Declaration by Candidate

I hereby state that the work which is being presented in the dissertation entitled "**Fuelling a Small Capacity Agricultural Unmodified Diesel Engine With Macro-emulsified Ethanol, Diesel and Jatropha Derived Biodiesel: Performance & Emission Studies**", in the partial fulfillment of the requirements for the award of the degree of Master of Engineering in Thermal Engineering, submitted to the Department of Mechanical Engineering, Delhi College of Engineering, Delhi is a genuine record of my work carried out under the supervision of Sh. Naveen Kumar (Ass. Professor and Co-coordinator for Advanced Studies of Biodiesel, Mechanical Engineering, Delhi College of Engineering, Delhi)

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Ftwi Yohaness
ME 2nd year
14/ ME (thermal)/03

CERTIFICATE

This is certify that the work which is being presented in the dissertation entitled "**Fuelling a Small Capacity Agricultural Unmodified Diesel Engine With Macro-emulsified Ethanol, Diesel and Jatropha Derived Biodiesel: Performance & Emission Studies**" is done by Ftwi Yohaness Roll No. 14/ME/03, towards the partial fulfillment of the requirements for the award of degree of "Master of Engineering" in Thermal engineering From Mechanical Engineering Department, Delhi College of Engineering under my supervision and guidance.

Up to my knowledge the matter embodied in this project report has not been submitted for the award of any other degree.

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Abstract

Due to rapid depletion of fossil fuels and environmental concerns, vegetable oils and alcohols are believed to be the potential replacements of petrodiesel. But reactivity of unsaturated hydrocarbon chains and undesirable combustion features of vegetable oils and material compatibility, dissolution of lubricant, and poor ignition of alcohols are some which prevented these two fuels to go long. Transesterification for vegetable oils (this brings modification in its molecular structure), thus converting it to biodiesel, was appropriate measure. Even with this, emission of excess NO_x becomes a major problem. Therefore instead of using pure biodiesel or alcohol as substitution, blending of these fuels with diesel was taken an alternative solution at present days.

An unmodified single cylinder, four stroke, direct injection, and water-cooled natural aspirated vertical compression ignition, typical to engines used in the agricultural sector (pumps, tractors) was fueled with macro-emulsified ethanol, diesel and jatropha biodiesel at different ratios in the current performance and emission studies.

Fuel characteristics (density, calorific value, viscosity and flash point), engine performance and emission characteristics have been investigated and significant improvements were observed. 5.86% (25.90% from 20.04%) in maximum thermal efficiency, 22.64% (13899.71 KJ/Kw-hr from17968.13 KJ/Kw-hr) in minimum brake specific energy consumption, and considerable improvement in smoke opacity was observed with sample fuel D75JB15E10 (75% diesel, 15%jatropha biodiesel and 10%ethanol) compared to that of D100 (100% diesel).

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CHAPTER ONE

INTRODUCTION

1.1 Background

Generally speaking, the idea of using biofuels has generated since the invention of internal combustion engines. In 1895 Rudolf Diesel designed the engine that bears his name to run on vegetable oil[a] particularly peanut oil and a report on the use of alcohol for the motor fuel was published in 1907 and detail research was conducted in 1920s and 1930s. Level of utilization of biofuels as a fuel followed the two main crisis of the globe namely: fuel shortages and air pollution. [1]

As far as air pollution is concerned, the environment affects our health and we and our activities, affect the environment. Since the number of humans on Earth increases exponentially, our technological activities have an increasing impact on the environment no matter how efficient our technology may be. [2] In urban areas, vehicle account for over 50% of the air pollution emitted. The targeted emissions from diesel operated vehicles are: NO_x, carbon monoxide (CO), Particulate Matters (PM) and air toxics. This high level greenhouse gas emission cause an increase in ground level ozone. Ground level ozone can cause aching lungs, wheezing, coughing and headaches. Serious health problem also arises for those people suffering from Asthma, emphysema and chronic bronchitis. Children appear to be at particular risk like 10% to 15% lung function.

In half of the world's cities, tailpipe emissions from gasoline and diesel powered vehicles are the single largest source of air pollution. Worldwide automobiles account for half of the oil consumed and a fifth of the greenhouse gas emitted. This situation is not expected to be improved in near future, as the number of cars and light trucks in the world over 500 million is expected to double in the next twenty-five years. Most of this growth will occur in developing countries, where they have little controls and other solutions such as CNG, catalysts and DPFs are costly, some still untested, and many require infrastructure changes. [3]

Apart from this, the world's economy is fully dependent on fuel with World oil demand is projected to rise from ~70 million barrels/day at present to ~92 million barrels/ day in 2010 (IEA 1996). This has been spurred on by the fact that the world's current crude oil reserves are set to run out in the next 50 to 60 years, and since bio-fuels are derived from renewable resources they are not likely to run out as long as plants can continue to grow on earth. [*4*]

Among the alterative fuels believed to be the solution of the energy and the environmental crisis, Biodiesel and Alcohol fuels were feasible fuels and much devotion was given to them. Since this time, a lot of researches have been conducted by different scientists of the globe and of course attractive and appreciable results have come out. These two fuels can be used as pure as well as blended with the fossil origin fuel in any concentration in existing diesel engines with little or no modification. As far as pollution and the fuel consumption are concerned the blends of these fuels with the fossil origin fuel are best. From extended researches 15:85% of alcohol to diesel and 20:80% of Biodiesel to diesel blends are most favorable fuels for engine as well as the environment are concerned.

This time the trend of Biodiesel is being practiced all over the globe. In USA, a blend of 20% Biodiesel with 80% diesel being used, while in European countries such as: France and Ireland, 5-15% blends are being practiced. As far as the production is concerned, in most European countries the production of Biodiesel is from sunflower and rapeseed whereas in USA it is produced from soybean. In India the country is now facing a shortage of edible oil. So researches are going on for the production of Biodiesel from no-edible oil. And the country is now under preparation and already set committee for the utilization of Biodiesel. The committee's name is "The committee of Development of Bio-Fuel" with a deputy commission of the planning commission of the government of India as a chairman of the committee. At present Biodiesel has been generated from oil trees of Jatropha curcas. The aim of the committee is to use 5% of Biodiesel in all part of the world by the year of 2006/7 and then by far to cover 20% at the year of 2012 all over the country. Thailand uses palm oil as a raw material for the production of Biodiesel, while Ireland uses frying and animal fats. [*5*]

In addition to this considerable attention was given on the development of alternative fuel sources, with particular reference to the alcohols. A blend of 10% dry ethanol and unleaded gasoline (E10) was commercially introduced into the US and continues to be marketed mainly in the Midwestern states. The use of ethanol blended with diesel was a subject of research in the 1980s and it was shown that ethanol–diesel blends were technically acceptable for existing diesel engines. The relatively high cost of ethanol production at that time meant that the fuel could only be considered in cases of fuel shortages. Recently the economics have become much more favorable in the production of ethanol and it is able to compete with standard diesel. Consequently there has been renewed interest in the ethanol–diesel blends with particular emphasis on emissions reductions. It has been widely used as fuel, mainly in Brazil, or as a gasoline additive for octane improver and better combustion in USA and Canada. Recently, surfer from degradation of global environment and foreseeable future depletion of world wide petrol reserves, the interest has turn to using ethanol–diesel blends in diesel engine, such as USA, France, Brazil, Turkey, Thailand, China and other countries. [*6*]

1.2 Project Introduction

As it has been seen in the background part, even the modified vegetable fuel (Biodiesel) has drawbacks in which it can not be a full replacement for diesel fuel. In the similar manner apart from the interesting outcomes, it is the same true to ethanol. Therefore due to this case this project was devised so that it was hoped that this project will give a better outcome taking the best characteristics of all core fuels. As it will be seen in this report, before coming to the analysis of this project literatures related to this topic has been studied and advantages and disadvantages, production, and experimental procedures (for engine performance, exhaust emission, fuel characteristics) have been reviewed.

1.3 Structure of the Thesis

After this introductory chapter, nine more chapters are following in which they can clearly show how and in what extent the project has been conducted.

The second chapter deals with the literatures reviewed related to the current work. It has been tried to show some among the papers and references which has been referred through out.

Third chapter deals with the energy utilization, environment situation and the search for alternative fuels. Here the context of energy globally, in Indian and Ethiopian aspect has been discussed. In addition green house gases, green house effect and global warming potential were seen in side the environmental situation.

In chapter four, it deals with the conventional diesel fuel. It has been tried to show what made diesel fuel suitable energy source up to now and properties and standards of diesel fuel has been covered.

Chapter five and six deal with the scope of biodiesel and ethanol as fuels in compression ignition (CI) engines respectively. Here their definition, production, properties, standards, blending with conventional diesel, emission reduction and storage and handling have been covered for each fuel.

Chapter seven deals why jatropha seed has been selected for the current work's source of biodiesel? And chapter eight deals with fuel sample formulation techniques and physical appearance of sample fuels.

Chapter nine goes much further to the results of the experiment in which it discusses the results of the fuel characteristics of all samples. The same to this chapter ten also discusses the experimental setups, observations and evaluations of performance characteristics of engine with the sample fuels.

CHAPTER TWO

LITRATURE REVIEW

2.1. Introduction

This section contains a review of various types of literature referred during the course of this project, which gave a more complete understanding of the subject of biodiesel & alcohol as a fuel, their properties for their suitability as a fuel for utilization in the compression ignition (CI) engine.

2.2. Biodiesel

As it has been mentioned in the introduction part, the trend of use of vegetable oil diesel fuel is as old as that of conventional petroleum diesel fuel. Humans have used renewable oils for thousands of years. An example is oil lamp. Portions of such lamps remain commercially available to this day, even in developed countries such as the USA. Renewable oil fuels were also used in early version of diesel engine- the engine actually predates the widespread availability of inexpensive fossil fuel. When Rudolph Diesel first displayed his engine at the 1900 at the world exhibition in Paris, he used peanut oil as the fuel. [*7*]

During World War II, different vegetable oils as a diesel fuel were under experimental stage. The results of this experiments showed that vegetable oils could be used to power a vehicle under normal operating conditions. However, it was realized that much more work was needed before vegetable oils could be used as a reliable substitute for diesel fuel. And most the work followed subsequently in next fifty years was concentrated on petroleum derived diesel fuel.

Since 1980s because of global concern of environmental degradation and fast depletion of fossil fuel, many researchers have investigated the important advantages and drawbacks of vegetable oils. (Robert Edward Beggs, 1997) has clearly indicated that renewable oils are considerably more viscous than that of petrodiesel fuels. If the viscosity is reduced to approximately to that of petrodiesel, they can be used as fuels in diesel engines without modifications to the engine or fuel injection system. There are, at present, two approaches to such viscosity reduction- “Renewable oil fuels system or heating vegetable oil up to 70^{o}C to reduce the viscosity” and “Biodiesel or alcoholysis (transesterification process)”. As far as reaction conditions and parameters on the Alcoholysis of triglycerides, such as fish oils, soybean, rapeseed, cottonseed, sunflower, safflower, peanut and linseed oils to produce ethyl and methyl esters (Chancellor et al., 1985; Feuge et al., 1949; Freedman et al., 1984; Harrington et al., 1985; Kusy, 1982; Lago et al., 1985; Nye et al., 1983; Peterson et al., 1984; Romano, 1982; Schwab et al., 1987; Stern et al., 1985; Stern et al., 1986). They also prepared methyl and ethyl esters from palm and sunflower oils using NaOH as the catalyst and using 100% excess alcohol and applied heat in the reaction. Lago et al. (1985) proposed the use of ethanol for both the oil extraction and the transesterification process. Clark et al. (1984) transesterified soybean oils into ethyl and methyl esters, and compared the performances of the fuels with diesel. DuPlessis et al. (1985) have produced both methyl and ethyl esters of degummed sunflower oil using NaOH catalyst. Stem et al. (1986) worked on a process with at least two transesterification.

In addition to the above stated works, S. M. Geyer et al. (1984) has conducted a test on a single-cylinder, 0.36 L, DI diesel engine fueling both certified diesel #2 fuel, cottonseed oil, sunflower seed oil, methyl ester of cottonseed oil, and methyl ester of sunflower seed oil. They have tried to compare performance and emission data when operating on neat vegetable oil, transesterified vegetable oil and diesel fuel. According to their result, Vegetable oils have showed slight improvements in thermal efficiency and higher exhaust gas temperatures compared to diesel No. 2 fuel. And showed equal or higher gas phase emissions, lower indicated specific revertant emissions and slightly higher aldehyde emissions, including an increase percentage of formaldehyde.

Anish Kumar Agarwal (1998) has eliminated almost all undesirable combustion features of vegetable oils using linseed oil esters. He has prepared linseed oil methyl esters (LOME) and linseed oil ethyl ester (LOEE), and showed viscosity, heat content, and density close to that of conventional diesel oil. As he has mentioned in his paper (*vegetable oils versus diesel fuel*), Esterification brings about a modification in the molecular structure of the linseed oil, thus, converting it into biodiesel, a fuel for utilization in diesel engines. He has managed to test blends of varying proportions of these biodiesel and diesel in a single cylinder compression ignition engine and significant improvements in the engine performance and emission characteristics were observed. As of his conclusion he has stated that the thermal efficiency of the engine improved, and the brake specific energy consumption reduced and there was a considerable decrease in the exhaust smoke density (particulate emissions).he has attributed this improvement to the characteristics of the modified fuels which permit a full degree of atomization in the injector nozzle.

Vegetable oils have the potential to substitute for a fraction of the petroleum distillates and petroleum based petrochemicals in the near future. Vegetable oil fuels are not now petroleum competitive fuels because they are more expensive than petroleum fuels. However, with the recent increases in petroleum prices and the uncertainties concerning petroleum availability, there is renewed interest in using vegetable oils in Diesel engines.

There are more than 350 oil bearing crops identified, among which only sunflower, safflower, soybean, cottonseed, rapeseed and peanut oils are considered as potential alternative fuels for Diesel engines [*16*]

Leon G. Schumacher et al., (1994) have tested 6V92TA Detroit Diesel Corporation diesel engine fueling with blends of 10, 20, 30, and 40 percent soydiesel/diesel fuel. And the conclusion of this experiment was Fueling with biodiesel/diesel fuel blends effectively reduced particulate matter, unburned hydrocarbons, and carbon monoxide while increasing oxides of nitrogen emissions. The optimum blend of biodiesel and diesel fuel, based on the trade-off of PM decrease and NOx increase, was a 20/80 biodiesel/diesel fuel blend.

C. L. Peterson et al. (1994) have conducted an experiment on Canola, rapeseed, soybean oils, and beef tallow methyl and ethyl esters. A complete set of fuel properties and a comparison of each fuel in engine performance tests are reported. According to their conclusion, the physical and chemical properties and the performance of ethyl esters were comparable to those of the methyl esters. Ethyl and methyl esters have almost the same heat content. The viscosities of the ethyl esters are slightly higher and the cloud and pour points are slightly lower than those of the methyl esters. Engine tests demonstrated that methyl esters produced slightly higher power and torque than ethyl esters. Fuel consumption when using the methyl and ethyl esters is nearly identical. Some desirable attributes of the ethyl esters over methyl esters were: significantly lower smoke opacity, lower exhaust temperatures, and lower pour point. The ethyl esters tended to have more injector coking than the methyl esters and the ethyl esters had higher glycerol content than the methyl esters.

L. G. Schumacher et al. (1998), have conducted an experiment on 1996 Dodge pickups equipped with the 5.9 L (360 in^3) Cummins diesel engine pickups fueling with a two blends of methyl-ester soybean oil (soy-diesel/biodiesel) and petroleum diesel fuel for more than 40,608 miles. Analysis of engine lubrication oil suggested that the engine was wearing at normal rate. The black smoke normally observed when a diesel engine accelerates has slightly reduced when the engine is fueled with this blend and finally it was observed that fueling with this blend has no impact with the fuel economy.

L. G. Schumacher et al. (2000), have conducted an experiment on 1991, 1992, 1996 and 1998 Dodge pickups equipped with the 5.9 L (360 in^3) Cummins diesel engine pickups fueling with one, two and 100% blends of methyl-ester soybean oil (soy-diesel/biodiesel). Analysis of engine lubrication oil, taken when the oil was changed on the vehicles, was compared to the analysis of oil samples pulled from 100% petroleum fueled diesel engines. The findings suggested that the biodiesel and biodiesel blend fueled engines were wearing at a normal rate. In addition they have also concluded that replacing the diesel fuel with biodiesel reduced the wear of aluminum, iron, chromium and lead components in a diesel engine.

K. Agarwal et al. (2001) have produced biodiesel from linseed oil and various properties of the biodiesel thus developed are evaluated and compared in relation to that of conventional diesel oil. These tests for biodiesel and diesel oil include density, viscosity, flash point, aniline point/cetane number, calorific value, etc. The prepared biodiesel was then subjected to performance and emission tests in order to evaluate its actual performance, when used as a diesel engine fuel. The data generated for various concentrations of biodiesel blends were compared with base line data generated for neat diesel oil. It was found that 20 percent blend of biodiesel gave the best performance amongst all blends. It gave net advantage of 2.5 percent in peak thermal efficiency, reduced the exhaust emissions and the brake specific energy consumption, and there was substantial reduction in smoke opacity values. They have also concluded that, Exhaust temperatures increased as a function of the concentration of biodiesel blend, i.e., higher the percentage of LOME; higher were the exhaust temperatures. Increase in the exhaust temperature of a biodiesel-fueled engine led to approximately 5 percent increase in NO_x emissions for 20 percent biodiesel blend. This is so because NO_x formation is a highly temperature dependent phenomenon.

The advantages of vegetable oils as Diesel fuel are:

- Liquid nature-portability,
- Ready availability,
- Renew ability,
- Higher heat content (about 88% of D2 fuel),
- Lower SC,
- Lower aromatic content,
- Biodegradability.

The Disadvantages of Vegetable Oils as Diesel Fuel are:

- Higher viscosity,
- Lower volatility,
- The reactivity of unsaturated hydrocarbon chains. [*19*]

2.3. Ethanol

E.A. Ajav et al (1999) have conducted an experiment on performance of a constant speed, stationary diesel engine using ethanol-diesel blends as fuel. The experiments were performed using 5, 10, 15 and 20% ethanol-diesel blends. Diesel fuel was used as a basis for comparison. They have studied the effect of using different blends of ethanol-diesel on engine horsepower, brake specific fuel consumption, brake thermal efficiency, the exhaust gas temperature and lubricating oil temperature. The results indicate no significant power reduction in the engine operation on ethanol-diesel blends (up to 20%) at a 5% level of significance. Brake specific fuel consumption increased by up to 9% with an increase of ethanol up to 20% in the blends as compared to diesel alone. The exhaust gas temperature, lubricating oil temperatures and exhaust emissions (CO and NO_x) were lower with operations on ethanol-diesel blends as compared to operation on diesel.

E. A. Ajav et al. (2002) they have used Six blends (5, 10, 15, 20, 25, and 30%) of ethanol by volume with diesel to determine relative density, viscosity, cloud and pour point, flash point and calorific value. They have concluded the following based on their investigations: Relative density of all the blends was found to be lower than that of diesel fuel alone. The relative density was dependent on temperature; Lower pour points were recorded for all the blends compared to 5°C pour point obtained for diesel fuel alone. The cloud point was same for all the fuels tested; the viscosities of the 5, 10, 15, 20, 25 and 30% blends were 1.4, 4.9, 8.0, 9.2, 12 and 16% less than that of diesel respectively; All the blends were highly flammable with flash point temperature that was below the ambient temperature; Calorific values of the blends were lower than that of diesel but the differences were not significant at 5% level of significance; In general, blends containing 5, 10, 15 and 20% ethanol have very close fuel properties compared to diesel fuel.

Michael Wang et al. (2003) Using Argonne's GREET model, they have conducted a WTW analysis of E-diesel blends vs. petroleum diesel for applications in farming tractors and urban buses. Their results show that use of ED10 or ED15 might result in increases in total energy use, but in reductions in fossil energy use and significant reductions in petroleum use relative to use of conventional or low-sulfur diesel fuel. Generally their analysis shows that the most noteworthy benefits of E-diesel use lie with petroleum reductions and reductions in urban PM10 and CO emissions by urban bus operations.

Henry Ford designed the famed Model T Ford to run on alcohol -- he said it was "*the fuel of the future*". The oil companies thought otherwise, however -- but the oil crisis of the early 1970s gave ethanol fuel a new lease of life.

Advantages of Ethanol over Fossil Fuels

Ethanol is a much cleaner fuel than fossil petroleum fuels:

- It is a renewable fuel made from plants
- It is not a fossil-fuel: manufacturing it and burning it does not increase the greenhouse effect

- It provides high octane at low cost as an alternative to harmful fuel additives compared to the gasoline fuel.
- Ethanol blends can be used in all engines without modifications
- Ethanol is biodegradable without harmful effects on the environment
- It significantly reduces harmful exhaust emissions
- Ethanol's high oxygen content reduces carbon monoxide levels more than any other oxygenate: by 25-30%, according to the US EPA
- Ethanol blends dramatically reduce emissions of hydrocarbons, a major contributor to the depletion of the ozone layer
- High-level ethanol blends reduce nitrogen oxide emissions by up to 20%
- Ethanol can reduce net carbon dioxide emissions by up to 100% on a full life-cycle basis

High-level ethanol blends can reduce emissions of Volatile Organic Compounds (VOC) by 30% or more (VOC) are major sources of ground-level [*b*]

Disadvantages of Alcohol

- There are many disadvantages to using alcohols, particularly methyl and ethyl alcohol. Although these alcohols, when used near their stoichiometric air-fuel ratios, produce more power, a larger quantity of fuel is required to produce a specified power output. For example, in an automobile, more fuel is required for each mile driven.
- The relatively low boiling points and high vapor pressures of methyl and ethyl alcohol indicate that vapor lock could be a serious problem, particularly at high altitudes on warm summer days. Butyl alcohol, because of its low vapor pressure, is the least likely of the alcohols to cause vapor lock.
- The relatively high latent heats of methyl and ethyl alcohol cause problems in mixing these alcohols with air and transporting them through the intake manifold of the engine. Heating the intake manifold may be necessary in cold weather or before the engine reaches operating temperatures. Without external heat to more completely vaporize the fuel, the engine may be difficult to start and sluggish for a considerable time after starting. Butyl alcohol is the least likely to cause starting

difficulties or problems during warm-up. Note that its latent heat is almost the same as the latent heat of octane.

- All of the alcohols are soluble in water, but butyl alcohol is relatively insoluble compared to methyl and ethyl alcohol. Less engine power is produced as the water content of an alcohol increases. Further, vapor lock, fuel mixing and starting problems increase with water. [*1*]

2.4. Chapter Summery

To conclude, as we can see from the total stated literatures in which these are some examples of I have gone through my study to this project, Biodiesel and Ethanol are the two main potential bio-fuels which can substitute fossil origin petroleum fuels. As far as biodiesel is concerned, it has almost competitive properties with conventional diesel fuels. Though it is having advantages to diesel fuel, but it is not worthy to use 100% biodiesel in unmodified internal combustion engine. This is because, it emits more NO_x compared to diesel fuel. Therefore to optimize the advantages with the disadvantages of biodiesel it is used by blending with petroleum as a ratio of 80:20. In the same manner the same is true with Ethanol in which its benefits and disadvantages are stated over. Therefore, by using the ratio of 15-20% of ethanol in diesel we can get the optimum result in the internal combustion engine as far as performance, emission and exhaust temperature are concerned.

CHAPTER THREE

ENERGY, ENVIRONMENT SITUATION AND SEARCH FOR ALTERNATIVE FUELS

3.1.Introduction

Energy is defined as the capacity for producing an effect. It plays an important role in the development of the nation, and runs major activities such as: transport sector, the industrial sector, agricultural sector, health sector, Service and others and in the household utility and daily activity, etc. In the absence or scarce of energy, the country is like a kid with shortage food affected with malnutrition. The nation's growth factor depends on the consumption of energy.

Energy is a primary question: how to meet its growing demand? This question is linked with attempts to economize on energy use and conserve energy for future generations. The West has been more concerned with this, given the big size of its demand. An added concern there has been the rising pollution levels also, which are linked closely with the amount and type of energy used. All these issues led to many scientific attempts and research on finding oil-substitutes, clean fuel or finding alternatives through which the possibility of oil conservation may improve.

The biggest potential for increasing energy demand lies in developing Asian countries such as China, India, Indonesia, and Pakistan. If the per capita incomes of these countries compared favorably with those of USA, Germany, and UK, they would be the world's most significant energy users. [*23*]

The mid of 1970s was the time for researchers of the world to think about an alternative energy due to the energy crisis of the world. At this time the demand of energy of the world has increased as a consequence of development in the economy of many nations, which leads to the shortage of natural resources and also those countries that produce oil were trying to increase the price due to so many reasons. In addition to the energy crisis, environmental degradation has become the main concern of the world since this time. On

October 24, 1992 the Energy Policy Act of 1992 was signed in to law. The Act contains a wide ranging set of provisions to increase the efficiency of energy usage, develop new fuels, increase production of energy and stimulate new generating capacity. Due to the above crises even the biggest country USA has funded much more money towards the research and development of an alternative fuel.

3.2. Energy Utilization and the Rising Demand

3.2.1. Global Context

Growing dependence on imported oil necessitates the search for viable alternative forms of energy. In the mid-seventies, there arose a sudden awareness that the availability of petroleum-based fuels was finite and depleting fast. By that time, petroleum fuels had already acquired monopoly in the mechanized agriculture sector employing diesel-operated engine pump sets, tractors, and farm equipments. The growing scarcity of diesel oils led to the search for non-petroleum fuels.

