ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

Experimental Investigations on Performance of Mixture of Jatropha and Castor Biodiesels as Alternative Fuel for Diesel Engines

A thesis submitted in partial fulfillment of the requirements for the

award of the degree of Master of Science in Automotive Engineering

By

Degaga Petros

Major Advisor:- N. Ramesh Babu (Associate Professor)
Co-Adviser:- Mr. Deresse Firew (Msc.)

MECHANICAL SYSTEMS AND VEHICLE ENGINEERING PROGRAM

September, 2017
Adama

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the project entitled "**Experimental Investigations on Performance of Mixture of Jatropha and Castor Biodiesels as Alternative Fuel for Diesel Engines**" in partial fulfillment of the requirement for the award of the degree of Masters Science in Automotive Engineering in an authentic record of my own work carried out from February, 2017 to September, 2017 under the supervision of Mr. N.Ramesh Babu (Asso. Prof), Department of Mechanical and Vehicle Engineering and Mr. Deresse Firew (Msc.), Department of Mechanical and Vehicle Engineering, Adama science and Technology University, Ethiopia.

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

Degaga Petros	____________________	__________________
Student	Signature	Date

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

N.Ramesh Babu (Associate Prof.)	______________	______________
Advisor	Signature	Date
Mr. Deresse Firew (Msc.)	______________	______________
Co-Advisor	Signature	Date

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

Experimental Investigations on Performance of Mixture of Jatropha and Castor Biodiesels as Alternative Fuel for Diesel Engines

By

Degaga Petros

Approved by Board of Examiners

______________________________________ ________________

Chairman, Department Graduate committee Signature

______________________________________ ________________

Internal Examiner Signature

______________________________________ ________________

External Examiner Signature

______________________________________ ________________

Advisor Signature

______________________________________ ________________

Co- Advisor Signature

ACKNOWLEDGMENT

First and foremost, I want to express my enormous thanks to the almighty God for his continuous and priceless help and permission to finish my graduate study successfully.

I would like to express my genuine thanks to my advisor Mr. Ramesh Babu (Ass. Proff) and co-advisor Mr. Deresse Firew (Msc.) for their valuable advices, constant motivations and guidances during this study.

I would like to thank Melkassa Agricultural Research Center for its support by providing the Castor and Jatropha seed used for this research and permission for the use of its laboratory facilities during the laboratory work. My special thanks go to Mr. Teshale, Mr. Getenet, and Mr. Degnachew.

My gratitude would also extend to Bako Agricultural Mechanization Research Center for its providing the mechanical pressing machine for castor seed. Special gratitude to Mr. Duresso, Mr. Gutu, and Mr. Chala for their valuable support.

I am strongly indebted to ASTU, Chemistry Department Laboratory technical staffs for their permission to use their laboratory and for their technical support. Also my deepest gratitude was extending to ASTU, Department of Mechanical and Vehicle Engineering staffs for their support by providing the test facilities. My special thanks go to Mr. Adugna Diriba for his technical guidance and assistance during the work. My gratitude also extended to ASTU, Department of Chemical Engineering for their support by providing the laboratory facilities.

Last but not least, my thanks go to my parents, relatives and friends who helped me in one way or another during the study. I am strongly indebted to my mom Aregash Dunbale and my dad Petros Areru, who toiled hard to offer me the opportunity of education from the very beginning.

I praise Jesus Christ my Lord, for his unlimited blessings!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

ASTM	American Standards Testing and materials
EPSE	Ethiopia petroleum supply enterprise
CI	Compression Ignition
FFA	Free fatty acid
B100	Pure biodiesel
COME	Castor oil methyl ester
PME	Palm methyl ester
BTE	Brake thermal efficiency
Bsfc	Brake specific fuel consumption
IC	Internal combustion
B_{20} JB	20% Jatropha biodiesel + 80% diesel
B_{20} CB	20% Castor biodiesel + 80% diesel
B_{20} JCB	10% Jatropha + 10% Castor biodiesel + 80% diesel
B_0	Pure diesel
mm	Millimeter
Kpa	Kilo pascal
Kg	Kilogram
Km/hr	Kilometer per hour
CO	Carbon monoxide
NOx	Nitrogen oxide
CO_2	Carbon dioxide
N/S	Not specified

ABSTRACT

Decline in fossil fuel resources along with high crude oil prices generated attention towards the development of fuel from alternate sources. Such fuel should be economically attractive and performance component in order to replace the fossil fuel. Biodiesel offer a very promising alternative to diesel oil since they are renewable and have similar properties. In the previous studies there are several works on the consumption of biodiesel and its blends in diesel engines have been performed and it is evident that single biodiesel offer acceptable engine performance and emissions for diesel engine operation. But, very few works have been conducted with the combination of diesel and two different biodiesel as an alternative fuel. In this context, this study have been investigated the performance of the mixture of Jatropha and Castor biodiesels with the conventional diesel in diesel engine. The four cylinder, four strokes cycle, water cooled, direct injection engine of rear wheel derived vehicle was used for the experiments. The chassis dynamometer was used to read the wheel power and wheel force of the vehicle. The blend were prepared as B_0 *(petro diesel),* B_{20} *JB (Jatropha biodiesel blend),* B_{20} *CB (Castor biodiesel blend), and* B_{20} *JCB (Jatropha and Castor biodiesel blend) for the comparison. The result investigated that mixing of biodiesel from Jatropha and Castor oil were used to improve the high viscosity and density of castor biodiesel, and to provide better cold weather operation of Jatropha biodiesel. From the performance test results the mixture of Jatropha and Castor biodiesel blend (*B_{20} *JCB) shows 3.06% and 3.37% reduction of brake power and brake torque compared to pure diesel (*B_0*), respectively. The average brake specific fuel consumption of* B_{20} *JCB was increased by 4.89% compared to the diesel. Generally, it may be concluded from the experimental investigations that the mixture of Jatropha and Castor biodiesel blend can become an alternative source of fuel in the future.*

Key words: *Biodiesel, Jatropha, Castor, diesel engine, brake power, brake torque, brake specific fuel consumption*.

1. INTRODUCTION

1.1.Background and Justification

The increasing industrialization and motorization of the world has led to a steep rise for the demand of petroleum-based fuels. Petroleum-based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these resources are facing energy/foreign exchange crisis, mainly due to the import of crude petroleum. Hence, it is necessary to look for alternative fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, vegetable oils etc [1].

Biodiesel is defined as mono-alkyl esters of long chain fatty acids derived from renewable biolipids via transesterification process, which conform to ASTM D6751 specifications for use in diesel engines [2]. Biodiesel is made from natural, renewable sources such as new/used vegetable oils and animal fats [1]. It is commonly prepared by transesterification reaction of vegetable oil with low molecular weight alcohol, such as ethanol or methanol [3]. The properties of biodiesel generally has higher density, viscosity, cloud point, cetane number, lower volatility and heating value compared to diesel fuel that affecting on the engine performance and emissions. However, neat biodiesel or its blends may be used in the existing diesel engines with little or no modification to the engine [4, 5].

In different countries various oils have been used as raw materials for biodiesel production owing to its availability. Soybeans are commonly used in the United States. In Malaysia and Indonesia palm oil is used as a significant biodiesel source. In Europe, rapeseed is the most common base oil used in biodiesel production. In India and Southeast Asia, the Jatropha tree is used as a significant fuel source [6]. In Ethiopia according to “The Biofuel Development & Utilization Strategy” the biodiesel that is to be produced from jatropha curcas, caster bean, and palm tree aimed to ensure use of biodiesel for transportation, a high level of blend, substitute biodiesel for domestic cooking and lighting fuel, etc [7].

From the literatures, several works on the consumption of biodiesel and its blends in diesel engines have been performed. The researchers are focused on single biodiesel like Soybean oil, Rapeseed oil, Pongamia pinnata oil, Cotton seed oil, Neem oil, Castor oil, Mahua oil, Jatropha oil, Linseed oil, Rice bran oil etc., and its blends with diesel [8-18]. The researchers left a gap for the combination of dual biodiesels (mixtures of two different biodiesel).

From previous studies, it is evident that single biodiesel offer acceptable engine performance and emissions for diesel engine operation. Very few works have been conducted with the combination of diesel and two different biodiesel as an alternative fuel. But the unrevealed concept of two biodiesels [19-23] really applies to diesel engines instead of the single biodiesel and producer gas/ ethanol. The performance of the mixture of Jatropha and Castor biodiesel blend was not found in previous works. The aim of this study is to evaluate the performance characteristics of the mixture of Jatropha and Castor biodiesel blended with diesel in diesel engine.

1.2. Statement of the Problem

From the previous experimental studies it could be seen that the Jatropha and Castor biodiesel blends were used as alternative fuel in the diesel engine. But, compared to Jatropha biodiesel the Castor biodiesel has higher viscosity, higher density and lower cloud point. That, the use of Castor oil biodiesel in the blends could lower the cloud point value but, simultaneously, increase the viscosity of the diesel–biodiesel blends. These properties of Castor biodiesel have a negative effect on the diesel engine performance. So, the viscosity of Castor biodiesel has to be decreased to improve diesel engine performance. In order to improve the viscosity of Castor biodiesel the blending of lower viscosity feedstock like Jatropha biodiesel is a one approach.

1.3. Objectives

1.3.1. General Objective

The objective of this study is to investigate the performance characteristics of diesel engine fueled by mixture of Jatropha and Castor biodiesel blended with diesel as alternative fuel.

1.3.2. Specific Objectives

The specific objectives of the study are as follows:

- To extract the Jatropha and Castor seed oil.
- To produce the biodiesels from the Jatropha and Castor seed oil.

- To determine the characteristic of the Jatropha and Castor biodiesel, and their mixtures.
- To investigate the performance of the diesel engine fueled by the mixture of Jatropha and Castor biodiesel blended with diesel.

1.4. Significance of the Study

The significance of the study is as follows:

- Reduce the dependency on fossil fuel
- Help to provide cheap, locally available energy to catalyze the all-round socioeconomic development process.
- Provide substitute/supplemental energy for conventional engines.
- Offer an effective low cost strategy for importing substitution of fossil fuel.
- The results are very important for future study and development as a reference to establish a new alternative energy that produced lower effects to our earth and further reduce dependence on fossil fuels.

1.5. Scope of the Study

The scopes of this study are extracting the oil from Jatropha and castor seed, producing the biodiesel from the Jatropha and Castor oil, and blending the Jatropha and Castor biodiesels together. To see the possibility and advantage of mixing Jatropha and Castor biodiesel the characterization is the activity included in this work. At the last, this work concerns with the blending of biodiesels with the conventional diesel (petro diesel) to investigate the performance of the diesel engine and compare the performance of diesel engine fueled by mixture of Jatropha and Castor biodiesels blend (B_{20} JCB) with petro diesel to see the possibility and advantage of mixing the Jatropha biodiesel with Castor biodiesel.

1.6. Limitations of the Study

Because of the difficulties of getting engine dynamometer which used to measure brake power and torque directly from engine, the performance test was carried out using the chassis dynamometer which measures the tractive effort and wheel power of the vehicle.

1.7.Organization of the Study

This study is divided into five chapters. Following this chapter the second chapter, Literature Review, deals with the overview of the biodiesel and the related experimental investigations done in this area.

The third chapter, Materials and Method, involves description of the materials and their procedure used to attain the objectives. Moreover it deals with the extraction of oil, laboratory biodiesel production procedure, and the procedure followed during the performance testing. And the method and equations used to analyze the data observed were included in this chapter.

The fourth chapter, Results and Discussions, describe the results that were obtained and discuss with those results and compare and contrast the results obtained by different blends.

The fifth chapter, Conclusions and Recommendation, describes the conclusion made from the results obtained and points out some points recommended for future work that is possible in this area.

2. LITRATURE REVIEW

This chapter reviews the history, sources, production methods, properties and specifications of the biodiesel. There are also the previous studies which are assisting to introduce the current study were reviewed in this section in detail. These are journals, thesis and dissertations which are directly and indirectly related to the current study.

2.1. Vegetable oils as Engine Fuels

The use of vegetable oils as alternative fuels has been around for 100 years when the inventor of the diesel engine Rudolph Diesel first tested peanut oil, in his compression ignition engine [24]. Rudolf Diesel invented the diesel engine to run on a host of fuels including coal dust suspended in water, heavy mineral oil, and, vegetable oils. Diesel's first engine experiments were catastrophic failures, but by the time he showed his engine at the World Exhibition in Paris in 1900, his engine was running on 100% peanut oil. 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'' [1].

In 1912, Diesel said, ''the use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time''. Since Diesel's untimely death in 1913, his engine has been modified to run on the polluting petroleum fuel, now known as ''diesel''. Nevertheless, his ideas on agriculture and his invention provided the foundation for a society fueled with clean, renewable, locally grown fuel [25].

In the 1930s and 1940s, vegetable oils were used as diesel substitutes from time to time, but usually only in emergency situations. Recently, because of increase in crude oil prices, limited resources of fossil oil and environmental concerns, there has been a renewed focus on vegetable oils and animal fats to make biodiesel. Continued and increasing use of petroleum will intensify local air pollution and magnify the global warming problems caused by carbon dioxide. In a particular case, such as the emission of pollutants in the closed environment of underground mines, biodiesel has the potential to reduce the level of pollutants and the level of potential for probable carcinogens [26]. So, Rudolf Diesel's prediction is becoming true today with more and more bio-diesel being used all over the world.

2.2. Biodiesel Definition

Biodiesel is defined as mono-alkyl esters of long chain fatty acids derived from renewable biolipids via transesterification process, which conform to ASTM D6751 specifications for use in diesel engines. “Bio” represents the renewable and biological source in contrast to petroleum-based diesel fuel and “Diesel” refers to its use in diesel engines [2].

Biodiesel is the name of a clean burning alternative fuel, produced from domestic, renewable resources like vegetable oils, recycled cooking oils, or animal fats. Because plants produce oils from sunlight and air, and can do so year after year on cropland; these oils are renewable. Animal fats are produced when the animal consumes plant oils and other fats, and they too are renewable. Used cooking oils are mostly made from vegetable oils, but may also contain animal fats. Used cooking oils are both recycled and renewable. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. It can be used in compression ignition (CI-diesel) engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics [27].

2.3. Biodiesel as a Fuel

The best way to use vegetable oil as fuel is to convert it in to biodiesel. Biodiesel is the name of a clean burning mono-alkyl ester-based oxygenated fuel made from natural, renewable sources such as new/used vegetable oils and animal fats [1].

Biodiesel is produced by transesterification reaction of vegetable oil with low molecular weight alcohol, such as ethanol or methanol [3]. The properties of biodiesel generally has higher density, viscosity, cloud point, cetane number, lower volatility and heating value compared to diesel fuel that affecting on the engine performance and emissions. However, neat biodiesel or its blends may be used in the existing diesel engines with little or no modification to the engine [4, 5].

Biodiesel contains no petroleum products, but it is compatible with conventional diesel and can be blended in any proportion with mineral diesel to create a stable biodiesel blend. The level of blending with petroleum diesel is referred as ‘Bxx’, where xx indicates the amount of biodiesel in the blend (i.e. B10 blend is 10% biodiesel and 90% diesel. It can be used in CI engine with no major modification in the engine hardware [1].

2.4. Biodiesel Feedstock’s

Biodiesel feedstock can be categorized into three groups: vegetable oils (edible or non-edible oils), animal fats, and used waste cooking oil. Biodiesel has been mainly produced from edible vegetable oils all over the world. More than 95% of global biodiesel production is made from edible vegetable oils and this fact has an influence on the global imbalance to the market demand and the food supply. In addition, the price of this kind of feedstock makes 70–80% of the total biodiesel cost. Non-edible oils, which are not used in human nutrition and whose plants could grow in barren lands, should be increasingly used. Non-edible oil plants usually can be cultivated in lands unsuitable for human crops with much lower cost and no influence in food market [28]. Various oils extracted from seeds or kernels of non-edible crops are potential feedstocks for biodiesel production. The important non-edible oil plants are jatropha, karanja, tobacco, mahua, neem, rubber, sea mango, castor, cotton, etc. Of these feedstocks; jatropha, karanja, mahua and castor oils are the most often used in biodiesel production [29]. Table 2.1 shows the oil contents of some non-edible plants as suitable feedstock for biodiesel production.

Table 2.1 The oil contents of some non-edible plants as suitable feedstock for biodiesel production [30].

S.No.	Species	Oil fraction (%)	Seed yield (10^3tonnes/hectare/year)	Oil yield (tonnes/hectare/year)
1	Jatropha	50-60	200	2-3
2	Mahua	35-40	200	1-4
3	Karanja	30-40	60	2-4
4	Castor	45-50	250	0.5-1.0
5	Linseed	35-45	150	0.5-1.0

2.4.1. Jatropha curcas

Jatropha curcas is a plant belonging to the Euphorbiaceae family that produces a significant amount of oil from its seeds. This is a non-edible oil-bearing plant widespread in arid, semi-arid, and tropical regions of the world. Jatropha is a drought resistant perennial tree that grows in marginal lands and can live for over 50 years. The oil content in jatropha seed is reported to be in the range of 30 to 50% by weight of the seed and ranges from 45 to 60% by weight of the kernel itself [31]. Jatropha curcas oil contains approximately 24.60% of crude protein, 47.25% of crude fat, and 5.54% of moisture content. Most of the non-edible oils including Jatropha curcas carry a high level of FFAs. The oil fraction of Jatropha curcas consists of both saturated (14.2% palmitic acid and 7.0% stearic acid) and unsaturated fatty acids (44.7% oleic acid and 32.8% linoleic acid) [32].

Figure 2.1 Jatropha plant and seeds.

Figure 2.2 Castor plant and seeds.

2.4.2. Castor Plant (Ricinus Communis)

Ricinus communis, commonly known as castor oil plant, is a plant species of the family Euphorbiaceae (see Figure 2.2). It originates in Africa but it is found in both wild and cultivated states in all the tropical and subtropical countries of the world. Ricinus communis is a small wooden tree that can reach a height of about 6m. The comparative advantage of Ricinus communis is that its growing period is much shorter than that of Jatropha curcas and Pongamia pinnata, and there is considerably greater experience and awareness among farmers about its cultivation. Ricinus communis is an ideal candidate for production of high value, industrial oil feedstock's because of the very high oil content (48%–60%) of the seed, and the extremely high levels of potential oil production (500–1000 l of oil/acre). The main constituent of Ricinus communis oil is ricinoleic acid (90%), which contains 18 carbon atoms with a hydroxyl group position 12. Therefore, Ricinus communis oil contains more oxygen than other oils and, therefore, Ricinus communis oil and its derivatives are more soluble in alcohols during the transesterification reactions. The main disadvantage of Ricinus communis oil is its high viscosity. The high viscosity of Ricinus communis oil results the poor atomization of the fuel, incomplete combustion, choking of the fuel injectors, and ring carbonization [32]. The chemical composition of castor oil is Ricinoleic Acid - 89.5%, Linoleic Acid- 4.2%, Oleic Acid- 3%, Stearic Acid - 1%, Paimiric Acid- 1%, Dihydroxvstearic Acid- 0.7%, Linolenic Acid-0.3%, and Eicosanoic Acid-0.3% [33].

2.4.3. Source of Biodiesel in Ethiopia

Various oils have been in use in different countries as raw materials for biodiesel production owing to its availability. Soybeans are commonly used in the United States. In Malaysia and Indonesia palm oil is used as a significant biodiesel source. In Europe, rapeseed is the most common base oil used in biodiesel production. In India and Southeast Asia, the Jatropha tree is used as a significant fuel source [6].

Jatropha and castor plants grow in Ethiopia, where the country is one of the leading castor producing areas in the world. Both Jatropha and castor plants are non-edible oil-bearing plants, that can be grown on marginal- Lands. Hence, the use of biodiesel from jatropha and castor oil are promising alternative to fossil fuel because they are renewable, and environmentally friendly, and can also be produced locally [34]. The FDRE ministry of Energy and Water has formulated “The Biofuel Development & Utilization Strategy” to facilitate adequate production of biofuels from indigenous resources in Ethiopia. According to the strategy the biodiesel that is to be produced from *jatropha curcas, caster bean,* and *palm tree* aimed to ensure use of biodiesel for transportation, a high level of blend, substitute biodiesel for domestic cooking and lighting fuel, etc [7].

2.5. Biodiesel Production Process

Biodiesel derived from biological resources is a renewable fuel, which has drawn more and more attention recently. A fatty acid methyl ester is the chemical composition of biodiesel. Transesterification is widely used for the transformation of triglyceride into fatty acid methyl ester.

The manufacturing process is based on the transesterification of triglycerides by alcohols to fatty acid methyl esters, with glycerol as a byproduct. The base catalyzed production of biodiesel generally has the following process steps [35]:

2.5.1. Mixing of Alcohol and Catalyst

This typical process is mainly done by mixing alkali hydroxide (commonly potassium hydroxide and sodium hydroxide) with common alcohols (methanol and ethanol) in the mixer with standard agitator to facilitate the mixing. Alkali hydroxide is dissolved in the alcohol to produce alkoxide solution.

2.5.2. Chemical Reaction

The alcohol and catalyst mixture is then charged into a closed reaction vessel and the oil is added. The reaction system is totally closed to the atmosphere to prevent the loss of alcohol, since it easily vaporizable. The reaction mixture is kept just near the boiling point of the alcohol (~60^{o}c) to speed up the reaction. Excess alcohol is normally used to ensure total conversion of the oil to its esters as there is no problem of recovering of the alcohol for later use after recycling.

2.5.3. Separation

After the reaction is completed, there exists glycerol and biodiesel formation. Both have a significant amount of the excess alcohol that was used in the reaction which is in need of being recovered. The reacted mixture is sometimes neutralized at this step if the basic media that is caused by alkali hydroxide is occurred. The glycerol phase is much denser than biodiesel phase, making biodiesel to be floated.

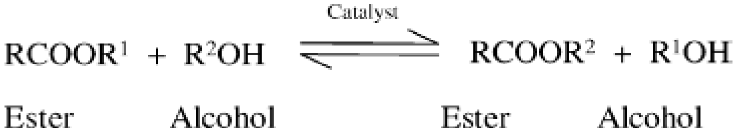
The two products can be separated by gravity using settling vessel. The glycerol is drawn off at the bottom of the settling vessel and biodiesel is drawn off at the top. In some cases, a centrifuge is used to separate the two materials faster by screening both phases.

