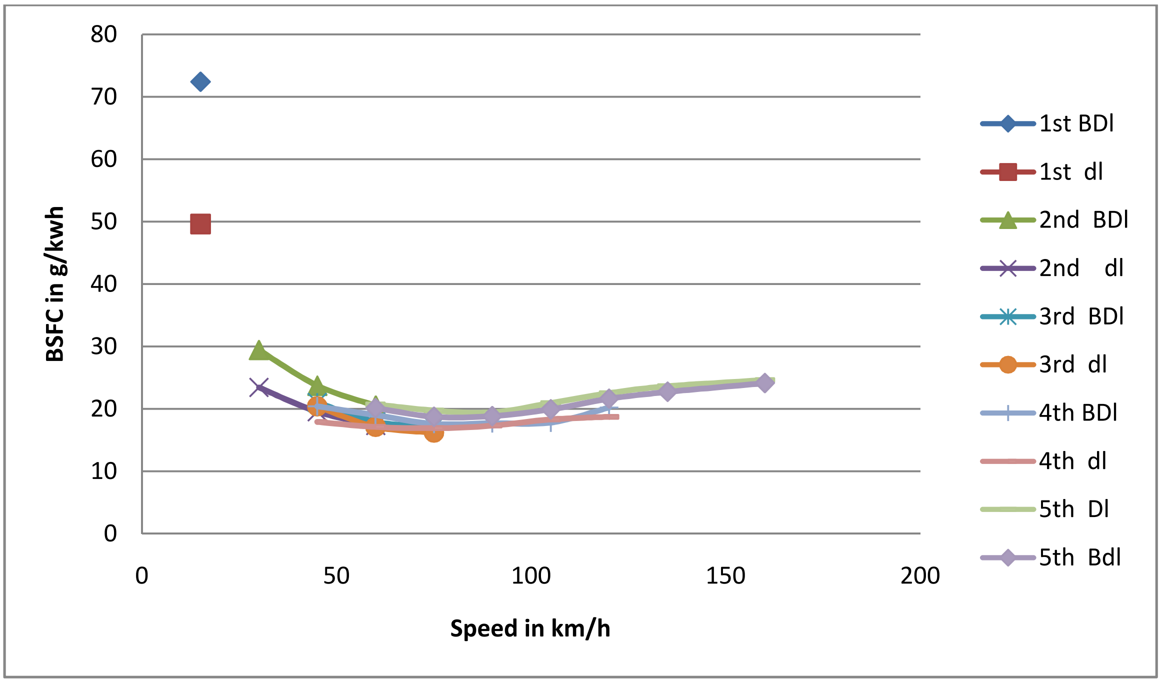


Figure 4.6. Performance curve of diesel Fuel and biodiesel BSFC respectively

As it is seen from the figures 4.6 the BSFC in better when diesel fuel was used than the of biodiesel fuel.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

In the oil extraction process the better to extract oil from castor seed is to use mechanical pressing than chemical and other extraction methods. This is because it is cheaper than the other methods.

In the blending process as the amount of diethyl ether as an additive increase in B20, the performance of the fuel increases. But using more additive could affect the viscosity of the fuel and in turn it could affect the lubrication property of the fuel on which the life of the fuel injection pump depends on.

In our project work transesterification reaction was carried using the castor seed oil. The quantity of potassium hydroxide catalyst for optimal biodiesel yield was 25gm per liter of methanol at reaction time of 45 minutes, reaction temperature of 60^0C to 65^0C and volume ratio of oil to methanol as 4:1.

Based on the experimental results, the following conclusions are drawn. The brake power of B20 is found to be higher. The higher power after the additions of diethyl ether to castor biodiesel is due to its oxygen content and effect on lowering the viscosity of the blend, which lead to an improvement in the combustion process.

5.2. Recommendations

This study has made us to confirm that castor seed oil can be used as a source to obtain biodiesel, which could offer more opportunities for generation of rural employment and increasing income. However, further research and development on additional fuel property blending conditions, engine performance and emission tests, technology and economic analysis are necessary.