According to IEA (International Energy Agency) assessment, the world energy use will increase steadily through 2030 though at a slower pace of 1.7% compared to 2.1% achieved over the past three decades. Fossil fuels will remain the primary source of energy meeting more than 90% of the increase in demand. Global oil demand will rise by about 1.6% from 75 Mb/d in 2000 to 120 Mb/d in 2030.

Transport demand almost entirely for oil will grow the most rapidly of all end use sectors at 2.1% per annum. It will overtake industry in the 2020s as the largest final use sector. Between 1973 and 1996 world transportation energy use of which petroleum derived fuels comprise over 95%, increased by 66%. Alternative energy sources have not played a significant role in the world's transport systems.

On a modal basis, road transport accounts for almost 80% of transport use. Light duty vehicles alone comprise about 50%. At the end of World War II, the world's motor vehicle fleet numbered 46 million vehicles and 75% of the world's cars and trucks were in USA. In 1996, there were 671 million highway vehicles world wide, and the US share stood at just over 30%. Since 1970 the US motor vehicle population has been growing at an average rate of 2.5% per year, but the population of vehicles in the rest of the world has been increasing almost twice at 4.8% per year.

Despite two decades of price upheavals in world oil markets, considerable research and development of alternate fuel technologies, and notable attempts to promote alternate fuels through tax subsidies and other policies, petroleum's share of transport energy use has not decreased (94.7% in 1973 and 96.0% in 1996) according to EPA statistics.

	PER CAPITA ENERGY CONSUMPTION (*KGOE*)		**PER CAPITA ELECTRICITY CONSUMPTION (*KWH*)**	
	1996	**1999**	**1996**	**1999**
World	1692.8	1671.1	2034.6	2107.3
USA	7966.0	8158.7	11663.8	11994.4
Japan	4063.9	4069.9	7085.9	7442.6
Germany	4288.7	4107.8	5595.7	5689.7
France	4354.7	4350.8	6127.4	6391.6
Singapore	6010.4	5742.2	5969.5	6640.9
India	483.8	481.6	344.2	379.2
China	918.6	868.2	685.7	757.8
Malaysia	1873.3	1878.0	2077.0	2474.4
Korea	3610.3	3870.5	4449.3	5159.8
UK	3964.8	3870.9	5198.1	5384.0

Table 3.1 Comparison of per capita energy end electricity consumption for some countries in 1996 and 1999 [*c*]

3.2.2. Ethiopian Context

Ethiopia is a country suited in the horn Africa with the area of 1,188,882 square kilometer and population of 67,673,031 according the 1997 population census. The country shares boundary with the following countries as follows: Kenya in the southern part, to the south east with Somalia, to the west with Sudan, to the east with Djibouti and to the north and north east with Eritrea. It has diversified climate with all four seasons. The country's GNP per capital in nominal is $100, with 85% of the population in rural area. Statistically the agriculture sector is 45%of the country's GDP and around 80% of work force.

According the data in 1995, the country's energy consumption is 723 peta joules (50 million tones of wood equivalent). Out of this 77% is fire wood and charcoal, 15.5% is agricultural residue (dung and crop residue), 6% is modern energy sector (petroleum and electricity) [*24*].

Consumption of liquid fuel products, in 1997, according to the US Department of Energy was approximately 550 000 metric tons. The supply of petroleum is met entirely by importation and has claimed 15-20% of imports in recent years, which is a big pain for a country where its imports are more than that of exports. Even recently as the report from Ethiopian Reporter on 13th of November, 2004 indicated, the country has lost extra money around 75 million US dollars due to the world crud price fluctuation. Out of the petroleum consumption, the transportation sector takes around 51% with diesel 46%, kerosene 20% and gasoline 18%.

On the Electricity sector even though some estimates indicated that the total potential could be as much as l43 billion kilowatts the country has produced 1,563,415 MWh. [*24*] Out of this 96.4% is from hydroelectric power and that of the balance is from diesel fuel. The main sources of this potential were thought to be the Abay (Blue Nile; 79.9 billion kilowatts), the Shebele (2l.6 billion kilowatts), and the Omo (l6.l billion kilowatts). The remaining 25.9 billion kilowatts would come from rivers such as the Tekezé, Awash, Baro, Genale, and Mereb. [*d*]

The urban house holds energy utilization of the country is 79.9% is from biomass where as the balance is from modern fuels. While the rural house holds energy utilization is entirely based on biomass. Ethiopia's forest resources have been disappearing at an alarming rate. A century ago, forests covered about 40 percent of the total land area. This proportion has been reduced to 16 percent in the early 1950s and to less than 3 percent today (MNRDEP, 1992). The Primary cause of deforestation is cutting trees with the aim of opening up new agriculture land to feed the ever growing population. Deforestation is estimated to take place at the rate of 200,000 ha/year. The Widespread use of fuel wood as energy has also contributed to the deforestation process. About 95 per cent of the total energy consumption in Ethiopia is composed of traditional biomass fuels, with only 5 per cent coming from modern energy sources. Most of the remaining forests are being confined to remnant patches in inaccessible areas. Of the remaining forests, 54 per cent are in the western regions of Illubabor (48%), Keffa, Wellega and Gojam and 38 per cent are in the southern regions of Bale (19%), Sidamo and Gamo Gofa. Shoa region is estimated to account for 3.1 per cent, Hararghe only 0.6 per cent and the rest (Tigray, Wello, Gonder as well as the now independent Eritrea) for only 4.1 per cent. The woodland/Savannah region originally covers 371,900 sq. km (30 % of the country) in the semi-arid and sub- humid regions surrounding the highlands. Only 7.6 per cent of the total area is currently covered by this vegetation type. [*e*] As we can see from this data [*Table 3.2*], the country's forestation is degrading in a very fast rate annually some part of the country's territory is changing its climate from forest zone to the arid zone.

Sector	Total		Biomass		Petroleum		Electricity	
	'000 Tera joule	%	'000 Tera joule	%	'000 Tera joule	%	'000 Tera joule	%
House hold	644.7	89.2	635.69	93.0	7.03	20.2	2.0	43.9
Urban	42.6	5.9	34.01	5.0	6.53	18.7	2.0	43.9
Rural	602.2	83.3	60.69	88.0	0.50	1.4	-	-
Agriculture	0.8	0.1	-	-	0.82	2.3	-	-
Industry	33.32	4.6	24.05	3.5	7.29	20.9	1.98	42.9
Medium and Large	11.89	1.6	5.57	0.8	4.36	12.5	1.97	42.6
Small scale	0.20	…	0.19	…	0.008	…	0.002	0.05
Cottage Industry	18.32	2.5	18.29	2.7	0.02	0.1	0.01	0.21
Mining	0.18	…	-	-	0.18	0.5	-	-
Construction	1.97	0.3	-	-	1.97	5.7	-	-
Grain milling	0.75	0.1	-	-	0.75	2.2	-	-
Transport	17.92	2.5	-	-	17.92	51.4	-	-
Road	16.18	2.2	-	-	16.18	4.6	-	-
Rail	0.96	…	-	-	0.09	0.3	-	-
Air	1.64	0.2	-	-	1.64	4.7	-	-
marine	-	-	-	-	-	-	-	-
Service and others	26.07	3.6	23.65	3.5	1.80	5.2	0.61	13.2
Commercial	24.57	3.4	23.65	3.5	0.34	1.0	0.58	12.6
Government	1.28	0.2	-	-	1.27	3.6	0.004	0.08
Others	0.22	…	-	-	0.20	0.6	0.026	0.57
Total	**722.87**	**100**	**683.4**	**100**	**34.87**	**100**	**4.61**	**100**
Total mtwe*	**49.9**		**47.1**		**2.5**		**0.3**	
Total mtoe**	**16.9**		**16.0**		**0.8**		**0.1**	
Percentage	**100.0**		**94.6**		**4.8**		**0.6**	

**: million tons of wood equivalents*
***: million tons of oil equivalents*

Table 3.2 Sectoral Energy consumption in the year 1995 [*24*]

The country has natural resources of primary solar radiation, Wind, forest, hydropower, biomass, animal Waste, and crop Residue oil seeds sugar cane and so on. Second to the food crisis the county is suffering from the energy crisis. The energy crises also aggravates the food crisis by increasing the rate of deforestation and there by causing erosion of farmlands. Even though the country has sufficient resource, due to mismanagement, lack of capital and skilled man power and improper utilization of locally available energy the country is importing its demand of energy.

3.2.3. Indian Context

India being a developing country requires much higher level of energy to sustain its rate of progress. There is a limited quantum of petroleum-based mineral oil available in particular. Even with the recent discoveries and increased extraction, the country imports almost 35% of the crude petroleum. As per the current estimates, oil reserves in India will last for the next 25-30 years.

Although India ranks sixth in total energy consumption in the world (294 MTOE [million tones of oil equivalent]), this is only 12% of the energy consumed by the largest consumer, i.e. USA (2278 MTOE). In per capita terms, its consumption is only about 20% of the global average. [*25*] While the world's consumption of energy grew by 1% in 1997 over previous year, it grew by 6.1% in India. [*23*] With India targeting ambitious growth rates of 7-8% over the next two decades, its per capita energy consumption must necessarily rise in the future and for that the availability of energy can pose a big hurdle.

The Indian scenario of the increasing gap between demand and domestically produced crude oil is a matter of serious concern. Our crude oil production as per the Tenth Plan Working Group is estimated to hover around 33-34 MMTPA. Though there will be increase in gas production from 86 MMSCMD (2002-03) to 103 MMSCMD in 2006-07). Only with joint venture abroad there is a hope of oil production to increase to 41 MMTk by 2016-17). The gas production would decline by this period to 73 MMSCMD [*5*]

Oil provides energy for 95% of transportation and the demand of transport fuel continues to rise. The requirement of Motor Spirit is expected to grow from little over 7 MMT in 2001–02 to over 10 MMT in 2006-07 and 12.848 MMT in 2011-12 and that of diesel (HSD) from 39.815 MMT in 2001-02 to 52.324 MMT in 2006-07 and just over 66 MMT in 2011-12. [5] Consumption of petroleum products has been rising by 5-6 per cent per annum in the last two and a half decades. The growth in the 1980s was stable at six per cent per annum. The growth rate fell to 5.4 percent per annum during the early 1990s as industrial activity slowed down during this period.

The domestic supply of crude will satisfy only about 22% of the demand and the rest will have to be met from imported crude. The country's dependence on import of oil will continue to increase in the foreseeable future. The crude prices and availability are subject to great volatility depending upon the international situation and, therefore, attempt needs to be made to reduce dependence on imports. India is attempting to limit its dependence on oil imports somewhat by expanding domestic exploration and production.

3.3. Environment

The environment affects our health and we, and our activities, affect the environment. Since the number of humans on Earth increases exponentially, our technological activities have an increasing impact on the environment no matter how efficient our technology may be. [26] Energy production and utilization involves a disturbance to the state of the environment. Coal exploration and mining causes land degradation through subsidence and mine fires. The impact of mining on forest areas is of particular concern as there is considerable overlap between forests and coal reserves in India. Similarly, oil and gas exploration and production poses a threat to the existing physical, chemical, and the biological status of the environment. The major concerns associated with onshore oil and gas production are drilling waste fluids, drilling waste solids, produced water and volatile organics, which can contaminate surrounding water bodies.

The utilization of fuels in the power, transport, and industrial sectors is associated with visible and adverse environmental impacts. One of the most significant problems is the generation of fly ash during the combustion of coal in power generation. In India with over 60% of power generation being coal-based and the inherently high ash content of indigenous coal (more than 40% in some cases), 80–100 million tones of fly ash are produced every year. India stands second only to China in the quantum of fly ash generated every year. Currently, nearly 90% of fly ash generated is dumped as slurry in ash ponds, which requires huge amounts of water, results in creation of wasteland and could also lead to leaching of heavy metals and soluble salts. Leakage from ash ponds to neighboring fields and water bodies can lead to surface and groundwater pollution. The utilization of fly ash in India remains low at 10%, compared with utilization rates of 30%–100% internationally. [*f*]

The energy and resource intensity of industrial production coupled with low resource use efficiency has caused environmental deterioration in areas where industrial units are located. The highest concentration of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) is found in cities in states where the bulk of industrial units are located. Seven resource-intensive and highly polluting industries (copper, aluminum, steel, cement, fertilizers, textiles, and PVC [polyvinyl chloride] are a major source of SPM (suspended particulate matter) emissions in the country. Industrial units located in densely populated urban areas discharge untreated effluents into surface water channels, land sites, and sewers. It is estimated that industrial activities contribute more than one-third of the total pollution in rivers and water bodies. About 1532 grossly polluting industries discharge effluents into water courses.

The use of gasoline and diesel in the transport sector generates a number of pollutants like lead (Pb), carbon monoxide (CO), toxic compounds such as benzene, and particulate matter which are discharged to the atmosphere along with vehicular exhaust gas (CPCB). As it has been mentioned in the introduction, the transport sector is the largest consumer of commercial energy next to industry. A combination of factors including increased travel demand, dominance of road based and personalized modes of transport and fuel combustion in inefficient vehicular technologies has resulted in air pollution in urban areas reaching critical levels. Of particular concern is the level of concentration of carbon monoxide and particulate matter. Data indicate that SPM levels are critical in 21 areas in the country [CPCB].

In addition to these local environmental impacts, the use of fossil fuels in energy combustion, transport, and industrial processes is a source of carbon dioxide (CO_2) emissions, which contribute to climate change. Fuel combustion in energy and transformation industries accounted for 87% of total carbon dioxide (CO_2) emissions in India in 1990. Although carbon dioxide emissions per capita in India are very low (1.1

tones) compared with the world average (4.1 tones) (World Bank), these concerns should be addressed in energy policies. [27] With all these impacts the globe is now at the critical condition, in which it is affected by green house gas effect and global warming and their effect is appearing in the daily life of mankind.

3.3.1. Greenhouse Gases

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither plays a significant role in enhancing the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide, and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth [IPCC 1996]. Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans.

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities.

Various external mechanisms influence the climate system leading to the externally imposed perturbation in the radiative energy budget of the earth. The most important influence is the sun. Other radiative forcing agents are the changing concentrations of Green House Gases (GHGs), other trace gases, aerosols, and Chlorofluorocarbons (CFCs) etc. released from human activities related to energy and transformation industries, industrial processes, agriculture, land use and land cover change and forestry, and management of waste.

Emissions can be classified in three categories: long-lived gases (Kyoto Protocol Gases), short lived gases ($CO_,$ $NO_{x,}$ SO_2) and particulate

Climate Forcing Pollutants				
Radiative forcing	Kyoto Protocol	Global Warming Potential (GWP)	Short Lived Gases	Particulates
1.56Wm^{-2}	CO_2	1	O_3	▪ Cooling Aerosols
0.47 Wm^{-2}	CH_4	23	CO	
0.14 Wm^{-2}	N_2O	296	NO_X	▪ Heating Aerosols
	HFC	140	SO_2	
Little now				
	SF6	23,900	(Transport over long distance	
	PFC	Large		
Global			Local to Regional	
Decades and Centuries			Weeks and Days	Days

Table 3.3 Characteristics of Long lived; short lived and particulates [28]

3.3.2. Greenhouse Effect

The greenhouse effect is a natural phenomenon. The sun’s energy heats the earth’s surface, and some of that heat is in turn radiated back. Certain gases in the earth’s atmosphere prevent this radiation from escaping into space. Thus the heat becomes trapped inside the atmosphere which, in essence, is like the glass cover of a greenhouse, hence the term “greenhouse effect”. This “greenhouse effect” maintains the earth’s average surface temperature at +15°C, and is therefore a precondition for life on the planet – without the “greenhouse effect”, the average temperature would be –18°C. This natural “greenhouse” effect derives mostly from water vapor present in the atmosphere. It is generally agreed that the quantity of water vapor in the atmosphere does not vary, so calculations take no account of its contribution to the “greenhouse” effect. Clouds, moreover, have a cooling effect by reflecting the sun’s rays. Most CO_2 emitted into the earth’s atmosphere results from natural processes. Today, however, concentrations of “greenhouse” gas are rapidly increasing and a proportion of the scientific community believes that humankind’s contribution, small though it is, could easily tip the balance and contributes to global warming. This study, therefore, focuses on the additional impact of other gases in the earth’s atmosphere on the “greenhouse” effect.

3.3.3. Global Warming Potential (GWP)

The various sources which influence the atmosphere can be quantified in terms of their global warming potentials (GWP) which represent the time integrated warming effect of a unit of mass of given GHG in today's atmosphere, relative to that of CO_2.

3.4. Alternative Fuels

Alternative fuels defined by as follow:

"Alternative fuel" means any fuel that is

- For use in motor vehicles to deliver direct propulsion.
- Less damaging to the environment than conventional fuels, and
- Prescribed by regulation, including, without limiting the generality of the Foregoing, ethanol, methanol, propane gas, natural gas, hydrogen or electricity when used as a sole source of direct propulsion energy and
- Satisfies the specifications that may be prescribed in this behalf.

Based on the above definition, several fuels have been considered from time to time all over the world as low cost substitutes for the for the gasoline & diesel. Lately they have gained importance as clean fuels. The prominent among these are: Biomass, Bio-fuels (includes Alcohols, vegetable oils, Biodiesel, etc.), Hydrogen, Natural gas (CNG/LNG), DME, P-series and solar fuels.

3.4.1. Biomass

Biomass is the term used to describe all the organic matter, produced by photosynthesis that exists on the earth's surface. The source of all energy in biomass is the sun, the biomass acting as a kind of chemical energy store. Biomass is constantly undergoing a complex series of physical and chemical transformations and being regenerated while giving off energy in the form of heat to the atmosphere. To make use of biomass for our own energy needs we can simply tap into this energy source, in its simplest form we know, this is a basic open fire used to provide heat for cooking, warming water or warming the air in our home. More sophisticated technologies exist for extracting this energy and converting it into useful heat or power in an efficient way. The exploitation of energy from biomass has played a key role in the evolution of mankind. Until relatively recently it was the only form of energy which was usefully exploited by humans and is still the main source of energy for more than half the world's population for domestic energy needs.

Traditionally the extraction of energy from biomass is split into 3 distinct categories:

Solid biomass - the use of trees, crop residues, animal and human waste (although not strictly a solid biomass source, it is often included in this category for the sake of convenience), household or industrial residues for direct combustion to provide heat. Often the solid biomass will undergo physical processing such as cutting, chipping, briquetting, etc. but retains its solid form.

Biogas - biogas is obtained by anaerobically (in an air free environment) digesting organic material to produce a combustible gas known as methane. Animal waste and municipal waste are two common feedstocks for anaerobic digestion.

Liquid Biofuels - are obtained by subjecting organic materials to one of various chemical or physical processes to produce a usable, combustible, liquid fuel. Biofuels such as vegetable oils or ethanol are often processed from industrial or commercial residues such as bagasse (sugarcane residue remaining after the sugar is extracted) or from energy crops grown specifically for this purpose. Biofuels are often used in place of petroleum derived liquid fuels.

3.4.2. Compressed Natural Gas (CNG)

Natural gas is a mixture of hydrocarbons-mainly methane and is produced either from gas wells or in conjunction with crude oil production. Due to its lower energy density for use as a vehicular fuel, it is compressed to a pressure of 200-250 bar to facilitate storage in cylinders mounted in vehicle and so it is called Compressed Natural Gas. India's recoverable resources of more than 690 billion cubic meters make it a long-term substitute fuel for use in petrol & diesel engines.

Advantages of Compressed Natural Gas

- No visible tail pipe emissions
- Eliminates sulfur and lead from the exhaust emissions.
- Reduce noise in operations

Disadvantages of CNG

CNG is now established as a very successful alternative fuel for automobiles throughout the world. The disadvantage of this fuel, are it need high initial investment for the development of refill stations, and the energy gives less torque compared to diesel fuel.

3.4.3. Liquefied Petroleum Gas (LPG)

LPG is a byproduct of Natural Gas processing or product that comes from crude oil refining and is composed primarily of propane and butane with smaller amounts of propylene and butylenes. Since LPG is largely propane, the characteristics of propane sometimes are taken as a close approximation to those of LPG.

Advantage of LPG

- Reduction in emissions.
- Very less carbon build-up increases life of engine parts like spark plugs.
- Fueling is akin to that of conventional diesel or gasoline.
- Service life of the vehicle increases with LPG
- Process by product used for fertilizers in agricultural fields

Disadvantages of LPG

Issues like safety, storage and handling, extreme volatility of the fuel etc. needs proper attention.

3.4.4. Di-methyl Ether (DME)

DME is an ether compound having a molecular structure in which one oxygen atom and two methyl groups are bonded. DME is a colorless gas and smelling etheric at room temperature and under normal pressure. Like LPG, DME is liquefied by applying a pressure of approx. 0.5 Mpa.

Advantages of DME

- The greatest advantage of DME when used as an automobile fuel is that its high cetane number makes its applicable to a diesel engine.
- Being an oxygen containing fuel, it prevents a diesel engine emitting soot and particulate matter to a greater extent than diesel fuel does.

Disadvantages of DME

- DME has a viscosity lower than that of diesel.
- Lubricity is also low causing wearing of engine parts.
- It is found to react with some rubber components.

3.4.5. Hydrogen as a Fuel

Hydrogen is the most abundant element in the universe, but is rarely found in its uncombined form on the earth. When combusted (oxidized) it creates only water vapour as a by-product. When burned in an internal combustion engine, however, combustion also produces small amounts of nitrogen dioxide and small amount of unburned HC and CO because of engine lubricants but the exhaust is free from CO2. It is a gas at normal temperature and pressure, which presents greater transportation and storage hurdles. Storage systems being developed include compressed hydrogen, liquid hydrogen and chemical bonding between hydrogen and a storage material.

Advantages of Hydrogen Fuel

- Very less emissions.
- High Octane rating.
- High energy content.
- Large base source for production is available.

Disadvantages of Hydrogen Fuel

- Problems of fuel storage.
- Vehicle range and power loss.
- Wider flammability limits.

3.4.6. P-Series Fuel

P-Series Fuel is new fuel that is now classified as alternative fuel by the US department of energy. This fuel was devolved by Dr. Stephen Paul of Princeton University. The class of p-series fuel includes certain blends of methyl-tetrahydrofuran, ethanol and hydrocarbons. Pure Energy Corporation's p-series fuels are blends of methyl-ltetrahydrofuran, ethanol and pentanes plus with butane added for blends that would be used in severe cold-weather conditions to meet the cold start requirements.

Advantages of P-Series Fuels

P-series fuel contains at least 60% non petroleum energy content derived from MTHF and ethanol. Most of the component of this fuel is derived form renewable domestic sources thereby making it a choice for the energy security.

3.4.7. Hybrid Electric Vehicle (HEV)

Hybrid electric vehicle (HEV) combines two or more energy conversion technologies (e.g., heat engines, fuel cells, generator or motors) with one or more energy storage technologies (e.g., fuels, batteries, ultra-capictor, or flywheels). The combination of conventional and electric propulsion system offers the possibility of greatly reducing emissions and fuel consumptions, while giving consumer both the extended range and convenient refueling they expect from a conventional vehicle. HEV can either have a parallel or series design. In a parallel design, the energy conversion unit and electric propulsion system are connected directly to the vehicle's wheels. The primary engine is used for highway deriving ; the electric motor provide added power during hill climbs, acceleration, and other periods of high demand. In series design, the primary engine is connected to generator that produces electricity. The electricity charges the batteries and derives an electric motor that power wheels.

Advantages of Hybrid electric vehicle

- HEV are two or three times more fuel efficient than conventional vehicle.
- Good emissions benefits.
- Easy and rapid refueling.

Disadvantages Hybrid electric vehicle

Hybrid electric vehicle (HEV) enjoys many advantages overruling the demerits associated with it, if any. As these vehicles are recently introduced in market, data on their road performance and servicing requirements are not yet to be analyzed.

3.5. Chapter Summery

In the developing world context, like in Indian and Ethiopia, the Bio-origin fuels can contribute significantly towards the problems related to fuel crisis because they can be produced from locally available resources. The fuels of bio-origin may be alcohol vegetable oils, biomass, and biogas, which can be formulated to bring their properties close to those conventional fuels. In this regard, a more elaborated discussion can be seen in the following chapters for bio-fuels especially for Biodiesel and Ethanol, as of these are the main core fuels in addition to Conventional diesel fuel in this work.

CHAPTER FOUR

CONVENTIONAL DIESEL FUEL

As it has been mentioned on the introduction part, our main goal is to bring up Biofuels (Alternative Fuel) as a replacement of petroleum driven diesel fuel. Therefore we have to keep in mind that biofuels should adapt the special features of Diesel fuel, which makes it as the main fuel for compression ignition internal combustion engines. Similarly they should have to get rid of the drawbacks associated with the diesel fuel such as the non-renew ability and environmental hazard ness.

What makes Diesel a source of energy in for internal combustion engine?

The fuels used for internal combustion engines are designed to satisfy the performance requirements of the engine system in which they are going to be used. Therefore to fulfill this fuel must have certain physical, chemical and combustion properties. Among these, here are some stated below:

- High energy density
- Good combustion quality
- High thermal stability
- Low deposit formation tendency
- Compatibility with the engine hardware
- Good fire safety
- Low toxicity
- Low pollution
- Easy transferability and onboard vehicle storage

Therefore any combustible liquid which can fulfill the above characteristics can be a fuel for the internal combustion engine.