2.5.4. Biodiesel Washing and Drying

After the Biodiesel is separated from the glycerol, it is sometimes purified by washing gently with warm water to remove residual catalyst, alcohol or soaps to make more pure. The washed biodiesel needs drying in order to remove trace impurities. In some processes washing step is not necessary depending on the quality of biodiesel produced.

2.6. Transesterification

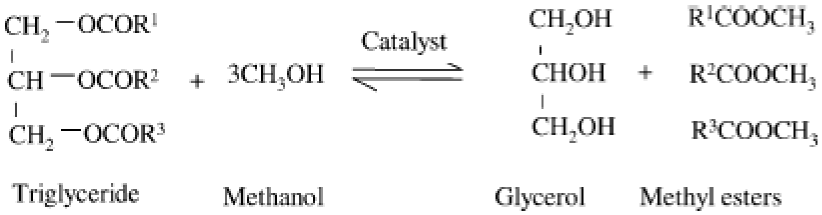
Transesterification also called alcoholysis is the displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis except that an alcohol is used instead of water [36, 37]. This has been widely used to reduce the viscosity of the triglycerides. The transesterification is represented as:



$$\underset{\text{Ester}}{RCOOR^1} + \underset{\text{Alcohol}}{R^2OH} \xrightleftharpoons{\text{Catalyst}} \underset{\text{Ester}}{RCOOR^2} + \underset{\text{Alcohol}}{R^1OH}$$

.... (Eq.2.1)

If methanol is used in this process then it is called *methanolysis*. Methanolysis of triglycerides represented in Eq. (2.2).



$$\begin{matrix} CH_2-OCOR^1 \\ | \\ CH-OCOR^2 \\ | \\ CH_2-OCOR^3 \end{matrix} + 3CH_3OH \xrightleftharpoons{\text{Catalyst}} \begin{matrix} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{matrix} + \begin{matrix} R^1COOCH_3 \\ R^2COOCH_3 \\ R^3COOCH_3 \end{matrix}$$

.... (Eq.2.2)

Transesterification is one of the reversible reactions and proceeds essentially by mixing the reactants. However, the presence of a catalyst (a strong acid or base) accelerates the conversion.

2.6.1. Chemistry of Transesterification Process

Transesterification of triglycerides produce fatty acid alkyl esters and glycerol. The glycerol layer settles down at the bottom of the reaction vessel. Diglycerides and monoglycerides are the intermediates in this process. The mechanism of transesterification is described in Eq. (2.3).

$$\text{Triglyceride} + R^1OH \rightleftharpoons \text{Diglyceride} + RCOOR^1$$

$$\text{Diglyceride} + R^1OH \rightleftharpoons \text{Monoglyceride} + RCOOR^1$$

$$\text{Monoglyceride} + R^1OH \rightleftharpoons \text{Glycerol} + RCOOR^1$$

.... (Eq.2.3)

The first step in the conversion is triglycerides to diglycerides followed by the conversion of diglycerides to monoglycerides and of monoglycerides to glycerol yielding one methyl ester molecule from each glyceride at each step [37].

The step wise reactions are reversible and a little excess of alcohol is used to shift the equilibrium towards the formation of esters. In presence of excess alcohol, the foreword reaction is pseudo-first order and the reverse reaction is found to be second order [36].

The alkali-catalyzed transesterification of vegetable oils proceeds faster than the acid catalyzed reaction and the mechanism of this alkali-catalyzed transesterification have been shown in Fig.2.1 below. The reaction mechanism is formulated in three steps. The first step is the reaction of the carbonyl carbon atom with the anion of the alcohol, forming a tetrahedral intermediate, from which the alkyl ester and corresponding anion of the diglycerides are formed. Another catalytic cycle is second molecule of alcohol. From there, diglycerides and monoglycerides are converted into alkyl esters and glycerol [38].

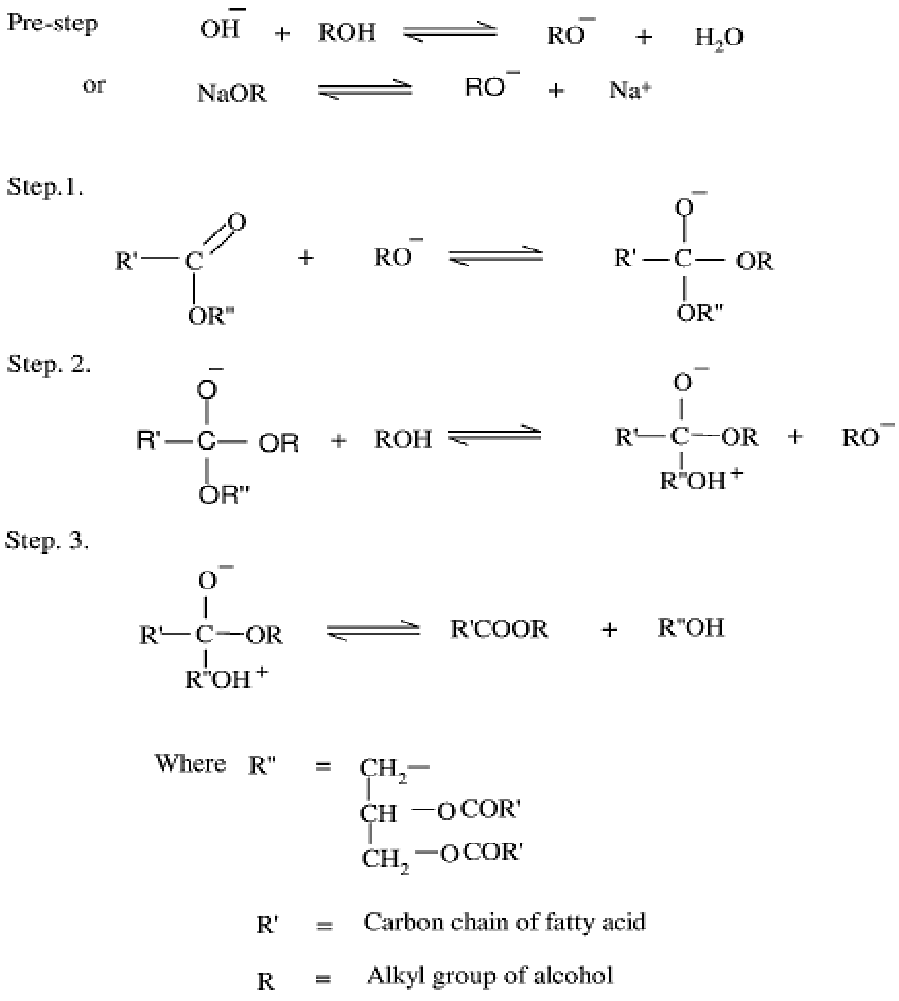


Fig. 2.1 Mechanism of base catalyzed transesterification [36]

2.6.2. Variables Affecting on Transesterification Reactions.

The yield of biodiesel in the process of transesterification is affected by several process parameters or variables. The most important variables affecting the yield of biodiesel from transesterification are; reaction temperature, molar ratio of alcohol and oil, catalyst, reaction time, presence of moisture and free fatty acids (FFA) [1, 39, and 40].

2.6.2.1. Effect of Molar Ratio of Alcohol

Molar ratio of alcohol plays a vital role in biodiesel yield. Normally the transesterification reaction requires 3 mol of alcohol for one mol of triglycerides to three mol of fatty acid ester and one mol of glycerol. Excess amount of alcohol increases conversion of fats into esters within a short time [40]. So the yield of biodiesel increases with increase in the concentration of alcohol up to certain concentration. However further increase of alcohol content does not increase the yield of biodiesel but it also increase the cost of alcohol recovery [41]. The molar ratio is associated closely with the type of catalyst used. For base-catalyzed transesterification where the free fatty acids are less than 1% after pretreatment, a molar ratio of methanol to oil of 5:1 or 6:1 is sufficient. However, where the percentage of free fatty acids in oils is high a molar ratio as high as 20:1 or 24:1 is needed when using acid-catalyzed transesterification [38].

2.6.2.2. Reaction Time

Freedman et al (1986) or [42] observed the increase in fatty acid esters conversion when there is an increase in reaction time. The reaction is slow at the beginning due to mixing and dispersion of alcohol and oil. After that the reaction proceeds very fast. However the maximum ester conversion was achieved within < 90 min. Further increase in reaction time does not increase the yield product i.e. biodiesel/mono alkyl ester [41, 43]. Besides, longer reaction time leads to the reduction of end product (biodiesel) due to the reversible reaction of transesterification resulting in loss of esters as well as soap formation [40].

2.6.2.3. The Water and Free Fatty Acid (FFA) Contents

The water and Free Fatty Acid (FFA) contents are critical factors for transesterification reaction. Base-catalyzed transesterification reaction requires water free and low acid value (< 1%) raw materials for biodiesel production. If the oil samples have high FFA content (more than 1%) then the reaction requires more alkali catalyst to neutralize the FFA. Presence of water gives greater negative effect than that of FFAs because water can cause soap formation and frothing which can cause increase in viscosity. Free fatty acid and water always produce negative result during transesterification and causes soap formation and consumes the catalyst which leads to reduction of catalyst effect. Water and FFA also leads to the reduction of methyl ester [40].

2.6.2.4. Catalyst Concentration

Biodiesel formation is also affected by the concentration of catalyst. Most commonly used catalyst for biodiesel production is sodium hydroxide (NaOH) or Potassium hydroxide (KOH) [40]. Freedman et al. [42] found that sodium methoxide was more effective than sodium hydroxide because of the reduced amount of water produced upon mixing sodium hydroxide with methanol. As the catalyst concentration increases, the conversion of triglycerides and the yield of biodiesel also increased. A concentration of NaOH in the range of 1.0–1.4% (w/w) has been found to produce 90–98% conversion from Jatropha oil to methyl ester. As for the concentration of KOH ranging from 0.55 to 2.0% (w/w), 95–99% of Jatropha biodiesel has been obtained [38]. However, the yield of biodiesel was reduced if the alkali catalysts were added above their optimum concentration. Because addition of excess amount of alkali catalyst react with triglycerides to form more soap [40].

2.6.2.5. Reaction Temperature

The rate of reaction is strongly influenced by the reaction temperature. However, given enough time, the reaction will proceed to near completion even at room temperature [1]. For example higher reaction temperature increases the reaction rate and shortened the reaction time due to the reduction in viscosity of oils. However, Leung and Guo [41] reported that increase in reaction temperature beyond the optimal level leads to decrease of biodiesel yield, because higher reaction temperature accelerates the saponification of triglycerides. Usually the transesterification reaction temperature should be below the boiling point of alcohol (60 -70°c) in order to prevent the alcohol evaporation. The range of optimal reaction temperature may vary from 50°c to 60°c depends upon the oils or fats used [40].

2.7. Biodiesel Properties and Specification Standards

2.7.1. Biodiesel Properties

1. Flash point: it is defined as the lowest temperature corrected to a barometric pressure of 101.3 kPa (760 mmHg), at which application of an ignition source causes the vapors of a specimen to ignite under specified conditions of test. For biodiesel, this test is a measure of residual alcohol and determinant for flammability classification of materials.
2. Water and Sediment: It is a test that determines the volume of free water and sediment in middle distillate fuels having viscosities at 40 °C in the range 1.0 to 4.1 mm^2/s and densities in the range of 700 to 900 kg/m^3. This test is a measure of cleanliness of fuel. For biodiesel, this test is determinant of presence of free water droplets and sediment particles.

3. Kinematic Viscosity: It is defined as the resistance to flow of a fluid under gravity. It is a basic design specification for fuel injectors used in diesel engines. For biodiesel it is quick and easy method for estimating the degree of completion of batch reaction.
4. Sulfated Ash: It is the residue remaining after a fuel sample has been carbonized, and the residue subsequently treated with sulfuric acid and heated to a constant weight. This test monitors the mineral ash residual when fuel is burned. For biodiesel, this test is an important indicator of the quantity of residual metals in the fuel that came from the catalyst used in the esterification process.
5. Sulfur: This method covers the determination of total sulfur in liquid hydrocarbons, boiling in the range from approximately 25 to 400 °C, with viscosities between approximately 0.2 and 20 cSt (mm^2/s) at room temperature. Biodiesel feedstock's typically have very little sulfur, but this test is an indicator of contamination of protein material and/or carryover catalyst material or neutralization material from the production process.
6. Copper Strip Corrosion: The copper strip corrosion is used for detection of the corrosiveness to copper of fuels and solvents. This test monitors the presence of acids in the fuel. For B100, the most likely source of a test failure would be excessive free fatty acids, which are determined in accordance with an additional specification.
7. Cetane Number: The cetane number is a measure of the ignition performance of a diesel fuel obtained by comparing it to reference fuels in a standardized engine test. This test is a measure of how easily the fuel will ignite in the engine. For biodiesel, the cetane number is seldom an issue because all of the common fatty acid esters have cetane numbers near or above 47.
8. Cloud Point: The cloud point is the temperature at which a cloud of wax crystals first appears in a liquid when it is cooled down under specific conditions. The cloud point is a critical factor in cold weather performance for all diesel fuels. For biodiesel, cloud point is typically higher than the cloud point of conventional diesel. It can then be modified in following ways to get the lower cloud point. These are:

- The use of additives that retard the formation of solid crystals in the B100 by various mechanisms.
- The blending feedstock that is relatively high in saturated fatty acids with feedstock that have lower saturated fatty acid content.

9. Carbon Residue: In petroleum products, the part remaining after a sample has been subjected to thermal decomposition, is the carbon residue. The carbon residue is a measure of how much residual carbon remains after combustion. The test basically involves heating the fuel to a high temperature in the absence of oxygen. The most common cause of excess carbon residues in biodiesel is an excessive level of total glycerin.
10. Acid Number: The acid number is the quantity of base, expressed as milligrams of potassium hydroxide per gram of sample, required to titrate a sample to a specified end point. The acid number is a direct measure of free fatty acids in B100. The free fatty acids can lead to corrosion and may be a symptom of water in the fuel.

2.7.2. Biodiesel Specifications

The American Society for Testing and Materials International (ASTM) specification for biodiesel (B100) is ASTM D6751-02 [2]. Also, the European standard (EN 14214) is adopted by all 31 member states of the European Committee for Standardization of biodiesel (B100) [44]. Some of the test methods listed in it performs more than one role. These methods ensure that the fuel performs same as intended in CI engines and as tests to ensure that the manufacturer produced a high quality B100 [2]. Each of these properties and the test method used to measure it are briefly described below.

Table 2.2 Specifications for biodiesel [44].

Properties of biodiesel	Units	ASTM D6751		EN 14214	
		limits	test methods	Limits	Test methods
kinematic viscosity (40^{o}c)	mm^2/s	1.9-6.0	D445	3.5-5.0	EN ISO 3104
Density (15^{o}c)	kg/m3	N/S	N/S	860-900	EN ISO 3675
Ester content	mass%	N/S	N/S	96.5 min	EN 14103
Cetane number	-	47min	D613	51 min	EN ISO 5165
Flash point	^{o}c	93min	D93	120 min	ISO/CD 3679
Water content	volume %	0.050 max	D2709	500 max	EN ISO 12937
Sulphated ash	mass %	0.020 max	D874	0.02 max	ISO 3987
Copper corrosion	grade	No.3 max	D130	No.1	EN ISO 2160
Acid number	mg KOH/g	0.80 max	D664	0.5 max	EN 14104
Iodine number	-	N/S	N/S	120 max	EN 14111
Oxidative stability (110^{o}c)	h	N/S	N/S	6 max	EN 14112
Oxygen content	%	N/S	N/S	N/S	N/S
High calorific value	MJ/kg	N/S	N/S	N/S	N/S
Free glycerol	mass %	0.020 max	D6584	0.020 max	EN 14105
Total glycerol	mass %	0.240 max	D6584	0.25 max	EN 14105
Phosphorous content	mass %	0.001 max	D4951	10 max	EN 14107

2.8. Previous Experimental Studies

2.8.1. Transesterification Process and Fuel Characterizations

As the objective of the study concerns the production and characterization of biodiesel from the Jatropha and Castor oil, the related experimental studies observed by different researchers are discussed below. It includes the papers done locally and internationally by the researchers previously.

Abrar Abdela et al. [45] have studied the performance of cotton seed biodiesel in diesel vehicle. From the experimental results optimum transesterification reaction for optimal biodiesel yield of

75.5% was 2.5 gm per liter at reaction time of one hour, the reaction temperature of 65^0c and volume ratio of oil to methanol as 5:1. From the performance test the brake power of B20 is found to be lower than of B0. This is because of the higher heating value of biodesel.

Mengesha Kassahun, B. et al. [46] were determining the fatty acid characteristics and biodiesel quality of Ethiopian Jatropha provenances. It was observed that the identified constituents of the Jatropha oils are linoleic acid, stearic acid, palmetic acid and oleic acid. From the identified fatty acids, oleic acid was the major constituent followed by stearic acid. The constituents of the fatty acids ranged from 42.8-51.4% for oleic acid, 10.9-19.3% for stearic acid, 10.62-15.91% for palmetic acid and 21.73-25.43% for linoleic acid. From the extracted oil a tranesterification reaction was carried out with molar ratio of 6:1 (crude oil: methanol), 0.5% NaOH and the mixture was heated at close to the boiling point of methanol, 60 to 70^0C at atmospheric pressure. The reaction mixture was stirred for 90 minute biodiesel quality characteristics of Ethiopian Jatropha seeds were found within the limits of American standard (D874) and European standard (EN 14214 standard).

Akanawa, T. T., et al. [8] have investigated the fuel properties of Castor oil Methyl Ester (CME) and its blend with diesel fuel in running a diesel engine. Trans-esterification of castor oil was comprised by dissolving of KOH (2grams) in methyl alcohol (100ml), heating of castor oil (100ml) to 50^0C, adding KOH and methyl alcohol solution (25ml) in to the heated oil, stirring of the mixture, separation of glycerol, washing with distilled water and addition of Na_2SO_4 for drying of water. The biodiesel production yield was found to be 98 % v/w. From the characterization result, it was proved that trans-esterified castor oil was found to be a promising alternative fuel for compression ignition (diesel) engines. But the viscosity of CME was still higher and the energy content was a little bit less as compared to petro diesel. To solve these problems CME was blended with petro diesel in different proportion.

Ayoola, A. A. et al. [47] have studied the jatropha curcas oil used as feedstock for biodiesel production by alkali-catalyzed methanolysis. To establish the optimum conditions for biodiesel production, effects of certain factors were investigated, these factors are oil-to-methanol molar ratios (1:4 - 1:8), KOH catalyst concentrations (0.5-1.5% w/w oil), reaction temperatures (50 - 70ºC), and reaction times (55 - 90minutes). These experimental investigations revealed that the optimum conditions for Jatropha curcas biodiesel production are a reaction temperature of 60^oC, KOH catalyst concentration of 1% w/w of oil, oil-to-methanol ratio of 1:6 and reaction time of 80 minutes. The methyl ester produced under these optimum conditions was 93.75 % w/w.

Nakpong, P., & Wootthikanokkhan, S. [48] have investigated the jatropha curcas oil as feedstock for biodiesel production by alkali-catalyzed methanolysis. The optimum conditions for Jatropha curcas biodiesel production were a methanol-to-oil molar ratio of 6:1, a catalyst concentration of 1.0% w/w of oil, a reaction temperature of 60°C, and a reaction time of 40 minutes. The methyl ester content under these optimum conditions was 98.6% w/w, and all of the measured properties of the Jatropha curcas biodiesel met the Thai biodiesel (B100) specifications and international standards EN 14214:2008 (E) and ASTM D 6751-07b, with the exception of lower oxidation stability.

Temu, A. K., & Apita, A. O. [49] have investigated the parameters affecting Castor oil transesterification reaction kinetics for biodiesel production. Castor oil was transesterified with methanol using a molar ratio of methanol to oil (6:1) and sodium hydroxide catalyst (1% wt of oil). High temperatures (55 and 65^{o}C) were unfavorable for castor transesterification; both temperatures provided yields of 91%. Low temperatures (35 and 45^{o}C) increased rate constants and produced highest yields (98% and 97% respectively). Increasing stirring rate does not favor conversion rates. The optimum transesterification conditions for castor oil were: temperature, 35^{o}C; reaction time, 60 minutes; molar ratio of 6:1 methanol to oil and moderate stirring (600 rpm). A product yield of 98% methyl ester was obtained under these conditions. It was observed that a reaction time longer than 90 minutes results in reactants formation due to the reversibility of the reaction.

Conceição, M. M., et al. [50] have studied the conversion of thermo analytical characterization of castor oil biodiesel. Castor oil was converted into biodiesel through the alkaline transesterification reaction. Methanol was added in the 20% ratio in mass and also 1% of the potassium hydroxide catalyst dissolved in alcohol. Then the mixture was shaken in ambient temperature for 30 min. Glycerin was removed after the decantation process which has taken 30 min and then biodiesel was purified, presenting a 98% yield. The presence of a bigger content of hydroxyacid (ricinoleic acid) in the castor oil is reflected in its colligative properties, such as high values of viscosity and density.

Okullo, A. A., et al. [51] have studied that physico-Chemical Property of Biodiesel from Jatropha and Castor Oils. Oil from castor seeds contained high proportion of ricinoleic acid with considerable amounts of lionleic, oleic, stearic and palmitic acids. Oil obtained from jatropha seeds consisted mainly of linoleic, oleic and palmitic acids with minor components of stearic and palmitoleic acids. Castor biodiesel yields were low. This was due to the formation of soap from crude castor oil during transesterification. Biodiesel from jatropha oil had a higher heat of combustion than biodiesel from castor oil. Castor biodiesel has a lower calorific value than jatropha. This is attributed to the structural differences in the constituent fatty acids of castor oil. Jatropha biodiesel viscosity complied with standard specification while castor biodiesel viscosity did not. Castor biodiesel had lower cloud point than jatropha biodiesel, making castor biodiesel more suited for use in cold countries than jatropha biodiesel. Jatropha biodiesel may require the use of additives to improve its cold weather property desirable in cold countries. Flash points of biodiesel from jatropha and castor oils meet the required specification.

Generally for the current study the reaction conditions used in [48] was selected for the production of biodiesel from jatropha oil due to its higher production yield and shorter reaction time. For the castor biodiesel production the reaction conditions used by [49] were selected for its higher production yield and low temperature operability.