The performance test is done on a Toyota engine which is found in the department of Mechanical and Vehicle Engineering.

The byproduct of castor biodiesel could be used for different purposes. The cake as fire wood for the society and also as feedstock for biogas digester. The glycerin could be used as raw material for cosmetic and pharmaceutical industry. Therefore biodiesel industries shall use the byproducts in order to compensate the biodiesel price. In addition to this the glycerol and soap can produce much money from cosmetics and cleaning producing industries.

5.3. Educational Implication

The objective of this project is to show how biodiesel can be produced from castor seed and usage of biodiesel-diethyl ether and diesel blends in diesel engine.

- Increase National incomes by reducing fuel importing amount
- Give job opportunity to many people by participating biodiesel production.
- Increase the capacity of small Industry, heavy Industry & machines which works by fuel
- Increases the country research scope.

From the above important advantages it requires working with TVET institution on either short term training or long term training. The institution should support the company or small enterprises by providing training for the workers to fill the skill gap, production, and safety, wisely using of resource, technical advancement and follow up. These indicate TVET institution needs to provide improved curriculum for coming generation based on labor market especially on Biodiesel production and blending technology, and testing their performance in engine.

References

[1] L. C. Meher, D. V. Sagar and S. N. Naik, "***Technical aspects of biodiesel production by transesterification*** – a review", Renew Sustain Energy Rev, vol. 10, (2006)

[2] F. Yasar, S. Altun and H. Adin, "***Fuel properties of biodiesels produced from blends of canola oil and animal tallow"***, Energy Educ Sci Technol, vol. 27, no. 1, (2011).

[3] A. S. Silitonga, A. E. Atabani, T. M. I. Mahlia, H. H. Masjuki, I. A. Badruddin and S. Mekhilef, "***A review on prospect of Jatropha curcas for biodiesel in Indonesia***", Renew Sustain Energy Rev, vol. 15, **(**2011).

[4] N. P. Bahadur, D. G. B. Boocock and S. K. Konar, "***Liquid hydrocarbons from catalytic pyrolysis of sewage sludge lipid and canola oil: evaluation of fuel properties***", Energy Fuels, vol. 9, (1995).

[5] M. Satyanarayana and C. Muraleedharan, ***"Biodiesel Production from Vegetable Oils: A Comparative Optimization Study***", Journal of Biobased Materials and Bioenergy, vol. 3, no. 4, (2009).

[6] N. K. Sahoo, M. K. Naik, S. Pradhan, S. N. Naik and L. M. Das, "***High Quality Biodiesel from Thevetia peruviana Juss: Physico-Chemical, Emission and Fuel Performance Characteristics"***, Journal of Biobased Materials and Bioenergy, vol. 6, no. 3, **(2012)**.

[8] Dan B. stevens, C. Erich's Andrew G., ***Chinese herbal medicine***; material medica, 3rd Edition (2004).

[36] Gu¨ru, M.; Karakaya, U.; Altiparmak, D.; Alicilar, A. Energy ConVers. Manage. 2002, 43, 1021 -1025.

[17] Pereira, P. A. P.; De Andrade, J. B.; Miguel, A. H. J. EnViron. Monit. 002, 4,

[9] Entezaam M. H. Broukhiyan and Samuel S. Lestz***, Fumigation of Alcohol in a Light Duty Automotive Diesel Engine,*** Hampton, Virginia**,** August, (1981).

[10] Demirbas, A., ***Comparison of transesterification methods for production of biodiesel from vegetable oils and fat***s. *Energy Convers. Manag,* (2008).

[11] P.S. De Caro, Z. Mouloungui, G. Vaitilingom, JCh. Berge, "***Interest of combining an additive with diesel–ethanol blends for use in diesel engines***". Fuel, Vol. 80, No. 4, (2001).