Diesel fuels are petroleum fractions that lie between kerosene and the lubricating oils. Diesel fuel properties are influenced by the crude source and the method of refining. Few of the properties required, such as high calorific values (energy content), are common to both gasoline and diesel power units, but most are much different. Diesel fuel mostly comprises fractions boiling off from approximately 150 to 355^{o}C, *Fig.4.1*, as compared with about 15 to 210oC for gasoline. [*29*]

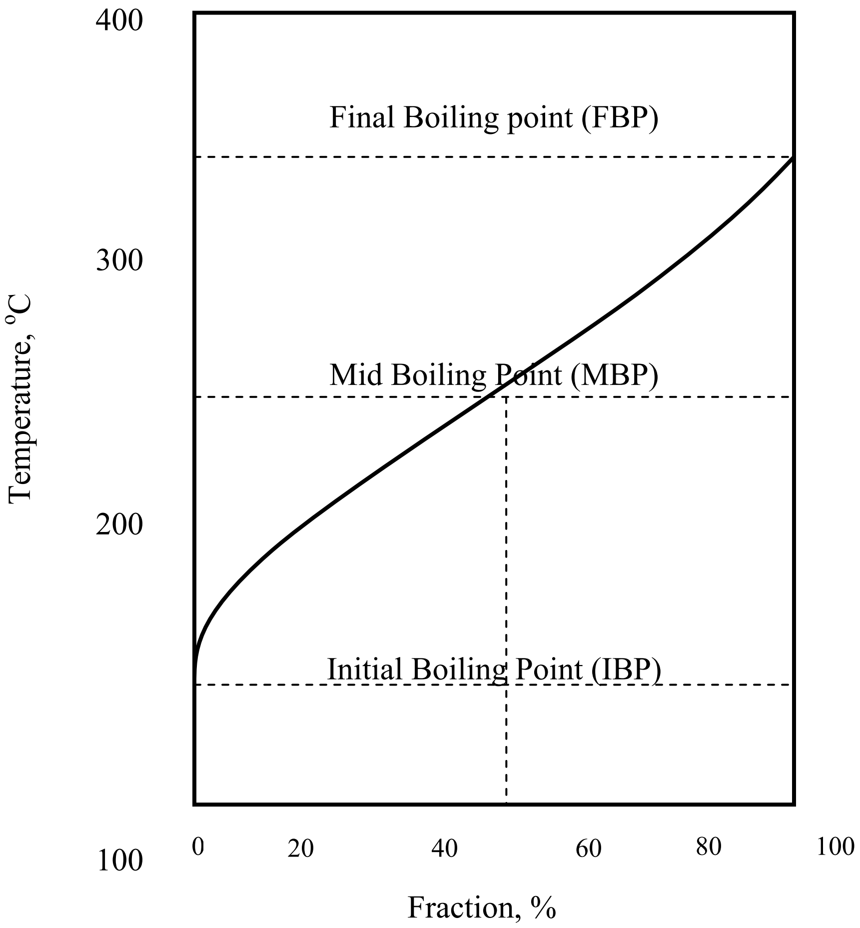


Fig 4.1: The characteristic distillation curve for diesel fuel is similar in form to that of ASTM distillation curve of gasoline fuel. [*30*]

The important properties for good diesel engine fuel can be grouped under three main categories:

1.satisfactory handling and storage
2.smooth and efficient burning
3.continued cleanliness during use

4.1 Handling and Storage

The properties of diesel fuels which control safety and convenient in handling are: flash and fire points, viscosity, and cloud and pour points.

a. ***Flash Point***: Flash point is the temperature at which a flammable liquid will produce, with a standardize apparatus and procedure, a mixture of its vapor and air which will ignite to give a visible flash by contact with an open flame.

b. ***Fire Point***: Fire point is the temperature at which the flash will sustain itself as a steady flame for at least five seconds.

The flash and fire points indicate the temperature below which oil (fuel) can be handled without danger of fire, otherwise they are of little consequence.

c. ***Viscosity***: Viscosity is a measure of its resistance to flow. Viscosity is defined as the time necessary for a quantity of fluid to pass through the orifice under the force of gravity. For convenience, the figures are usually expressed in Centipoises and Centistokes (cP and cSt). The two are related in that cP = cSt* Density of the fluid. The SI unit is m^2/s. Viscosity is important in lubrication and in pumping flow and spraying of liquids.

   Liquid fuel is injected in to combustion space of the diesel cylinder by a high pressure pump and this pump must overcome the resistance of the liquid to flow and the friction which resists the motion of the pump. Viscosity should be low to permit bulk flow in pumping and high enough to do necessary lubrication. Very high viscosity can render starting from cold difficult and produce undesirable high pressure on the pump and fuel lines. An upper limit for viscosity has to be specified to ensure adequate fuel flow for cold start. Lucas Diesel Systems quoted a figure of 48cSt at -20^{o}C as the upper end and, to guard against loss of power at high temperatures, 1.6cSt at 70^{o}C as the lower limit. Too low a viscosity can cause undue wear of pump and increased maintenance. BS2869 calls for a maximum value of 5cSt and minimum of 2.5cSt at 40^{o}C. In *Fig. 4.2*, all these points are plotted and viscosity tolerance band established. The viscosity of the average fuel lies approximately mid-way between the upper and lower limits.

d. ***Cloud Point***: The temperature below which the wax content of the petroleum oil separates out in the form of a solid is called cloud point. Such waxy solid can clog fuel lines and filters.

e. ***Pour Point***: Pour point is the temperature below which the entire mass of the fuel, solid and liquid together, freeze and thus cause flow of the fuel impossible. Pour point is usually 5 to 10°C below the cloud point. [29]

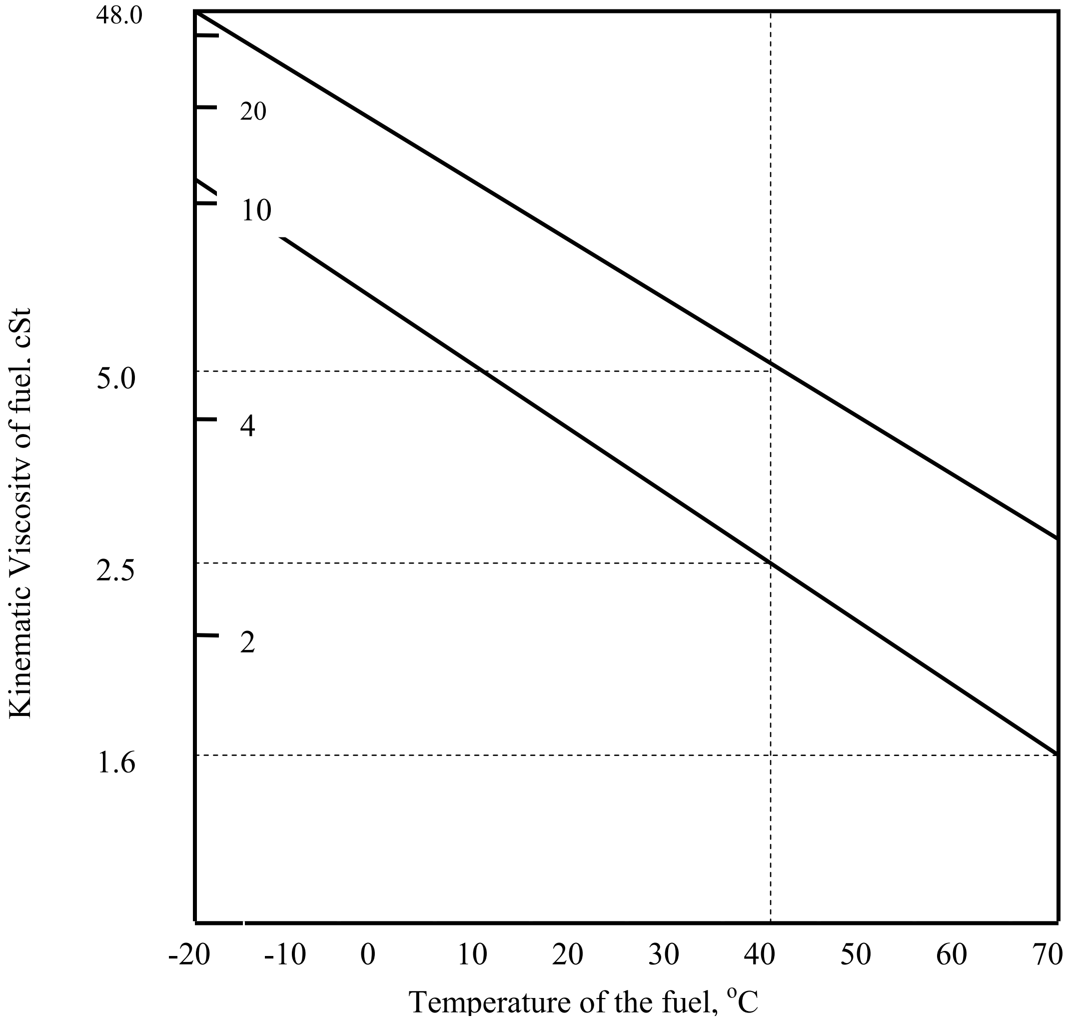


Fig. 4.2: A typical tolerance band for fuel viscosity. At 40°C, the limits are from 2.5 to 5.0 cSt. [30]

4.2 Smooth and Efficient Burning

In order to burn well a diesel fuel should atomize properly, ignite quickly, and burn completely. Atomization is controlled by surface tension and viscosity. Surface tension is particularly same for all petroleum fractions for kerosene to medium lubricating oil but the viscosity changes. However, more important are the properties which affect the ignition qualities of the diesel fuel. Volatility, cetane number and aromatic contents are important properties which affect ignition quality of a diesel fuel. Specific gravity of the fuel is related to the energy content of the fuel and is greatly affects the specific as well as the volumetric fuel consumption of a diesel engine. Here are the details of these properties:

a) ***Volatility***: Evaporation and mixing of diesel fuel with air is essential for ignition and burning. However, since unlike spark ignition engine this vaporization and mixing takes place inside the engine, the volatility of the diesel fuel is not as high as that for the gasoline fuels. Like gasoline, the volatility of diesel fuels is measured by the distillation temperatures versus percent evaporated. The ASTM distribution curve of a typical diesel fuel is given by *Fig.4.1*. The boiling range varies from the initial boiling point of 220^{o}C to end boiling point of 390^{o}C with 50% evaporation at 170^{o}C. The normal range of 10% evaporation point is 204-250^{o}C and that for 95%point is 320 to 385^{o}C.

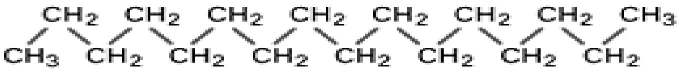
The volatility characteristic of the diesel fuel affect the hydrocarbon, NO_x emissions, smoke density and odor of the engine exhaust. Decreasing volatility reduces the amount of the fuel boil-off from the injectors during the exhaust stroke, thus reducing the unburned hydrocarbons in the exhaust. There is a strong correlation between 50% point and cetane number of the fuel. The 10% point and 90% point do not have a significant effect on hydrocarbon emissions. There is very little effect of fuel volatility on carbon monoxide, smoke, power and fuel consumption.

b) ***Ignition Quality***: For a diesel fuel smooth spontaneous ignition at relatively low temperature is essential. Ignition delay, the time period between start of injection and start of combustion, has a great influence on the correct optimization. If it is too long the rate of pressure rise, once it starts, can become so rapid that severe diesel knock and engine damage can occur. If it is too short then there is not sufficient time for complete mixing and smoke can result.

c) ***Cetane Number***: The cetane rating of a diesel fuel is a measure of its ability to auto-ignite quickly when it is injected into the compressed and heated air in the engine. Though ignition delay is affected by several engine design parameters such as: compression ratio, injection rate, injection time, inlet air temperature etc., it is also dependent on hydrocarbon composition of the fuel and to some extent on its volatility characteristics. The cetane number is a numerical measure of the influence the diesel fuel has in determining the ignition delay. Higher the cetane rating of the fuel lesser is the propensity for diesel knock.

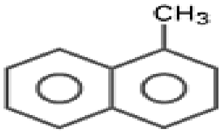
In practice, cetane number is actually measured in a single cylinder CRF test engine. In the standard test, fuel injection is begun 13 degrees before top dead centre (TDC) and the compression ratio of the engine is adjusted till the ignition begins at exactly top dead centre, that is, an ignition delay of 13 degrees is achieved. The actual numerical values are set means of reference fuel. The cetane number of a fuel is the percentage by volume of cetane in a mixture of cetane and α-methylnaphthalene ($C_{10}H_7CH_3$) that has the same performance in the standard test engine as that of the fuel. Cetane ($C_{16}H_{34}$) is arbitrarily given a number 100 and originally α-methylnaphthalene was given a number 0 but now reference is heptamethylnonane which is given the value 15.

n-Hexadecane



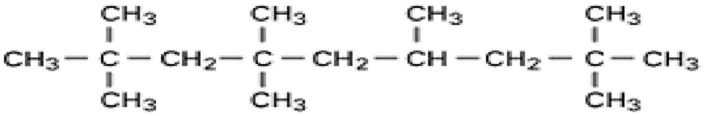
Hexadecane (cetane), cetane number = 100

1-Methylnaphthalene



1-Methylnaphthalene, cetane number = 0

Heptamethylnonane



$$CH_3-\underset{CH_3}{\overset{CH_3}{C}}-CH_2-\underset{CH_3}{\overset{CH_3}{C}}-CH_2-\overset{CH_3}{CH}-CH_2-\underset{CH_3}{\overset{CH_3}{C}}-CH_3$$

2,2,4,4,6,8,8-Heptamethylnonane (Isocetane), cetane number = 15

Fig 4.3- Reference fuels to set the actual numerical cetane value [*31*]

Cetane number is the most important single fuel property which affects the exhaust emissions, noise and start ability of a diesel engine. In general, lower the cetane number higher is the hydrocarbon emissions and noise levels. Low cetane fuels increase ignition delay so that start of combustion is nearer to top dead centre. This is similar to retarding of injection timing which is also known to result in higher hydrocarbon levels.

4.3. Cleanliness

This is a very important for a diesel fuel. Even a small amount of dust can affect engine operation as the plunger of the injection pump is lapped to tolerance of 0.00025*mm*.

The cleanliness of an engine depends to a large extent on the completeness with which the fuel burns, which in turn depends partly on the design and service conditions of the engine. However, other properties of the fuel which also affect the deposit formation in the engine are:

a) ***Contamination*:** The contents of sand and rust particles can clog orifices, and abrasive particles can damage injector surface piston rings and cylinder walls. The water content of fuel can freeze and clog filter and fuel lines and at higher temperature can promote rusting in fuel systems.

b) ***Sulfur***: High sulfur content in diesel fuel causes corrosion, wear of engine parts, especially the cylinder wear, and tends to increase the rate of sticky and sludge-like deposits. [*29*]

Based on the above properties of conventional diesel fuel, it is classified in to three main grades for utilization. Among these D-2 is mostly used in high speed engines. ASTM 975 classifies conventional diesel fuels into different grades. This classification is as follows:

- No 1 diesel fuel (*1-D*) comprises of volatile fuel oils from kerosene to intermediate distillates. They are applicable for high-speed engines whose operation involves frequent and relatively wide variations in engine load and speed. Such fuel is required for use at abnormally low temperatures.
- No 2 diesel fuel (*2-D*) includes distillate gas oils of lower volatility. This grade is suitable for use in high-speed engines under relatively high loads and uniform speeds. DF2 can be used in engines not requiring fuel having the greater volatility and other properties specified for No.1 diesel fuel.
- No 4 diesel fuel (*4-D*) covers the more viscous distillates and their blends with residual fuel oils. It is usually satisfactory only for low speed and medium speed engines operated under sustained load at nearly constant speed.

Below are some data regarding the emission from diesel driven engines of Light Duty (LD) and Heavy Duty (HD) Vehicles and the limits of diesel fuel. Note that this data doesn't include the emissions from fuel production, fuel distribution, and well- to- wheel.

Vehicle type	**NOx (g/KM)**	**Carbon monoxide CO (g/KM)**	**Hydrocarbons HC (g/KM)**	**Particulate Maters PM (g/KM)**	**Carbon dioxide CO2 (g/KM)**
Light Duty Vehicles (LDV)	0.6-1.224	0.42-1.2	0.057-0.456	0.2	139.37-197.12
Heavy Duty Vehicles (HDV)	14.1-16	0.5-4.3	0.4-0.5	1.1	885-1195

Table 4.1: Emissions data from Diesel fuel [32]

American Standard testing Methods (ASTM) tests and limits for diesel fuels

Test	**ASTM Test Number**	**ASTM Limits for #2 Diesel fuel**
Carbon Residue (Wt %)	D524	0.35%max.
Cetane number	D613	40min
Distillation Range (K)	D86	555-611
Flash point (K)	D93	325min.
Higher Heating Value (MJ Kg-1)	D2015	45.2min.
Viscosity mm2s-1	D445	1.9-4.1

Table 4.2 ASTM Tests and limits for Diesel #2 fuel [33]

Test Property	**Commercial No. 2 Diesel Fuel**	**Commercial No.1 Diesel Fuel**
Carbon (% mass)	86.70[a]	86.83[a]
Hydrogen (% mass)	12.71[a]	12.72[a]
Oxygen (% mass)	-	-
C/H Ratio	6.82	6.826
Sulfur (% mass)	0.041[a]	0.045[a]
Cetane Number (ASTM D613)	42.6[a]	45.3[a]
Gross Heat of Combustion (kJ/kg)	45,339[a]	45,991[a]
Net Heat of Combustion (kJ/kg)	42,640[a]	43281[a]
Specific Gravity (@21 °C)	0.8537[c]	0.8162[c]
Kinematic Viscosity (cSt, @40 C)	2.8271[c]	1.759[c]
Total Glycerin (%)	-	-
Free Glycerin (%)	-	-
Distillation (ASTM D86, °F)[a]		
Initial Boiling Point	*352*	348
5%	392	373
10%	413	384
20%	440	394
30%	462	406
40%	482	416
50%	502	426
60%	522	440
70%	543	454
80%	569	474
90%	602	503
95%	630	535
End Point	653	580
Recovery (%)	98.0	98.0
Residue (%)	1.9	1.9
Loss (%)	0.1	0.1

[a] *Measured by Phoenix Chemical Laboratory Inc., Chicago IL*

[b] *Measured by Williams Laboratory Services, Kansas City, KS*

[c] *Measured in the Department of Mechanical Engineering, Iowa State University, Ames, IA*

Table 4.3: Physical and chemical properties of commercial No.2 and no.1 Diesel fuels. [34]

CHAPTER FIVE

SCOPE OF BIODIESEL AS A FUEL FOR COMPRESSION IGNITION (CI) ENGINES

5.1 Definition

Biodiesel can be defined as a pure vegetable oil (most importantly rapeseed, soybean, sunflower, karanja (pongamia pinnata), jatropha (jatropha carcus), cotton seed and palm) or animal fats which can be used as a fuel for internal combustion engine. Here using pure vegetable oil or animal fat for fuel may lead the blockage of the engine and the plunger pump with sluggish materials due to the glycerol content of the oil as well as the density of the oil. [*35, 36*] Due to the above problem these pure vegetable oil and animal fats are formulated so that they are engine and environmental friendly fuels. These days the word biodiesel represents the formulated fuel "methyl ester" which is produces by transesterification. In an article on proposed ASTM standards, biodiesel was defined as "the mono alkyl esters of long chain fatty acids derived from renewable lipid feedstock, such as vegetable oils or animal fats, for use in compression ignition (diesel) engines." Nevertheless, clear distinction between these different vegetable oil-based or -derived alternative diesel fuels is necessary. Therefore, generally speaking the term biodiesel is defined as a diesel fuel derived from vegetable oils or animal fats. The ratio can be 100% or blend with the conventional diesel fuel. The 100% biodiesel is designated with B100 and the blend is designated with B followed by the percentage of the biodiesel. Example, for 20% of biodiesel and 80%of diesel the designation will be: B20.

5.2 Production

Neat vegetable oils are not ideally suitable as fuel for diesel engines because of various problems. These problems encountered during engine tests can be classified in to two groups: operational problems and durability problems. The operational problems relate to starting ability, ignition, combustion and performance. The durability problems relate to deposit formation, carbonization of injector tip, ring sticking, and lubrication oil dilution/degradation. [*15*] Considerable efforts have been made to develop vegetable oil derivatives that approximate their properties and performance similar to the hydrocarbon-based diesel fuels. The problems with substituting triglycerides for diesel fuels are mostly associated with their high viscosities that lead to poor atomization, large droplets, and high spray jet penetration, low volatilities and polyunsaturated character. The viscosity of the vegetable oils when used as fuel can be reduced by two different ways:

I. Engine Modification
   - Dual fueling , like CNG and diesel
   - Modifying the injection system
   - Heating the fuel line before reaching the engine cylinder

II. Fuel Modification
   - Dilution (Blending)
   - Transesterification or esterfication
   - Thermal Cracking/ Pyrolysis
   - micro emulsion

a. Dilution

Dilution of vegetable oils can be accomplished with a solvent e.g. diesel, methanol, ethanol etc. Vegetable oil can be directly mixed with diesel fuel and may be used for running an engine. The blending of vegetable oil with diesel fuel were experimented successfully by various researchers. Dilute the vegetable oils with other fuels like alcohols and diesel oil, etc to bring the viscosity to near specific range. For example, the dilution of sunflower oil with diesel fuels in the ratio 1:3 by volume has been studied and engine tests were carried out. The viscosity of this blend was 4.88 cSt at 40^{o}C. They concluded that the blend could not be recommended for long-term use in the direct injection diesel engines because of severe injector nozzle coking and ring sticking. A comparable blend with high oleic sunflower oil was also tested and it gave satisfactory results, but its use in the long term was not applicable as it leads to thickening of lubricant. A 1:1 blend of soybean oil and Stoddard solvent (48% paraffin and 52% napthenes) had viscosity of 5.12 cSt at 38^{o}C. This fuel produced heavy carbon deposit on the tulips of the intake valves and considerable top ring wear. [37]

b. Pyrolysis (Thermal cracking)

Pyrolysis is defined as the conversion of one substance into another by means of heat with or without the catalyst. It involves heating in the absence of air or oxygen and cleavage chemical bond to yield small molecules. Pyrolytic chemistry is difficult to characterize because of variety of reaction paths and variety of reactions taking place. The pyrolyzed material can be vegetable oil, animal fats, natural fatty acids or methyl esters of fatty acids. The Pyrolysis of the fats has been studied for more than 100 years, especially in those areas of the world which lacked the petroleum reserve.

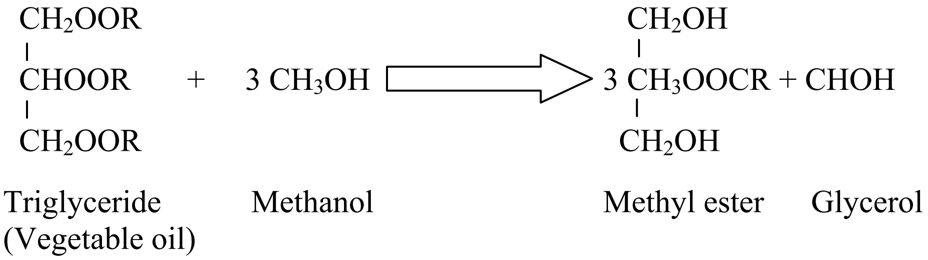
c. Micro Emulsification

Micro-emulsion is isotropic, clear, or translucent thermodynamically stable dispersions of oil, water, surfactant, and often an amphiphilic molecule, called co-surfactant. In micro-emulsion, the droplet diameter ranges from 100 to 1000 Å. A micro-emulsion can be made of vegetable oils with an ester and dispersant (Co-solvent), or of vegetable oils, an alcohol and a surfactant, with or without diesel fuels. Micro-emulsions because of their alcohol content have lower volumetric heating values than diesel fuels, but alcohol has high latent heat of vaporization and tends to cool the combustion chamber, which would reduce nozzle coking. A micro-emulsion of methanol with vegetable oils can perform nearly as well as diesel fuels.