2.8.2. Performance Analysis of Biodiesel Blends in Diesel Engines

As the objective of this study concerns the performance analysis of biodiesel, the related experimental studies investigated by different researchers are discussed below. The performance parameters such as torque output, power output, specific fuel consumption, brake thermal efficiency of different biodiesels has been reviewed as follows:

Akanawa, T. T., et al. [8] have studied the Castor biodiesel performance in four stroke diesel engine. The performance test results depict the tested blends (B_5, B_{10}, B_{20}, and B_{40}) 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. The performance result also showed that out of the blends, B_5 is most nearer to petro diesel performances and hence it is possible to start driving diesel engine vehicles with 5%

biodiesel and 95% petro diesel blend. But small generators and water pump engines (because the load imposed on them is not that much bigger) can be fuelled with B_{20}, a 20% biodiesel and 80% petro diesel blend; which brings a great cost reduction especially for farmers (because biodiesel can be locally produced).

Firew Deresse at al. [9] have investigated to test and compare the performance of Jatropha biodiesel – diethyl-ether and diesel blends with pure petro diesel, using diesel engine test rig with hydraulic dynamometer and roller chassis dynamometer. Different amount of DEE, 40ml, 30ml, 20ml, and 10ml per litter was used. The Brake power of B-20 + 20% DEE is found to be higher than that of other biodiesel blends but lower than the B-0. The higher Power after the addition of DEE to JOME is due to its oxygen content and effect on lowering the viscosity of the blend, which led to an improvement in the combustion. The brake specific fuel consumption for B-20 + 10% DEE is lower than that of the others at the maximum load, however at lower load conditions B-20 + 20% DEE gives the lowest break specific fuel consumption. The results were concluded that the performance of the fuels with additive show that the power output as well as the specific fuel consumption of the B-20 with 40ml of DEE has given the best result next to the petro diesel.

Tiku Tesfahun [10] has investigated the performance of biodiesel produced from avocado seed in diesel engine. The engine test was carried out on chassis dynamometer on 4-stoke 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. From the experimental results, the blended fuels brake power was generally lower than of diesel fuel 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 speed. Generally, the torque and power performances get reduced and fuel consumption increase as the percentage of biodiesel in the blend increases. This is because of the fact that biodiesel's are oxygenated fuels and hence has less energy content compared to petro diesel.

Derege Dagne et al. [11] have studied the production of biodiesel from Argemone seed oil and testing its performance in conventional diesel engine. From the result the most favorable conditions for transesterification of argemone oil with methanol in the presence of KOH as a catalyst was found with molar ratio 1:6 (oil to methanol), reaction temperature 78^0c, and catalyst 2.5 gram. The experimental result shows the argemone biodiesel blend of B20 have improved fuel property and brake thermal efficiency, brake power and specific fuel consumption value is closer to diesel value.

Kumar, K., & Sharma, M. P. [12] have studied the performance and emission characteristics of diesel engine fueled with biodiesel blends. Biodiesel prepared from the raw oils of Jatropha, moringa and palm was investigated. In this study, 20% biodiesel of each and 80% of diesel fuel (JB_{20}, MB_{20} and PB_{20}) has been used in a diesel engine, because 20% biodiesel blend has the fuel properties like: density, kinematic viscosity, calorific value etc. similar to diesel and can be used in diesel engine without any engine modification. The biodiesel blends PB_{20}, MB_{20} and JB_{20} reduced the BP as 8.11%, 10.81%, and 13.51% compared to diesel fuel at engine speed of 3500 rpm. The BSFC increased for MB_{20}, JB_{20}, and PB_{20} by 8.60%, 8.14% and 6.98% respectively compared to diesel fuel at engine speed of 3500 rpm, because biodiesel and its blends having the lower calorific value as compared to diesel. From all the biodiesel blends, palm biodiesel blend (PB_{20}) shows higher performance than other biodiesel blend.

Mofijur, M., et al. [13] studied the feasibility of Jatropha as a potential biodiesel feedstock for Malaysia. The results show that viscosities of B_{10} and B_{20} are closer to diesel. Therefore, only B_{10} and B_{20} have been used to evaluate engine performance and emission. Compared to B0, the average reduction in brake power (BP) is 4.67% for B_{10} and 8.86% for B_{20}. It can be seen that the engine torque of B_0 fuel is always higher than that of the $B_{10}$and B_{20} fuels. The average torque reduction for $B_{10}$and B_{20} as compared to B_0 was 3.08% and 4.6%, respectively. It is seen that the BSFC for biodiesel-blended fuels is higher compared to diesel. The average BSFC for B_0, B_{10} and B_{20} is 273.5 g/kWh, 278.46 g/kWh, and 281.9 g/kWh, respectively. As a conclusion, B_{10} and B_{20} can be used in a diesel engine without any modifications.

Valente, O. S., et al. [14] have investigated the impacts on fuel consumption and exhaust emissions of a diesel power generator operating with biodiesel. Fuel blends with 5%, 20%, 35%, 50%, and 85% of soybean biodiesel in diesel oil, and fuel blends containing 5%, 20%, and 35% of castor oil biodiesel in diesel oil were tested, varying engine load from 9.6 to 35.7 kW. The results showed increased fuel consumption with higher biodiesel concentration in the fuel. Soybean biodiesel blends showed lower fuel consumption than castor biodiesel blends at a given concentration.

Gopal, K. N., & Karupparaj, R. T. [15] have investigated the emission and combustion characteristics bio-diesel from pongamia oil (PME 100) tested on a diesel engine for different blends such as PME_{20}, PME_{40}, PME_{60} and PME_{80}. It is found that the brake specific fuel consumption (BSFC) of PME_{100}, PME_{80}, PME_{60}, PME_{40}, PME_{20} and petroleum diesel is 53.3%, 41.9%, 26.3%, 22.96% and 11.1% higher than that of diesel respectively. The maximum brake thermal efficiencies (BTE) at full load condition for diesel, PME_{20}, PME_{40}, PME_{60}, PME_{80} and PME_{100} are calculated as 30.03%, 29.1%, 27.74%, 27.78%, 26.34% and 25.37%. It can be observed that the brake thermal efficiency of pongamia biodiesel is 15.5% lower than that of petroleum diesel at rated load. Thus, results indicate that pongamia oil methyl ester can be used as an alternative and environment friendly fuel for a diesel engine.

Salvi, B. L., & Jindal, S. [16] have studied the performance and emissions characteristics of direct injection diesel engine fueled with linseed oil biodiesel blends and diesel fuel. The experiments were conducted with various blends of linseed biodiesel at different engine loads. At full load, with LB_{10}, comparable mass fraction burnt, rate of pressure rise and maximum peak pressure, BMEP were observed. The brake power decreases with increase in biodiesel blends, as calorific value of the biodiesel decreases. With LB_{10}, better thermal efficiency (8–11 %) and lower specific fuel consumption (3.5–6 %), lower CO, lesser smoke and hydrocarbon emission are the advantages while a little increase in NOx emission is confronted. With the advantages, the linseed proves to be a potential source for deriving alternative and renewable fuel for IC engines.

Özcanli, M., et al. [17] studied to evaluate the use of various blends of castor (Ricinus Communis) oil methyl ester with diesel fuel. Biodiesel produced from castor oil was blended with diesel fuel at the volumetric ratios of 5% (B5), 10% (B10), 25% (B25), 50% (B50), and 100% (B100). Engine performance and exhaust emission tests were performed on a commercial three cylinders, four strokes, and naturally aspirated, water-cooled, direct injection compression ignition engine. Test fuels were run from 1,000 to 2,400 rpm engine speeds with an interval of 200 rpm at full load condition. A hydraulic dynamometer was used for determination of power output. Fuel consumption was measured on a volumetric basis. From the results, the power output of the engine with blends decreased by a maximum of 4.12% with B25 blend compared with diesel fuel. Bsfc is increased with COME blend ratios, due to lower heating value of COME.

Dishika [18] have evaluated the performance and emissions characteristics of a compression ignition engine using castor oil based biodiesel. An experimental investigation has been carried out in a single cylinder diesel engine at a constant speed of 1500 rpm from no load to 60% of full power to evaluate biodiesel blends such as B_{20}, B_{40}, and B_{50}. The test results indicate that at full load, the brake power produced by castor biodiesel blend B_{20} is 3.125% less than that of diesel and brake specific fuel consumption of castor biodiesel blend B_{20} and diesel is almost the same. It is concluded that castor biodiesel blend B_{20} is a best candidate of alternative fuel among all tested fuel at full load conditions.

2.8.3. Experimental Investigation on Mixing of Two Biodiesels Blended with Diesel

The current study concerns with the mixture of two biodiesel (Jatropha and Castor) blends and its performance test in the diesel engine. So, the previous related works done by the different researchers are reviewed here below.

Kuthalingam, A. B., et al. [52] have investigated the possibilities of the application of mixtures of two biodiesel and its blends with diesel as a fuel for diesel engines. The combinations of Pongamia pinnata biodiesel, Mustard oil biodiesel along with diesel (PMD) and combinations of Cotton seed biodiesel, Pongamia pinnata biodiesel along with diesel (CPD) are taken for the experimental analysis. From the experiment results, the brake specific fuel consumptions (BSFC) of blend CPD- 1(10:10:80) is 0.32 kg/kW-h whereas for diesel is 0.31 kg/kW-h. CPD blends having lower exhaust temperature in all loads than PMD and diesel. The PMD- 1 (10:10:80), CPD- 1 and CPD- 2 (30:30:40) produced low CO_2 emissions than diesel. The PMD- 1 and CPD- 1 produced low CO emissions than diesel. The CPD blends produced low CO_2 emissions than PMD blends. Therefore, the CPD blends are promising alternate substitute for stationary and agricultural diesel engines.

Rao, V. [53] studied the performance of diesel engine with dual biodiesels – diesel blends as an alternative future fuel. The mixture of pongamia and jatropha biodiesel (BPJBD) was blend with diesel to prepare biodiesel-diesel blends (DPJBD). It is observed that, $D_{90}PJBD_{10}$ gives the maximum thermal efficiency of 26.2% and $D_{80}PJBD_{20}$ gives 24.7% as compared to the diesel

26.6% at the same load condition. At maximum load, the brake specific fuel consumption (BSFC) value of $D_{90}PJBD_{10}$ is 0.35kg/kWh, $D_{80}PJBD_{20}$ is 0.365kg/kWh, $D_{70}PJBD_{30}$ is 0.368kg/kWh and for the diesel fuel is of 0.364 kg/kWh. Based on these results, $D_{90}PJBD_{10}$ and $D_{80}PJBD_{20}$ were very closer to diesel fuel values. Hence they can be used as fuels for stationary diesel engines for the purpose of agriculture.

Srithar, K., et al. [54] have carried out the experimental investigation on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines. Two biodiesels from pongamia pinnata oil and mustard oil and they are blended with diesel at various mixing ratios. From the experimental analysis results, the thermal efficiency and mechanical efficiency of Blend A (Diesel 90%, PPEE 5% and MEE 5%) were slightly higher than the diesel. Blend B (Diesel 80%, PPEE 10% and MEE 10%) and Blend C (Diesel 60%, PPEE 20% and MEE 20%) were very closer to the diesel values. The specific fuel consumption values of dual biodiesel blends were comparable to diesel. Blend A and Blend B produced slightly lower CO and CO_2 than diesel. This is a considerable advantage over diesel while using the dual biodiesel blends. The dual biodiesel blends gave higher smoke opacity, HC and NOx than diesel. But for the Blend A, Blend B and Blend C the smoke opacity was nearer to diesel. Therefore, it may be concluded that dual biodiesel blends of Blend A, Blend B and Blend C would be used as an alternative fuel for diesel in the diesel engines.

Nalgundwar, A., et al. [55] studied the comparison of performance and emissions characteristics of DI CI engine fueled with dual biodiesel blends of palm and jatropha. From the experiments, the results for lower blend of biodiesel $D_{90}PB_5JB_5$ (i.e. 90% diesel & 10% biodiesel) with diesel showed 4.65% average increase in brake power than diesel. There was slight reduction seen in BSFC for lower blends. Higher biodiesel blend $D_{20}JB_{40}PB_{40}$ (i.e. 20% diesel & 80% biodiesel) have showed up to 15% average increase in brake thermal efficiency. A notable decrease in exhaust gas temperature for most of biodiesel blends was observed. There were 7.1%, 17.7% and 14.5% average reductions in CO emissions with samples $D_{90}JB_5PB_5$, $D_{80}JB_{10}PB_{10}$ and $D_{70}JB_{15}PB_{15}$ (biodiesel blends containing 10%, 20% & 30% biodiesel) respectively, when compared to diesel. Lower blends of biodiesel samples $D_{90}JB_5PB_5$ and $D_{80}JB_{10}PB_{10}$ showed 5.3% and 9.2% average increase in NOx emissions respectively, than diesel.

Kini, K., et al. [56] have investigated the properties, performance and emission characteristics of blends of Castor and Pongamia Pinnata biodiesel in blend proportion of B20P, B15P5C, B10P10C, B5P15C, B20C. Based on properties it was found that density, kinematic viscosity, gross calorific value, flash and fire point was higher compared to diesel, pH was found to be neutral. From the experimental analysis it was found that emission characteristics like CO2, CO and HC were found to be decreased and NOx emission was increased in comparison to diesel and performance characteristics like Exhaust gas temperature was higher for diesel, BTE and SFC was higher for biodiesel, BP remained almost same for both. Based on the results and analysis it was concluded that blend B5P15C is an optimum blend among all 5 blends.

From the reviewed literatures, numerous works in the utilization of biodiesel as well as its blends in engines have been done. However, most of the literatures focused on single biodiesel and its blends. From previous studies, it is evident that single biodiesel offers acceptable engine performance and emissions for diesel engine operation. But, very few experiments have been conducted with the combination of dual biodiesel and diesel as a fuel [19-23]. The Jatropha and castor biodiesel were selected for this current study because the performance of the mixture of castor and jatropha biodiesel blends was not found in previous works. On other hand, they are easily and locally available, and non-edible. Compared to jatropha biodiesel the castor biodiesel has higher viscosity, higher density and lower cloud point. Also, the use of castor oil biodiesel in the blends could lower the cloud point value but, simultaneously, increase the viscosity of the diesel–biodiesel blends. In this study there were evaluated four properties (densities, viscosities, flash and cloud point.) of castor biodiesel, jatropha biodiesel and mixture of both biodiesels. Their blends were examined in diesel engine for comparison.

3. MATERIALS AND METHODS

In order to successfully accomplish the general as well as specific objectives of the study there would be a combination of materials and methods intended to use. These are the extraction of the oil from the Castor and Jatropha seed, production of biodiesel from the extracted oils, characterizing the properties of the biodiesel produced, blending, and performance testing of the blended fuels in the diesel engines.

3.1. Materials

The Jatropha seed and Castor seed were obtained from Melkassa Agricultural Research Center. Methanol, Potassium hydroxide, and Distilled water were purchased from chemical selling and suppliers companies (Ranchem chemicals Plc, Addis Ababa) for laboratory scale amount. Diesel fuel was purchased from Oil Olibya, Adama. All chemicals used for the research were analytical grade.

Additional materials were used for this research: volumetric flasks, beakers, measuring cylinders, separator funnels, protective equipment's, four cylinder engine of diesel vehicle, Chassis dynamometer, thermometer, hot plate with magnetic stirrer, Tephra quantity measuring devices, Oven and digital balance.

3.2. Methodology of the Research

The methodology of the research were the batch laboratory scale production of biodiesel from Jatropha and Castor oil, methanol, and potassium hydroxide catalysis through transesterification methods and the performance of biodiesel blends and petro diesel were conducted in a four stroke, 4cylinder diesel engine.

3.2.1. General Method to Conduct the Experiment

This research was conducted mainly based on the following experimental procedures shown in the figure 3.1. These are the extracting of oil, preheating of oil to remove the water, preparation of methoxide, transesterification reaction, separation of glycerol from the biodiesel, biodiesel washing, drying to remove remaining water and alcohol in the biodiesel, characterization, blending and performance testing of the biodiesel blended with petro diesel.

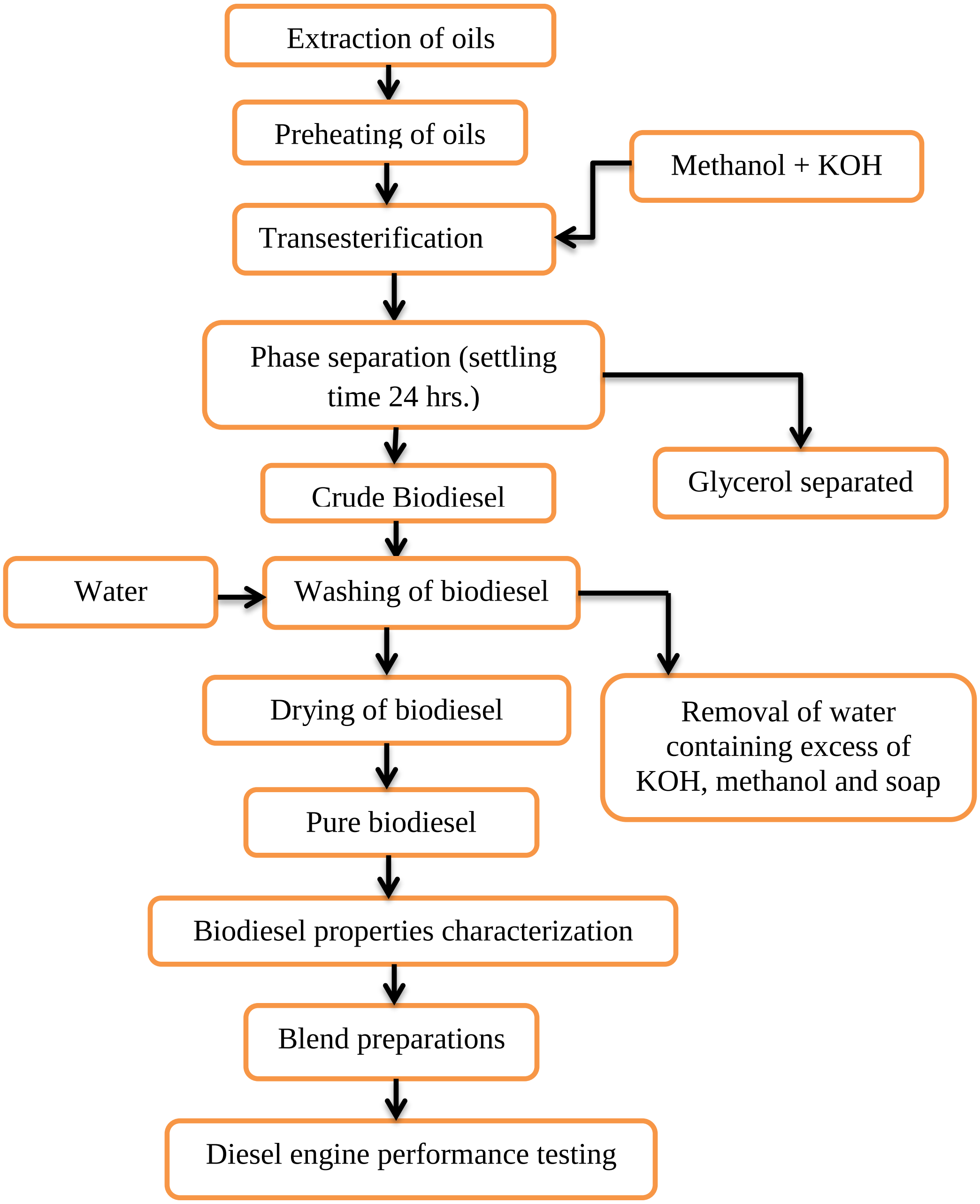


Figure 3.1 General methods to conduct the experiment

3.2.1.1. Extraction of Jatropha and Castor oil

The Jatropha and Castor seed were obtained from Melkassa Agricultural Research Center. The method used to extract the Jatropha oil was mechanical pressing of the Jatropha seed by a human operated hydraulic pressing machine which is available in the work shop of Melkassa

Agricultural Research Center, Ethiopia. The extracted oil was filtered and the pure Jatropha oil was obtained as shown in the figure 3.2.

Fig.3.2 Mechanical pressing of Jatropha seed.

The amount of oil extracted was calculated as follows:

$$\%\ \text{oil} = \frac{mass\ of\ oil}{mass\ of\ seed}\ x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (3.1)}$$

The Castor oil was obtained by mechanical pressing of the Castor seed by a human operated hydraulic pressing machine which was developed by the Bako Agricultural Mechanization Research Center (Fig.3.3). The amount of crude oil extracted was calculated by Eq. (3.1).

Fig.3.3 Mechanical pressing of Castor seed

3.2.1.2. Laboratory Preparation of Biodiesel

The transesterification reaction of Jatropha oil was carried out at Melkassa Agricultural Research Center, Food and Nutritional Department laboratory. While the transesterification of Castor oil was carried out at Adama Science and Technology University, Chemistry department laboratory.

Step by step approach used in the production of the Jatropha and Castor biodiesel is given below:

1. 500ml of oil was measured and poured into beaker and heated to temperature of 120 ^{o}c for 30 minutes to remove the water (Fig.3.4). Then the Jatropha oil was cooled down to 60^{o}c [48] and ready for transesterification reaction. While Castor oil was cooled down to 35 ^{o}c [49].
2. The solution of potassium methoxide was prepared in volumetric flask using 5 gm of KOH (i.e., catalyst concentration of 1%) and 250 ml of methanol (i.e., mole ratio of oil to methanol of 1: 6). The solution was properly stirred until potassium hydroxide pellet was completely dissolved (i.e., at least for 10 minutes).
3. The potassium methoxide solution was then poured into the warm oil (i.e., at 60^{o}c of Jatropha and at 35^{o}c of Castor oil) and stirred vigorously (for 40 minutes for Jatropha and 60 minutes for Castor) using a magnetic stirrer. During the transesterification reaction the mixture of Jatropha oil and methoxide were covered by aluminum foil to prevent the loss of methanol since its boiling point was closer to 60^{o}c (Fig.3.5).The mixture was then allowed to settle for 24 hours in a separating funnel to separate glycerol from methyl ester (Fig.3.6).
4. The biodiesel was then poured into a separate beaker, while the lower layer (which comprises of glycerol and soap) was collected from the bottom of the separating funnel (Fig.3.7).
5. Warm water (30% v/v) was then used to wash the biodiesel to remove any excess glycerol and soap that remain in the funnel. This was done until the clear water was seen below the biodiesel in the separating funnel (Fig.3.8).
6. The washed sample was dried by placing it on a hot plate for 1hr at 120^{o}c (for Castor biodiesel) [57] and in oven for 2hr at 110^{o}c [47] (for Jatropha biodiesel). Then the quantity of biodiesel collected was measured and yield of biodiesel was calculated (Fig.3.9).