[14] Kalay Tesfaye, ***Biodiesel Production From Wado Seed Oil: Addis Ababa***, Ethiopia Kurki, A., Hill, A., Morris, M. (2006). *ATTRA Publications*,12, (2011).

[13] Dennis K. J. and Schrag D. P., ***Clumped isotope thermometry of carbonatites as an indicator of diagenetic alteration***. Geochim. Cosmochim. Acta 74, (2010).

[12] Qiang, L., Wei, D and Dehua, L, ***Perspectives of microbial oils for biodiesel Production***. Mini- Review. *Applied Microbiological and Biotechnology Journal*, (2008).

[15] Carvalho da Silva, Flávio; Paulo Roberto da Costa Brum and Taís Neno dos Santos, ***Nanotechnology/Nanoscience Knowledge Managament emphasizing nano structured polymers***. Presentation, School of Chemistry, UFRJ, Brazil. (2005).

[16] Gerpen J.V.; Shanks B.; Pruszko R.; Clements D. and Knothe G., ***Biodiesel Production Technology***'. Report from Iowa State University for the National Renewable Energy Laboratory, NREL/SR-510-36244, (2004),

[25] Ali, Y.; Hanna, M.A, ***Fuel properties of tallow and soybean oil esters.*** J. Am. Oil Chem. Soc. .(1995

[26] Leung DYC, Guo Y., ***Transesterification of neat and used frying oil***: optimization for biodiesel production. Fuel Process Technol, (2006).

[18] Bondioli P., Gasparoli A.,Lanzani A., Fedeli E., Veronese S. and Sala M., "***Storage stability of Biodiesel***", *JAOCS,* 72 (6). (1995).

[19] M. Bloch, L. Bournay, D. Casanave, J. A. Chodorge, V. Coupard, G. Hillion, D. Lorne, ***Oil & Gas Science and Technology****, Rev. IFP*. (2008).

[20] ***Western Biofuels***, http://www.westernbiofuelsinc.com/

[21] Hemant Y. et.al, ***Bio Diesel from Castor Oil*** - A Green Energy Option, Department of Environmental Sciences, Mohan Lal Sukhadia University, Udaipur, Rajasthan, India, (2011).

[22] J. Krahl, A. Munack, D. Bockey, ***Landbauforschung Völkenrode,*** *, 57,* (2007).

[23] Tat M, Van Gerpen J., ***Measurement of biodiesel speed of sound and its impact on injection timing***. National Renewable Energy Laboratory NREL/SR- 510-31462, (2003).

[24] Wang W,Lyons D,Clark N,Gautam M,Norton P., ***Emissions from nine heavy trucks fueled by diesel and biodiesel blend without engine modification. Environmental Science & Technology***;34, (2000).

[27] Hoekman SK, Robbins C, ***Review of the effects of biodiesel on NOx emissions.*** Fuel Processing Technology. (2012).

[28] McCormick R L,Tennant C,Hayes R,Black S,Ireland J,Mc Daniel T,etal. ***Regulated emissions from biodiesel tested in heavy-duty engines meeting 2004 emission standards***, (2005).

[37] Basha S A, Raja Gopal K. ***A review of the effects of catalyst and additive on biodiesel production, performance, combustion and emission characteristics***. Renewable and

Sustainable Energy Reviews, (2011).

[38] Misra R D, Murthy M S. ***Blending of additives with biodiesels to improve the cold flow properties, combustion and emission performance in a compression ignition engine***: a review. Renewable and Sustainable EnergyReviews, (2011);15.

[33] J. P. Iranmanesh, M. Subrahmanyam and M. K. G. Babu, "***Potential of Diethyl ether as a supplementary fuel to improve combustion and emission characteristics of diesel engine"***, SAE Paper, (2008).

[29] C. Swaminathan and J. Sarangan, "***Performance and exhaust emission characteristics of a CI engine fueled with biodiesel (fish oil) with DEE as additive***", biomass and bioenergy., vol. xxx, (2012).