Either of the above mentioned procedures for modifying vegetable oils results in an improvement in engine performance. However, transesterification has proven to be the alternative with the best results. This improvement is attributed to the characteristics of modified fuels which permit a full degree of atomization in the injector nozzle and are believed to be a direct result of viscosity reduction.

d. Transesterification

The production of biodiesel (methyl ester) by transesterification requires three moles of alcohol with the presence of catalyst to facilitate the reaction. Acids or alkalis can be used as a catalyst in this process. By using acid, there will a problem in corrosion on the material. While in the case of an alkaline catalyst, a removal of both the catalyst and the new produced product is necessary after the reaction. This conventional method not only makes the process longer, but also results in lower yield. [38] Commonly used catalysts are potassium hydroxide (KOH) and sodium hydroxide (NaOH). The procedure for the transesterification is as follows: first it is necessary to remove the water content of the oil, we have to boil the oil up to 100°C then cool it to 60°C so that it will be a favorable condition for the reaction, the reaction is strongly dependent on heat and catalyst to be completed. At this time we can add alcohol with the catalyst, where the catalyst will be dissolved with in the alcohol at atmospheric temperature before the reaction begins. The reaction should stay up to 1 hrs stirring with a magnetic stirring or any other means at this 60°C. Then finally it will be cooled and settled under gravity separating funnel for at least 24hrs. [39] The biodiesel and glycerol will be separated by their weight with the biodiesel on the upper level. After the process, the viscosity of the biodiesel will be 1/12 of the original oil and the large vegetable is reduced up to 1/3 of its original size lowering its viscosity making it similar to diesel fuel. Below *Figure 5.1* and *5.2* is the chemical process and process flow diagram for the production of Biodiesel.



$$\begin{array}{l} CH_2OOR \\ | \\ CHOOR \\ | \\ CH_2OOR \end{array} + 3\ CH_3OH \Longrightarrow 3\ CH_3OOCR + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

Fig 5.1: Structure of triglycerides (vegetable oil) and principle of the transesterification reaction (The "R" groups are the fatty acids, which are usually 12 to 22 carbons in length) [31]

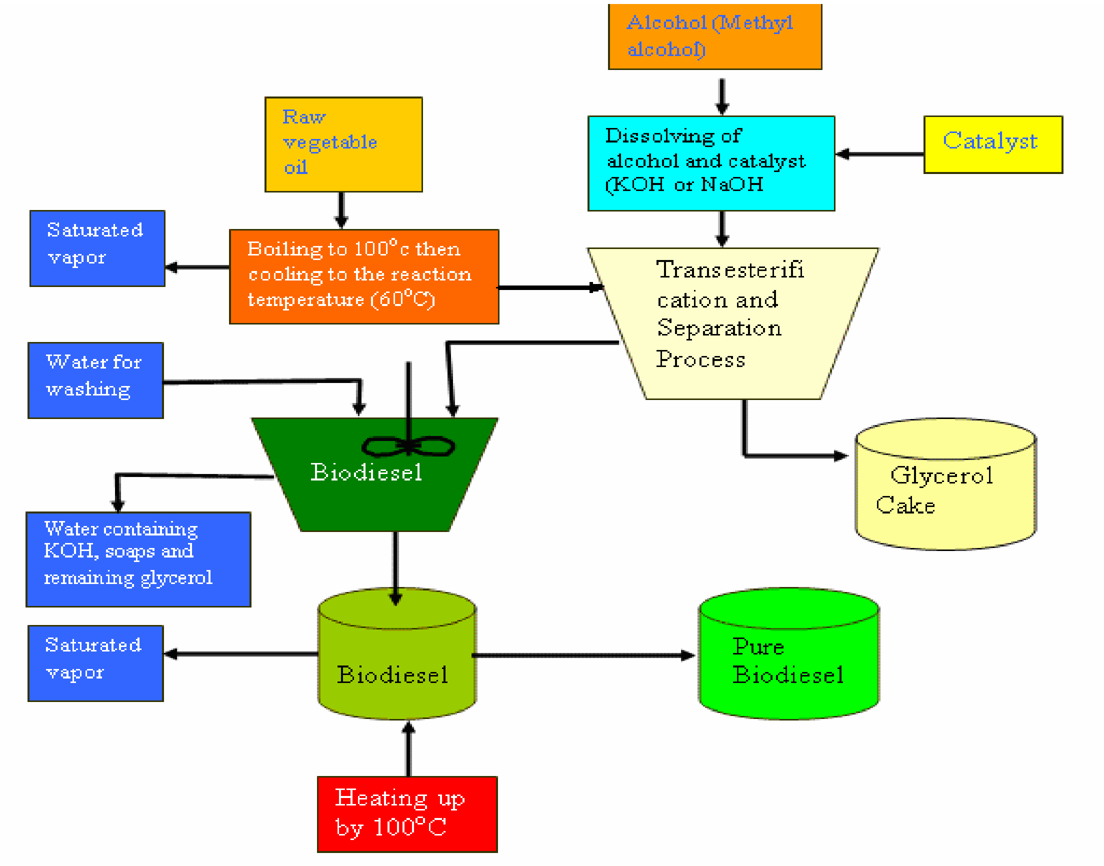


Fig 5.2: The transesterification process flow diagram

Chemically, Biodiesel is called a methyl ester if the alcohol used is methanol. If ethanol is used, it is called an ethyl ester. They are similar and currently, methyl ester is cheaper due to the lower cost for methanol. Biodiesel can be used in the pure form, or blended in any amount with diesel fuel for use in compression ignition engines.

5.3 Properties of Biodiesel

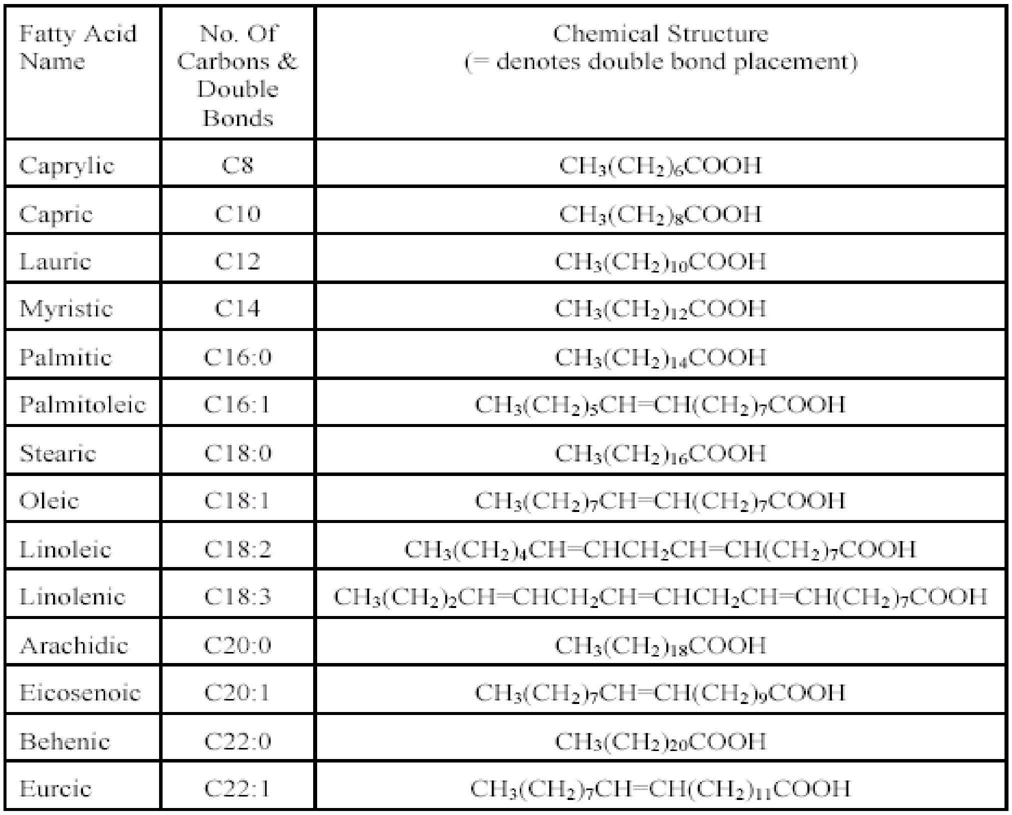
The main reason that biodiesel is becoming the key subject by researchers is that it is chemically high biodegradable than that of fossil origin internal combustion engine fuels. It can be mixed with any diesel fuel at any ratio. It emits no sulfur oxides, a pollutant that causes acid rain and burns the lungs, throats and eyes. It has a great roll in the global warming reduction, reducing the contributors such as carbon dioxide by 78% over its life cycle. There are three ways that carbon dioxide is reduced by the utilization of biodiesel:

By using biodiesel products instead of petroleum related products, we can avoid the emissions associated to petroleum. Using biodiesel, we are reducing the consumption of fossil fuels that allows the carbon dioxide content of fossil fuels to remain in storage. To boost the production of biodiesel we need extra plantation that will be a mechanism for the absorption of carbon dioxide. Some technical problems facing biodiesel include the reduction of NO_x exhaust emissions and the improvement of cold-flow properties among others such as oxidative stability and economics. [*40*] That is: biodiesel from some feed stacks might produce slightly more oxides of nitrogen (1-6%), an ozone depressor, than that of fossil origin fuels. This is the case with the 100% biodiesel fuel and we can manage this with the utilization of blended fuel of biodiesel and high speed diesel fuel.

Fuel Standards	**ASTM PS121**
Fuel Composition	C12-C22FAME
Lower Heating Value, Btu/gal	117,093
Kinetic Viscosity @40^{o}C	1.9-6.0
Specific Gravity Kg/l @ 60^{o}F	0.88
Density, lb/gal @ 15^{o}C	7.328
Water, ppm by wt%	0.05
Carbon, wt %	77
Hydrogen, wt %	12
Oxygen, wt %	11
Sulfur, wt %	0.0-0.0024
Boiling Point, ^{o}C	182-338
Flash Point, ^{o}C	100-170
Cloud Point, ^{o}C	-3 to 12
Pour Point, ^{o}C	-15 to 10
Cetane Number	48-65
Stoichiometric air to fuel ratio, wt/wt	13.8
BOCLE scuff, grams	>7000
HFRR, microns	314

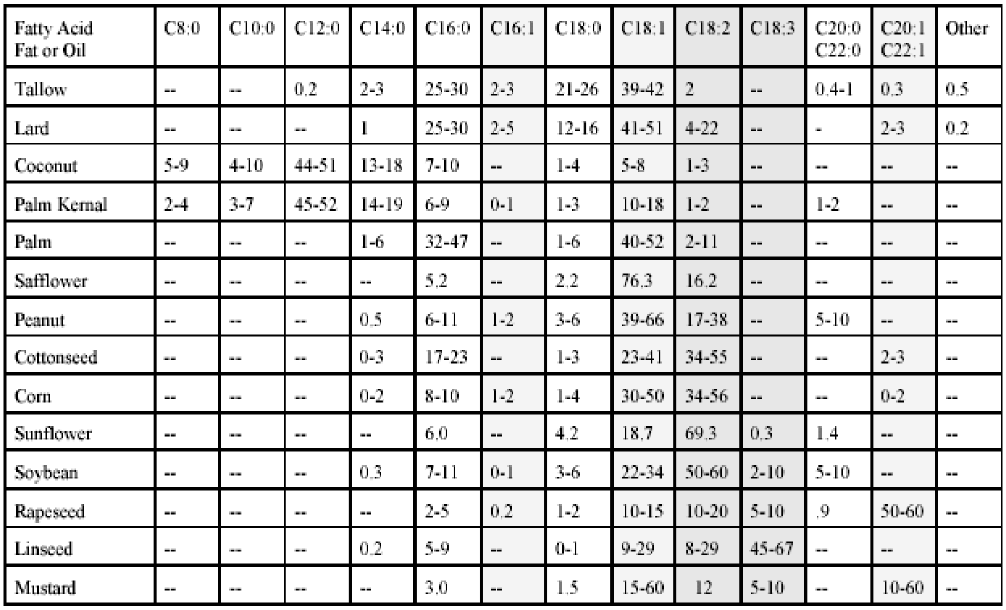
Table 5.1: Chemical and Physical properties of biodiesel with the fuel standard of ASTM PS121 [*41*]

The most common ratio is 80% conventional diesel fuel and 20% vegetable oil ester (biodiesel). It has more than 20% less of particulate matters than that of ordinary high speed diesel fuel. Some of the physical properties are: it has the flash point of greater that 100°C and the viscosity is higher (1.9-6cSt). Here in *Table 5.1* are the characteristics biodiesel with the American standards of ASTM PS121.



Fatty Acid Name	No. Of Carbons & Double Bonds	Chemical Structure (= denotes double bond placement)
Caprylic	C8	$CH_3(CH_2)_6COOH$
Capric	C10	$CH_3(CH_2)_8COOH$
Lauric	C12	$CH_3(CH_2)_{10}COOH$
Myristic	C14	$CH_3(CH_2)_{12}COOH$
Palmitic	C16:0	$CH_3(CH_2)_{14}COOH$
Palmitoleic	C16:1	$CH_3(CH_2)_5CH=CH(CH_2)_7COOH$
Stearic	C18:0	$CH_3(CH_2)_{16}COOH$
Oleic	C18:1	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$
Linoleic	C18:2	$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOH$
Linolenic	C18:3	$CH_3(CH_2)_2CH=CHCH_2CH=CHCH_2CH=CH(CH_2)_7COOH$
Arachidic	C20:0	$CH_3(CH_2)_{18}COOH$
Eicosenoic	C20:1	$CH_3(CH_2)_7CH=CH(CH_2)_9COOH$
Behenic	C22:0	$CH_3(CH_2)_{20}COOH$
Eurcic	C22:1	$CH_3(CH_2)_7CH=CH(CH_2)_{11}COOH$

Table 5.2: Structural Formula for Fatty Acids used in Biodiesel [g]



Fatty Acid Fat or Oil	C8:0	C10:0	C12:0	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0 C22:0	C20:1 C22:1	Other
Tallow	--	--	0.2	2-3	25-30	2-3	21-26	39-42	2	--	0.4-1	0.3	0.5
Lard	--	--	--	1	25-30	2-5	12-16	41-51	4-22	--	-	2-3	0.2
Coconut	5-9	4-10	44-51	13-18	7-10	--	1-4	5-8	1-3	--	--	--	--
Palm Kernal	2-4	3-7	45-52	14-19	6-9	0-1	1-3	10-18	1-2	--	1-2	--	--
Palm	--	--	--	1-6	32-47	--	1-6	40-52	2-11	--	--	--	--
Safflower	--	--	--	--	5.2	--	2.2	76.3	16.2	--	--	--	--
Peanut	--	--	--	0.5	6-11	1-2	3-6	39-66	17-38	--	5-10	--	--
Cottonseed	--	--	--	0-3	17-23	--	1-3	23-41	34-55	--	--	2-3	--
Corn	--	--	--	0-2	8-10	1-2	1-4	30-50	34-56	--	--	0-2	--
Sunflower	--	--	--	--	6.0	--	4.2	18.7	69.3	0.3	1.4	--	--
Soybean	--	--	--	0.3	7-11	0-1	3-6	22-34	50-60	2-10	5-10	--	--
Rapeseed	--	--	--	--	2-5	0.2	1-2	10-15	10-20	5-10	.9	50-60	--
Linseed	--	--	--	0.2	5-9	--	0-1	9-29	8-29	45-67	--	--	--
Mustard	--	--	--	--	3.0	--	1.5	15-60	12	5-10	--	10-60	--

Table 5.3: Weight Percent of Fatty Acids in Fat and Oil Feedstock [g]

5.4 Biodiesel Standards

The development of reliable standard gives confidence in biodiesel users, engine manufactures and for any other parties. Therefore, it is a base in facilitating the production, trade and commercialization of biodiesel. Here in Table 3 are some standards of biodiesel used in different nations.

Country	Biodiesel standards
United states of America (USA)	ASTM has issued Biodiesel standard D6751 in 2001
Austria	C1190 later changed to ONC1191
France	JO
Italy	UNI 10635
Germany	DIN E51606
Sweden	EN14214
European Union	EN14214

Table 5.4: Biodiesel standards for some nations [5]

5.5 Blending Biodiesel with Diesel Fuel

As it is mentioned in the properties of biodiesel part, it has kinetic viscosity and specific gravity higher than that of fossil origin diesel fuel. Therefore it is taken as an advantage in the simplicity of preparation of biodiesel blends. Due to its heaviness nature compared to that of conventional diesel fuel, blending will be conducted by pouring of the biodiesel over a filled tank of conventional diesel so that due to the gravity difference the fuels will be mixed. As it has been mentioned in the same topic, the application of pure biodiesel as a fuel in a high speed diesel engine leads to increase the emissions of nitrogen oxides compared to that of diesel fuel. The best solution to this problem is to use a blend of biodiesel with the conventional diesel fuel. The most common ratio is 80% conventional diesel fuel and 20% vegetable oil ester (biodiesel). There have been numerous reports that significant emission reductions are achieved with these blends and no engine problems were reported.

5.6 Emission Reduction with Biodiesel

As far as emission is concerned, here are the substances separately as follows:

Absence of Sulfur

The absence of sulfur means that there will be a reduction in acid rain and off course it was a means for the burning of lungs, throats and eyes. It also decreases the levels of corrosive sulfuric acid accumulation in the engine crankcase oil over time.

Absence of Aromatics

The lack of toxic and carcinogenic aromatic (benzene, toluene and xylene) means that the fuel mixture combustion gases will have reduced impact on human health and the environment

Lower Hydrocarbon Emissions

The presence of the hydrocarbons in the exhaust is the principal cause of the unpleasant smell of the diesel engine. The reason for this are: the low temperatures and light loads or because of the low volatility of the diesel fuel [5]. As it can be seen from the chemical property of biodiesel that, the oxygen content of biodiesel is higher than that of the conventional diesel fuel that means the reaction in the internal combustion engine with the utilization of biodiesel blend is reach in oxygen so that the hydrocarbons will be burnt completely. Therefore there will be less emission of hydrocarbon emissions that has greater impact in the improvement of the environment.

Smoke and Soot reduction

The particulate matters (Smoke and Soot reduction) are feasible particles (include liquids as well as solids) emitted from internal combustion engines and are harmful for health of human being especially in the respiratory organs. The size range from 0.01 to 10μm, the black smoke comprises mainly carbon; the heavier particles comprise ash and other substances, while the internal combustion engine operating with biodiesel will have less smoke, and less soot produced from unburned fuel. [5] Further, since the biodiesel contains oxygen, there is an increased efficiency of combustion even for the petroleum fraction of the blend.

Carbon Monoxide Emissions

Carbon monoxide is the toxic by product of the combustion of an internal combustion engine. The reason why carbon monoxide is produced is that, in local areas of the combustion chamber, most of the oxygen has been consumed before injection stops and, therefore, fuel injected into these areas cannot burn completely to CO_2. Therefore complete oxidation of the fuel results in more complete combustion to carbon dioxide rather than leading to the formation of carbon monoxide. With the change of the fuel from the conventional diesel fuel to the clean biodiesel, there is a 28% to 37% drop of carbon monoxide emissions. [30]

Poly aromatic Hydrocarbons Emissions

Poly-aromatic hydrocarbons are a class of heavy oil petroleum hydrocarbons defined by their complex ring structures and unique qualities. They consist of multiple benzene ring structures that make them insoluble, slow to burn and carcinogenic. The Cummins N-14 engine had a 12% drop in poly aromatic hydrocarbon emissions when operating on 20%biodiesel and 80%conventional diesel fuel (B-20) blend relative to petro-diesel, and a 74% drop Poly aromatic Hydrocarbons in when the fuel was switched to neat biodiesel. The Detroit Diesel engine had a 29% reduction in poly aromatic hydrocarbons operating on 20%biodiesel and 80%conventional diesel fuel (B-20) and a 68% reduction when operating on neat biodiesel. [42] As we can see from the data, by utilizing the blends of biodiesel we can get improved emissions.

As it has been mentioned in the introduction part, one of the main reasons to find new working fuel for the fast speed internal combustion engine is the environmental problem. By the utilization of the conventional diesel fuel, there has been a major problem on the emissions as can be seen in the *Table-5.5* There fore here are some of the improvements obtained while utilizing the pure methyl ester (biodiesel) as well as that of the blend with the conventional diesel fuel (*Table 5.6*)

Emission in (g/Km)	Vehicle type	
	Light Duty Vehicles (LDV)	Heavy Duty Vehicles (HDV)
Nitrogen Oxides (NO_x)	0.6-1.224	14.1-16
Carbon monoxide (CO)	0.42-1.2	0.5-4.3
Hydrocarbons (HC)	0.057-0.456	0.4-0.5
Particulate Maters (PM)	0.2	1.1
Carbon dioxide (CO_2)	139.37-197.12	885-1195

Table 5.5: Emissions data from Diesel fuel [32]

Emission In (g/Km)	Fuel Type	
	100% Methyl Ester Fuel B100	20% Methyl Ester and 80% Conventional Diesel Fuel B20
Nitrogen Oxides (NO_x)	5.8%	1.29%
Carbon monoxide (CO)	-43.2%	-12.6%
Hydrocarbons (HC)	-56.3%	-11.0%
Particulate Maters (PM)	-55.4%	-18.0%
Carbon dioxide (CO_2)	-78.3%	-15.7%
Air Toxics	-60% to -90%	-12% to -20%
Sulfur	-100%	-100%

Table 5.6: The exhaust emission changes obtained by the utilization of pure methyl ester (B100) and blend of 20% Methyl ester to 80% conventional diesel (B20) fuels. [*41*]

5.7 Storage and Handling of Biodiesel

Biodiesel can be mixed with all kind of petroleum origin diesel fuels and it can stay blended even at low temperature. Similar to conventional diesel fuel it is recommended not to store blends of biodiesel (methyl ester) for long period of time. The time limit is up to six months.

It can be stored for long period of time in closed containers with a small heading protecting from weather, direct sun light and low temperature and off course the tank should be full so that to prevent of moisture formation at the cold weather particularly during rainy winter months or periods of inactivity, to minimize the condensation of moisture. Condensed moisture accumulates as water in the bottom of your tank and can contribute to the corrosion of metal fuel tanks, especially with petroleum diesel that also contains sulfur. Low temperature can cause for the biodiesel to separate from the diesel and form wax so that it will clog the pipe lines, but it can quickly liquidate again as it gets warm up.

As a general rule, blends of biodiesel and conventional diesel fuel should be treated like the conventional diesel fuel. It is recommended to store biodiesel in clean, dry and quality approved tanks.

As far as handling is of biodiesel is concerned, unlike that of the conventional diesel fuel, it contains no volatile organic compounds that can give rise to poisonous or toxic fumes. There are no aromatic hydrocarbons or chlorinated hydrocarbons. Even there are no lead and sulfur to react and release any harmful or corrosive gases. But on contact with the eye, biodiesel may cause irritation. In addition to eye irritation, safety should be taken as for the fire hazard.

5.8 Chapter Summery

As it has been seen through out this chapter, it tried to cover from the production up the handing and safety. Though biodiesel has got the modified properties compared to its source, vegetable oil, still it is having properties unable it to fuel internal combustion engines alone. These properties are emission, lower heat value and increase in the exhaust temperature some. As far as the emission is concerned, though the exhaust of all other gases reduced from 43-100% (see *Table 5.5*) compared to these exhausts from conventional diesel, there is an increase in an emission of nitrogen oxides (NO_x). This is associated with the increase in exhaust temperature. Therefore it is believed that there should be a means to manipulate the advantages and to reduce the drawbacks so that we can get the dream fuel. In this regard, it was tried by many researchers that blending this biodiesel with the conventional diesel fuel can give the desired result. Apart from this the current work has tried to blend three core fuels.

CHAPTER SIX

SCOPE OF ETHANOL AS A FUEL FOR COMPRESSION IGINITION (CI) ENGINES

6.1 Introduction

Alcohol is bio product extracted with the help of chemical processes. Although beverage and fuel alcohols are produced in a similar manner, fuel alcohol is denatured or poisoned to prevent ingestion. Denaturing can be accomplished by adding a “bitterent” or a form of hydrocarbon such as gasoline. Its raw material is: grains, agricultural wastes, or any material containing starch or sugar, wood, etc.

Ethyl alcohol or ethanol has been used in Germany and France as early as 1894 by the then incipient industry of internal combustion engines. Brazil has utilized ethanol as a fuel since 1925. By that time, the production of ethanol was 70 times bigger than the production and consumption of petrol. There have been times when the push for alternatives to petrol were more vigorous, mainly dictated by strategic and economic reasons. It is interesting to note that in Brazil, there was an intense use of ethanol in the year 1930, 1940, 1950, 1958, and 1973. Unfortunately, petroleum has always been considered abundant, almost limitless in availability. It was cheap and versatile, so the industry has always been very keen in the intensive use of this apparently miraculous fuel. All the development effort was toward the use of petrol and so the engines were developed for this fuel. [*h*]

Historically, the level of interest in using alcohol as a motor fuel has followed cycles of fuel shortages and/or low feed-grain prices. There are different alcohol types used as fuel. Among Bio ethanol and Bio methanol are the main alcohols widely used in the internal combustion engine

The properties of methyl and ethyl alcohol are compared with octane (high quality gasoline) and hexadecane (high quality diesel fuel). Octane and hexadecane (petroleum fuels) have higher boiling points, lower latent heats and are insoluble in water. The alcohols become more like petroleum fuels as their chemical weights increase.

Ethyl alcohol is also known as ethanol or grain alcohol. Like petroleum driven fuels, ethanol contains hydrogen and carbon, but ethanol also contains oxygen in its chemical structure. The oxygen makes ethanol a cleaner burning fuel than fossil origin fuels. It can be produced chemically from ethylene or biologically from grains, agricultural wastes, or any material containing starch or sugar. Ethanol can also be produced from cheese whey, spilled beer, and dated soda. Because ethanol can be produced from crops, it is classified as a renewable fuel.

Same to biodiesel, Ethanol can be used as a fuel either pure or else blended with gasoline and diesel with different ratio. Below are detail of Bio ethanol, with its production, application and contribution for the solution of energy and environment degradation problems.

6.2 Production

In all, three different classes of sources can be used:

a) starch as grain, corn and tubers like cassava
b) sugar plants (sugar beet or sugar cane)
c) cellulose or woody plants (general tree and biomass)

The basic steps of the processes are as follows. First, the corn, grapes juice, molasses etc are processed, with various enzymes added to separate fermentable sugars. Next, yeast is added to the mixture for fermentation to make alcohol. The major reaction is depicted below. The equations should show that fermentation of glucose/sugar to ethanol is energy efficient, about 93% of the feed energy is converted as ethanol and only a small amount is taken by fermenting organism.