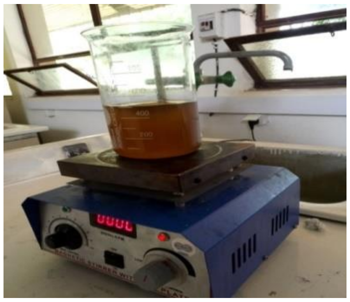


Fig.3.4 Preheating of the oil

Fig.3.5 Transesterification of Jatropha and Castor oil

(a) Jatropha

(b) Castor

Fig. 3.6 Separation of the glycerol

(a) Glycerol

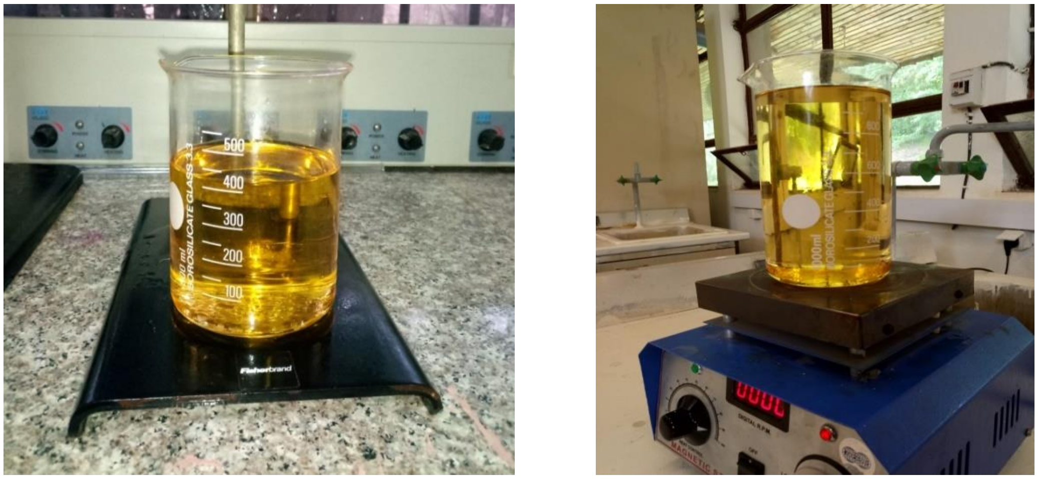
(b) Biodiesel before washing

Fig.3.7 Separated glycerol and biodiesel before washing

(a) first washing process (b) The second washing process

(b) The last washing process

Fig. 3.8 Biodiesel washing processes



(a) Jatropha (b) Castor

Fig. 3.9 The final pure biodiesel after dried

3.2.1.3. Characterization of Biodiesel

In this study characterization of biodiesel was done in partial that is only for density, viscosity, flash point and cloud point at Ethiopian petroleum supply Enterprise laboratory and the test was done as per the procedure of the enterprise in reference to ASTM methods with no involvement of the researcher. The sample drawn for characterization was only Jatropha biodiesel (B_{100} JB), Castor biodiesel (B_{100}CB) and mixture of Jatropha and Castor biodiesel (50% Jatropha and 50% Castor) or $B_{50}JB_{50}CB$.

3.2.1.3. Biodiesel Blend Preparation

Biodiesel can be blended with petrol diesel in any proportion, with B_5 (5% biodiesel and 95% diesel) and B_{20} (20% biodiesel and 80% diesel) being the most common. No vehicle alternations are necessary if blended at levels of B_{20} or lower, although original equipment manufacturers have varying policies approving different blends for use in their vehicles. In this study only B_{20} (20% biodiesel and 80 % diesel fuel) was being used in a conventional CI engine for the comparison. These are pure diesel (B_0), Jatropha biodiesel blends (B_{20} JB), Castor biodiesel blends (B_{20} CB) and mixture of Jatropha and Castor biodiesel blends (B_{20} JCB). Fuel blends were prepared by volume as shown in the table 3.1 below.

(a) B_{20}JB (b) B_{20}CB (c) B_{20}JCB

Fig. 3.10 Prepared biodiesel blends.

Table 3.1 Blend Proportions of Test Fuels.

Fuel type	Petro diesel	Jatropha biodiesel	Castor biodiesel	Total
B_0	2000 ml	-	-	2000 ml
B_{20} JB	1600 ml	400ml	-	2000 ml
B_{20} CB	1600 ml	-	400 ml	2000 ml
B_{20} JCB	1600 ml	200 ml	200 ml	2000 ml

3.2.2. Engine/Vehicle Performance Testing

The performance test was conducted at the Mechanical and Vehicle Engineering work shop of Adama Science and Technology University.

Vehicle performance was measured in terms of tractive effort and wheel power. The chassis dynamometer was used to measure these tractive effort and wheel power. A chassis dynamometer sometimes referred to as a rolling road, measures power delivered to the surface of the "drive roller" by the drive wheels. The vehicle is often parked on the roller or rollers, which the car then turns, and the output measured thereby.

3.2.2.1. Sun ROAD-A-MATIC RAM XII Chassis Dynamometer

Figure 3.11 shows the Sun ROAD-A-MATIC RAM XII chassis dynamometer which was used for vehicle performance testing in this study. An air cooled eddy current dynamometer absorbs the energy from the traction wheel of the car. A handled remote is used to control the loading whilst the speed and tractive effort are displayed on two large analogue dials. The specifications of Sun ROAD-A-MATIC RAM XII chassis dynamometer used were given in the table 3.2.

Fig. 3.11 Sun ROAD-A-MATIC RAM XII Chassis Dynamometer

Table 3.2 Sun ROAD-A-MATIC RAM XII Chassis Dynamometer Specifications.

Model	RAM XII
Serial	988
Highest Axle Loads	2580
Volts	220
Amps	161
Phase	15
Frequency	50
Year Of Manufacture	04/92

Table 3.3 below shows the specification of the engine of diesel vehicle used for performance test. The vehicle was a rear wheel drive vehicle and allowed to run on the chassis dynamometer. So, the wheel power, speed, and force readings are taken from the gauge.

Table 3.3 Engine and Vehicle specifications

Engine model	3L
Maximum power	67 KW @4000rpm
Displacement	2779 cc
Compression ratios	22.2
Maximum torque	188 Nm@2400RPM
Tire size	215R15-6

3.2.2.2.Experimental Test Set up

Figure 3.12 shows a schematic of the rolling road test set up. A Sun ROAD—MATIC chassis dynamometer was used for measurement of power, tractive effort and road speed. A cooling fan (blower) was placed in front of the vehicle radiator to provide sufficient cooling to the vehicle. Speed was controlled by the operator using dynamometer load switch.

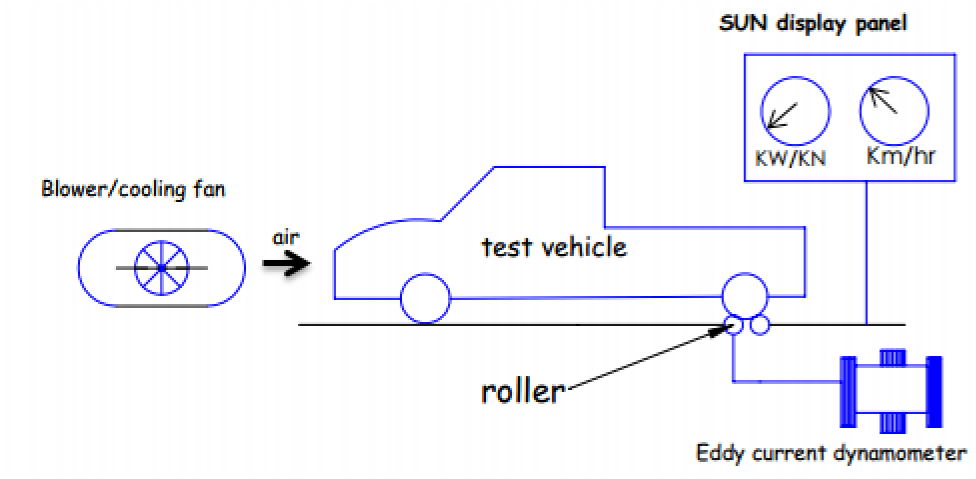


Figure 3.12 Schematic of test set up used for vehicle mounted on the rolling road.

Experimental procedure:

- The vehicle was attached safely to the rolling road and allowed to idle for approximately 20 to 30 minutes before commencing a test run to allow for sufficient engine warm up, this ensured that all operating temperatures had been reached.
- All tests were subjected to full loading.
- The measurement process used in this experiment was a constant speed mode. That the tester sets the speed of the vehicles and then the driver accelerates the car, pressing the accelerator pedal completely down (since the measurement is supposed to be made for full opening of the throttling valve). The dynamometer then burdens the car automatically until the revolutions are equal to the set value of the speed and the car will neither speed up neither slow down. The value of power, measured by the load cell is presented on the screen in real time. The tuner can make changes during the measurement and immediately see the result of his work on the screen.
- The measurement time is about 10 s of the full load (for the stabilization of speed and result reading) for each measurement point (an individual value of speed).
- Data was measured at test speed selected with 5 km/hr intervals starting from 25 km/hr to 75 Km/hr.
- The experiment was conducted in first gear, second gear, third gear and fourth gear.

- The test was start with pure diesel fuel (B_0) and followed by the B_{20} JB, B_{20} JCB, and B_{20} CB.
- For accuracy of the measurement the test was repeated two times for each tested fuel samples.

3.2.2.3. Fuel Consumption Measurement

In the current study the amount of the fuel consumed by an engine was measured by Thepra quantity measuring device. This device was used to measure the volumetric flow rate of the fuel flow (see the figure 3.13 below). The device was attached between the fuel filter and the injection pump, thus at one side it was connected with the fuel filter out let and in one side it connected to the injection pump inlet to measure volume of the fuel flow in to the engine during the test.

Fuel Consumption Measurement Procedure:

- The device was properly attached to the place.
- The driver accelerates the car, pressing the accelerator pedal completely down (since the measurement is supposed to be made for full opening of the throttling valve). Then the device was display volume of the fuel flow into the engine.
- The measurement was taken by waiting for about 5 to 10 seconds for the stabilization of measurement point.

Figure 3.13 Fuel consumption measurement setup

3.2.2.4. Data Analysis

From the experiment wheel power, tractive effort data were directly collected from chassis dynamometer. These data were obtained in accordance with specified vehicle speed and converted into brake power and brake torque of the engine relative to the engine speed. Also the fuel flow rate was directly obtained at different vehicle speed. This flow rate has to be converted to brake specific fuel consumption relative to the engine speed.

i. **Wheel Torque (T_w)**: having known tractive effort and the drive wheel radius, the drive wheel torque can be calculated as:

$$F = \frac{T_w}{r} \qquad \text{(Eq.3.2)}$$

Where: F = tractive effort

T_w =wheel torque

r = wheel radius

ii. **Brake Torque (T_b):** is the torque available at the 'Flywheel'. After wheel torque at the wheel is known the brake torque can be calculated with the following formula:

$$T_w = (g.r. \times a.r.) * \eta_t * Tb \qquad \text{(Eq.3.3)}$$

Where: T_w = wheel torque T_b =brake torque

g.r. = gear box gear ratio η_t = overall transmission efficiency

a.r. = axle ratio or final drive ratios (F_d)

The test vehicle uses manual gear box type. It has been 5 speed transmissions with the following gear ratio:

Table 3.4 Gear ratio of test vehicle

(Source:*www.goo-net exchange.com/catalog/TOYOTA_HILUX_PICK_UP/)*

Gear	1st	2nd	3rd	4th	5th
Gear ratio	3.928	2.333	1.451	1	0.851
Back axle ratio or final drive ratios				4.3	

Transmission efficiency is 0.9 at the top gear and 0.8 at lower gear can be used [45]. From equation (3.3) engine torque (T_b) can be calculated as follows:

$$T_b = \frac{T_w}{(gr \times ar)\eta_t} \quad \text{(Eq.3.4)}$$

Since the chassis dynamometer used for the test does not have revolution counter, rather it displays the wheel speed in km/hr, it is necessary to calculate the engine speed (N) from wheel speed. The engine speed and revolution can be related as the following equation:

$$N = \frac{2.65 \times v \times g.r \times a.r}{r} \text{ (rev/min)} \quad \text{(Eq.3.5)}$$

Where: N = engine speed (rev/min)

r = the driving wheel tyre radius (0.34m)

g.r =gear ratio

a.r = back axle ratio

v=vehicle speed (km/hr)

iii. **Brake Power (P_b)**: is the net power available at the 'Flywheel' (at crank shaft). It can be found by converting wheel power displayed from chassis dynamometer to break power by using transmission efficiency.

$$P_b = \frac{P_w}{\eta_t} \quad \text{(Eq.3.6)}$$

Where: P_b = brake power kW P_w = power at the wheels

η_t =overall transmission efficiency (gear efficiency × rear axle efficiency)

iv. **Brake Specific Fuel Consumption (Bsfc):** is the ratio of the amount of fuel consumed by the engine in gram per hour (gm/hr) to a unit brake power of the engine in 'kW'. Since the measurement was taken by volumetric flow rate, mass flow rate of the fuel was obtained by multiplying with its density. The density of tested fuel samples are given in the Appendix-C.

$$Bsfc = \frac{\dot{m}_f\left(\frac{gm}{sec}\right) \times 3600}{P_b(kW)} \quad \text{(Eq.3.7)}$$

Where: Bsfc = brake specific fuel consumption

$\dot{m}_f$ = mass flow rate P_b= brake power

4. RESULTS AND DISCUSSIONS

4.1. Extraction of Jatropha and Castor oil

The amount of oil extracted from the seeds was calculated according to the formula given in the methodology (Eq.3.1). The machine extracts about 25% (m/m ratio) of Jatropha oil (i.e. from 20 kg Jatropha seed 5 kg oil were obtained) and 29.2 % (m/m ratio) of Castor oil (i.e. from 12 Kg of castor seed 3.5 kg of oils were obtained) from the seed sample. If the residue from mechanical pressing was again continued to chemical extraction method, more oil had been expected from the sample; but this method was not applied to the residue after mechanical pressing.

4.2. Biodiesel Yield

The biodiesel production was done by transestrification reaction process using methanol alcohol and KOH catalyst. After washing three times by distilled water and drying the biodiesel production yield is found to be 80 % and 84 % for Jatropha and Castor, respectively.

Table 4.1 Reaction Condition and Biodiesel Yield.

Sample name	Molar ratios	Oil sample (ml)	Methanol (ml)	KOH (%w/v)	Reaction temp. (^{o}c)	Reaction time (minutes)	Yield (%)
Jatropha	1:6	500	250	1	60	40	80
Castor	1:6	500	250	1	35	60	84

From table 4.1 the biodiesel yield from crude Jatropha oil was 80% while from crude Castor oil was 84%. Jatropha biodiesel yields were low.

4.3. Characterization Result

Characterization was done to know the properties of the biodiesel produced whether it satisfies the ASTM standards for biodiesel prior to testing its performance in the existing diesel engines without doing any modification. The characterization results of the biodiesel produced from Jatropha and Castor seed oil and their mixture were shown in the table 4.2 (or in Appendix-B). From the table 4.2, the density of Jatropha biodiesel was lower than that of castor biodiesel. The density observed by Jatropha biodiesel was within the range given by European standard (EN 14214). The viscosity of Jatropha biodiesel was somewhat higher than of the ASTM standard. This may due to the absence of acid pretreatment to reduce the free fatty acid content of the oil before the transesterification. But the viscosity result was correlated with the result observed by Mengesha Kassahun, B. et al. [30]. Compared to the Jatropha biodiesel the viscosity of castor biodiesel is higher. The high viscosity and high density of castor biodiesel was due to the presence of recionelic acid. Castor biodiesel had lower cloud point than Jatropha biodiesel, making castor biodiesel more suited for use in cold countries than Jatropha biodiesel. But the biodiesel blends of Castor oil with Jatropha cause to the improvement for the operation in cold weather. Flash points of the Castor and Jatropha biodiesels were within the standard. Compared to the castor biodiesel the blend of Jatropha and Castor biodiesel gives the less viscosity and lower density. The flash point of their blend was within the standard. Since the fuel with the flash point more than 66^{o}c is considered as a safe, the results of all samples of biodiesels are considered to be safe to store and to use in the engine.

Table 4.2 The properties of Biodiesel Produced

SN.	Property	Test method, ASTM	EPSE diesel limits	ASTM D6751* limit for B100	Test results		
					B100 CB	B100 JB	B100 of 50%CB + 50%JB
1	Density@15^{o}C, g/ml	D4052	report	-	0.9284	0.8900	0.9084
	Density@20^{o}C, g/ml	D4052	Report	-	0.9251	0.8865	0.9050
2	Flash point, ^{o}C	D93	Min.60	Min. 93	>116	>116	>116
3	Cloud point, ^{o}C	D2500	Max.+5	Report	<-10	+5	-4
4	Kinematic viscosity at 40^{o}C, mm^{2}/sec	D445	1.9-6.0	1.9-6	16.34	6.52	11.67

4.4.Engine/Vehicle Performance Testing

Vehicle performance was measured in terms of tractive effort and wheel power. While engine performance was measured in terms of brake power, brake torque and brake specific fuel consumption. In this section the vehicle performance and engine performance of standard diesel fuel was compared with all blends.

4.4.1. Tractive Effort

The tractive effort (F_{tr}) obtained directly from chassis dynamometer test for standard diesel fuel (B_0) and the all three blends (B_{20}JB, B_{20}CB, B_{20}JCB) are presented in table 4.3 to 4.6.

Table 4.3 B_0 and tractive effort data

Tractive effort (kN) for B_0				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	3.8	3.6	2.25	1.3
30	3.35	3.25	2.3	1.35
35	1.7	2.9	2.4	1.3
40		2.75	2.35	1.45
45		2.5	2.4	1.5
50		1.3	2.25	1.45
55		0.9	1.7	1.55
60			1.65	1.4
65			1.25	1.3
70			1.1	1.25
75			0.5	1.2

Table 4.4 B_{20}JB tractive effort data

Tractive effort (kN) for B_{20} JB				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	3.7	3.5	2.2	1.2
30	3.3	3.25	2.25	1.25
35	1.7	2.7	2.3	1.35
40		2.7	2.4	1.45
45		2.45	2.35	1.4
50		1.3	2.35	1.5
55		0.7	1.7	1.45
60			1.5	1.3
65			1.25	1.25
70			1.1	1.25
75			0.8	1.1

Figure 4.1 and figure 4.2 shows the variation of tractive effort relative to the vehicle speed. From the figures the values of tractive effort was decreased for 1st gear and 2nd gear as the vehicle speed increases, while for 3rd and 4th gear it increases slightly and then starts to fall down with the increment of the vehicle speed.

Table 4.5 B_{20} CB tractive effort data

Tractive effort (kN) for B_{20}CB				
V (km/hr)	1^{st} gear	2^{nd} gear	3^{rd} gear	4^{th} gear
25	3.65	3.4	2.2	1.25
30	3.3	3.2	2.25	1.2
35	1.5	2.7	2.35	1.35
40		2.5	2.3	1.35
45		2.3	2.35	1.4
50		1.2	2.35	1.45
55		0.9	1.6	1.4
60			1.45	1.25
65			1.2	1.2
70			1	1.15
75			0.85	1.15

Table 4.6 B_{20}JCB tractive effort data

Tractive effort (kN) for B_{20}JCB				
V (km/hr)	1^{st} gear	2^{nd} gear	3^{rd} gear	4^{th} gear
25	3.7	3.45	2.2	1.2
30	3.3	3.2	2.25	1.25
35	1.5	2.7	2.3	1.35
40		2.65	2.35	1.4
45		2.35	2.25	1.35
50		1.2	2.35	1.4
55		0.7	1.75	1.45
60			1.5	1.3
65			1.2	1.25
70			1.1	1.2
75			0.8	1.15

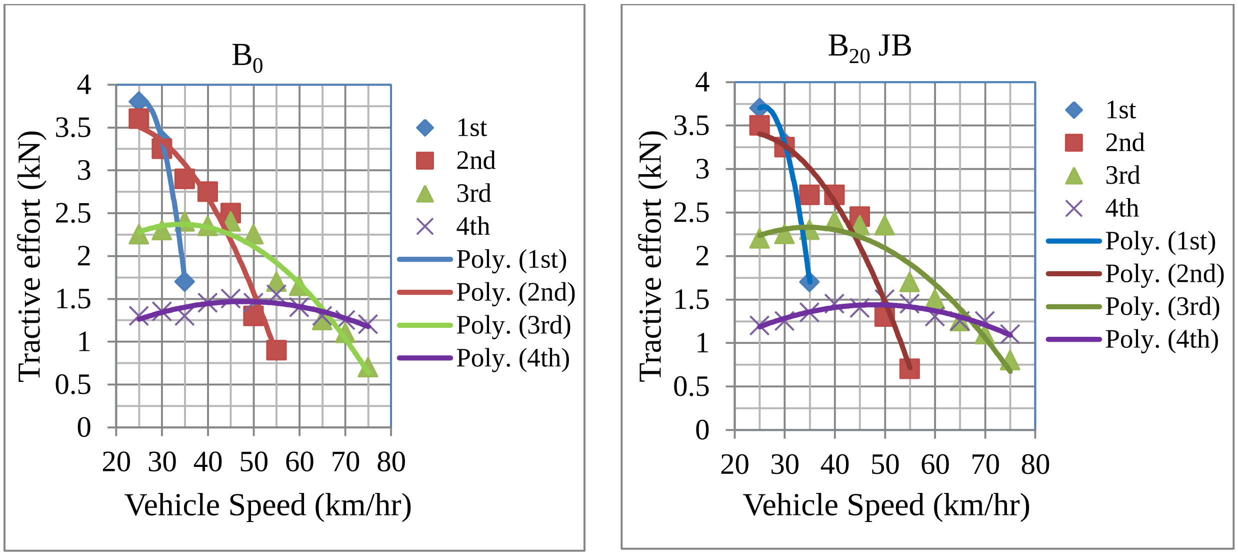


Figure 4.1 Tractive efforts vs. vehicle speed for B_0 and B_{20} JB

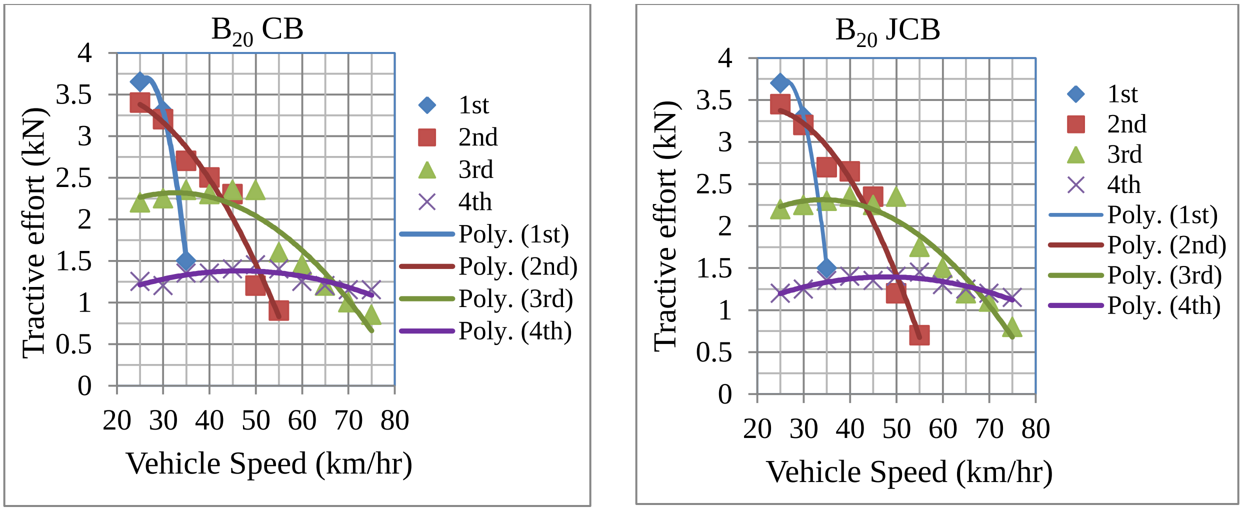


Figure 4.2 Tractive efforts vs. vehicle speed for B_{20} CB and B_{20} JCB

4.4.2. Wheel Torque

Wheel torque can be calculated using the measured tractive effort and the wheel radius according to the equation (3.2) given in the methodology. Then calculated wheel torque will be given in the table 4.7 to table 4.10 for all tested fuels.