[30] Franzke D.E***. Beitrag zur Ermittlung eines Klopfkriterium derottomotorischen Verbrennungund zur Vorausberechnung der Klpofgrenze***.Ph.D thesis,TU M unchen, (1981)

[31] Demirbas A. Biodiesel Impacts on Compression Ignition Engine (CIE): ***Analysis of Air Pollution Issues Relating to Exhaust Emissions. Energy Sources*** (2005);27(6).

[32] Korres DM, Karonis D, Lois E, Linck MB, Gupta AK., ***Aviation fuel JP-5 and biodiesel on a diesel engine***. Fuel (2008);87(1).

[34] Lin Y, Wu YG, Chang CT., ***Combustion characteristics of waste-oil produced biodiesel/diesel fuel blends***. Fuel (2007);86.

[35] Raheman H, Ghadge SV., ***Performance of compression ignition engine with mahua (Madhucaindica) biodiesel***. Fuel (2007);86(16).

[38] Rathore V, Madras G. ***Synthesis of biodiesel from edible and non-edible oils in supercritical alcohols and enzymatic synthesis in supercritical carbon dioxide***. Fuel (2007);86.

[39] Nwafor OMI. ***Emission Characteristics of Diesel Engine Operating on Rapeseed Methyl Ester***. Renew Energy (2004);29(1).

[40] The Royal society, ***Susteinabl biofuels***: prospects andchallenges, (2008).

[41] Hazar, H., & Aydin, H. P***erformance and emission evaluation of a CI engine fueled with preheated raw rapeseed oil (RR0)-diesel blends***. Applied Energy, (2010), 87(3).

[42] Karabektas, M., Ergen, G., & Hosoz, M., ***The effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a diesel engine***. Applied Thermal Engineering, 28, (2008).

[43] Pugazhvadivu, M., & Jeyachandran, K. ***Investigations on the performance and exhaust emissions of a diesel engine using preheated waste frying oil as fuel.*** Renewable Energy, (2005). 30(14).

APPENDIX

Formulas used in the project process

1. $$\text{bsfc} = \frac{(m_f / time)}{P_b} x3600$$

2. $$P_{w-max} = P_{b-max} \times \eta_t$$

3. $$P_{b-max} = \frac{P_{w-max}}{\eta_{GT} \times \eta_F}$$

4. $$F_{tr-max} = \frac{T_{w-max}}{r_w}$$

5. $$T_b = \frac{60 \times P}{2\pi \times N} \quad \Rightarrow \quad 'T_b' \text{ in 'Nm'}$$

6. $$N_{@Pb\text{-}max} = N_{w\text{-}max} \times GR_t \quad \text{and} \quad P_{b\text{-}max} = \frac{P_{w\text{-}max}}{\eta_t}$$

7. $$\text{bmep} = \frac{2\pi N \times T_b}{60 \times E_c \times n} \quad \Rightarrow \quad \text{'bmep' in 'bar'.} \quad ;$$

8. $$P_{w\text{-}max} = P_{b\text{-}max} \times \eta_{GT} \times \eta_F \quad \text{...}$$

where, P_{b-max} is the maximum (rated) engine brake power.
η_{GT} is the efficiency of the Top Gear.
η_F is the efficiency of the Final drive.

9. $$\text{bmep} = \frac{4\pi \times T_b}{E_c \times 10^5}$$

10. $$bmep = \frac{P_b}{v_s\, n} = \frac{2\pi\, N\, T_b}{60\, v_s\, n} = \eta_m\, imep$$

11. $$T_{b\max} = \frac{60 * P_{b@Tb\max}}{2\pi N_{@Tb\max}}$$

12. $$\mathrm{N}_{@\mathrm{Pb-max}} = 2.65 \times \frac{\mathrm{GR}_{\mathrm{T}} \times \mathrm{GR}_{\mathrm{F}}}{\mathrm{r}_{\mathrm{w}}} \times \mathrm{v}_{\max}$$

13. $$T_w = P_w x r_w$$