Hydrolysis ↓ $[C_6H_{10}O_5]_n + nH_2O \rightarrow nC_6H_{12}O_6$ (glucose)

Fermentation ↓ $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

Energy balance Glucose → 2 ethanol + 75 KJ

180gms 2 x 46gms
2.82 MJ 2 x 1.37 MJ

Fig 6.1: The chemical equation of the process of production of ethanol [5]

The alcohol is then distilled to fuel-grade ethanol that is 85-95% pure. Finally, for fuel and industrial purposes the ethanol is denatured with a small amount of a displeasing or noxious chemical to make it unfit for human consumption.

6.3 Properties of Bio ethanol

Ethanol is a flammable, colorless liquid (E100 is clear like water) with a faint alcohol odor. As it has been proofed with many researchers of the globe, the use of pure bio ethanol in the compression ignition as well as in the spark ignition engines causes different problems. Among them the following are some:

- a larger quantity of fuel is required to produce a specified power output
- The relatively low boiling points and high vapor pressures of ethyl alcohol indicate that vapor lock could be a serious problem, especially at high altitudes on warm summer days.
- The relatively high latent heats of ethyl alcohol cause problems in mixing these alcohols with air and transporting them through the intake manifold of the engine.
- Heating the intake manifold may be necessary in cold weather or before the engine reaches operating temperatures.
- Less engine power is produced as the water content of an alcohol increases. Further, vapor lock, fuel mixing and starting problems increase with water.

Therefore due to the above problems, it is difficult to use even blend ratio of alcohol more than 15% in both with gasoline as well as diesel fuels. Here are the properties of selected alcohols (*Table 6.1*)

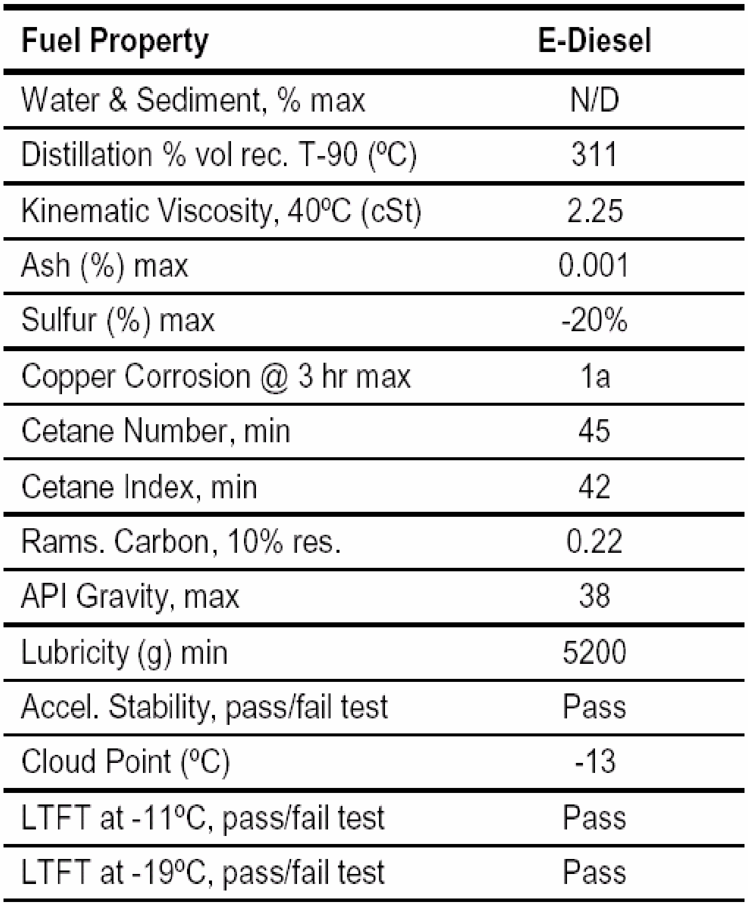
6.4 Blending Ethanol with Diesel

Alcohol has been used in diesel and in spark ignition engines. In diesel engine in which we are concerned with, the alcohol may be blended with diesel fuel to produce diesohol, or the alcohol may be added to the air intake of the engine. A system for adding a mixture of ethanol and water to the air intake of a turbocharged diesel engine is commercially available. The primary function of the system is to cool the turbocharged air (using the latent heat), and thereby to increase the volumetric efficiency of the engine and produce more output power. A similar result can be obtained using an intercooler. Control of the quantity of alcohol added to the air intake may be difficult and could cause erratic engine operation and/or failure if a large quantity of alcohol was added to the air intake. Tests results using blends of ethanol in diesel fuel are shown in *Fig 6.2.*

Item	Isooctane	Methanol	Ethanol
1. Formula	C8H18	CH3OH	C2H5OH
2. Molecular weight	114.224	32.042	46.07
3. Carbon/Hydrogen (W)	5.25	3.0	4.0
4.% Carbon (W)	84.0	37.5	52.17
5.% Hydrogen (W)	16.0	12.5	13.4
6. % Oxygen (W)	0	50.0	34.78
7. Boiling point @ 1atm °C	99.239	64.5	78.40
8. Freezing point @ 1atm °C	-107.378	-97.778	-80.00
9. Density @ 15.5 °C lb/gal	5.795	6.637	6.63
10. Viscosity @ 20°C/1atm, Centipoise	0.503	0.596	1.20
11. Specific heat @ 25°C/1atm BTU/lb	0.5	0.6	0.6
12. Heat of vaporization,® boiling point/1atm, BTU/lb	116.69	473.0	361.0
13. Heat of vaporization, @ 25°C/1atm, BTU/lb	132.0	503.3	
14. Heat of combustion @ 25°C, BTU/lb			
a). Higher heating value	20555	9776	12780
b).Lower heating value	19065	8593	11550
15. Stoichiometric, lb air/lb fuel	15.13	6.463	9.0
16. Research octane number	100	106	105
17. Flash point temp. °C	-42.778	11.112	12.778
18. Auto-ignition temp. °C	257.23	463.889	422.778
19. Flammability limits			
a).Lower	1.4	6.7	4.3
b).Higher	7.6	36.0	19.0
20. Latent heat of vaporization @ 20°C, KJ/Kg	349	1177	921.36
21. Cetane number	-	5	8

Table 6.1 properties of selected alcohols [*h*]

The engine used in these tests was naturally aspirated. As with gasohol, the primary effect of the ethanol was to lean the air-fuel mixture and produce more efficient combustion. Ethanol can be mixed with diesel fuel provided there is little water in the ethanol. A diesel engine normally will not operate on ethanol nor will ethanol provide lubrication for the fuel injection system. Another problem with adding ethanol to diesel fuel is that the cetane number (ignition characteristic) may decrease below the level recommended by the engine manufacturer. Below in *Table 6.2* are the physio-chemical properties of blends of diesel with ethanol (E-Diesel). [*1*]



Fuel Property	E-Diesel
Water & Sediment, % max	N/D
Distillation % vol rec. T-90 (ºC)	311
Kinematic Viscosity, 40ºC (cSt)	2.25
Ash (%) max	0.001
Sulfur (%) max	-20%
Copper Corrosion @ 3 hr max	1a
Cetane Number, min	45
Cetane Index, min	42
Rams. Carbon, 10% res.	0.22
API Gravity, max	38
Lubricity (g) min	5200
Accel. Stability, pass/fail test	Pass
Cloud Point (ºC)	-13
LTFT at -11ºC, pass/fail test	Pass
LTFT at -19ºC, pass/fail test	Pass

Table 6.2: Critical E-Diesel fuel properties based on a 15- percent ethanol, Puranol and No. 2 diesel formulation [*43*]

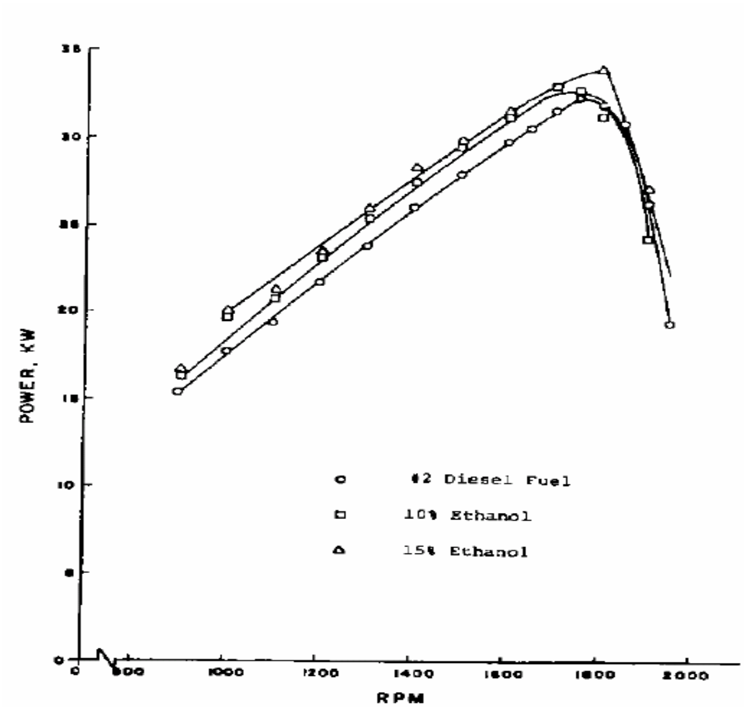


Fig 6.2 Diesel engine power output using ethanol fuel blends. [*1*]

6.5 Emission from E-Diesel Fuel

As far as emission from bio Ethanol is concerned, as we can see from *Table 6.3*, it is full considered as the best alternative fuel. There is a big reduction in all the emission particles including NO_x which is not the way in Biodiesel. Therefore regarding the emission Bio Ethanol is the best fuel.

Emission Change Compared to Neat No. 2 Diesel		
	15% Ethanol Blend	10% Ethanol Blend
PM	-41%	-27%
NOx	-5%	-4%
CO	-27%	-20%
HC	Neutral	Neutral

Table 6.3: Average percentage change for the transient emissions between E-Diesel containing 10-percent and 15-percent fuel-grade ethanol, Pure Energy's Puranol additive and No. 2 reference diesel fuels.[*43*]

6.6 Summery on E-Diesel

E-Diesel has several performance benefits in addition to superior emission advantages when compared with other regular diesel alternatives such as ultra low sulfur diesel.

- Lower emissions of PM, NO_x and CO
- No engine modifications required
- Cost competitive at commercial scale
- Low-cost alternative to modified or new engine equipment
- Low-cost alternative to expensive oil refinery modification to produce ultra low sulfur diesel
- Clear stable liquid with same cloud point as diesel
- Improved lubricity
- Readily biodegradable as per ASTM protocol
- Improved cold-weather performance
- Blend able at terminal

Disadvantages of Alcohol

- There are many disadvantages to using alcohols, particularly methyl and ethyl alcohol. Although these alcohols, when used near their stoichiometric air-fuel ratios, produce more power, a larger quantity of fuel is required to produce a specified power output. For example, in an automobile, more fuel is required for each mile driven.
- The relatively low boiling point and high vapor pressure of ethyl alcohol indicate that vapor lock could be a serious problem, particularly at high altitudes on warm summer days.
- The dynamic viscosity of ethanol is much lower than that of the diesel fuel, so that the lubricity is a potential concern of ethanol–diesel blend fuel.[*6*]
- The relatively high latent heats of methyl and ethyl alcohol cause problems in mixing these alcohols with air and transporting them through the intake manifold of the engine. Heating the intake manifold may be necessary in cold weather or before the engine reaches operating temperatures. Without external heat to more completely vaporize the fuel, the engine may be difficult to start and sluggish for

a considerable time after starting. Butyl alcohol is the least likely to cause starting difficulties or problems during warm-up. Note that its latent heat is almost the same as the latent heat of octane.

- Ethanol has limited solubility in diesel fuel. [*6*] Less engine power is produced as the water content of an alcohol increases. Further, vapor lock, fuel mixing and starting problems increase with water. [*1*]
- Ethanol always contains acetic acid and is particularly corrosive to aluminum alloys. Also certain alloys containing lead are attacked with general result of the lead being leached out, leaving a porous surface.[*h*]

CHAPTER SEVEN

WHY JATROPHA?

There are many tree species which bear seeds rich in oil having properties of an excellent fuel and which can be processed into a diesel-substitute. Though all seeds which give oil can be a source of oil for biodiesel transformation, edible oils are having high demand in every direction of the globe. Therefore the main commodity sources for bio-diesel could be non-edible oils obtained from plant species such as Jatropha Curcas (Ratanjyot), Pongamia Pinnata (Karanj), Calophyllum inophyllum (Nagchampa), Hevca brasiliensis (Rubber) etc.

In India, of these some promising tree species have been evaluated and it has been found that there are a number of them such as *Pongamia pinnata* ('Honge' or 'Karanja') and *Jatropha curcas* (Ratanjyot) which would be very suitable in our conditions.

Jatropha curcas is a drought-resistant perennial, growing well in marginal/poor soil. It is easy to establish, grows relatively quickly and lives, producing seeds for 40 years.

Jatropha curcas has been found the most suitable tree specie for the reasons summarized below:

- It can be grown as a quick yielding plant even in adverse land situations viz. degraded and barren lands under forest and non-forest use, dry and drought prone areas, marginal lands and as agro-forestry crop.
- It can survive long drought period.
- Can be used a fence or boundary for agricultural lands.
- The seeds of Jatropha are available during the non-rainy season, which facilitates better collection and processing. The cost of plantation is largely incurred in the first year and improved planting material can make a huge difference in yield.
- Jatropha Curcas growth is rapid; forms a thick live hedge after only a month's planting.

- Raising Jatropha plant and its maintenance creates jobs for the rural poor, particularly the landless, in plantation and primary processing through expellers.
- The oil cake which is extracted after the oil has been refined by using the press machine can be used as a bi product to nourish agricultural land because it is rich in nitrogen. The seed cake is an excellent source of plant nutrients.
- Jatropha is easy to establish, grows relatively quickly and is hardy.
- Jatropha is not a food for animal, so is not brows able.
- Like all trees, Jatropha removes carbon from the atmosphere, stores it in the woody tissues and assists in the build up of soil carbon. It is thus environment friendly.
- Medically it is used for diseases like cancer, piles, snakebite, paralysis, dropsy etc
- Retains soil moisture and improve land capability and environment.
- Jatropha adds to the capital stock of the farmers and the community, for sustainable generation of income and employment.
- Jatropha can be established from seed, seedlings and vegetatively from cuttings.

Countries like Ethiopia where her geographical topography is almost similar to the northern India, Jatropha plantation is most needed to prevent soil erosion. The country has lost its fertile soil due to erosion caused by lack of plantation in the mountainous areas. In this regard it is believed that while planting jatropha trees, in addition to the solution to the energy demand it will also help in the food security of the country.

7.1 Economics of Jatropha Biodiesel

As far as the economy is concerned, first of all we should have to begin from the collection of the oil seed. The over all price needed for the process are: collection of seeds, extraction of seeds from its cover, extraction of oil by press machine, then finally the process of production which has been discussed in chapter five.

In India, it is estimated that cost of Bio-Diesel produced by transesterification of oil obtained from Jatropha Curcas oil-seeds shall be approximately same as that of petro-diesel. On The cost of Bio-diesel varies between Rs. 16.59 –14.98 per liter. Assumptions are that the seed contains 35% oil, oil extraction will be 91-92%, 1.05 Kg of oil will be required to produce 1 Kg of Biodiesel, and recovery from sale of glycerol will be at the rate of Rs. 40-60 per Kg. [5] The price of Glycerol is likely to be depressed with processing of such large quantities of oil and consequent production of Glycerol raising the cost of Bio-diesel. However, new applications are likely to be found creating additional demand and stabilizing its price. With volatility in the price of crude, the use of Bio-diesel is economically feasible and a strategic option.

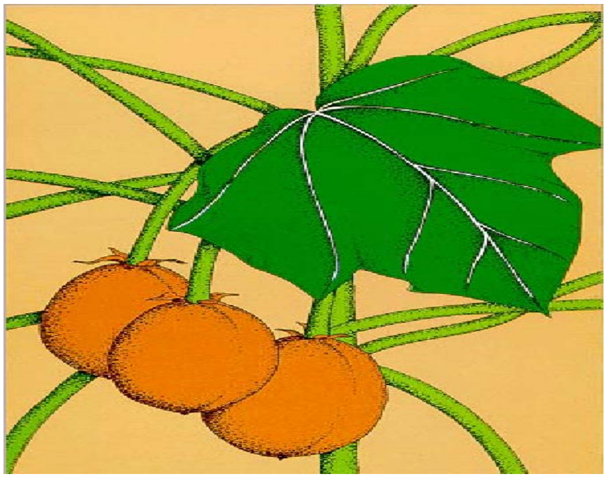
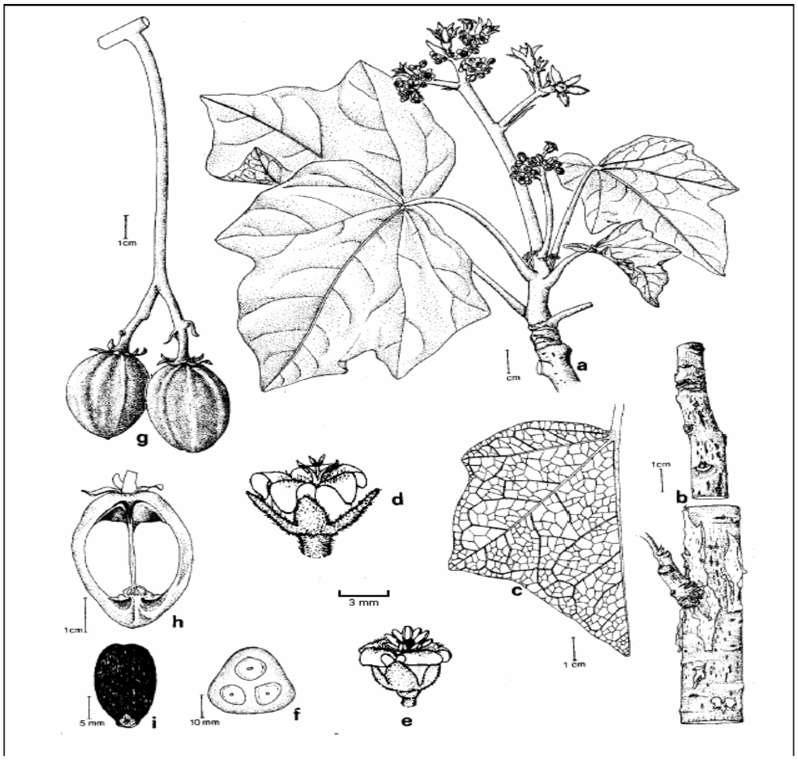


Fig 7.1 Jatropha leaf and ripe jatropha fruit [44]



a - flowering branch,
b - Bark,
c - Leaf veinature,
d – pistillate flower,
e - Staminate flower,
f - cross-cut of immature fruit,
g - Fruits,
h- Longitudinal cut of fruits;

a - c and f - h from Aponte 1978; d and e from Dehgan 1984 (reprinted with permission)

Fig 7.2-Important parts of the physic nut [44]

CHAPTER EIGHT

FUEL SAMPLE FORMULATION TECHNIQUES AND PHYSICAL APPEARANCE OF SAMPLES

8.1 Fuel Sample Formulation Techniques

8.1.1.Introduction

As can be seen from the title of this project the fuel is a combination of three core fuels named: Jatropha biodiesel, ethanol and conventional diesel #2. By using these three main fuels with different proportions the samples are macro-emulsified with a high speed blender. Before stating the procedures of this macro-emulsion, first let me say some thing how I have got the core fuels.

8.1.2.Jatropha Biodiesel Preparation Procedures

Laboratory Procedures for the Production of Jatropha Biodiesel

1. First oil is produced by using the press machine squeezing the jatropha seed. Normally there are different kinds of production of oil from their seeds. Though loss is more, for the current operation this press machine is used.
2. The oil produced by this mechanism has some residues remained with it, and then it requires some filtration using filter. Therefore the oil has been filtered.
3. Now we have come with pure oil but here we should have to note that the oil is having water contents. This water affects the chemical reaction by reacting with the catalyst. There fore with the presence of water with in the oil the chemical process (transesterification) delays. For that purpose the oil is heated up to $100^{o}C$ to dehydrate the water content fully.
4. The favorable condition for the transesterification is at $60^{o}C$ temperature. Therefore in order to facilitate the reaction, we should have to cool the temperature of the oil up to $60^{o}C$.
5. Methyl alcohol-catalyst mixture was prepared separately in another beaker by dissolving 8.0 gm of solid potassium hydroxide in pallet form into about 425 ml (slightly excess than stoichiometric) of methanol this proportion is as per one litter of oil.

6. Ethanol/catalyst mixture was added to the 60^{o}C jatropha oil and continuous stirring of the mixture was carried out using magnetic stirrer.

Fig 8.1 Process of preparation of Biodiesel with the help of magnetic stirrer

7. The mixture was stirred vigorously and maintained at about 60^{o}C for about an hour and then transferred to glass separating funnel and allowed to settle under gravity for 24 hrs. Due to difference in gravity, two layers were formed, out of which upper layer was of methyl ester of jatropha oil and lower layer was of dark syrup-like layer of glycerol.

Fig 8.2 separations of biodiesel and glycerol taken place by the help of gravity in the separation funnel, as can be seen the black part is the settled part of glycerol.

8. The lower layer of glycerol was separated out and the methyl ester was washed gently to remove residual catalyst or soaps by spraying the liquid surface by10% (by volume) warmed water, using a spray bottle and again allowed to settle down for 24 hrs. [*15*] The washing is most effective if drops travel through the solution fall directly on the surface of the oil. As the drops travel through the solution they extract alcohol and glycerol from the product.

9. Water containing KOH, soaps and remaining glycerol formed lower layer in a separating funnel and was removed. The remaining moisture from the ester was removed by heating up again up to 100°C, in which the water content dehydrates as a saturated vapor.
10. The biodiesel is then ready for the preparation of the required samples. Two litters of biodiesel were required for the samples.

8.1.3.Conventional Diesel

The required diesel has been purchased from the near by petrol pump. For the current experiment a conventional diesel No 2 was required and 5*lts* of this fuel has been obtained.

8.1.4.Ethanol

Similarly it was not necessary to produce ethanol in our laboratory. The production method of ethanol is already stated in different literatures. For the current experiment the required ethanol was taken from the laboratory store.

8.1.5.Preparation of Samples

As has been stated in the above topics the core fuels have been prepares and the remaining task is now to formulate the required samples. 500ml of each sample was required for the total experimental checkups. As per the volume and the ratio,

The proportions of the core fuels have been decided as per the following:

Sample Naming	Ratio of Conventional Diesel #2 Fuel		Ratio of Jatropha Biodiesel		Ratio of Ethanol	
	(%)	By Volume (ml)	(%)	By Volume (ml)	(%)	By Volume (ml)
D100	100	500	0	0	0	0
JB100	0	0	100	500	0	0
D80JB15E5	80	400	15	75	5	25
D80JB5E15	80	400	5	25	15	75
D75JB15E10	75	375	15	75	10	50
D75JB10E15	75	375	10	50	15	75
D70JB15E15	70	350	15	75	15	75
D65JB30E5	65	325	30	150	5	25
D63JB28E9	63	315	28	140	9	45

Table 8.1 Proportions and the quantity of the core fuels which formulate the required samples

8.1.6.Macro-emulsion

As it has been mentioned in the introduction part of this chapter these samples has been prepared by the macro-emulsion process. The procedure is as follows:

1. First the required ratio of all core fuels has been measured by volume 0.01*ml* accuracy measuring bicker.
2. These three core fuels of different proportion have been mixed so that they can be ready in a 2*l* plastic bicker for the macro-emulsion process.
3. The mixture has been emulsified by using a high speed blender so that the mixture can form a homogenized mixture.

Figure 8.3 High Speed Blending Machine

4. This mixing process has lasted for 10minutes.
5. samples are now ready for experiment

8.2 Samples Physical Appearance

Naturally Fuel has a particular physical appearance based on its composition. As far as Conventional Diesel (HSD) is concerned, its appearance is like a light yellowish color with fully transparent and clear form. In the similar manner those fuels in which they have been produced in our laboratory have also their own particular physical appearance based on their composition. Here two main and clearly visible differences have been noticed:

- Of the samples which have homogeneous physical appearance and have stable mixture and,
- Of the samples which form different layers and they are partially miscible, in which a separation line is clearly visible with in the top part of the samples.

here are the physical appearances of these samples:

Fig 8.4-Of the samples which have homogeneous physical appearance

Fig 8.5- Of the samples which form different layers and they are partially miscible

D100

This sample is of conventional diesel #2, and it is known that diesel is homogenous and is single color. The color of this sample looks light brownish yellow and is fully transparent.

Fig 8.6- Physical Appearance of D100

JB100

The physical appearance of this sample is also a uniformly homogenized with a color of slightly darkish yellow. This sample is made of only Jatropha biodiesel and due to this it is a single mixture with out any separation. This sample is also transparent.

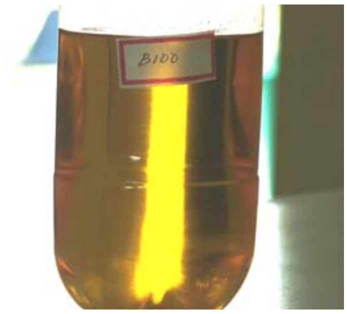


Fig 8.7- physical Appearance of JB100

D75JB10E15

This sample as we can see from the naming is produced from the emulsification of three fuels with the ratio of diesel 75%, Jatropha biodiesel 10% and ethanol 10%. Therefore there is a clear separation line with the upper part fully transparent and the majority lower part with cloudy yellowish color. This sample is partially miscible.