Table 4.7 Wheel Torque of B_0

Wheel Torque (Nm) for B_0				
V (km/hr)	1^{st} gear	2^{nd} gear	3^{rd} gear	4^{th} gear
25	1292	1224	765	442
30	1139	1105	782	459
35	578	986	816	442
40		935	799	493
45		850	816	510
50		442	765	493
55		306	578	527
60			561	476
65			425	442
70			374	425
75			170	408

Table 4.8 Wheel Torque of B_{20} JB

Wheel Torque (Nm) for B_{20} JB				
V (km/hr)	1^{st} gear	2^{nd} gear	3^{rd} gear	4^{th} gear
25	1258	1190	748	408
30	1122	1105	765	425
35	578	918	782	459
40		918	816	493
45		833	799	476
50		442	799	510
55		238	578	493
60			510	442
65			425	425
70			374	425
75			272	374

Table 4.9 Wheel Torque for B_{20} CB

Wheel Torque (Nm) for B_{20} CB				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	1241	1156	748	425
30	1122	1088	765	408
35	510	918	799	459
40		850	782	459
45		782	799	476
50		408	799	493
55		306	544	476
60			493	425
65			408	408
70			340	391
75			289	391

Table 4.10 Wheel Torque for B_{20} JCB

Wheel Torque (Nm) for B_{20} JCB				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	1258	1173	748	408
30	1122	1088	765	425
35	510	918	782	459
40		901	799	476
45		799	765	459
50		408	799	476
55		238	595	493
60			510	442
65			408	425
70			374	408
75			272	391

4.4.3. Brake Torque

After the torque available at wheel is known the brake torque or engine torque was calculated based on the formula give in the equation (3.4) of the methodology. The engine speed was calculated according to the formula given in the equation (3.5) of methodology. Depending on the gear selected, there is speed reduction from the engine to drive wheels consequently so, the engine speed for each gear has to be treated separately (seen in the table 4.11 to table 4.14). The brake torque or engine torque obtained at different engine speed with different gear ratios were shown in the table 4.11 to table 4.14 below for all tested fuel samples.

Figure 4.3 to figure 4.6 shows the variation of brake torque relative to the engine speed for all tested fuel samples of B0, B_{20} JB, B_{20} CB and B_{20} JCB.

Table 4.11 Brake torque of B_0

Brake torque (Nm) for B0								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	T_b	N	T_b	N	T_b	N	T_b
25	3291	96	1955	148	1216	144	838	117
30	3949	84	2346	134	1459	147	1005	122
35	4608	43	2737	119	1702	154	1173	117
40			3128	113	1945	151	1341	131
45			3519	103	2188	154	1508	136
50			3909	53	2431	144	1676	131
55			4300	37	2675	109	1843	140
60					2918	106	2011	127
65					3161	80	2178	117
70					3404	71	2346	113
75					3647	32	2514	108

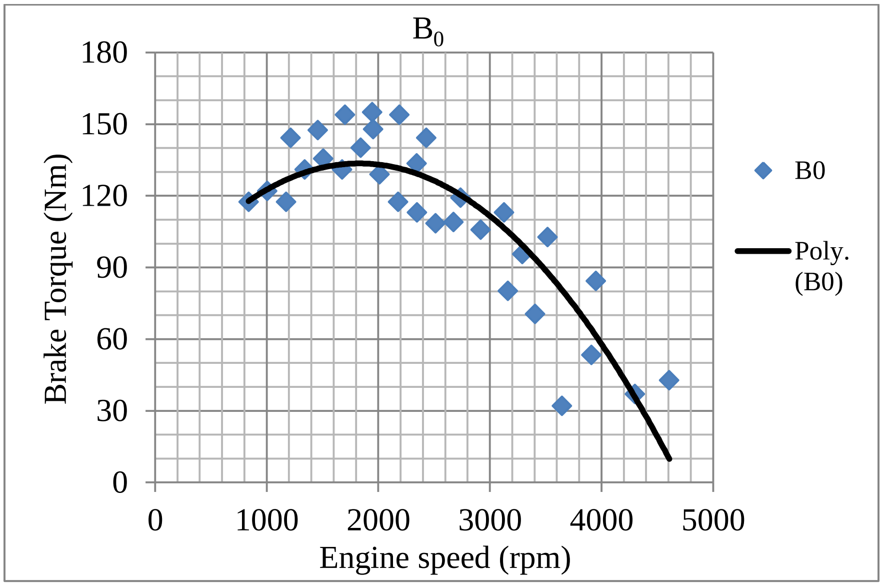


Figure 4.3 Variation of brake torque vs. engine speed of B_0

From the figure 4.3 the maximum brake torque observed by B_0 was 133.5Nm at 1800 rpm of engine speed. The figure shows that at lower speed the value of brake torque was slightly smaller and as the engine speed increases the engine torque increases up to 1800 rpm, then as the engine speed continue to increases the torque of the engine falls down.

Table 4.12 Brake torque of B_{20} JB

Brake torque (Nm) for B_{20} JB								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	T_b	N	T_b	N	T_b	N	T_b
25	3291	93	1955	144	1216	141	838	108
30	3949	83	2346	134	1459	144	1005	113
35	4608	43	2737	111	1702	147	1173	122
40			3128	111	1945	154	1341	131
45			3519	101	2188	151	1508	127
50			3909	53	2431	151	1676	136
55			4300	29	2675	109	1843	131
60					2918	96	2011	117
65					3161	80	2178	113
70					3404	71	2346	113
75					3647	51	2514	99

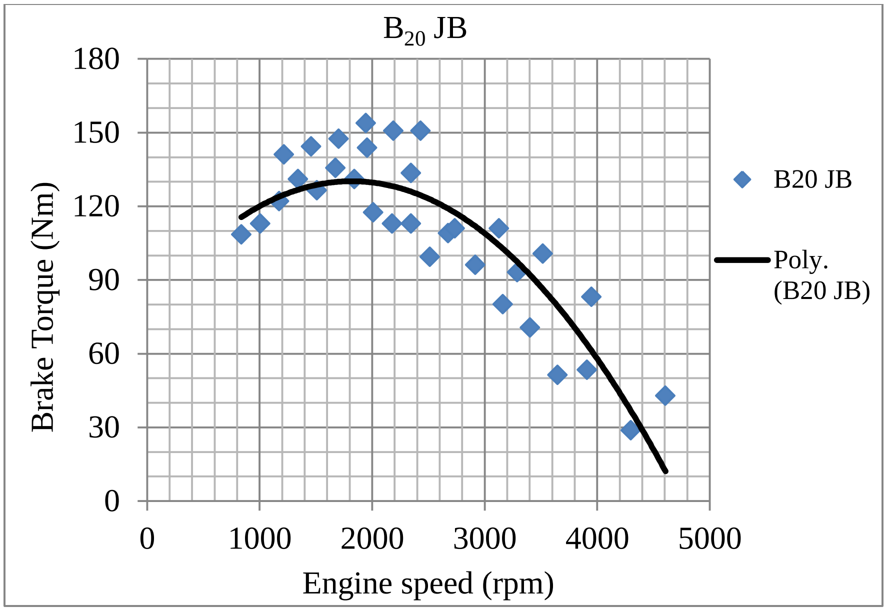


Figure 4.4 Variation of brake torque vs. engine speed of B_{20} JB

The maximum engine torque obtained by the B_{20} JB was 130 Nm at engine speed of 1800rpm (Fig.4.4 above). The curve shows that the same trend with the curve observed by B_0. But the value of brake torque observed by B_{20} JB was lower than of $B_{0.}$

Table 4.13 Brake torque of B_{20} CB

Brake torque (Nm) for B_{20} CB								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	T_b	N	T_b	N	T_b	N	T_b
25	3291	92	1955	140	1216	141	838	113
30	3949	83	2346	131	1459	144	1005	108
35	4608	38	2737	111	1702	151	1173	122
40			3128	103	1945	147	1341	122
45			3519	94	2188	151	1508	127
50			3909	49	2431	151	1676	131
55			4300	37	2675	103	1843	131
60					2918	93	2011	113
65					3161	77	2178	108
70					3404	64	2346	104
75					3647	54	2514	104

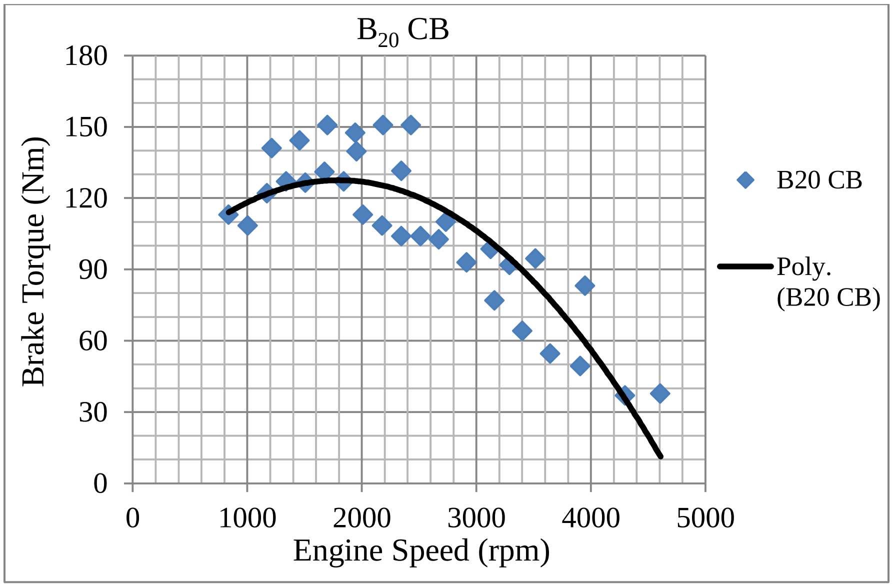


Figure 4.5 Variation of brake torque vs. engine speed of B_{20} CB

From the figure 4.5 above the maximum brake torque observed by B_{20} CB was 127.5 Nm at engine speed of 1800rpm. Compared to the B_0 and B_{20} JB the value observed by the castor biodiesel was lower.

Table 4.14 Brake torque of B_{20} JCB

Brake torque (Nm) for B_{20} JCB								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	T_b	N	T_b	N	T_b	N	T_b
25	3291	93	1955	142	1216	141	838	108
30	3949	83	2346	131	1459	144	1005	113
35	4608	38	2737	111	1702	147	1173	122
40			3128	109	1945	151	1341	127
45			3519	97	2188	144	1508	122
50			3909	49	2431	151	1676	127
55			4300	29	2675	112	1843	131
60					2918	96	2011	117
65					3161	77	2178	113
70					3404	71	2346	108
75					3647	51	2514	104

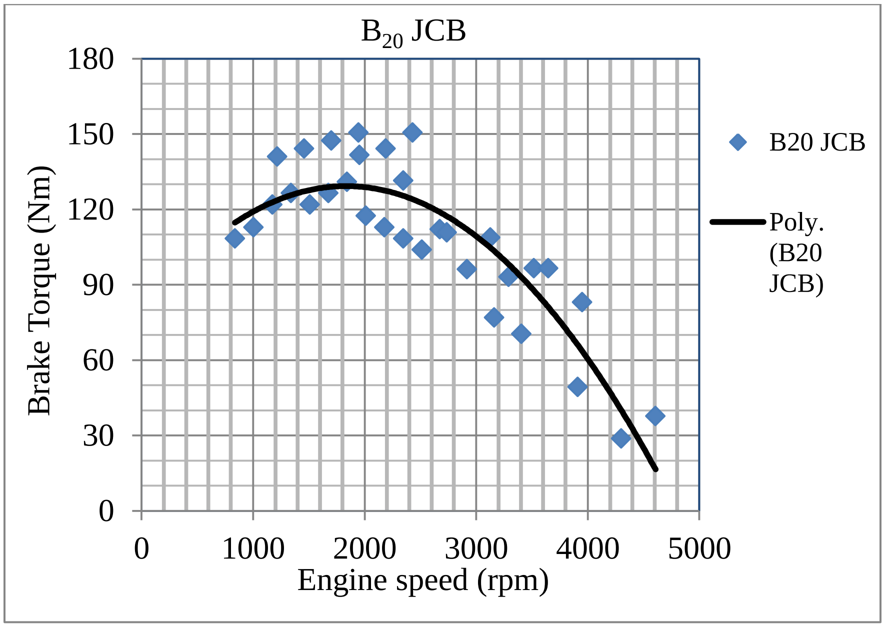


Figure 4.6 Variation of brake torque vs. engine speed of B_{20} JCB

From the figure 4.6 above the maximum brake torque observed by B_{20} JCB is 129 Nm at engine speed of 1800rpm. Relative to the brake torque observed by B_0 and B_{20} JB the value observed by B20 JCB was lower, while compared to the value observed by B_{20} CB it was higher.

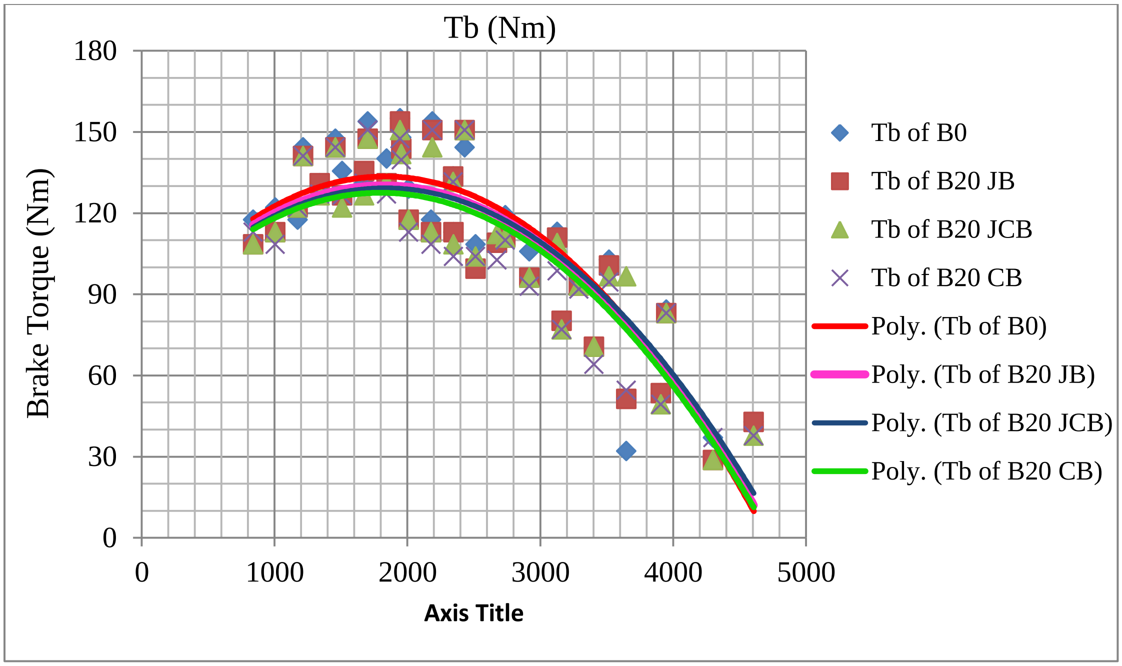


Figure 4.7 Comparison of brake torque vs. Engine speed of all tested fuel samples.

The figure 4.7 above shows that the curves of the engine torque versus engine speed has almost similar trends with neat diesel fuel (B_0) for all tested fuel samples. It can be seen that slightly torque is minimum at low speed and increases as engine speed increases. As engine speed increases further, torque reaches a maximum and then decreases. The reason is that at very low engine speed (rpm), the cylinders don't take in all the air they can. As you climb in engine speed and get to peak torque, the engine is sucking in peak amount of air and making the biggest 'bang' it can. After peak torque, as engine speed gets high the air is restricted by the inlet, so torque begins to drop.

Generally, it can be seen that the engine torque of B_0 fuel is higher than that of the B_{20} JB, B_{20} CB and B_{20} JCB fuels. The maximum torque was recorded at 1800 rpm, and it was 133.5 Nm, 130 Nm, 127.5, and 129 Nm for B_0, B_{20} JB, B_{20} CB and B_{20} JCB respectively. The average torque reduction for B_{20} JB, B_{20} CB and B_{20} JCB as compared to B_0 was 2.62%, 4.49 %, and 3.37% respectively. The reason of reduction of torque with the blended fuels is due to the higher viscosity and lower calorific value of the biodiesel fuel. But Jatropha biodiesel blend produces large amount of torque than Castor biodiesel. Also, the mixture of Jatropha and Castor biodiesel blend produces the higher torque than Castor biodiesel blend. This is due to the higher viscosity and density of Castor biodiesel than the Jatropha and their mixture.

4.4.4. Wheel Power

Like tractive effort, the wheel power was directly measured from the chassis dynamometer for all tested fuel samples and the data recorded was given in the table 4.15 to table 4.18 below.

Table 4.15 Wheel power measured for B_0

Wheel Power (kW) for B_0				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	34	30	20	11
30	38	33.5	22.5	14.5
35	33.5	36	26	17
40		38.5	29	20
45		40	31.5	23.5
50		36.5	35	27
55		32	39	31
60			34.5	30.5
65			30	34
70			27.5	28
75			24	26

Table 4.16 Wheel power measured for B_{20}JB

Wheel Power (kW) for B_{20} JB				
V km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	34	30	19	11.5
30	37.5	32	22	14
35	32	35.5	25.5	16
40		37	28	18.5
45		39.5	31	22
50		35	34	27.5
55		32	37.5	29
60			33.5	30.5
65			30	35
70			26	27.5
75			24.5	26

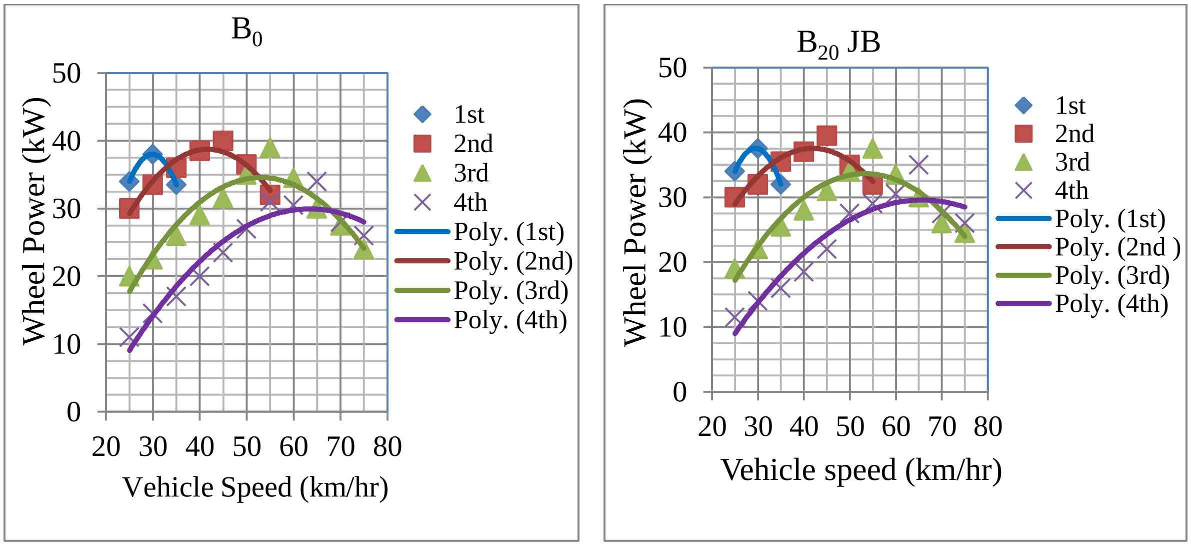


Figure 4.8 Variation of wheel power vs. vehicle speed for B_0 and B_{20}JB

Figure 4.8 indicates that the variation of vehicle wheel power relative to the vehicle speed. That the highest brake power was observed by the second gear for both tested fuels. As the gear shifted from first to the fourth the wheel powers were decreasing. The wheel power recorded by B_0 is greater than that of other tested fuel samples.