Fig 8.8- physical Appearance of D75JB10E15

D80JB5E15

Similarly this sample is a combination of these three core fuels with the ratio in the naming. There is a clear separation line with the upper portion transparent and the majority lower part with cloudy white color. It has two phases and shows that this sample is partially miscible and not homogenized.

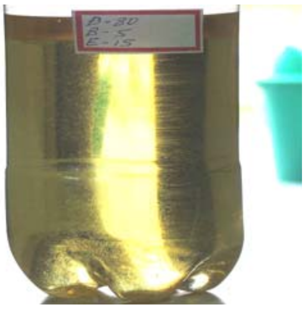


Fig 8.9- physical Appearance of D80JB5E15

D70JB15E15

Here also there is separation too, the upper portion is a wax type with sluggish and some what with air bubbles. The upper layer is comparatively very small in quantity.

Apart to the sluggish upper layer this sample looks like to the B100 sample as far as the color is concerned.

Fig 8.10- physical Appearance of D70JB15E15

D80JB15E5

This sample is a uniformly homogenized sample with a single phase. The color of this sample is a cloudy yellowish.

Fig 8.11- physical Appearance of D80JB15E5

D65JB30E5

Similarly this sample is uniformly homogenized and has got a single phase. The color of this sample is some what darker than the above sample, but same cloudy.

Fig 8.12 -physical Appearance of D65JB30E5

D63JB28E9

This sample has got a transparent light yellowish uniformly homogenized single phase physical appearance.

Fig 8.13- physical Appearance of D63JB28E9

D75JB15E10

This sample has got a transparent light yellowish uniformly homogenized single phase physical appearance.

Fig 8.14- physical Appearance of D75JB15E10

Generally we can see all the samples as of the following table.

S. No	Sample	Temperature	Result
1.	D100	Room air temperature (approximately 25°C)	Stable and uniformly Homogenized mixture
2.	JB100	"	Stable and uniformly Homogenized mixture
3.	D75JB10E15	"	Partially miscible
4.	D80JB5E15	"	Partially miscible
5.	D70JB15E15	"	Partially Miscible with wax type and air bubbles in the upper layer
6.	D75JB15E10	"	Stable and uniformly Homogenized mixture
7.	D80JB15E5	"	Stable and uniform but light cloudy color
8.	D65JB30E5	"	Stable and uniform but cloudy color
9.	D63JB28E9	"	Stable and uniformly Homogenized mixture

Table 8.2: Description of the physical appearance of all samples, which shows the stable and partially miscible samples

8.2.1.Discussion on Physical Appearance of Samples

As we can see from the pictures, the samples can be categorized in two to groups. These are: the samples in which their physical appearance is homogeneous (these samples are uniformly homogenized and they form a single mixture), while the other group is the samples in which there is a clear separation with in the mixture (here as we can see from the picture there is a clear layer near the top part). I have come to conclude that the samples in which their percentage of composition of Jatropha Biodiesel is larger than that of the percentage of composition of ethanol are homogeneous mixtures so that the mixture is uniformly mixed mixture and form single phase. While those of the samples in which their percentage of composition of Ethanol is greater than that of percentage of composition of Jatropha biodiesel, there is a clear separation line. Note that this applies of the all percentage of composition of conventional Diesel fuel.

CHAPTER NINE

FUEL CHARACTERSTIC PROPERTIES AND THEIR EXPERIMENTAL RESULTS

9.1 Density (Specific Gravity) of Fuels

9.1.1. Theory

Density is defined as mass per unit volume.

$$\rho = \frac{m}{V} \qquad kg / m^3$$

The density of a substance, in general, depends on temperature and pressure. The density of most gases is proportional to pressure, and inversely proportional to temperature. Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible. The density of liquids and solids depends more strongly on temperatures than they do on pressure.

Sometimes the density of a substance is given relative to the density of a well-known substance. Then it is called specific gravity, or relative density, and is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4^oC, for which $\rho_{h_2O} = 1000kg/m^3$). That is,

$$\rho_s = \frac{\rho}{\rho_{H_2O}}$$

Note that the specific gravity of a substance is a dimensionless quantity. However, in SI units, the numerical value of the specific gravity of a substance will be exactly equal to its density in g/cm^3 or *Kg/L* (or *0.001* times the density in Kg/m^3) since the density of water at 4^oC is $1g/cm^3 = 1Kg/L = 1000Kg/m^3$. [45]

9.1.2. Density Measurement Technique

Apparatus used:

To determine the density of all samples I have used simple apparatus as follows:

- A 25*ml* bottle
- Filling funnel
- Weighing machine, with and accuracy of *0.0001g*

By using the above apparatus I have followed the following steps:

Step1-An empty of the 25*ml* bottle's weight was taken

Step2- This bottle again filled with one of the sample fuels has been weighed.

Step3-Since the weight and the volume of this 25*ml* bottle are known, then the same procedure to step2 has been taken to all of the samples.

Step4-Results have been recorded.

9.1.3. Results of the Experiment and Calculated Values

After taking all the records, here are the results of the experiment and the calculated values of Density and Specific Gravity.

Sample Name	Volume of Bottle *ml*	Mass of Sample *g*	Density *g/ml*	Specific Gravity
D100	25.00	19.714	788.548	0.789
JB100	25.00	20.871	834.84	0.835
D75JB10E15	25.00	19.644	785.772	0.786
D80JB5E15	25.00	19.561	782.444	0.782
D70JB15E15	25.00	19.756	790.22	0.790
D75JB15E10	25.00	19.801	792.028	0.792
D80JB15E5	25.00	19.780	791.216	0.791
D65JB30E5	25.00	19.996	799.836	0.800
D63JB28E9	25.00	19.929	797.14	0.797

Table9.1 experimental results and the calculated values of Density and Specific Gravity

9.1.4. Specific Gravity Chart

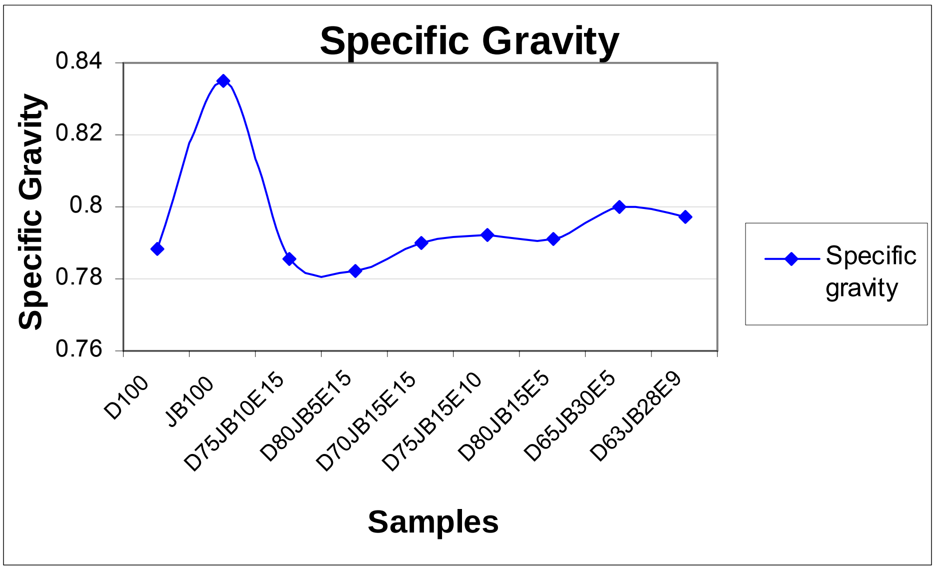


Fig 9.1 a chart which shows the range of specific gravity, as can be seen the pure jatropha biodiesel has the largest specific gravity but less than that of Water.

9.1.5. Discussion on the Calculated Results of Specific Gravity

As we can see from the table and from the graph, all fuels except jatropha biodiesel have a specific gravity almost near to the specific gravity of conventional diesel #2 fuel. Pure jatropha exhibits the largest specific gravity of all the fuels, which is clear evidence that this project is necessary that by macro-emulsification of biodiesel and other fuels we can bring biodiesel to a better engine friendly fuel.

9.2 Calorific Value of the Fuel Samples

9.2.1. The Heat of Combustion and its Determination

Fuels are those substances predominantly containing carbon, or carbon and hydrogen, or carbon, hydrogen and oxygen, which are utilized for the energy they produce upon union with oxygen, which is called combustion. The products of combustion are carbon dioxide, water and other oxides.

The amount of heat given out in a chemical reaction depends on the conditions under which the reaction is carried out. The standard heat of reaction is the heat released when the reaction is carried out under standard conditions, STP: pure components, pressure (1 ATM.), temperature, usually but not necessarily, at 25°C.

The Heat of Combustion (Calorific Value or Heat Value) of a compound is the standard heat of reaction for complete combustion of the compound with oxygen. The terms higher calorific value (HCV) or Higher Heating Value (HHV) (which is the heat transferred when water (H_2O) in the product is in liquid form or state) and lower calorific value (LCV) or Lower Heating Value (LHV) (Which is the heat transferred in the reaction when water (H_2O) in the products is in the vapor state), are used, respectively, to distinguish the cases in which any water formed is in the liquid or gaseous phase. The two calorific values are related as follows:

$$HCV = LCV + M_m * H_e$$

Where

M_m: mass of water produced per unit mass of fuel

H_e: latent heat of evaporation of water.

The heat of combustion is a required value in the design of any type of combustion system. There are two methods for its determination - one by calculation based on the chemical composition and the other by actual combustion in a bomb calorimeter. The determination of calorific value by calculation requires a complete determination of the chemical formulas of each of the combustion reactants and products which is more cumbersome to perform when the material under investigation are with unknown chemical formula. Therefore for fuels with complex chemical formulae, it is more reliable and simpler to evaluate the heat of combustion by doing a bomb calorimeter test. Further, if there is any doubt in the composition and structure of a fuel or the formula for calculating the heat of combustion, it may prove more reliable to do a bomb calorimeter test, as it is a direct measure of the heat of combustion.

Bomb calorimeters for rapid combustion are composed of a combustion chamber (bomb) and a calorimetric bath, usually a cylinder surrounding the bomb and containing a known quantity of water, the elevation in temperature of which is measured. The combustion is made in oxygen, pure or diluted. Combustion chambers are either under a constant pressure or with a constant volume. The results obtained with a calorimeter of constant volume are not exactly the same as those obtained with constant pressure, but for solid or liquid substances the difference is too small to consider.

The standard procedure used for measuring calorific value of fuel in India is given by IS: 1448 part I, 1960 that gives details of equipments to be used and procedure for conducting the experiments. Most commonly, Bomb Calorimeter is used to find out calorific value of solid and liquid fuels.

9.2.2. Calorific Value Measurement (IS: 1448 part I, 1960)

Apparatus Used: The Adiabatic Bomb Calorimeter

This instrument (*Fig 9.2a*) consists of:

1. The bomb;
2. The container of water in which the bomb is placed and
3. A surrounding compartment of temperature controlled water.

The bomb is a small cylindrical pressure vessel with a tight fitting head clamped on the external face of the bomb by a screw cap, a port for a pressure relief valve and two ports for the two electrodes. The material to be combusted is put in a metal cup that is suspended in the bomb by two supports that also are part of the electrical circuit containing the fuse wire. The fuse wire spans across the top of the metal cup and when current is passed through the fuse wire it heats up rapidly and ignites the fuel.

The bomb is placed in a container with a known amount of water, together with an agitator and thermometer. The agitator is used to maintain a uniform temperature in the water and aid heat transfer from the bomb. The thermometer measures the water temperature (its range is 24 to 30°C with 0.01°C precision). Between the container of water and the surrounding compartment of water is an air gap, which is an excellent heat insulator. When the calorimeter is running, the temperature of the calorimeter body is automatically maintained at the same temperature as that in the container of water holding the bomb. This provides an adiabatic condition and thus, no heat transfers to or from the container of water, except from the heat released in the bomb.

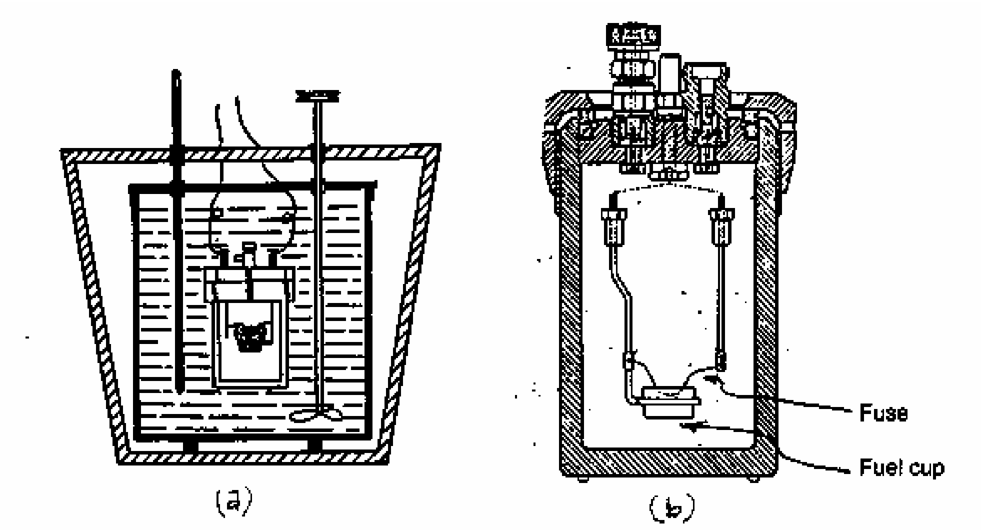


Fig 9.2

a) Calorimeter

b) The fuel bomb to be used for energy content measurement

To determine the calorific value of the fuel, a known mass of the given fuel was taken in clean crucible .The crucible was then supported over the ring. A fine magnesium wire, touching the fuel sample, was stretched across the electrode. A cotton thread was made to attach with the magnesium wire and touches the fuel sample. The bomb lid was tightly screwed and bomb was filled with oxygen to about 20 -25 atmospheric pressure. The bomb was then lowered into copper calorimeter, containing a known mass of water. Electrical circuit was completed by connecting the electrodes to a 6-volt battery and stirring of the water was also started. Due to burning of the sample, heat is liberated. Uniform stirring of water was continued and maximum temperature attained recorded. It may be noted that before determining the calorific value of the unknown fuel the water equivalent of the calorimeter was determined by burning known quantity of Benzoic acid (CV, 26460 KJ /Kg). The capacity of the bomb calorimeter was 1.994 liters. The water equivalent of the calorimeter is measured by the following equation.

$$LCV \times m = (W + w) \times \Delta t \times C_p$$

Where: - LCV - The calorific value of the fuel burnt in KJ/Kg.

m - The quantity of the fuel burnt. Obtained by weighing the used fuel in (Kg)

W - The water contained in the calorimeter. Here the amount of water used is around 2litres which is approximately around

1.994Kg. This can be seen as follows: At 25°C the density of water is given by ρ=997kg/m^3. Therefore, 1litre of water will be 0.997kg

w - The water equivalent of the bomb calorimeter. It will be determined from the known calorific value of Benzoic Acid. This was done by similar procedure to the experiment.

Δt - The temperature of the water. (°C)

C_p - Specific heat of water, at 25°C the value 4.18KJ/kg °C which can be obtained from any thermodynamics data book.

9.2.3. Experimental Results and Obtained Calculations

Observation and calculated values of the Calorific Value of various Fuels

Sample	Weight of the Empty Crucible	Weight of the Crucible with fuel	Weight of the fuel *(m)*	Change in water temp Δt	Calorific Value *LCV*	Water equivalent of calorimeter *w*
	(gm)	*(gm)*	*(gm)*	*0C*	*KJ/Kg*	*Kg*
Benzoic Acid	10.2836	12.7003	2.4167	6.1	26460 (Known)	0.5139
D100	10.2758	12.24	1.9642	8.7	46432.28	
JB100	10.2987	11.7216	1.4229	5.25	38678.66	
D75JB10E15	10.2706	12.35	2.0794	8.4	42347.50	
D80JB5E15	10.2679	12.1433	1.8754	7.64	42705.71	
D70JB15E15	10.2526	13.067	2.8144	10.02	37322.30	
D75JB15E10	10.2448	13.2422	2.9974	10.56	36932.25	
D80JB15E5	10.2647	12.6679	2.4032	9.47	41309.18	
D65JB30E5	10.2387	13.2819	3.0432	10.5	36374.48	
D63JB28E9	10.2448	13.2422	2.9974	10.56	36932.25	

Table 9.2 Observation and calculated values of the Calorific Value of various Fuels

9.2.4. Calorific Value Chart

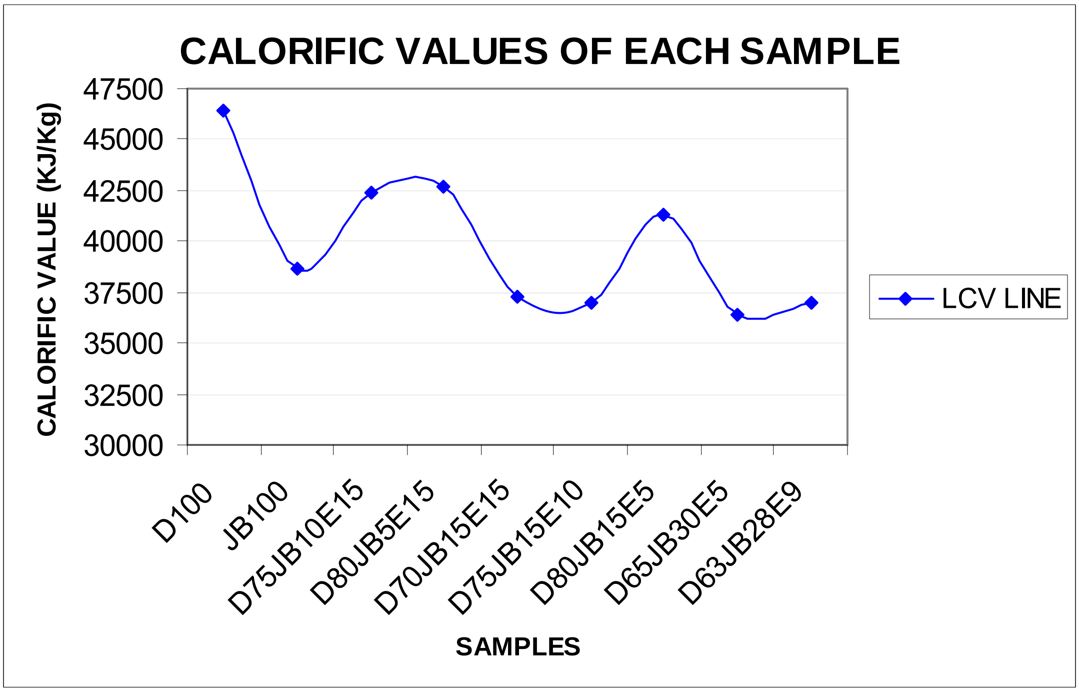


Fig 9.3 this chart indicates the variation of calorific value of each samples

9.2.5. Discussion on the Calorific Value of all Samples

As we can see from the table as well as from the chart, the calorific value of conventional diesel fuel is by far greater than that of all sample fuels. If we try to see particular results of the calorific values of conventional diesel (D100) and that of the Jatropha Biodiesel (JB100), the same is also true here. And that is why the maximum calorific value of all the samples produced in our laboratory is less than that of conventional diesel fuel (D100). Therefore we can conclude from here that the heat value of those fuels which are produced in our laboratory is less than that of the conventional diesel fuel (D100). But, fuels D75JB10E15 and D80JB5E15 have better calorific value in which we are going to give them special attention through out our experiment.

9.3 Kinematic Viscosity of Fuel

9.3.1. Theory

Viscosity is a measure of its resistance to flow. Viscosity is defined as the time necessary for a quantity of fluid to pass through the orifice under the force of gravity. For convenience, the figures are usually expressed in Centipoises and Centistokes (cP and cSt). The two are related in that $cP = cSt * \text{Density of the fluid}$. The SI unit is m^2/s. Viscosity is an important physical property of a diesel fuel. Improper viscosity leads to poor combustion, which results in loss of power and excessive exhaust smoke. Diesel fuels with extremely low viscosities may not provide sufficient lubrication for the closely fit pumps and injector plungers. They can promote abnormal wear and cause injector and injector pump leakage and dribbling leading to loss of power. Diesel fuel with higher viscosity is also not desirable as too viscous fuel increases pumping losses in injector pump and injectors, which reduces injection pressure resulting in poor atomization and inefficient mixing with air ultimately affecting the combustion process.

Lucas Diesel Systems quoted a figure of 48cSt at -20°C as the upper end and, to guard against loss of power at high temperatures, 1.6cSt at 70°C as the lower limit. Too low a viscosity can cause undue wear of pump and increased maintenance. BS2869 calls for a maximum value of 5cSt and minimum of 2.5cSt at 40°C. In *Fig. 4.2 chapter 4*, all these points are plotted and viscosity tolerance band established. The viscosity of the average fuel lies approximately mid-way between the upper and lower limits.

Various methods are employed for measuring viscosity. One is the use of rotary viscometer, with which the viscosity is a function of the torque required to rotate the rotor at constant velocity in the liquid. Another indicator of viscosity is the kinematic viscosity, which is defined as the absolute viscosity divided by the density of the liquid at a given temperature. This can be determined with greater precision than absolute viscosity, by measuring the flow rate of the liquid through a capillary tube under the influence of gravity. The relevant standards are ASTM D445 and IP71. [*30*]

9.3.2. Kinematic Viscosity Measurement (ASTM D445)

Apparatus used: Saybolt kinematic viscometer:

Kinematic viscosity was measured by determining the time required to flow a fixed volume of fuel under gravity through standard capillary tubes. See fig 9.4 Say bolt viscometer had six capillary tubes having different diameters ranging from 0.01 to 5.0 *mm*. With the help of the chart, supplied with the apparatus, suitable viscometer tube was selected.

As viscosity of oil is very sensitive to its temperature, the capillary tubes were kept in a special oil bath, the temperature of which was maintained very accurately. Before injecting the fuel in capillary tube, it was cleaned with suitable solvent and dried for about three minutes. Then about 0.4ml of fuel sample was injected in selected capillary tube. Stopwatch was used for measurement of the time. Measured time was multiplied by the tube constant to get the kinemaitc viscosity in cSt.

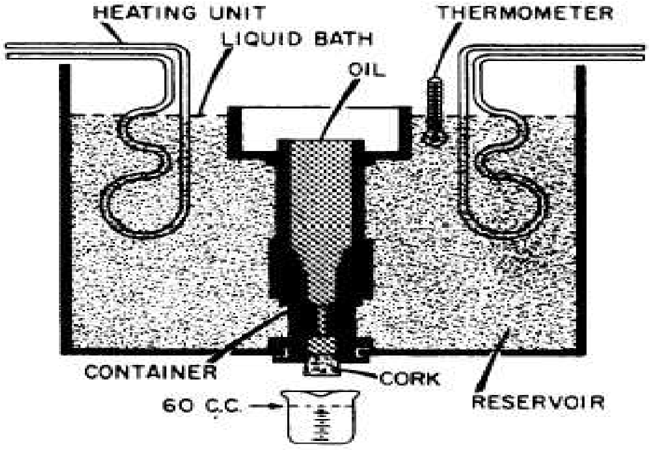


*Fig 9.4*Apparatus of a Saybolt Viscometer

9.3.3. Experimental Results and Calculated Kinematic Viscosity in cSt

S NO.	Fuel Sample	Tube Constant of Capillary Tube	Time taken by 60ml of the Fuel to Flow Through the Capillary Tube. (Seconds)	Kinematic Viscosity (40^0C) (cSt)
1	D100	0.1101	33.816	3.72
2	JB100	0.1101	66.040	7.27
5	D75JB10E15	0.1101	35.252	3.88
6	D80JB5E15	0.1101	35.560	3.92
8	D70JB15E15	0.1101	42.144	4.64
10	D75JB15E10	0.1101	49.594	5.46
11	D80JB15E5	0.1101	45.148	4.97
12	D65JB30E5	0.1101	45.630	5.02
14	D63JB28E9	0.1101	49.442	5.44

Table 9.3 Time taken by 60*ml* of the fuel to flow through the Capillary Tube (in Seconds) and Kinematic Viscosity of Various Fuel Samples at 40^0C calculated in cSt

9.3.4. Kinematic Viscosity Chart

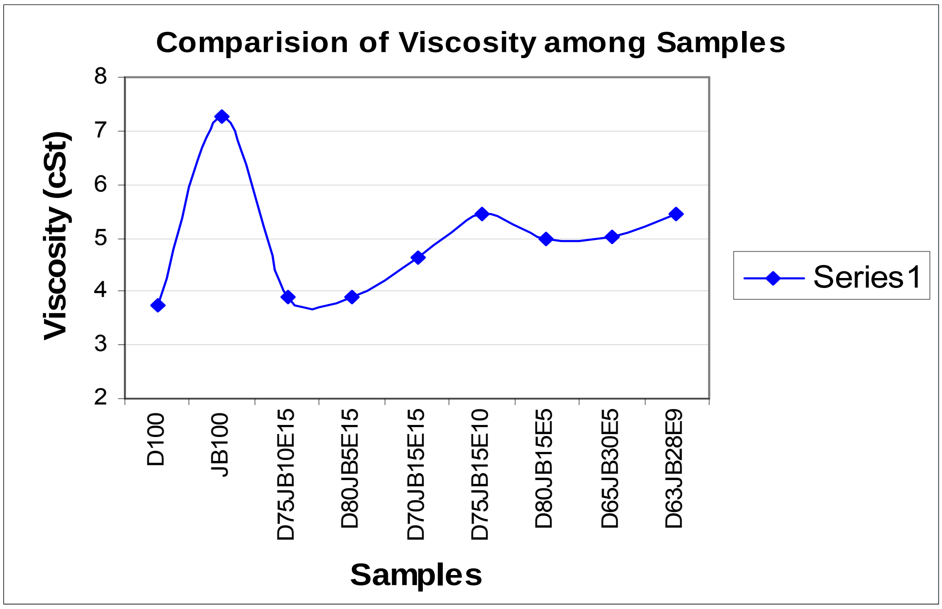


*Fig 9.5*This chart indicates the relative compression of viscosity among the samples. As it can be seen Viscosity of D100 is the lowest of all while viscosity of JB100 is the highest of all.

9.3.5. Discussion on Calculated Value

As it can be seen from the tabulated value and clearly visible in the chart, viscosity of the pure Jatropha biodiesel is much greater than of all samples. This can be evidence why we need modify the already modified Biodiesel. And as it can be seen, the viscosity is the conventional diesel #2 (D100) is less than that of all sample fuels. In this case we can say that there will be a problem associated with the increase in viscosity such as: difficulty on the high pressure pump, therefore frequent blockage of the pump, Atomization problem, etc. Apart from these problems, they can rectify also those problems created due to the law viscosity of diesel fuel.

9.4 Flash Point

9.4.1. Introduction

Flash point is the temperature at which a flammable liquid will produce, with a standardize apparatus and procedure, a mixture of its vapor and air which will ignite to give a visible flash by contact with an open flame. [*29*] Generally, the lower the flash point the greater is the safety in handling and storage.

Flash point of oil is generally measured by using Pensky-Marten's Closed Cup Flash Point meter. It is desirable that the fuel should have high flash point. Too low a flash point will cause fuel to be a fire hazard, subject to flashing and explosion.

9.4.2. Flash Point Measurement (ASTM D- 93)

Apparatus Used: Pensky-Marten's Closed Cup Apparatus

This apparatus essentially consists of:

An oil cup: It is about 5.0 cm. in diameter and 5.5 cm. deep. The level to which the oil is to be filled is marked inside the cup. The cup lid is provided with four openings of standard sizes. Through one of these passes a thermometer; while the second opening is used for introducing test flame. Through third opening passes stirrer carrying two blades; while the fourth is meant for admission of air.

Shutter: It is provided at the top of the cup. By moving the shutter, opening in the shutter opens and flame is dipped into this opening, thereby bringing the flame over the fuel surface.

Flame exposure device: It has a tiny flame, connected to the shutter by a lever mechanism. To determine the flash point of the fuel, thoroughly cleaned and dried oil cup was filled up to the mark. The lid was placed on the cup, thermometer was inserted and then oil cup was heated by heating the air bath by burner. The test flame was also ignited. Fuel was stirred well during the test. Heat was applied at such a rate that the temperature as indicated by the thermometer increases 5^oC to 6^oC /minute.

9.4.3. Experimental Results of Flash Point

Below are the test results under the above stated apparatus with the stated procedures.

Samples	Flash Point
D100	65
JB100	165
D75JB10E15	43
D80JB5E15	45
D70JB15E15	47
D75JB15E10	43
D80JB15E5	62
D65JB30E5	62
D63JB28E9	45

Table 9.4 Results from the flash point measurement, using Pensky-Marten's Closed Cup Apparatus

9.4.4. Discussion on the Measurement Values of Flash Point

As it can be seen from the tabulated results, the sample named JB100 (Pure jatropha biodiesel) exhibits the largest flash point and the samples which have ethanol in their composition have the lowest flash point readings. As it has been mentioned in the introduction part, those fuels which have lower flash point need special safety in handling.

9.5 Chapter Summery

Below is a tabulated fuel characteristics measured and evaluated for all samples.

Sample Name	Specific Gravity	Calorific Value *LCV(KJ/Kg)*	Kinematic Viscosity (40^0C) (cSt)	Flash Point
D100	0.789	46432.28	3.72	65
JB100	0.835	38678.66	7.27	165
D75JB10E15	0.786	42347.50	3.88	43
D80JB5E15	0.782	42705.71	3.92	45
D70JB15E15	0.790	37322.30	4.64	47
D75JB15E10	0.792	36932.25	5.46	43
D80JB15E5	0.791	41309.18	4.97	62
D65JB30E5	0.800	36374.48	5.02	62
D63JB28E9	0.797	36932.25	5.44	45

Table 9.5 Fuel characteristics of all samples

CHAPTER TEN

EXPERIMENTAL SETUP, OBSERVATION AND EVALUATION OF PERFORMANCE CHARACTERISTICS

10.1 Introduction

The aim of the present work is to study the out comes of the experiment of using Macro-emulsion of Conventional Diesel #2 fuel, jatropha Biodiesel and Ethanol with different concentrations used in a H.S. Diesel by evaluating the performance, combustion and exhaust emission characteristics of a diesel fueled C.I engine. It was also aimed to find out the optimal concentration of this Macro-emulsified fuel sample so that it can be directed for the future long run analysis, based on the performance characteristics and also to ascertain whether there was any specific combustion related problem of biodiesel fuel with unmodified C.I engine. The various stages of experimentation were planned out as follows.

The experiment initially supposed under the performance characteristics and emission test was to analyze the following engine performance and emission characteristics properties:

- Heat released rate
- Brake specific fuel consumption
- Brake thermal efficiency
- Exhaust gas temperature
- Pressure crank angle Diagram
- Emission
- Smoke

But unfortunately with lack of apparatus and some materials related with this experiment, I have managed to perform the test with the following experimental methods.

- To evaluate the relevant performance parameters such as power developed, fuel consumption rate, brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), thermal efficiency, and brake mean effective pressure (BMEP) for various samples at different load conditions.

- To find out the optimal concentration of biodiesel in diesel based on the performance characteristics of the engine.
- To measure smoke density experimentally for different blends and comparison with pure diesel operation.
- To analyze the experimental data from biodiesel and diesel fuelled CI engine and comparative evaluation of performance and emission characteristics.

To achieve the above-mentioned goals, several macro-emulsified samples of varying concentration ranging from 100% Conventional diesel #2 fuels (HSD) to 100% biodiesel and to the maximum concentration of alcohol 15% were prepared and subjected to emission and performance tests on the CI engine running at 1500 rpm. Here I want to mention that at the beginning of the project I have tried to include samples which include alcohol with concentration of more than 15%. But on the way to come to this big experiment I have failed to include them here because these fuels which have alcohol (Ethanol) more than 15% resembles that of the Spark ignition engine fuel (gasoline). Therefore these fuels would disperse the lubrication oil of the engine when they are used in the compression ignition engine. In addition to this these sample have law cetane number so that they will create big problem in the engine associated with this particular problem. The testing was done in Biodiesel laboratory, Mechanical Engineering Department, at Delhi College of Engineering, Delhi, Bawana road-42. Engine performance and exhaust emission data were recorded and relevant parameters like Brake power (Pb), Brake Mean Effective pressure (BMEP), Brake Specific Fuel Consumption (BSFC), Brake Specific energy Consumption (BSEC) and thermal efficiency etc were calculated. Based on these parameters, various curves were drawn and compared to base line diesel curve in order to assess the performance of the engine with different samples

10.2Measurement of Various Parameters

10.2.1. Measurement of Power Output

As it has been mentioned in the introduction part, this experiment's main intention is to see the performance characteristics of the engine with the newly produced fuels from the macro-emulsified of different core fuels. Therefore one way of knowing the performance characteristics is to determine the power output of the engine. This power output helps us to determine other performance characteristics parameters.

Generally there are different methods to measure the power out of an engine. Among them:

- Rope-drum Brake dynamometer
- Hydraulic dynamometer and
- An eddy current dynamometer or Electrical braking device.

As can be seen from the figure, our apparatus is fully mechanical in which the engine is connected with a rope-drum brake dynamometer so that load is applied on the pan weight. The load was applied on the engine by putting weight on the pan and from spring balance reading of resisting force can be noted down. Though eddy current or electrical dynamometer is an accurate apparatus I have used rope-drum brake dynamometer, which is available in our laboratory. In order to help me to get the accurate result, Water flow arrangement was there to cool the drum so that correct reading can be obtained.

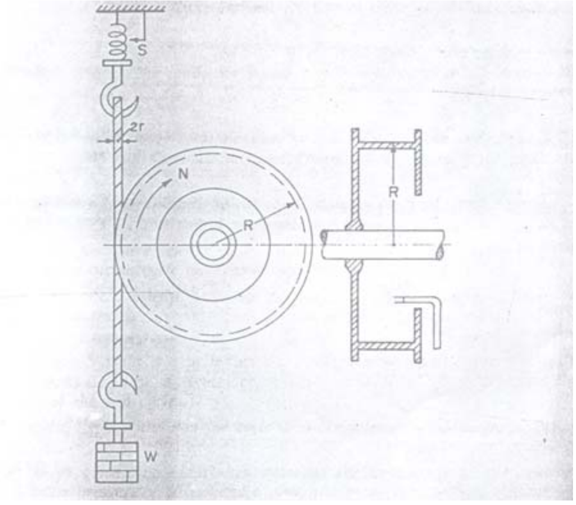


Fig 10.1 Arrangement of Brake-drum Dynamometer or power output Measurement [S. k. Kulshrestha, ‘*Thermal Engineering*”, 2nd edition, New Delhi]

10.2.2. Fuel Flow Measurement

Measurement of fluid velocity, Flow rate, and flow quantity with varying degree of accuracy are a fundamental necessity in almost all the flaw situations in engineering activities. There are different kinds of fuel measurement techniques used so far. To mention some:

- Venturi meter
- Flow nozzle
- Orifice plate
- Pitot tube
- Rota meter
- Cylinder and piston arrangement
- Weirs and flumes
- Current meters and anemometers etc

Accurate measurement of fuel consumption is very important in engine testing work and simplest method of measurement is to use a glass burette column of calibrated volume measurement. Time taken by the engine to consume the known volume of fuel is measured by a stopwatch. Volume divided by the time gives the volumetric fuel flow rate.

This glass burette column was directly attached with the fuel container so that the measured quantity of fuel will pass directly to the engine. In this case a stopwatch was used to take the time taken by the engine to consume 20*ml* of fuel of different samples at different loads.

10.2.3. Smoke and Exhaust Temperature Measurement

On the similar manner to the power output measurement, measurement if smoke and exhaust gas temperature helps us to identify the drawback and the quality of the experimental fuels as far as pollution is concerned. As it is widely known, Smoke is the main source of CO_2 and some other health hazardous gases. Therefore with a clear determination of these gases and with their outcome, we will be able to know the best fuel for our engine. The smoke of the engine exhaust is a visible indicator of the combustion process in the engine. Smoke is also due to incomplete combustion. Smoke in the diesel engine, in general, can be divided into two categories viz., blue white smoke and black smoke. The blue- white smoke from the engine is caused by liquid droplets of fuel oil or lubricating oil while it starts from the cold. On the other hand in black smoke carbon particles are suspended in the exhaust gas. It largely depends upon the air fuel ratio and increases rapidly as the load is increased and available air is depleted.

The AVL-437 Smoke meter, manufactured by M/s AVL India Pvt is a widely used apparatus for the indication of the smoke density and the exhaust gas temperature. This equipment has been used in the present work so that we have determined the smoke density. As far as the exhaust gas is concerned, the engine has its own measuring device. Therefore it will be enough to use this device it self.

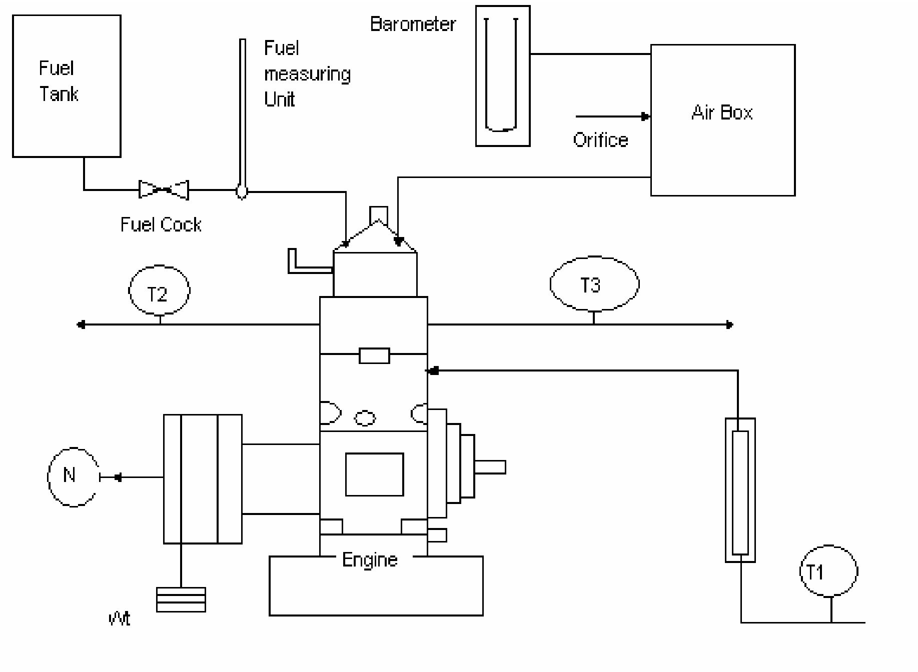
Fig 10.2: smoke density measuring device, the AVL-437 Smoke meter

10.3Engine System

As it is known the most engine users in the country are the rural people, in which they used this engine for the cultivation of their agricultural farms utilizing the engine as a tractor for plough their land and as a pump in irrigating their farm land. Therefore we have to select an engine so that it is suitable for rural area. It is a single cylinder, four stroke, direct injection, and water-cooled natural aspirated vertical diesel engine. Kirloskar India Limited has manufactured the engine, & it develops 5.2 KW power output at the rated speed of 1500 rpm. This engine is a typical engine of our requirement.

Below are the specifications of Kirloskar AV1/TV1/SV1/AK65 water cooled Diesel Engine where the experiment has been conducted.

No. of Cylinders	1
No. of strokes	4
Fuel	H.S. diesel
Rated power	5.2 KW @ 1500 rpm
Cylinder diameter	87.5 mm
Stroke length	110 mm
Compression Ratio	17.5 : 1
Orifice diameter	20 mm
Inlet Valve Opens	4.5° Before TDC
Inlet Valve Closes	35.5°After BDC
Fuel Injection	23° Before TDC
Exhaust Valve opens	35.5° Before BDC
Exhaust Valve Closes	4.5° After TDC
Rope Diameter	20mm
Drum Brake diameter	347 mm
Pan weight	1.5 kg
Dimension of the engine	617mm*292mm*843mm



Description:

T1- Cooling Water Inlet temperature

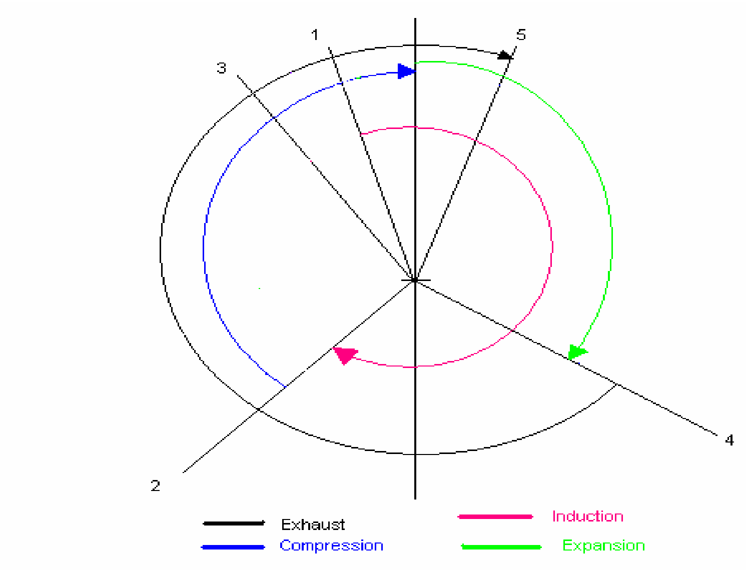
T2- Cooling Water Outlet Temperature

T3- Exhaust Gas Temperature

Wt- Added load in the pan weight to vary the load of the engine

Fig 10.3: Kirloskar AV1/TV1/SV1/AK65 water cooled Diesel Engine Flow diagram

Fig 10.4: Kirloskar AV1/TV1/SV1/AK65 water cooled Diesel Engine Set up



Description:

Line 1- Inlet valve opens before TDC: 4.5°

Line2- Inlet valve closes after BDC: 35.5°

Line3- Fuel Injection starts before TDC: 23°

Line4- Exhaust valve opens before BDC: 35.5°

Line5- Exhaust valve closes after TDC: 4.5°

Fig 10.5: Valve Timing of Kirloskar AV1/TV1/SV1/AK65 water cooled Diesel Engine

10.4Engine Performance Characteristics Test Procedures

Step 1

The engine was started at no load by pressing the inlet with decompression valve lever and it was released suddenly when the engine was hand cranked at sufficient speed.

Step 2

Feed controlled was adjusted to obtain the engine rated speed and it was allowed to run for about 30 minutes till the steady state conditions reached. To assess the present condition of the engine, a constant speed test with diesel as a fuel was carried out and base line data were generated. Test results with all other fuels were compared with base line data to evaluate the performance of the engine.

Step 3

As it has been stated in the flow measurement portion, with the help of fuel measuring device and stopwatch, the time elapsed for consumption of 20ml of fuel, RPM, the applied load and the spring load in order to determine the effective load, smoke density, exhaust gas temperature were also measured.

Step 4

The engine was loaded gradually keeping the rated speed within variation of permissible range and the observations of various parameter were recorded. Short-term performance test were carried out on the engine with various samples

10.5Theories Used in Calculating the Performance Characteristics of Engine

Brake Power Output

The brake power also termed as shaft power is the actual power available at the drive shaft. As can be seen in Fig (), the brake power is found by braking the engine. The braking agreement is by a rope brake, or hydraulic device known as hydraulic dynamometer. An eddy current dynamometer is an electrical braking device. Knowing indicated power by engine indicator, frictional power by a motoring test of the engine, brake power can be obtained. ($Pb=P_i-P_f$) Which is long proves. Most of the time, the engine is braked by a belt or rope round the flywheel with a hanging load at one end and a spring balance at the other. The brake power is given by:

$$P_b = (W-S)(R+r)2\pi \frac{N}{60} \times 10^{-3} Kw$$

Where-

$W = mg =$ Braking load, *N*

$S = sg =$ Spring balance force, *N*

R = radius of Brake Pulley or the flywheel of the engine, *m*

r = radius of the rope, *m*

N = engine rpm.

The product (W-S) (R+r) is known as Brake Torque exerted by the braking device.

Therefore

$$P_b = 2\pi T \frac{N}{60} Kw$$

Where-

T= Brake torque, *Nm*

Mass Flow Rate of the Fuel

In the fuel characteristics part I have already obtained the density of each samples of my experiment. In addition to this by the above stated method of measuring the flow measurement has been taken for each sample at different load conditions. Therefore the remaining part is to calculate the mass flow rate by the following relationship.

$$Mass\ \ flow\,Rate(gm/ml) = Volume\,Flow\,Rate(ml/s) \times Density(gm/ml)$$

Here the volume flow rate I have already got is in (*ml/second*) and the density in (*gm/ml*) therefore it necessary to convert it in to *kg/hr*

Therefore

$$\dot{M} = \dot{V} \times \rho \times 3600\,Kg/hr$$

Where $\dot{M}$ – Mass flow rate in (*kg/hr*)

$\dot{V}$ - Volume flow rate in (m^3/sec)

ρ - Density in (kg/m^3)

Brake Mean Effective Pressure:

The torque has a direct relation ship with the brake mean effective mean pressure ($bmep$), as follows:

$$P_b = bmep \times L \times A \times \frac{N}{60}$$

Where:-

$bmep$ = Brake means effective pressure, *Kpa*

L=stroke Length which is provided by the engine manufacture, *m*

A= Area of the piston, in this case, m^2

$$A = \frac{\pi D^2}{4}$$

D= Diameter of the Cylinder, similarly it is given by the material manufacturer, *m*

N= engine *RPM*

Here N also shows number of working strokes per minute. For a 2- stroke engine, there are N working strokes for N revolutions per minute. For a 4-stroke engine there are N/2 working strokes, for N revolutions per minute of the engine. Therefore the general formula is as follows:

$$bmep\,(Kpa) = \frac{60P_b}{LAnK}$$

Where, P_b = Brake Power (kW)

L = Length of Stroke (m),

A = Cross Sectional Area of the cylinder, defined before

n = N/2 for 4-Stroke Engine, and N for 2-Stroke Engine

N = Engine Speed (RPM)

K = No of Cylinders.

Brake Specific Fuel Consumption (BSFC)

Brake specific fuel consumption (BSFC) is the fuel consumed by the engine per unit of power out put or produced. It can be calculated as:

$$BSFC(kg/Kw-hr)=\frac{The\ fuel\ Consumed\ Per\ unit\ time(Kg/hr)}{Brake\ Power\ Output(Kw)}$$

$$BSFC=\frac{\dot{M}}{P_b}$$

Brake Specific Energy Consumption

Brake specific energy consumption (BSEC) is the energy used by the engine to produce unit power. It is the energy input to the system. It is calculated by the following relationship –

$$BSEC(Kj/Kw-hr)=BSFC(Kg/Kw-hr)\times Calorific\ Value(Kj/kg)$$

$$BSEC=BSFC\times LCV$$

Brake Thermal Efficiency

Taking our system as a heat engine, with certain energy input by the fuel, equal to $\dot{M}\times LCV$, and power output P_b**,** the over all performance is given by overall efficiency or Thermal efficiency**.** Brake thermal efficiency is the ratio of the power output of the engine to the rate of heat liberated by the fuel during the combustion.

$$Brake\ Thermal\ Efficiency(\eta_{Th}\%)=\frac{P_b}{\dot{M}\times LVC}\times 100\%$$

10.6 Observation and Evaluated Test Result Tables

Sample Name: D100

Experiment Date: *23/02/2005*

Density=*0.788548gm/ml*

LVC (calorific Value) *=46432.28KJ/kg*

Observed Values from Engine Performance Test

. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) (^oC)	Smoke Opacity *%*	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.2	108	170	2.6	1584
2	2	0.6	100	179	3	1567
3	3	0.65	98	189	3	1567
4	4	1.15	93	196	4	1561
5	5	1.5	90	206	8.2	1556
6	6	1.8	88	215	9.2	1551

Table 10.1 Observed Values from Engine Performance Test, D100

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} *%*
14.72	1.96	12.75	0.39	0.44	0.53	1.35	62856.46	5.73
34.34	5.89	28.45	0.86	0.99	0.57	0.66	30761.34	11.70
44.15	6.38	37.77	1.14	1.32	0.58	0.51	23643.75	15.23
53.96	11.28	42.67	1.28	1.49	0.61	0.48	22135.89	16.26
63.77	14.72	49.05	1.47	1.71	0.63	0.43	19964.12	18.03
73.58	17.66	55.92	1.67	1.95	0.65	0.39	17968.13	20.04

Table 10.2 Evaluated Values, D100

Sample Name: JB100

Experiment Date: *23/02/2005*

Density= *0.83484gm/ml*

LVC (calorific Value) = *38678.66kj/kg*

Observed Values from Engine Performance Test

S. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) ^{o}C	Smoke Opacity *%*	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.1	124	157	2.1	1579
2	2	0.5	107	170	2.6	1566
3	3	0.6	105	178	3.4	1559
4	4	1	94	184	6.7	1557
5	5	1.25	87	197	7.4	1554
6	6	1.9	82	209	8.4	1549

Table 10.3 Observed Values from Engine Performance Test, JB100

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} *%*
14.72	0.98	13.73	0.42	0.48	0.48	1.16	44974.55	7.89
34.34	4.91	29.43	0.89	1.03	0.56	0.63	24524.60	14.68
44.15	5.89	38.26	1.15	1.33	0.57	0.50	19310.73	18.64
53.96	9.81	44.15	1.32	1.54	0.64	0.48	18718.44	19.23
63.77	12.26	51.50	1.54	1.80	0.69	0.45	17368.77	20.73
73.58	18.64	54.94	1.64	1.92	0.73	0.45	17331.87	20.77

Table 10.4 Evaluated Values, JB100

Sample Name: D80JB15E5

Experiment Date: *01/03/2005*

Density= *0.791216gm/ml*

LVC (calorific Value) = *41309.18kj/kg*

Observed Values from Engine Performance Test

S. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) ^oC	Smoke Opacity *%*	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.15	120	150	2.3	1580
2	2	0.4	108	168	3.3	1567
3	3	0.6	104	195	3.7	1563
4	4	1	99	208	3.8	1560
5	5	1.25	91	221	4.8	1559
6	6	1.6	81	230	7.9	1555

Table 10.5 Observed Values from Engine Performance Test, D80JB15E5

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} *%*
14.72	1.47	13.24	0.40	0.46	0.47	1.18	48752.13	7.38
34.34	3.92	30.41	0.92	1.06	0.53	0.58	23785.44	15.14
44.15	5.89	38.26	1.15	1.33	0.55	0.48	19683.79	18.29
53.96	9.81	44.15	1.32	1.54	0.58	0.43	17955.33	20.05
63.77	12.26	51.50	1.54	1.80	0.63	0.41	16754.01	21.49
73.58	15.70	57.88	1.73	2.02	0.70	0.41	16791.84	21.44