Table 4.17 Wheel power measured for B_{20} CB

Wheel Power (kW) for B_{20} CB				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	33	28.5	18.5	11
30	36.5	30	21	13
35	32	34.5	24.5	15.5
40		37	26	17.5
45		38.5	29.5	21
50		34	33	26
55		30	36	28
60			33	29.5
65			28.5	34
70			24.5	27
75			24	24.5

Table 4.18 Wheel power measured for B_{20}JCB

Wheel Power (kW) for B_{20} JCB				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	34	30	18	11
30	37	32.5	22	14
35	32.5	35	25	15.5
40		37	27.5	18
45		38.5	30	22
50		34	33.5	26
55		31	38	29
60			33	30
65			29.5	34
70			26	27.5
75			24	25

The figure 4.9 below shows the variation of wheel power relative to the vehicle speed for B_{20} CB and B_{20} JCB. The curves show that the highest value of the wheel power was observed by the second gear similar to the pure diesel.

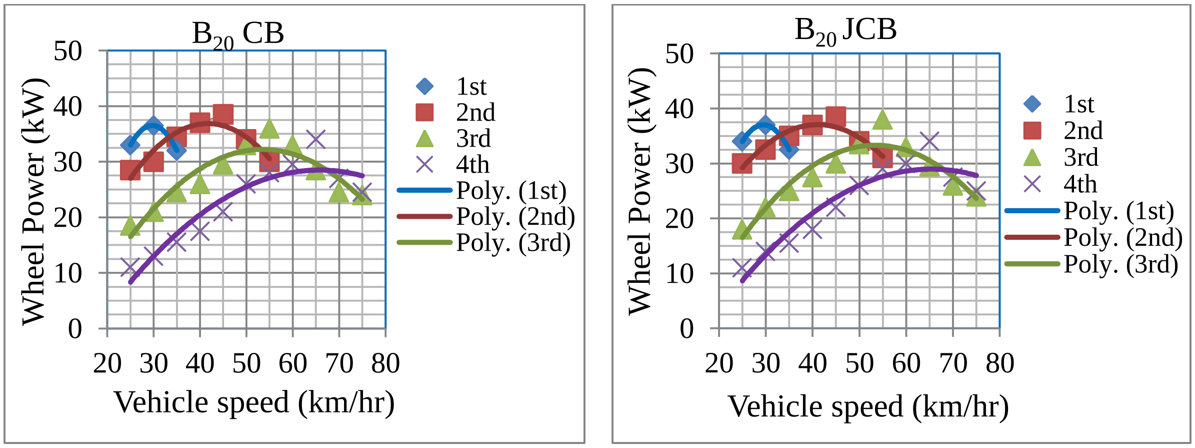


Figure 4.9 Variation of wheel power vs. vehicle speed for B_{20}CB and B_{20} JCB

4.4.5. Brake Power

Brake power can be founded by converting the wheel power displayed by chassis dynamometer and by using transmission efficiency according to the formula give in the methodology (see Eq.3.6). The brake power founded relative to the engine speed for all tested fuel samples are given in the table 4.19 to table 4.22 below.

Table 4.19 Brake power of B_0

Brake Power (kW) for B_0								
V	1st gear		2nd gear		3rd gear		4th gear	
(km/hr)	N	P_b	N	P_b	N	P_b	N	P_b
25	3291	42.5	1955	36.4	1216	23.5	838	12.6
30	3949	47.5	2346	40.6	1459	26.5	1005	16.6
35	4608	41.9	2737	43.6	1702	30.6	1173	19.4
40			3128	46.7	1945	34.1	1341	22.9
45			3519	48.5	2188	37.1	1508	26.9
50			3909	44.2	2431	41.2	1676	30.9
55			4300	38.8	2675	45.9	1843	35.4
60					2918	40.6	2011	34.9
65					3161	35.3	2178	38.9
70					3404	32.4	2346	32.0
75					3647	28.2	2514	29.7

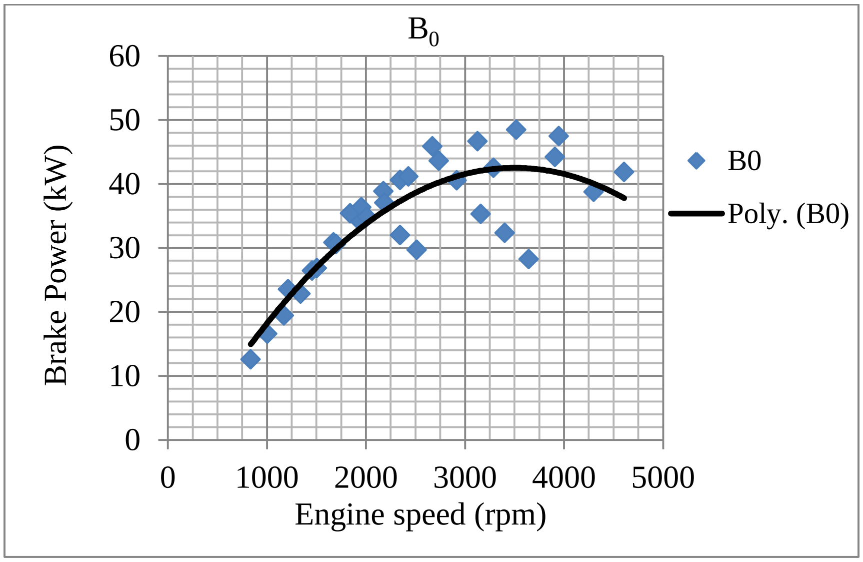


Figure 4.10 Variation of brake power vs. engine speed of B_0

From the figure 4.10 above the maximum brake power produced by B_0 (petro diesel) is 42.5 kW at engine speed of 3500 rpm. The curve shows that at lowest engine speed the brake power is lower, but as the engine speed keep increasing the brake power was also increased until it reaches its maximum and then start to fall down at higher engine speed.

Table 4.20 Brake power of B_{20} JB

Brake Power (kW) for B_{20} JB								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	P_b	N	P_b	N	P_b	N	P_b
25	3291	42.5	1955	36.4	1216	22.4	838	13.1
30	3949	46.9	2346	38.8	1459	25.9	1005	16.0
35	4608	40.0	2737	43.0	1702	30.0	1173	18.3
40			3128	44.8	1945	32.9	1341	21.1
45			3519	47.9	2188	36.5	1508	25.1
50			3909	42.4	2431	40.0	1676	31.4
55			4300	38.8	2675	44.1	1843	33.1
60					2918	39.4	2011	34.9
65					3161	35.3	2178	40.0
70					3404	30.6	2346	31.4
75					3647	28.8	2514	29.7

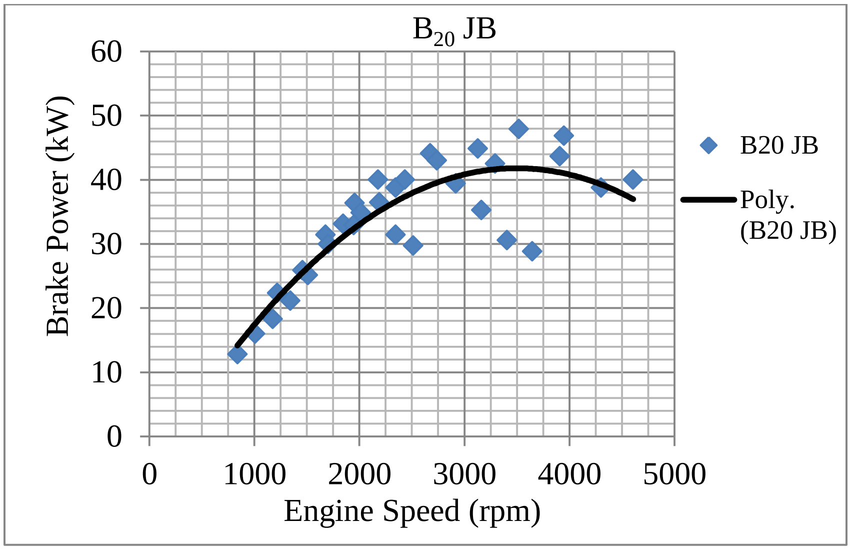


Figure 4.11 Variation of brake power vs. engine speed of B_{20} JB

Figure 4.11 above shows that the maximum brake power observed by B_{20} JB (Jatropha biodiesel blend) was 41.8 kW at engine speed of 3500 rpm. The trends of the curve were similar with the brake power curve of B_0. But the brake power value obtained by the B_{20} JB is lower than that of B_0.

The table 4.21 below shows the value of brake power calculated for B_{20} CB (castor biodiesel blend) with respect to the engine speed calculated at different gear ratios.

The figure 4.12 shows that the variation of the brake power with respect to the engine speed for B_{20} CB. From the figure the maximum brake power observed was 40.4 kW at engine speed of 3500 rpm. Compared to the pure diesel (B_0) and jatropha biodiesel blends (B_{20} JB) the value of brake power observed by castor biodiesel blend (B_{20} CB) is lower. But, the trend of the B_{20} CB curve was similar to the curve of pure biodiesel (B_0). That at lower engine speeds the observed brake power is minimum but as the engine speed increases the brake power increases continuously and as the engine speed keep increasing the bake power start to decrease.

Table 4.21 Brake power of B_{20} CB

Brake Power (kW) for B_{20} CB								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	P_b	N	P_b	N	P_b	N	P_b
25	3291	41.3	1955	34.5	1216	21.8	838	12.6
30	3949	45.6	2346	36.4	1459	24.7	1005	14.9
35	4608	40.0	2737	41.8	1702	28.8	1173	17.7
40			3128	44.8	1945	30.6	1341	20.0
45			3519	46.7	2188	34.7	1508	24.0
50			3909	41.2	2431	38.8	1676	29.7
55			4300	36.4	2675	42.4	1843	32.0
60					2918	38.8	2011	33.7
65					3161	33.5	2178	38.9
70					3404	28.8	2346	30.9
75					3647	28.2	2514	28.0

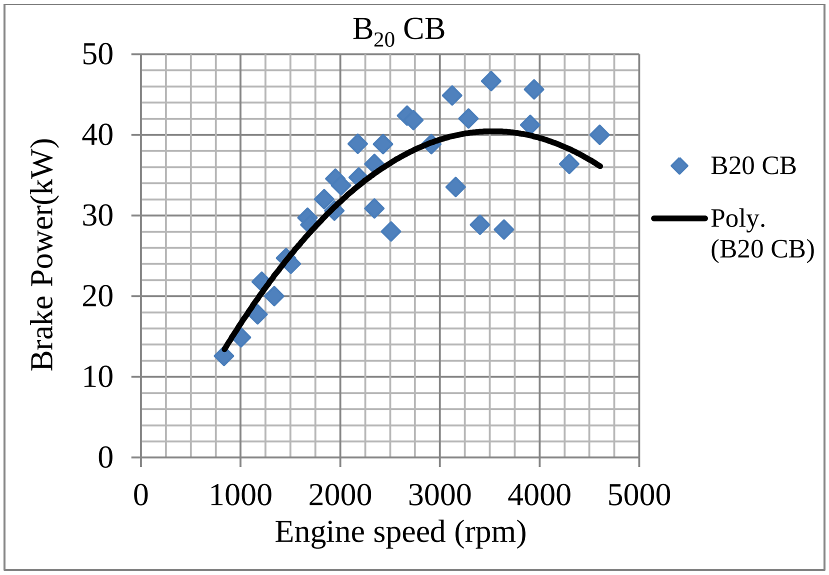


Figure 4.12 Variation of brake power vs. engine speed of B_{20} CB

Table 4.22 below indicates that the calculated value of brake power with respect to engine speed at the different gears for the mixture of jatropha and castor biodiesel blends (B_{20} JCB).

Table 4.22 Brake power of B_{20} JCB

Brake Power (kW) for B_{20} JCB								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	P_b	N	P_b	N	P_b	N	P_b
25	3291	42.5	1955	36.4	1216	21.2	838	12.6
30	3949	46.3	2346	39.4	1459	25.9	1005	16.0
35	4608	40.6	2737	42.4	1702	29.4	1173	17.7
40			3128	44.8	1945	32.4	1341	20.6
45			3519	46.7	2188	35.3	1508	25.1
50			3909	41.2	2431	39.4	1676	29.7
55			4300	37.6	2675	44.7	1843	33.1
60					2918	38.8	2011	34.3
65					3161	34.7	2178	38.9
70					3404	30.6	2346	31.4
75					3647	28.2	2514	28.6

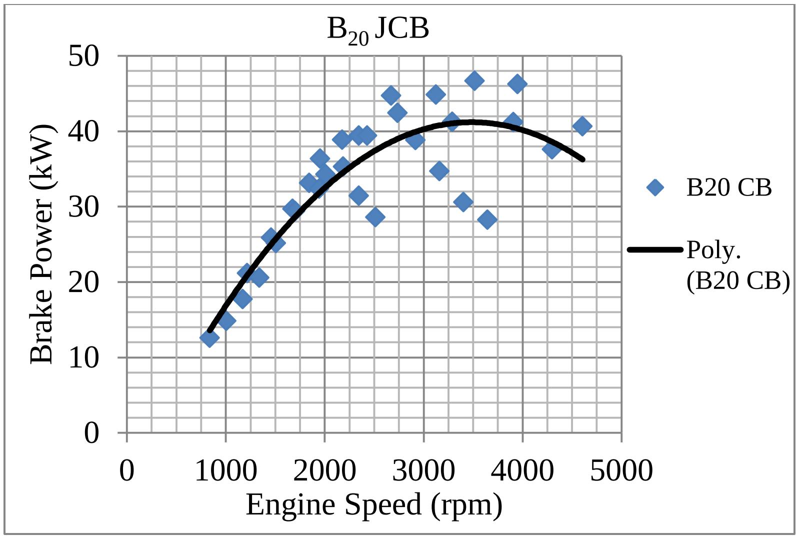


Figure 4.13 Variation of brake power vs. engine speed of B_{20} JCB

Figure 4.13 above shows that the variations of the brake power relative to the engine speed for the mixture of jatropha and castor biodiesel blend (B_{20} JCB). The maximum brake power observed by B_{20} JCB was 41.2 kW at engine speed of 3500 rpm. The trends of the curve were similar with the other tested fuels. But the value observed by mixture of Jatropha and Castor biodiesel blend (B_{20} JCB) is lower than that of B_0 and B_{20} JB, while it was higher than of castor biodiesel blends (B_{20} CB).

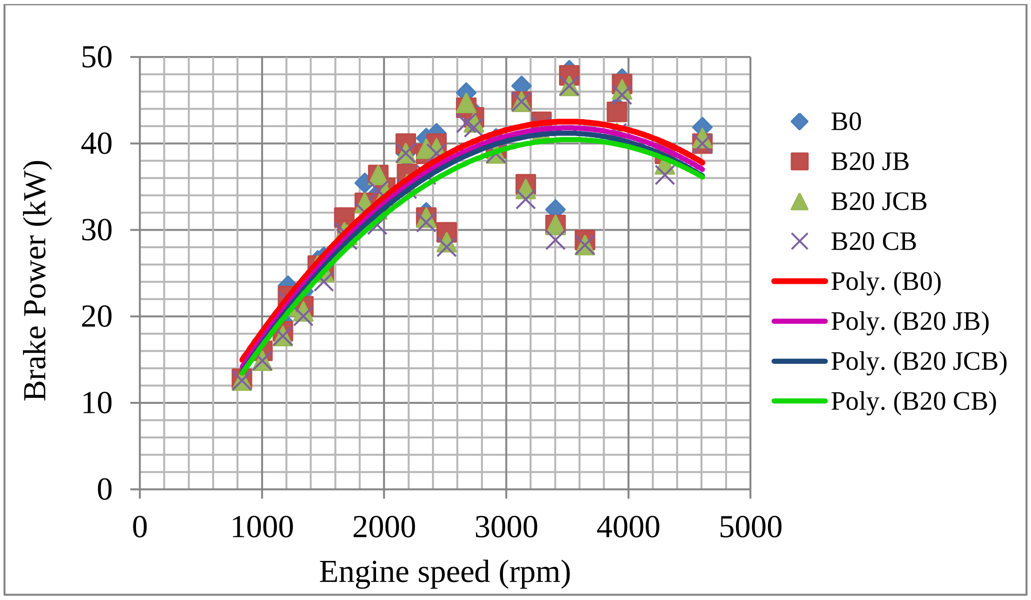


Figure 4.14 Comparison of brake power vs. engine speed for all tested fuel samples.

From figure 4.14 above it is possible to say that the trend of the curves is almost similar. But the power output from diesel fuel (B_0) is higher than of all others. At low engine speed the friction power is relatively low and therefore the brake power increases with speed. As engine speed increases, however, the friction power starts to increase at continuously greater rate and therefore brake power reaches a peak and starts reducing. As engine speeds above the usual operating range, friction power increases very rapidly. Another reason for the falling off brake power at high speed is less complete filling of the cylinder consequent on greater reduction of pressure. As engine speed increases there is relatively shorter opening duration for the intake valves, the valves close before the cylinder is fully filled with air fuel mixture, consequently brake power starts to fall.

It can be seen that the maximum brake power of the engine was recorded at 3500 rpm, and it was 42.5kW, 41.8 kW, 40.4 kW, and 41.2 kW for B_0, B_{20} JB, B_{20} CB, and B_{20} JCB respectively. The reason for the lower brake power of biodiesels compared to diesel can be attributed to their lower calorific values and higher viscosities. Both the calorific value and viscosity have an effect on the combustion. Additionally, uneven combustion characteristics of biodiesel fuel decreased the engine brake power. Furthermore, it is seen that the average brake power reduction for B_{20} JB, B_{20} CB, and B_{20} JCB in compared to B_0 fuel is 1.65%, 4.94% and 3.06%, respectively.

4.4.6. Evaluation of Brake Specific Fuel Consumption

The fuel consumption of the engine was directly measured as volume of the fuel flow (volume flow rate of the fuel). The observed volume of the fuel flow into the engine at each gear is shown in the table 4.23 to table 4.26 below. The volume flow rate of the fuel was converted into the mass flow rate ($\dot{m}_f$) by multiplying with the fuel density and the brake specific fuel consumption (Bsfc) of the engine at each engine speed was calculated based on the formula given in the methodology (Eq.3.7) and shown in the table 4.27 to table 4.30.

Table 4.23 Volume flow rate of B0

Fuel Consumption (ml/sec) of B_0				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	4.2	3.7	2.4	1.7
30	4.5	4.1	2.8	1.9
35	4.8	4.5	3.1	2.0
40		4.9	3.4	2.3
45		5.3	3.5	2.4
50		5.7	3.7	2.6
55		5.7	4.0	2.9
60			4.2	3.2
65			4.4	3.5
70			4.3	3.7
75			4.6	4.1

Table 4.24 Volume flow rate of B20 JB

Fuel Consumption (ml/sec) of B_{20} JB				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	4.3	3.8	2.4	1.5
30	4.6	4.1	2.7	1.8
35	4.8	4.4	2.9	2.2
40		4.9	3.2	2.5
45		5.2	3.5	2.8
50		5.4	3.7	2.9
55		5.7	3.8	3.3
60			4.1	3.5
65			4.3	3.7
70			4.4	3.9
75			4.7	4.1

Table 4.25 Volume flow rate of B_{20} CB

Fuel Consumption (ml/sec) of B_{20} CB				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	4.1	3.5	2.3	1.5
30	4.5	3.9	2.6	1.9
35	5.1	4.4	2.8	2.1
40		4.6	3.2	2.4
45		5.0	3.5	2.7
50		5.2	3.7	3.2
55		5.5	4.0	3.3
60			4.3	3.7
65			4.5	3.9
70			4.7	4.3
75			4.8	4.2

Table 4.26 Volume flow rate of B_{20} JCB

Fuel Consumption (ml/sec) of B_{20} JCB				
V (km/hr)	1st gear	2nd gear	3rd gear	4th gear
25	4.3	3.6	2.4	1.5
30	4.7	4.2	2.5	1.8
35	5.0	4.4	2.8	2.1
40		4.7	3.1	2.3
45		5.1	3.5	2.7
50		5.4	3.8	3.1
55		5.6	4.1	3.3
60			4.3	3.7
65			4.5	3.9
70			4.4	4.2
75			4.7	4.3

Figure 4.15 below shows that the variation of brake specific fuel consumption (Bsfc) with respect to the engine speeds (N) for B_0. The curve shows that at the lower engine speed there is a

higher fuel consumption of the engine. At the higher engine speed the fuel consumption was also increased. The average brake specific fuel consumption (Bsfc $_{Avg.}$) of B_0 is 330 gm/kw.hr.

Table 4.27 Bsfc of B_0

Bsfc (gm/KW.hr) for B_0								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	Bsfc	N	Bsfc	N	Bsfc	N	Bsfc
25	3291	303	1955	312	1216	312	838	414
30	3949	290	2346	309	1459	324	1005	351
35	4608	351	2737	316	1702	310	1173	315
40			3128	322	1945	305	1341	308
45			3519	335	2188	289	1508	274
50			3909	395	2431	275	1676	258
55			4300	450	2675	275	1843	251
60					2918	317	2011	281
65					3161	382	2178	276
70					3404	407	2346	354
75					3647	499	2514	423

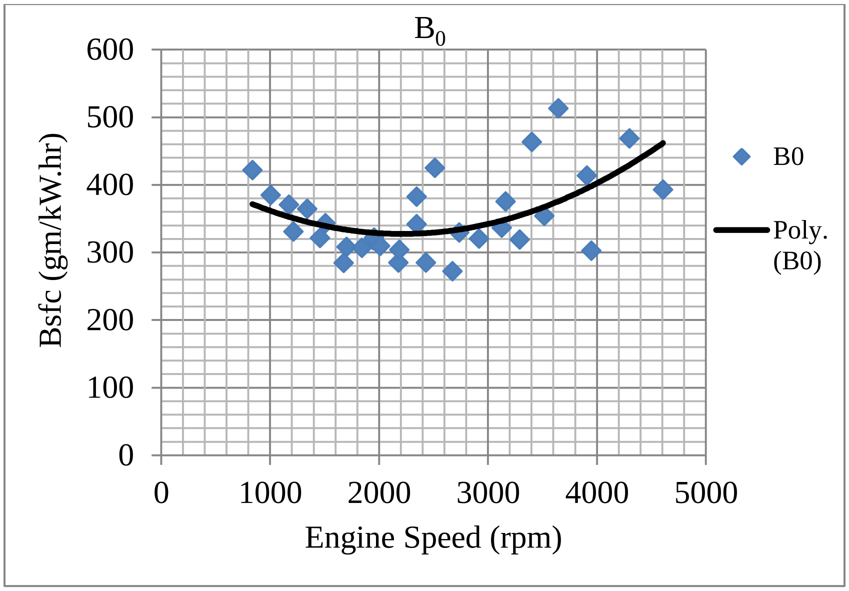


Figure 4.15 Variation of brake specific fuel consumption vs. engine speed of B_0

Table 4.28 Bsfc of B_{20} JB

Bsfc (gm/kW.hr) for B_{20} JB								
V	1st gear		2nd gear		3rd gear		4th gear	
(km/hr)	N	Bsfc	N	Bsfc	N	Bsfc	N	Bsfc
25	3291	304	1955	322	1216	330	838	351
30	3949	302	2346	325	1459	321	1005	346
35	4608	369	2737	315	1702	298	1173	370
40			3128	336	1945	299	1341	364
45			3519	334	2188	295	1508	343
50			3909	392	2431	285	1676	284
55			4300	452	2675	265	1843	306
60					2918	320	2011	309
65					3161	375	2178	285
70					3404	443	2346	382
75					3647	502	2514	425

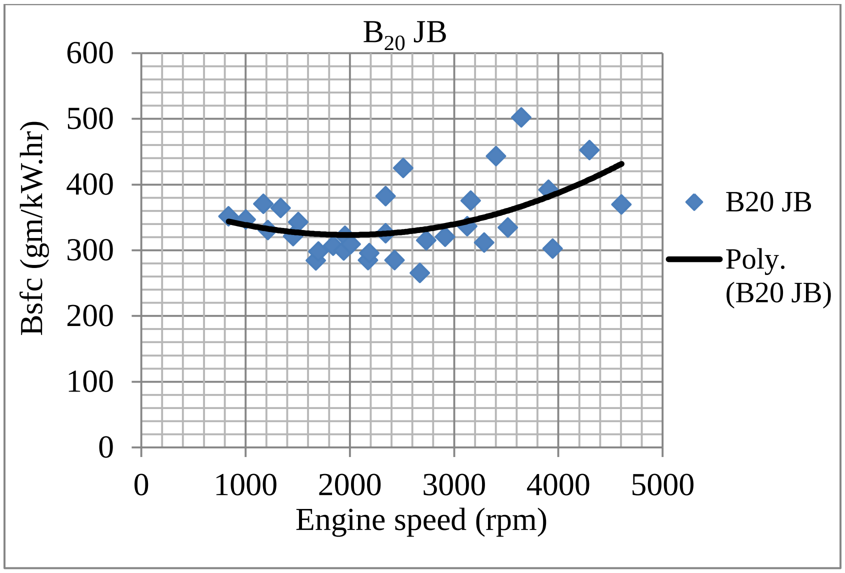


Figure 4.16 Variation of brake specific fuel consumption vs. engine speed of B_{20} JB

From the figure 4.16 the average brake specific fuel consumption observed by B_{20} JB is 347 gm/kW.hr Compared to the value observed by B_0 the value of B_{20} JB was higher.

Table 4.29 Bsfc of B_{20} CB

Bsfc (gm/kW.hr) for B_{20} CB								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	Bsfc	N	Bsfc	N	Bsfc	N	Bsfc
25	3291	310	1955	316	1216	329	838	372
30	3949	307	2346	334	1459	328	1005	399
35	4608	397	2737	328	1702	303	1173	370
40			3128	320	1945	326	1341	374
45			3519	334	2188	314	1508	351
50			3909	393	2431	297	1676	336
55			4300	472	2675	294	1843	322
60					2918	345	2011	342
65					3161	418	2178	313
70					3404	508	2346	434
75					3647	530	2514	540

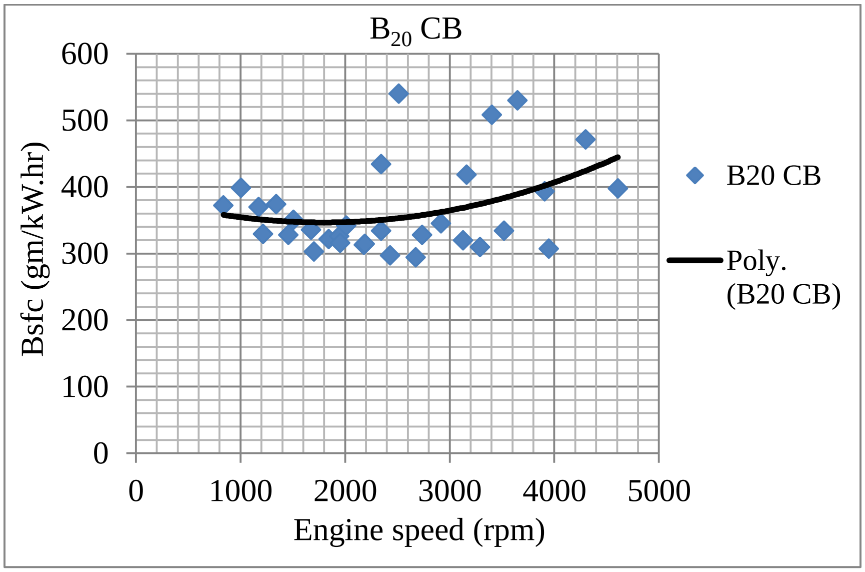


Figure 4.17 Variation of brake specific fuel consumption vs. engine speed of B_{20} CB

The figure 4.17 shows the average brake specific fuel consumption ($Bsfc_{min}$) observed by B_{20} CB is 364 gm/kW.hr.

Table 4.30 Bsfc of B_{20} JCB

Bsfc (gm/kW.hr) for B_{20} JCB								
V (km/hr)	1st gear		2nd gear		3rd gear		4th gear	
	N	Bsfc	N	Bsfc	N	Bsfc	N	Bsfc
25	3291	314	1955	307	1216	352	838	370
30	3949	315	2346	331	1459	300	1005	349
35	4608	382	2737	322	1702	295	1173	368
40			3128	325	1945	297	1341	347
45			3519	339	2188	308	1508	333
50			3909	407	2431	299	1676	324
55			4300	462	2675	285	1843	309
60					2918	344	2011	335
65					3161	402	2178	311
70					3404	446	2346	415
75					3647	517	2514	467

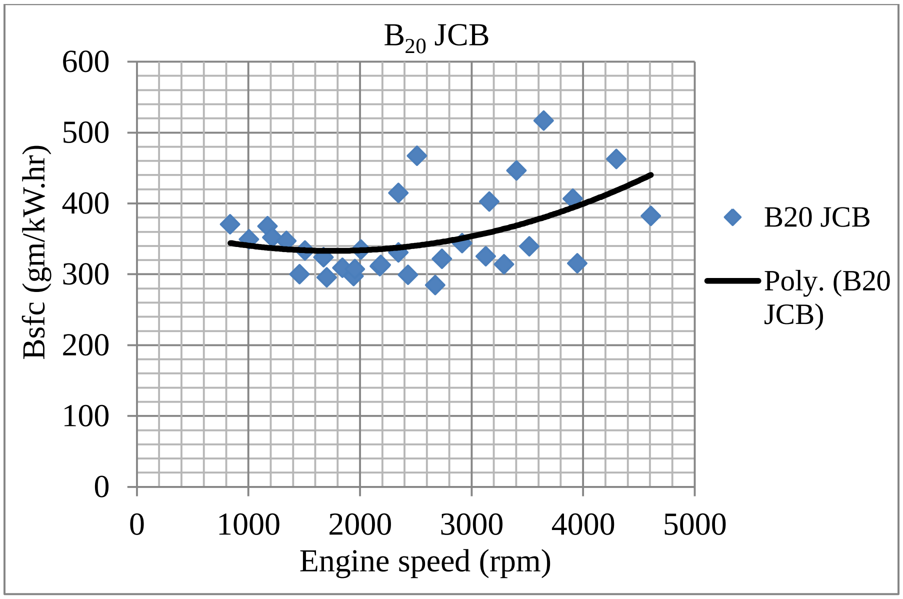


Figure 4.18 Variation of brake specific fuel consumption vs. engine speed of B_{20} JCB

From the figure 4.18 the brake specific fuel consumption observed by B_{20} JCB is ($Bsfc_{Avg.}$) 353 gm/kW.hr. Compared to the B_0 and B_{20} JB the value was higher but compared to B_{20} CB its lower.

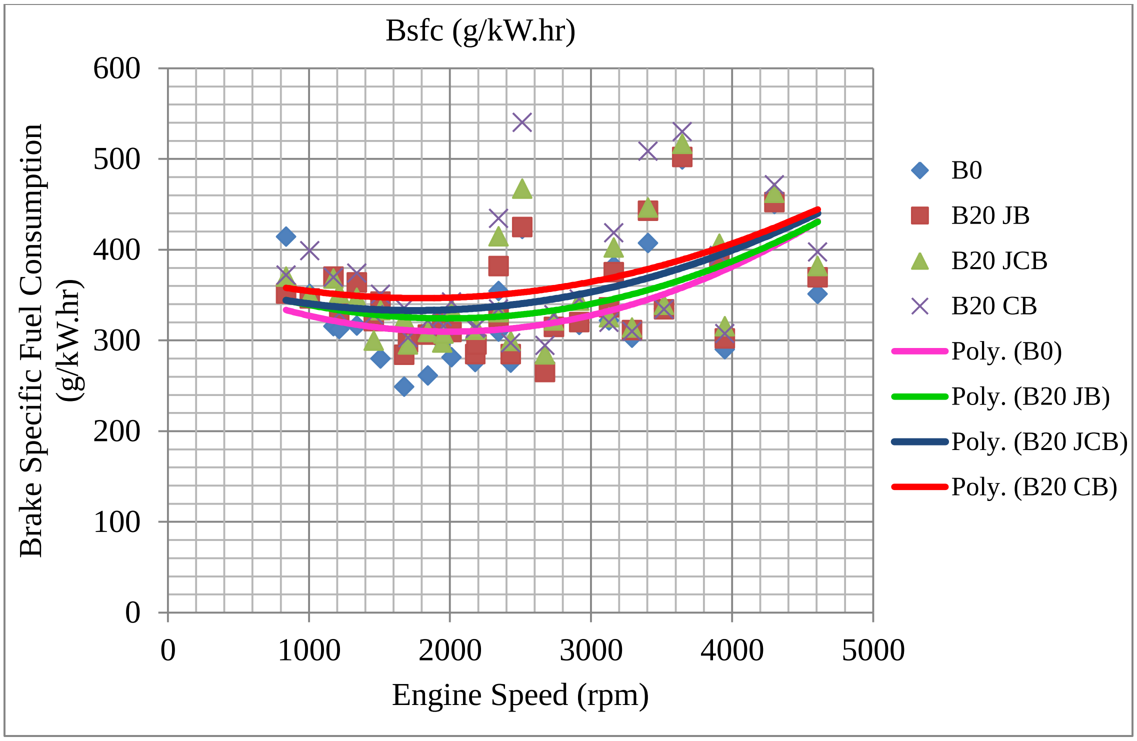


Figure 4.19 Comparison of Bsfc vs. engine speed for tested fuel samples.

From the figure 4.19 above the curve shows the same trends for all tested sample of fuels. That the brake specific fuel consumption rate is higher at low speed increases a little for medium speeds and increases more at high speeds. This is because at lower engine speed fuel is intentionally made rich. Hence there is not complete combustion and unburned fuel exits with the exhaust gas. At higher engine speeds the consumption rises, because the frictional losses of the engine increases rapidly and so the energy of combustion is again being wasted. The reason that brake specific fuel consumption is lowest at ‘middle’ rpm, because the engine is tuned to develop best cylinder filling at middle speed, the engine’s breathing is at highest efficiency at these speeds.

Generally, it was seen that the brake specific fuel consumption (Bsfc) of biodiesel blended fuels are higher compared to the diesel. From the results, the average brake specific fuel consumption (Bsfc) of B_0, B_{20} JB, B_{20} CB, and B_{20} JCB is 330 g/kWh, 347 g/kWh, 364, and 353 g/kWh, respectively. The reason for the higher Bsfc of biodiesels can be attributed to the combined effects of the relative fuel density, viscosity and heating value of the blends. Since, the brake specific fuel consumption (Bsfc) of diesel engine depends on the relationship among volumetric fuel injection system, fuel density, viscosity and lower heating value. Biodiesel fuel is delivered into the engine on a volumetric basis per stroke; thus, larger quantities of biodiesel are fed into the engine. Therefore, to produce the same power, more biodiesel fuel is needed because biodiesel has a lower calorific value compared to diesel fuel. Compared to B_0 the average brake specific fuel consumption increment for B_{20} JB, B_{20} CB, and B_{20} JCB is 4.89%, 9.34%, and 6.51% respectively.

4.4.7. Evaluation of Engine Performance Curve's

Figure 20 to 23 below shows the performance curves for all tested fuel samples. From the performance curve the trends of the curve were similar for all tested fuel samples. Even if their values were varies. The curves were correlated with each other's according to the proportion give in the Appendix-A.

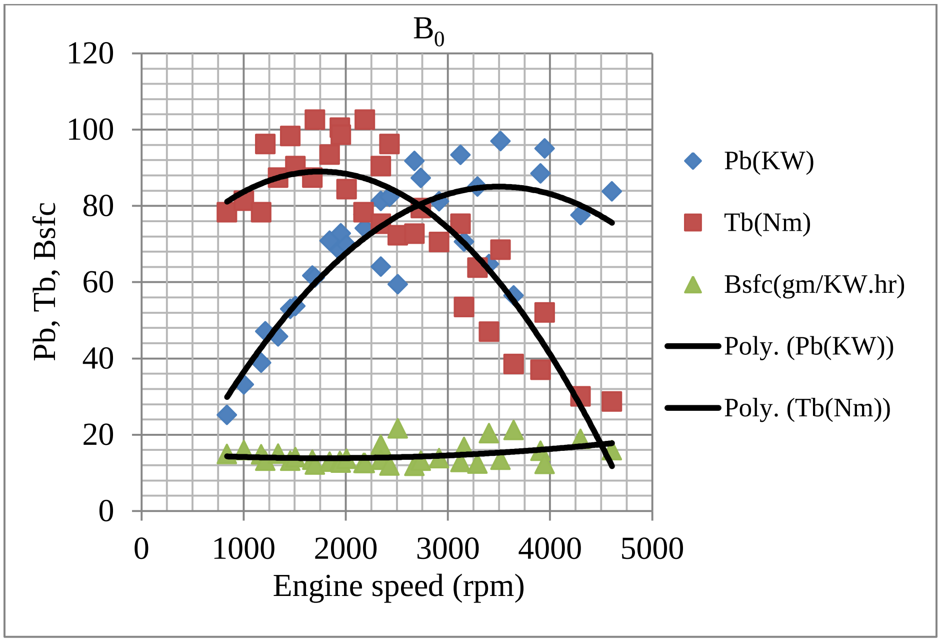


Figure 4.20 Performance curve of B_0

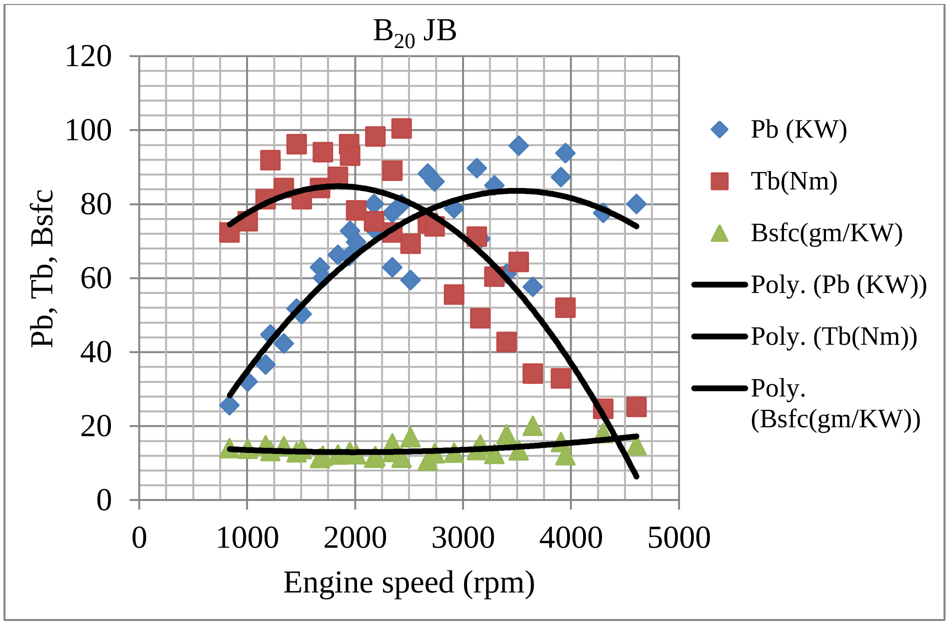


Figure 4.21 Performance curve of B_{20} JB

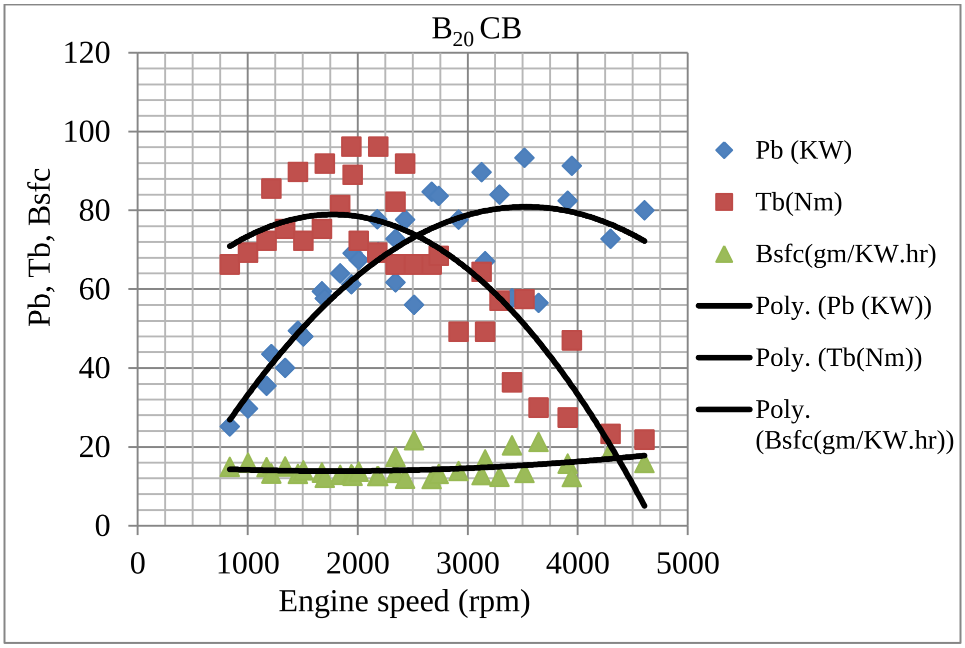


Figure 4.22 Performance curve of B_{20} CB

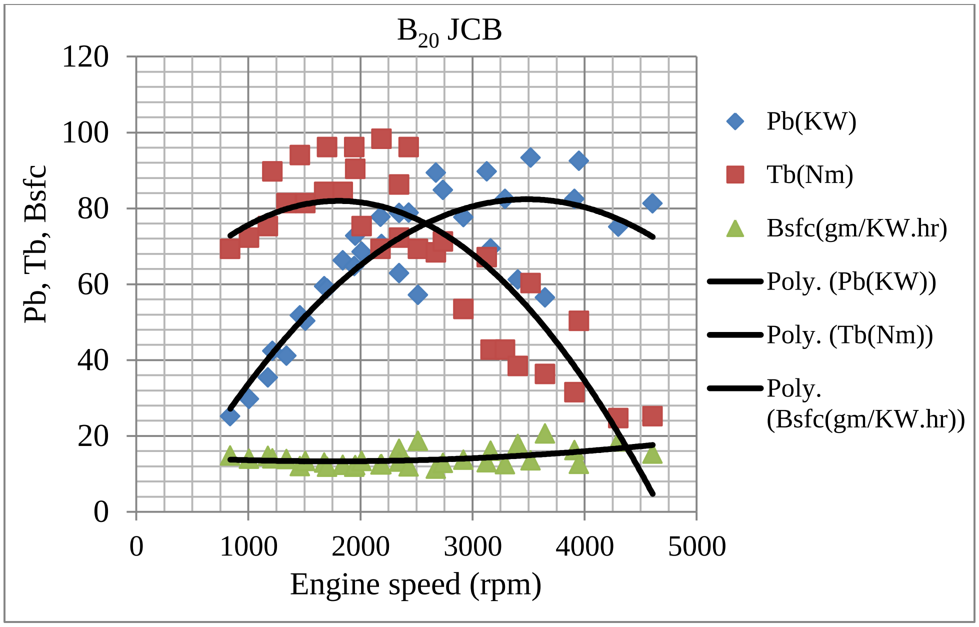


Figure 4.23 Performance curve of B_{20} JCB

Above figure 18 to 21 shows that at low engine speed the brake torque and brake power are lower, while the brake specific fuel consumption of the engine was slightly higher. As the engine speed increases the torque and power are increase up to some point and then start to fall down. The reason is that at very low engine speed (rpm), the cylinders don't take in all the air they can. As you climb in engine speed and get to peak torque, the engine is sucking in peak amount of air and making the biggest 'bang' it can. After peak torque, as engine speed gets high the air is restricted by the inlet, so torque begins to drop. However power will still increase because although you are getting a smaller 'bang' per cycle, you are doing more bangs per unit time. There is a point where torque will drop off enough that no increase in rpm will compensate. At this point power output will drop, and you have reached the maximum useful rpm of the engine.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The overall studies based on extraction, production of biodiesel, characterization, and engine performance test of Jatropha, castor, and mixture of castor and Jatropha biodiesel blends were carried out. Based on the results the following conclusions were found out:-

- Biodiesel produced from Castor and Jatropha oil is completely miscible with each other and also with diesel fuel thus allowing the use of blends of diesel and biodiesel in any percentage.
- The characteristics of biodiesel produced from Castor oil show the higher viscosity and density than those of Jatropha oil. The mixture of Jatropha and Castor oil biodiesel gives the lesser viscosity and density. The flash points of Castor, Jatropha and the blend of both biodiesel were within the standard.
- The properties of biodiesel from Jatropha oil at low temperatures are poorer than those of Castor oil. The biodiesel blends of Castor oil with Jatropha cause to the improvement for the operation in cold weather.
- Brake power and brake torque produced by Jatropha biodiesel blend B_{20} JB is higher than that of other blends B_{20} CB and B_{20} JCB. But compared to B_{20} CB the brake power and brake torque produced by B_{20} JCB is higher. The brake power and brake torque produced by B_{20} JCB is 3.06% and 3.37% less than that of petro diesel (B_0), respectively.
- The average brake specific fuel consumption (Bsfc) of Castor biodiesel blend B_{20} CB is higher than that of other blends B_{20} JB and B_{20} JCB. Relative to the Castor biodiesel blend B_{20} CB the mixture of Jatropha and Castor biodiesel blend B_{20} JCB gives the minimum fuel consumption. The average brake specific fuel consumption by B_{20} JCB is 4.89% higher than that of petro diesel (B_0).
- From the performance test result it is seen that the torque and power performances get reduced and fuel consumption increase for biodiesel blends compared to the petro diesel fuel. 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 lots of its advantages like its usage in unmodified engine, better

lubricity, renewability, degradability, very less contribution to global warming, and its provision of great ecological advantages in terms of erosion control and wasteland recovery.

Generally, biodiesel produced from Castor and Jatropha oil is completely miscible with each other and also diesel fuel, used to improve the high viscosity and density of castor biodiesel and improve the Jatropha biodiesel properties in cold weather operation. Compared to Castor biodiesel blend (B_{20} CB) the mixture of Jatropha and Castor biodiesel blend (B_{20} JCB) reflect good performance characteristic in diesel engine. From the experimental investigations it may be concluded that the mixture of Jatropha and Castor biodiesel blend (B_{20} JCB) can become an alternative source of fuel in the future.

5.2. Recommendations

The present study was only focused on to evaluate the performance of mixing Jatropha and Castor biodiesel blended with petro diesel in a four stroke, four cylinder diesel engine. For better investigations the emission test should have to be carried out.

In this study the characterizations were only carried out for viscosity, density, cloud point, and flash point of pure Jatropha and castor biodiesel, and their mixture. To have a better comparison the characterization for all properties of biodiesel should have to be carried out.

The byproduct of the oil extraction process is a good fertilizer. So it is recommended that the farmers should use this as fertilizer adding value to this process. Its glycerol which is obtained as a byproduct during transesterification process is a very valuable product. So it is recommended to find the ways to refine the crude glycerol obtained and use for different purpose.

The researcher recommends it is possible to mix Jatropha and Castor biodiesel together considerably to decrease viscosity and density of castor biodiesel and to improve the cold weather properties of Jatropha biodiesel. And also it's possible to use it as an alternative fuel in the diesel engine.

Department of Mechanical and Vehicle engineering must have to establish the engine testing facilities for future research work on alternative fuels.

Since, the present study was carried out on only one blending ratio (i.e. B_{20}) for comparison, it is recommended to conduct further research on different blending ratio to have better evaluations.

REFERENCES

[1] Agarwal, A. K. (2007). Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in energy and combustion science, 33(3), 233-271.

[2] Akhtar, T. (2011). Synthesis of biodiesel from triglyceride oil (Master's thesis, University of Stavanger, Norway).

[3] Mekhilef, S., Siga, S., & Saidur, R. (2011). A review on palm oil biodiesel as a source of renewable fuel. Renewable and Sustainable Energy Reviews, 15(4), 1937-1949.

[4] Benjumea, P., Agudelo, J., & Agudelo, A. (2008). Basic properties of palm oil biodiesel–diesel blends. Fuel, 87(10), 2069-2075.

[5] Haseeb, A. S. M. A., Sia, S. Y., Fazal, M. A., & Masjuki, H. H. (2010). Effect of temperature on tribological properties of palm biodiesel. Energy, 35(3), 1460-1464.

[6] Demirbas, A. (2007). Importance of biodiesel as transportation fuel. Energy policy, 35(9), 4661-4670.

[7] FDRE Ministry of Mines and Energy, (2007), “The Biofuel Development & Utilization Strategy”, Ethiopia.

[8] Akanawa, T. T., Moges, H. G., Babu, R., & Bisrat, D. (2014). Castor Seed from Melkasa Agricultural Research Centre, East Showa, Ethiopia and it's biodiesel performance in Four Stroke Diesel Engine. International Journal of Renewable Energy Development, 3(2), 99.

[9] Firew Deresse at al. (2016), ‘The performance evaluation of diethyl-ether (DEE) additive with Diesel blends using Diesel Engine test rig’, International Journal of Scientific & Engineering Research, Volume 7, Issue 6, pp 23-29.

[10] Tiku Tesfahun (2015). ‘Performance Evaluation of Biodiesel Produced from Avocado Seed in Diesel Engine.’, unpublished Masters Thessis, Adama science and Technology University, pp.63.

[11] Derege Dagne et al. (2015), ‘Production of biodesel from Argemone Mexicana seed oil and testing its performance in diesel engine’, unpublished Masters Thessis, Adama science and Technology University, pp.56.

[12] Kumar, K., & Sharma, M. P. (2016). Performance and emission characteristics of a diesel engine fuelled with biodiesel blends. International Journal of Renewable Energy Research (IJRER), 6(2), 658-662.

[13] Mofijur, M., Masjuki, H. H., Kalam, M. A., & Atabani, A. E. (2013). Evaluation of biodiesel blending, engine performance and emissions characteristics of Jatropha curcas methyl ester: Malaysian perspective. Energy, 55, 879-887.

[14] Valente, O. S., Da Silva, M. J., Pasa, V. M. D., Belchior, C. R. P., & Sodré, J. R. (2010). Fuel consumption and emissions from a diesel power generator fuelled with castor oil and soybean biodiesel. Fuel, 89(12), 3637-3642.

[15] Gopal, K. N., & Karupparaj, R. T. (2015). Effect of pongamia biodiesel on emission and combustion characteristics of DI compression ignition engine. Ain Shams Engineering Journal, 6(1), 297-305.

[16] Salvi, B. L., & Jindal, S. (2013). A comparative study of engine performance and exhaust emissions characteristics of linseed oil biodiesel blends with diesel fuel in a direct injection diesel engine. Journal of The Institution of Engineers (India): Series C, 94(1), 1-8.

[17] Özcanli, M., Serin, H., Saribiyik, O. Y., Aydin, K., & Serin, S. (2012). Performance and emission studies of castor bean (Ricinus Communis) oil biodiesel and its blends with diesel fuel. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 34(19), 1808-1814.

[18] Dishika. (2014). "Performance Evaluation and Emissions characteristics of a Compression Ignition Engine Using Castor oil based Biodesel, unpublished" Master's Thesis submitted to Thapar University, Patiala, 69 pp.

[19] Kuthalingam, A. B., Asokan, G., Marta, V., Skryabin, I., & Karuppiah, S. (2013). Performance and emission characteristics of double biodiesel blends with diesel. Thermal Science, 17(1), 255-262.

[20] Rao, V. (2015). Dual Biodiesel-Diesel blends Performance on Diesel engine as an Alternative Fuel.

[21] Srithar, K., Balasubramanian, K. A., Pavendan, V., & Kumar, B. A. (2017). Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines. Journal of King Saud University-Engineering Sciences, 29(1), 50-56.

[22] Nalgundwar, A., Paul, B., & Sharma, S. K. (2016). Comparison of performance and emissions characteristics of DI CI engine fueled with dual biodiesel blends of palm and jatropha. Fuel, 173, 172-179.

[23] Kini, K., Dsouza, H. S., & Kumar, N. S. (2016). Investigation of Properties of Different Blends of Castor and Pongamia Biodiesels and Their Performance in a Compression Ignition Engine. Energy and Power, 6(1A), 8-14.

[24] Meher, L. C., Sagar, D. V., & Naik, S. N. (2006). Technical aspects of biodiesel production by transesterification—a review. Renewable and sustainable energy reviews, 10(3), 248-268.

[25] Bryant, L. (1976). The development of the diesel engine. Technology and Culture, 17(3), 432-446.

[26] Krawczyk, T. (1996). Biodiesel-alternative fuel makes inroads but hurdles remain. Inform, 7, 801-829.

[27] Nelson, W. (2007). On the Clean Road Again: Biodiesel and the Future of the Family Farm. Fulcrum Publishing.

[28] Sánchez, N., Sánchez, R., Encinar, J. M., González, J. F., & Martínez, G. (2015). Complete analysis of castor oil methanolysis to obtain biodiesel. Fuel, 147, 95-99.

[29] Banković-Ilić, I. B., Stamenković, O. S., & Veljković, V. B. (2012). Biodiesel production from non-edible plant oils. Renewable and Sustainable Energy Reviews, 16(6), 3621-3647.

[30] Bajpai, S., & Das, L. M. (2014). Experimental investigations of an IC Engine operating with alkyl esters of Jatropha, Karanja and Castor seed oil. Energy Procedia, 54, 701-717.

[31] Vashist, D., & Ahmad, M. (2014). Statistical analysis of diesel engine performance for castor and jatropha biodiesel-blended fuel. International Journal of Automotive and Mechanical Engineering, 10, 2155.

[32] Demirbas, A., Bafail, A., Ahmad, W., & Sheikh, M. (2016). Biodiesel production from non-edible plant oils. Energy Exploration & Exploitation, 34(2), 290-318.

[33] Tesfaye, F. (2016). Performance Evaluation of Castor Biodiesel and Petro Diesel Blends with Diethyl ether Additive.

[34] Ahmed, K. (2013). Developing, Testing And Promotion Of Small Scale Jatropha And Castor Seed Processing Technologies.

[35] Wen, Z., Bachmann, C., Grisso, R., Arogo, J., & Vaughan, D. (2006). Making Your Own Biodiesel.

[36] Meher, L. C., Sagar, D. V., & Naik, S. N. (2006). Technical aspects of biodiesel production by transesterification—a review. Renewable and sustainable energy reviews, 10(3), 248-268.

[37] Murugesan, A., Umarani, C., Chinnusamy, T. R., Krishnan, M., Subramanian, R., & Neduzchezhain, N. (2009). Production and analysis of bio-diesel from non-edible oils—a review. Renewable and Sustainable Energy Reviews, 13(4), 825-834.

[38] Koh, M. Y., & Ghazi, T. I. M. (2011). A review of biodiesel production from Jatropha curcas L. oil. Renewable and Sustainable Energy Reviews, 15(5), 2240-2251.

[39] Ma, F., & Hanna, M. A. (1999). Biodiesel production: a review. Bioresource technology, 70(1), 1-15.

[40] Mathiyazhagan, M., & Ganapathi, A. (2011). Factors affecting biodiesel production. Research in plant Biology, 1(2).

[41] Leung, D. Y. C., & Guo, Y. (2006). Transesterification of neat and used frying oil: optimization for biodiesel production. Fuel Processing Technology, 87(10), 883-890.

[42] Freedman, B., Butterfield, R. O., & Pryde, E. H. (1986). Transesterification kinetics of soybean oil 1. Journal of the American Oil Chemists' Society, 63(10), 1375-1380.

[43] Alamu, O. J., Waheed, M. A., Jekayinfa, S. O., & Akintola, T. A. (2007). Optimal transesterification duration for biodiesel production from Nigerian palm kernel oil. Agricultural Engineering International: CIGR Journal.

[44] István Barabás and Ioan-Adrian Todoruţ (2011). Biodiesel Quality, Standards and Properties, Biodiesel-Quality, Emissions and By-Products, Dr. Gisela Montero (Ed.), ISBN: 978-953-307-784-0, InTech,

[45] Abrar Abdela et al. (2015). 'Testing the performance of cotton seed biodiesel in diesel vehicle', unpublished Masters Thessis, Adama science and Technology University, pp.55.

[46] Mengesha Kassahun, B., Balcha, M., Damtew, Z., BIsrat, D., Asaminew, G., Tadese, S., & Abate, S. (2016). Fatty acid and biodiesel characteristics Ethiopian Jatropha (Jatropha curcas L.) provenances. International Journal of Advanced Biological and Biomedical Research, 4(1), 15-31.

[47] Ayoola, A. A., Efeovbokhan, V. E., Adeeyo, O. A., & Johnson, O. (2013). Methanolysis of triglycerides using jatropha oil and KOH catalyst. International Journal of Advanced Research in IT and Engineering, 2(3), 61-69.

[48] Nakpong, P., & Wootthikanokkhan, S. (2010). Optimization of biodiesel production from Jatropha curcas L. oil via alkali-catalyzed methanolysis. Journal of Sustainable Energy & Environment, 1(3), 105-109.

[49] Temu, A. K., & Apita, A. O. (2013). Investigation of the parameters affecting castor oil transesterification reaction kinetics for biodiesel production.

[50] Conceição, M. M., Candeia, R. A., Silva, F. C., Bezerra, A. F., Fernandes, V. J., & Souza, A. G. (2007). Thermoanalytical characterization of castor oil biodiesel. Renewable and Sustainable Energy Reviews, 11(5), 964-975.

[51] Okullo, A. A., Temu, A. K., Ogwok, P., & Ntalikwa, J. W. (2012). Physico-chemical properties of biodiesel from jatropha and castor oils. International Journal of Renewable Energy Research (IJRER), 2(1), 47-52.

[52] Kuthalingam, A. B., Asokan, G., Marta, V., Skryabin, I., & Karuppiah, S. (2013). Performance and emission characteristics of double biodiesel blends with diesel. Thermal Science, 17(1), 255-262.

[53] Rao, V. (2015). Dual Biodiesel-Diesel blends Performance on Diesel engine as an Alternative Fuel.

[54] Srithar, K., Balasubramanian, K. A., Pavendan, V., & Kumar, B. A. (2017). Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines. Journal of King Saud University-Engineering Sciences, 29(1), 50-56.

[55] Nalgundwar, A., Paul, B., & Sharma, S. K. (2016). Comparison of performance and emissions characteristics of DI CI engine fueled with dual biodiesel blends of palm and jatropha. Fuel, 173, 172-179.

[56] Kini, K., Dsouza, H. S., & Kumar, N. S. (2016). Investigation of Properties of Different Blends of Castor and Pongamia Biodiesels and Their Performance in a Compression Ignition Engine. Energy and Power, 6(1A), 8-14.

[57] Molla Asmare and Nigus Gabbiye (2014). 'Synthesis and characterization of biodiesel from castor bean as alternative fuel for diesel engine', *American Journal of Energy Engineering, 2(1)*: 1-15

APPENDIX

Appendix-A.

Here below tables are shows the relation between the brake torque, brake power, and brake specific fuel consumption of tested fuel samples. The can related to each other by the proportion of (T_b/1.5), (P_b*2), and (Bsfc/25).

Table A.1 Engine performance data of B_0

P_b (kW), T_b (Nm), and Bsfc (g/kW.hr) for B_0																
V	1st gear				2nd gear				3rd gear				4th gear			
(km/hr)	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc
25	3291	42.5	96	303	1955	36.4	148	312	1216	23.5	144	312	838	12.6	117	414
30	3949	47.5	84	290	2346	40.6	134	309	1459	26.5	147	324	1005	16.6	122	351
35	4608	41.9	43	351	2737	43.6	119	316	1702	30.6	154	310	1173	19.4	117	315
40					3128	46.7	113	322	1945	34.1	151	305	1341	22.9	131	308
45					3519	48.5	103	335	2188	37.1	154	289	1508	26.9	136	274
50					3909	44.2	53	395	2431	41.2	144	275	1676	30.9	131	258
55					4300	38.8	37	450	2675	45.9	109	275	1843	35.4	140	251
60									2918	40.6	106	317	2011	34.9	127	281
65									3161	35.3	80	382	2178	38.9	117	276
70									3404	32.4	71	407	2346	32.0	113	354
75									3647	28.2	32	499	2514	29.7	108	423

Table A.2 Engine performance data of B_{20} JB

P_b (kW), T_b (Nm), and Bsfc (g/kW.hr) for B_{20} JB																
V	1st gear				2nd gear				3rd gear				4th gear			
(km/hr)	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc
25	3291	42.5	93	304	1955	36.4	142	322	1216	22.4	141	330	838	13.1	108	351
30	3949	46.9	83	302	2346	38.8	131	325	1459	25.9	144	321	1005	16.0	113	346
35	4608	40.0	38	369	2737	43.0	111	315	1702	30.0	147	298	1173	18.3	122	370
40					3128	44.8	109	336	1945	32.9	151	299	1341	21.1	127	364
45					3519	47.9	97	334	2188	36.5	144	295	1508	25.1	122	343
50					3909	42.4	49	392	2431	40.0	151	285	1676	31.4	127	284
55					4300	38.8	29	452	2675	44.1	112	265	1843	33.1	131	306
60									2918	39.4	96	320	2011	34.9	117	309
65									3161	35.3	77	375	2178	40.0	113	285
70									3404	30.6	71	443	2346	31.4	108	382
75									3647	28.8	51	502	2514	29.7	104	425

Table A.3 Engine performance data of B_{20} CB

P_b (kW), T_b (Nm), and Bsfc (g/kW.hr) for B_{20} CB																
V	1st gear				2nd gear				3rd gear				4th gear			
(km/hr)	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc	N	P_b	T_b	Bsfc
25	3291	41.3	92	310	1955	34.5	136	316	1216	21.8	141	329	838	12.6	108	372
30	3949	45.6	81	307	2346	36.4	131	334	1459	24.7	144	328	1005	14.9	113	399
35	4608	40.0	35	397	2737	41.8	111	328	1702	28.8	147	303	1173	17.7	113	370
40					3128	44.8	101	320	1945	30.6	151	326	1341	20.0	117	374
45					3519	46.7	86	334	2188	34.7	144	314	1508	24.0	122	351
50					3909	41.2	45	393	2431	38.8	151	297	1676	29.7	122	336
55					4300	36.4	29	472	2675	42.4	112	294	1843	32.0	117	322
60									2918	38.8	96	345	2011	33.7	113	342
65									3161	33.5	77	418	2178	38.9	104	313
70									3404	28.8	71	508	2346	30.9	99	434
75									3647	28.2	51	530	2514	28.0	104	540

Table A.4 Engine performance data of B_{20} JCB

P_b (kW), T_b (Nm), and Bsfc (g/kW.hr) for B_{20} JCB																
V (km/hr)	1st gear				2nd gear				3rd gear				4th gear			
	N	Pb	Tb	Bsfc	N	Pb	Tb	Bsfc	N	Pb	Tb	Bsfc	N	Pb	Tb	Bsfc
25	3291	42.5	92	314	1955	36.4	140	307	1216	21.2	141	352	838	12.6	113	370
30	3949	46.3	83	315	2346	39.4	131	331	1459	25.9	144	300	1005	16.0	108	349
35	4608	40.6	38	382	2737	42.4	111	322	1702	29.4	151	295	1173	17.7	122	368
40					3128	44.8	103	325	1945	32.4	147	297	1341	20.6	122	347
45					3519	46.7	94	339	2188	35.3	151	308	1508	25.1	127	333
50					3909	41.2	49	407	2431	39.4	151	299	1676	29.7	131	324
55					4300	37.6	37	462	2675	44.7	103	285	1843	33.1	131	309
60									2918	38.8	93	344	2011	34.3	113	335
65									3161	34.7	77	402	2178	38.9	108	311
70									3404	30.6	64	446	2346	31.4	104	415
75									3647	28.2	54	517	2514	28.6	104	467

Appendix-B

The below data shows the results of the fuel samples characterized by Ethiopia Petroleum Supply Enterprise (EPSE).

Telefax 251 - (0)11 - 551 29 38
251 - (0)11 - 551 79 56
251 - (0)11 - 554 19 05
Email - eth-petroleum@ethionet.et

የኢትዮጵያ ነዳጅ አቅራቢ ድርጅት
ETHIOPIAN PETROLEUM SUPPLY ENTERPRISE

Telephones:
P.B.X. (251) - 011 - 551 32 88,
Direct: (251) - 011 - 551 00 45,
(251) - 011 - 552 60 30,
(251) - 011 - 554 19 04,
P.O.Box 3375
Addis Ababa - Ethiopia

Ref. No. 304/6.1.3.4.4/2012
2 6 ሐምሌ 2009

ለአዳማ ሳይንስና ቴክኖሎጂ ኒቨርስቲ
አዳማ

በቀን 27/10/2009 ዓ.ም በቁጥር MSVE/0050/3/2009 በተፃፈ ደብዳቤ ተማሪ ደጋጋ ጴጥሮስ በምርምር ያመረቱትን ባዮ-ዲዝል ናሙና የላብራቶሪ የጥራት ፍተሻ እንድንሰራላቸው በጠየቃችሁት መሰረት የፍተሻው ውጤት እንደሚከተለው ቀርቧል፡፡

SN.	Property	Test Method AS TM	EPSE diesel Limits	ASTM D6751* limit for B100	Test Result		
					Castor oil	Jatropha	50% Castor oil 50% Jatropha
1.	Density @ 15°C,g/ml	D 4052	Report	-	0.9284	0.8900	0.9084
2.	Density @ 20°C,g/ml	D 4052	Report	-	0.9251	0.8865	0.9050
3.	Flash Point (PMCC), °C	D 93	Min. 60	Min. 93	>116	>116	>116
4.	Cloud point, °C	D 2500	Max. +5	Report	< -10	+5	-4
5.	Kinematic viscosity at 40 °C, mm^2/sec	D 445	1.9- 6.0	1.9 – 6.0	16.34	6.52	11.67

- The results in this report relate only to the samples tested.

* D6751 is the limit for B100 to be used for blending with petro diesel up to B20.

Liability

Ethiopian Petroleum Enterprise, its Laboratory, its Servants or agents Shall not be held liable for any damages, loss, claims or expenses direct or indirect howsoever caused, arising in connection with the laboratory test carried out on biodiesel samples submitted to it for analysis whether in tort or in contract, due to any act, omission or error of whatever nature, whether or not negligence and howsoever caused. Furthermore all expenses and implied warranties are specifically disclaimed.

Best regards

Wolelaw Teka
A/petroleum Quality Assurance
Service Head

1959
1966

© This test report shall not be reproduced or given to a third party without written approval of the **Petroleum Quality Assurance Service Head.**

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

Appendix-C

The densities of fuels were measured by conventional method at Chemical Engineering department laboratory, Adama Science and Technology. Procedure used to measure the density of blended fuel samples are given as follows:

- Weigh a clean, dry 25 ml graduated cylinder.
- Add 10ml of liquid to your weighed 25 ml graduated cylinder.
- Now carefully read and record amount of liquid there is in the cylinder.
- Then calculate the density of the liquid.
- Repeat the above procedure to find the density of each blended fuel samples.

Table C-1 Measured Data for density (g/ml)

Trial	B_0	B_{20} JB	B_{20} JCB	B_{20} CB
1	8.53	8.55	8.62	8.67
2	8.49	8.56	8.64	8.65
3	8.52	8.54	8.61	8.66
Average	8.51	8.55	8.62	8.66
Density	0.851	0.855	0.862	0.866

Fig.C-1 Density measuring