Table 10.6 Evaluated Values, D80JB15E5

Sample Name: D65JB30E5

Experiment Date: *03/03/2005*

Density= *0.799836gm/ml*

LVC (calorific Value) = *36374.48kj/kg*

Observed Values from Engine Performance Test

S. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) ^oC	Smoke Opacity *%*	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.15	110	173	3.4	1586
2	2	0.6	102	180	4.4	1566
3	3	0.9	93	190	4.7	1561
4	4	1.2	89	201	6.8	1561
5	5	1.6	84	208	9.5	1555
6	6	2	81	220	9.5	1555

Table 10.7 Observed Values from Engine Performance Test, D65JB30E5

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} *%*
14.72	1.47	13.24	0.40	0.46	0.52	1.30	47161.99	7.63
34.34	5.89	28.45	0.86	0.99	0.56	0.66	23979.04	15.01
44.15	8.83	35.32	1.06	1.23	0.62	0.58	21253.65	16.94
53.96	11.77	42.18	1.27	1.47	0.65	0.51	18593.47	19.36
63.77	15.70	48.07	1.44	1.68	0.69	0.48	17354.66	20.74
73.58	19.62	53.96	1.61	1.88	0.71	0.44	16034.07	22.45

Table 10.8 Evaluated Values, D65JB30E5

Sample Name: D63JB28E9

Experiment Date: *03/03/2005*

Density= *0.79714gm/ml*

LVC (calorific Value) = *36932.25kj/kg*

Observed Values from Engine Performance Test

S. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) ^oC	Smoke Opacity *%*	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.2	116	165	4.3	1578
2	2	0.55	108	181	4.7	1566
3	3	0.8	102	194	9.7	1562
4	4	1.2	97	212	15.7	1558
5	5	1.55	91	234	18	1556
6	6	1.9	82	230	12	1552

Table 10.9 Observed Values from Engine Performance Test, D63JB28E9

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} *%*
14.72	1.96	12.75	0.39	0.44	0.49	1.28	47234.15	7.62
34.34	5.40	28.94	0.87	1.01	0.53	0.61	22528.22	15.98
44.15	7.85	36.30	1.09	1.27	0.56	0.52	19066.96	18.88
53.96	11.77	42.18	1.26	1.47	0.59	0.47	17296.44	20.81
63.77	15.21	48.56	1.45	1.69	0.63	0.43	16036.45	22.45
73.58	18.64	54.94	1.64	1.92	0.70	0.43	15771.42	22.83

Table 10.10 Evaluated Values, D63JB28E9

Sample Name: D75JB15E10

Experiment Date: *04/03/2005*

Density= *0.792020gm/ml*

LVC (calorific Value) = *42347.50kj/kg*

Observed Values from Engine Performance Test

S. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) ^oC	Smoke Opacity *%*	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.2	98	176	3.4	1582
2	2	0.6	92	184	3.7	1574
3	3	0.8	90	190	4	1564
4	4	1.1	87	198	3.6	1560
5	5	1.4	83	210	4.9	1558
6	6	1.8	75	232	11.9	1549

Table 10.11 Observed Values from Engine Performance Test, D75JB15E10

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} *%*
14.72	1.96	12.75	0.39	0.44	0.58	1.50	63534.86	5.67
34.34	5.89	28.45	0.86	0.99	0.62	0.72	30492.81	11.81
44.15	7.85	36.30	1.09	1.27	0.63	0.58	24587.08	14.64
53.96	10.79	43.16	1.29	1.51	0.66	0.51	21443.29	16.79
63.77	13.73	50.03	1.50	1.74	0.69	0.46	19416.56	18.54
73.58	17.66	55.92	1.67	1.95	0.76	0.46	19337.50	18.62

Table 10.12 Evaluated Values, D75JB15E10

Sample Name: D70JB15E15

Experiment Date: *17/03/2005*

Density= *0.790220gm/ml*

LVC (calorific Value) = *37322.30kj/kg*

Observed Values from Engine Performance Test

S. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) ^oC	Smoke Opacity %	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.2	108	171	1.9	1585
2	2	0.5	102	180	2.4	1582
3	3	0.8	98	189	2.8	1569
4	4	1.1	89	200	3	1564
5	5	1.35	85	208	3.8	1560
6	6	1.6	74	219	7	1554

Table 10.13 Observed Values from Engine Performance Test, D70JB15E15

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} *%*
14.72	1.96	12.75	0.39	0.44	0.53	1.36	50599.25	7.11
34.34	4.91	29.43	0.90	1.03	0.56	0.62	23260.15	15.48
44.15	7.85	36.30	1.09	1.27	0.58	0.53	19792.00	18.19
53.96	10.79	43.16	1.30	1.51	0.64	0.49	18384.89	19.58
63.77	13.24	50.52	1.52	1.76	0.67	0.44	16488.82	21.83
73.58	15.70	57.88	1.73	2.02	0.77	0.44	16596.09	21.69

Table 10.14 Evaluated Values, D70JB15E15

Sample Name: D75JB10E15

Experiment Date: *17/03/2005*

Density= *0.785772gm/ml*

LVC (calorific Value) = *36932.30kj/kg*

Observed Values from Engine Performance Test

S. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) ^{o}C	Smoke Opacity %	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.2	125	161	2.1	1575
2	2	0.65	115	172	2.5	1571
3	3	0.55	107	184	3	1567
4	4	0.8	94	194	4.1	1560
5	5	1.2	93	206	4.4	1557
6	6	1.3	83	221	9.3	1549

Table 10.15 Observed Values from Engine Performance Test, D75JB10E15

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} %
14.72	1.96	12.75	0.39	0.44	0.45	1.17	43290.54	8.32
34.34	6.38	27.96	0.84	0.98	0.49	0.58	21518.30	16.73
44.15	5.40	38.75	1.17	1.35	0.53	0.45	16729.27	21.52
53.96	7.85	46.11	1.38	1.61	0.60	0.44	16075.95	22.39
63.77	11.77	51.99	1.56	1.81	0.61	0.39	14437.08	24.94
73.58	12.75	60.82	1.81	2.12	0.68	0.38	13899.71	25.90

Table 10.16 Evaluated Values, D75JB10E15

Sample Name: D80JB5E15

Experiment Date: *17/03/2005*

Density= *0.782444gm/ml*

LVC (calorific Value) *=42705.71kj/kg*

Observed Values from Engine Performance Test

S. No	Load		Time Taken for 20ml of Fuel Consumption (*Seconds*)	T3 (Exhaust Gas Temperature) ^oC	Smoke Opacity %	Speed *RPM*
	Load (*Kg*)	Spring Weight (*Kg*)				
1	0	0.25	119	158	2.8	1570
2	2	0.7	109	169	2.9	1563
3	3	0.7	103	84	2.8	1560
4	4	0.9	93	199	4.2	1553
5	5	1.2	87	212	4.8	1550
6	6	1.6	83	221	7.7	1550

Table 10.17 Observed Values from Engine Performance Test, D80JB5E15

Evaluated Values

Applied Brake Load *Wt* *N*	Spring Load *S* *N*	Effective Load *(Wt-S)* *N*	Brake Power P_b *Kw*	Brake Mean Effective Pressure *bmep* *bar*	Mass Flow Rate $\dot{M}$ *Kg/hr*	Brake Specific Fuel Consumption *BSFC* *Kg/Kw-hr*	Brake Specific Energy Consumption *BSEC* *KJ/Kw-hr*	Brake Thermal Efficiency η_{Th} %
14.72	2.45	12.26	0.37	0.43	0.47	1.28	54626.91	6.59
34.34	6.87	27.47	0.83	0.96	0.52	0.63	26743.59	13.46
44.15	6.87	37.28	1.12	1.30	0.55	0.49	20893.82	17.23
53.96	8.83	45.13	1.35	1.57	0.61	0.45	19202.20	18.75
63.77	11.77	51.99	1.55	1.81	0.65	0.42	17849.93	20.17
73.58	15.70	57.88	1.72	2.02	0.68	0.39	16807.44	21.42

Table 10.18 Evaluated Values, D80JB5E15

10.7 Comparison of Performance Parameters by Using Charts

10.7.1. Brake Specific Effective Pressure (BMEP) versus Brake Power (P_b) Charts

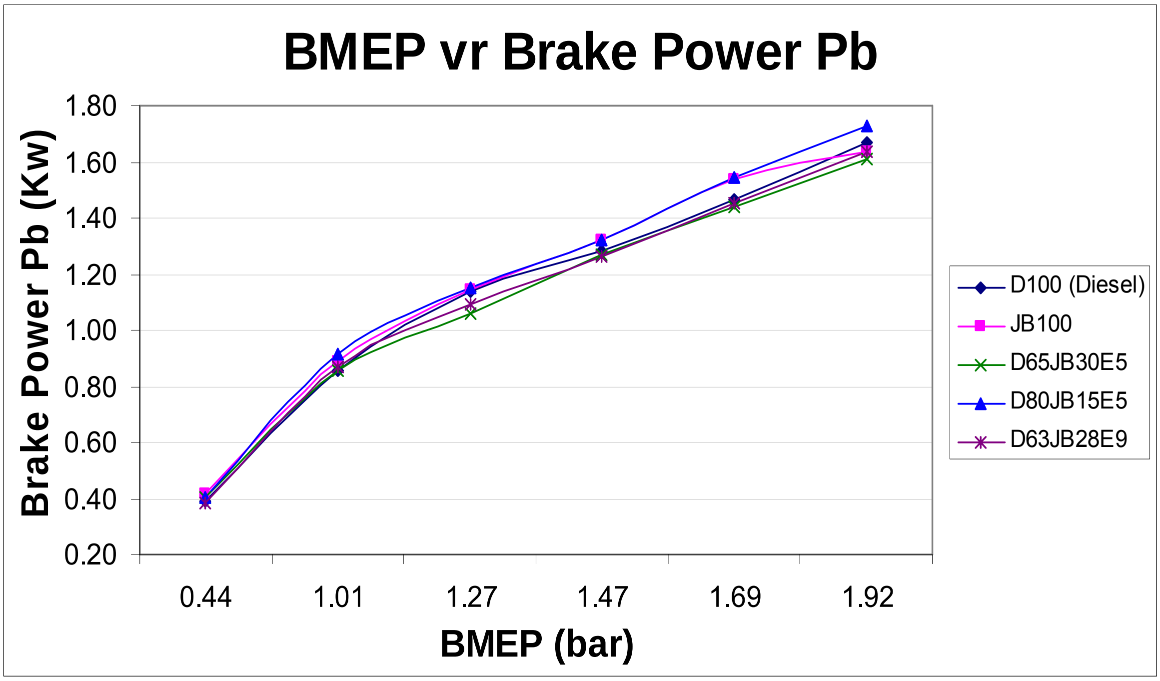


Chart 1

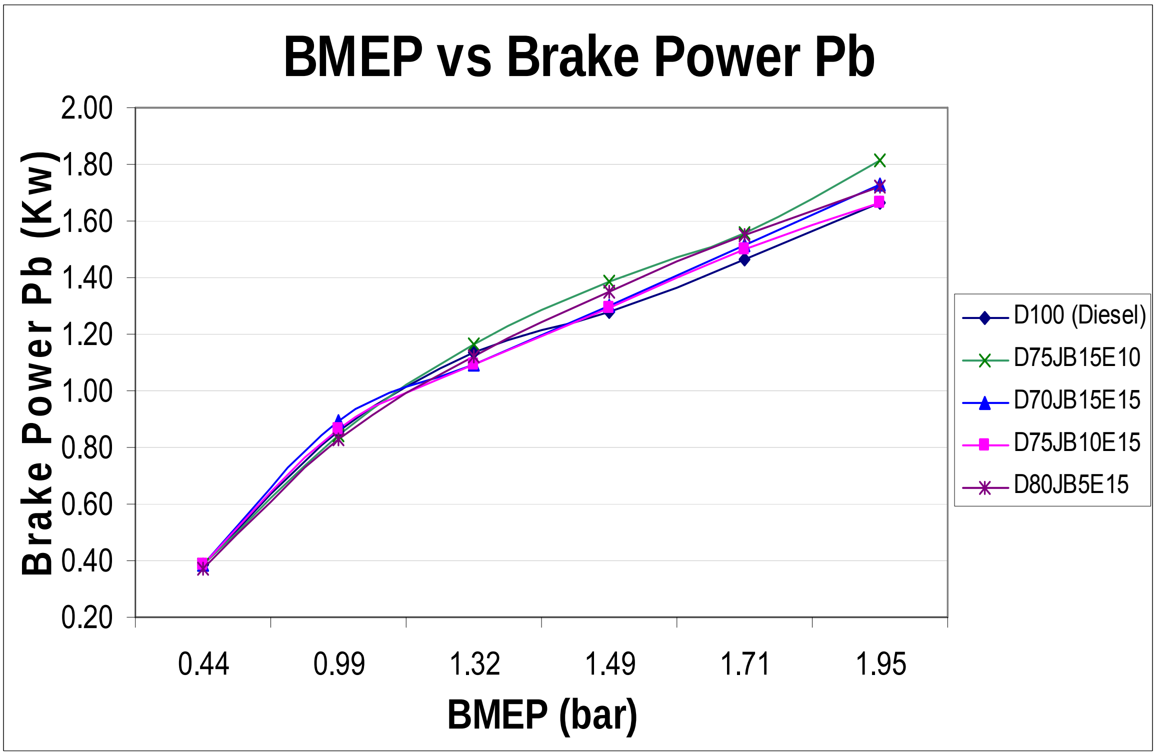


Chart 2

10.7.2. Brake Mean Effective Pressure (BMEP) versus Brake Specific Fuel Consumption (BSFC) Charts

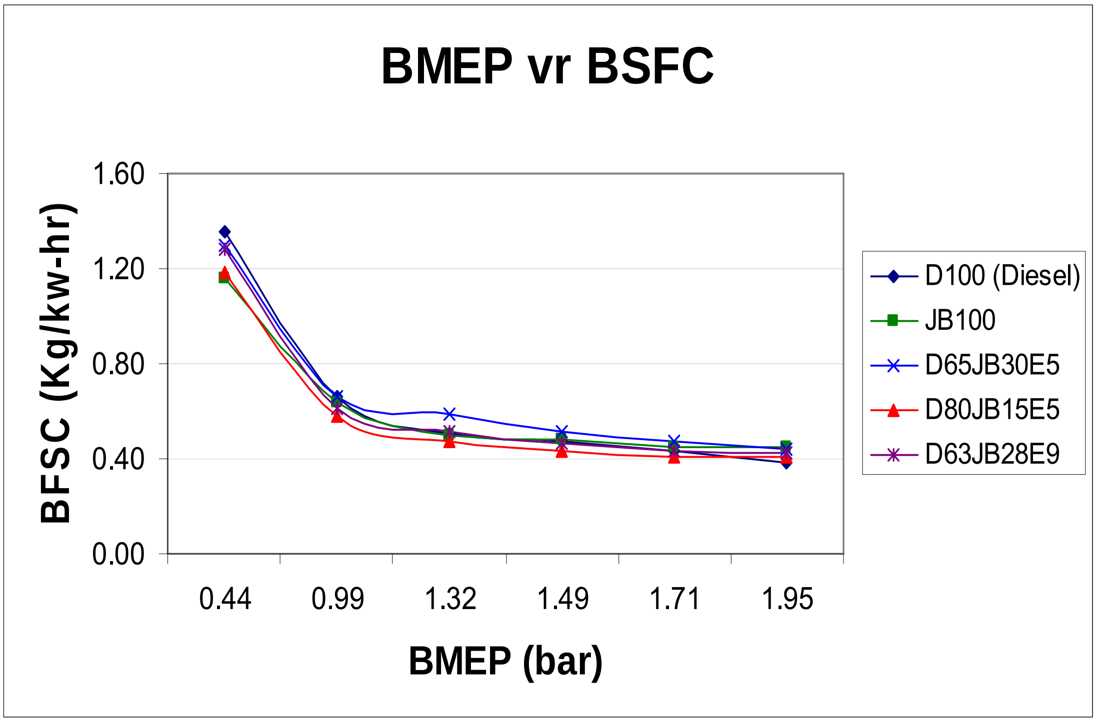


Chart 3

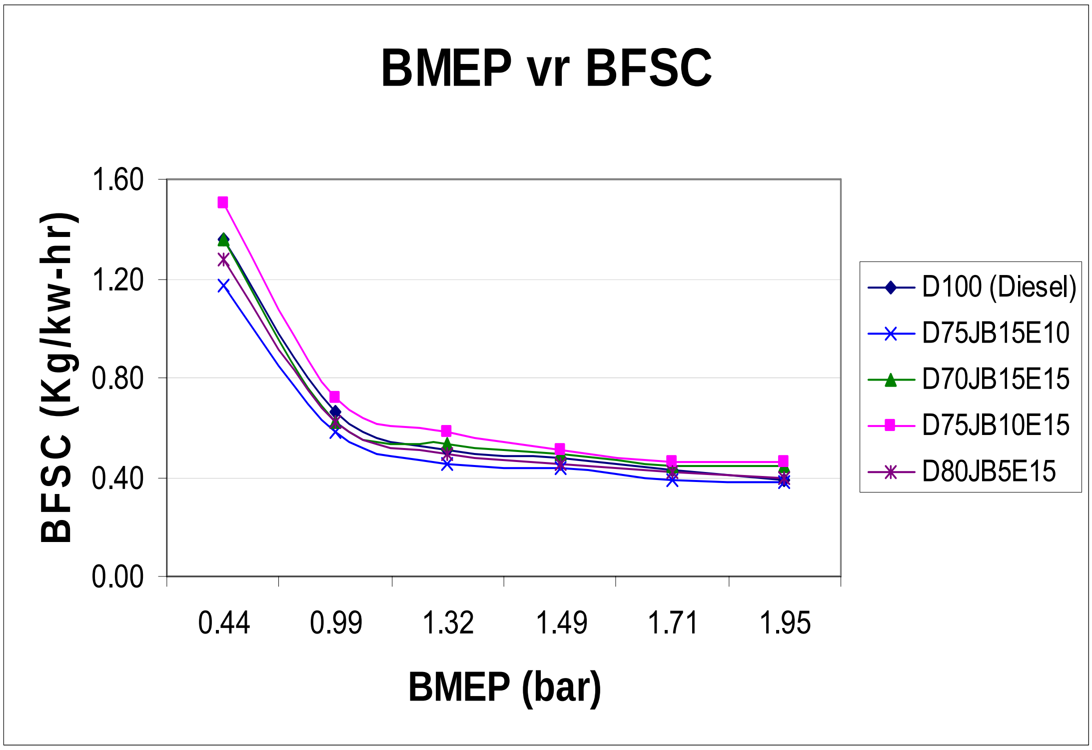


Chart 4

Discussion on Brake Mean Effective Pressure (BMEP) versus Brake Specific Fuel Consumption (BSFC) Charts

As it can be seen from both charts, the brake specific fuel consumption decreases as it goes from the low load to full load for all samples. This indicates that the compression ignition engine we have used for this experiment is more efficient at full load. In addition to this at lower load, both samples except D75JB10E15 have lower brake specific fuel consumption compared to the conventional diesel fuel. At full load condition both samples' brake specific fuel consumption converges to same point. As we can see from both charts, they resemble in all test conditions as far as this brake specific fuel consumption is concerned.

10.7.3. Brake Mean Effective Pressure (BMEP) versus Mass Flaw rate ($\dot{M}$) Charts

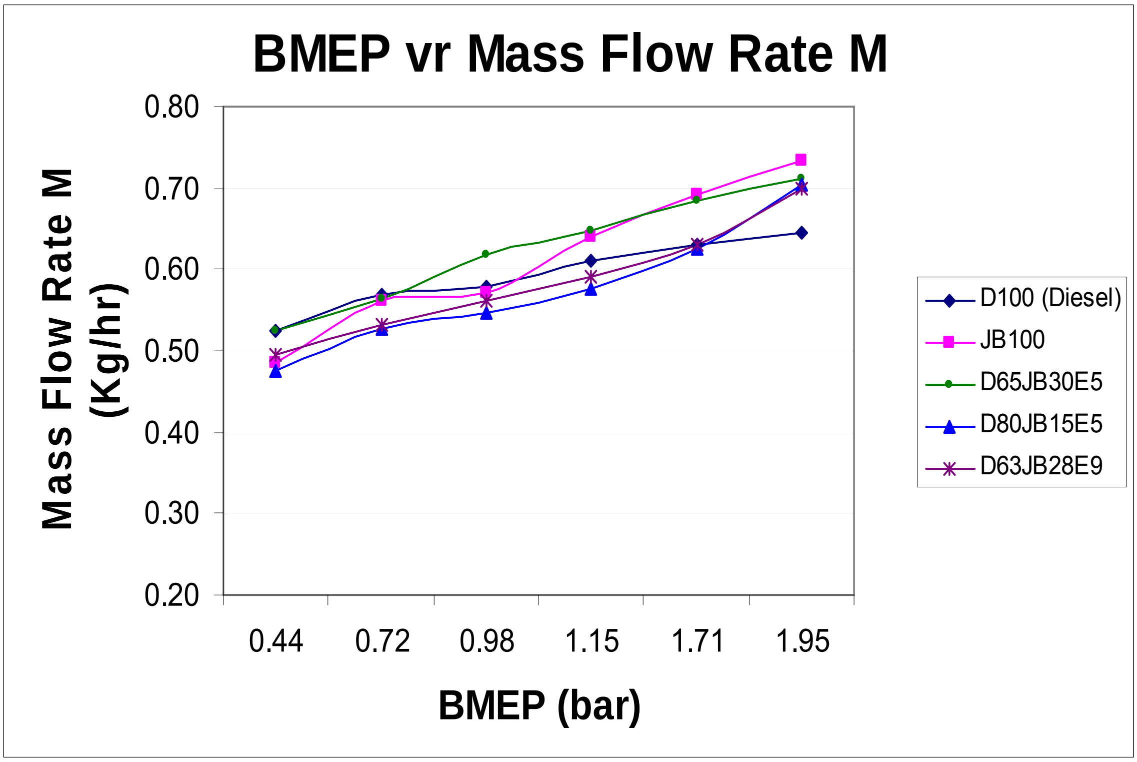


Chart 5

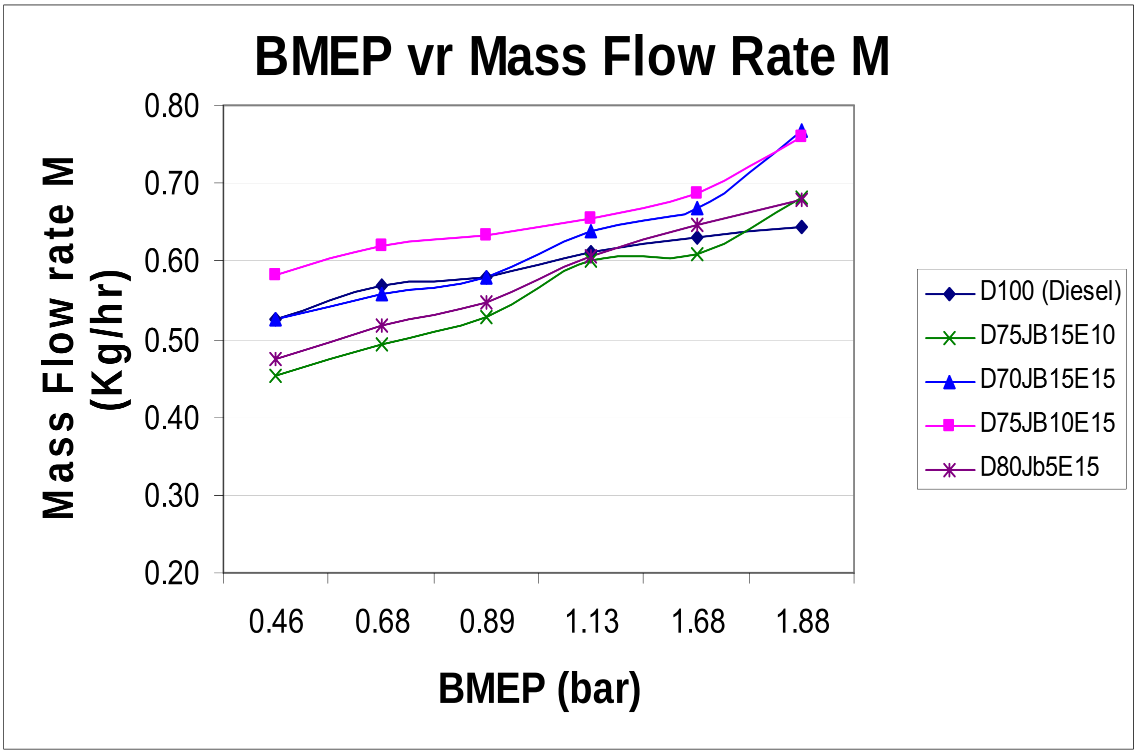


Chart 6

Discussion on Brake Mean Effective Pressure (BMEP) versus Mass Flaw rate ($\dot{M}$) Charts

These charts shows a pre mature data in which they give us the way for fuel flow rate at different engine load conditions. As we can see from both charts, the fuel flow rate of conventional diesel fuel (D100) his lower at full load and higher at no load conditions compared to rest samples, while D75JB10E15's fuel flow rate is generally greater than all test fuels at all conditions.

10.7.4. Brake Mean Effective Pressure (BMEP) versus Brake Specific Energy Consumption (BSEC) Charts

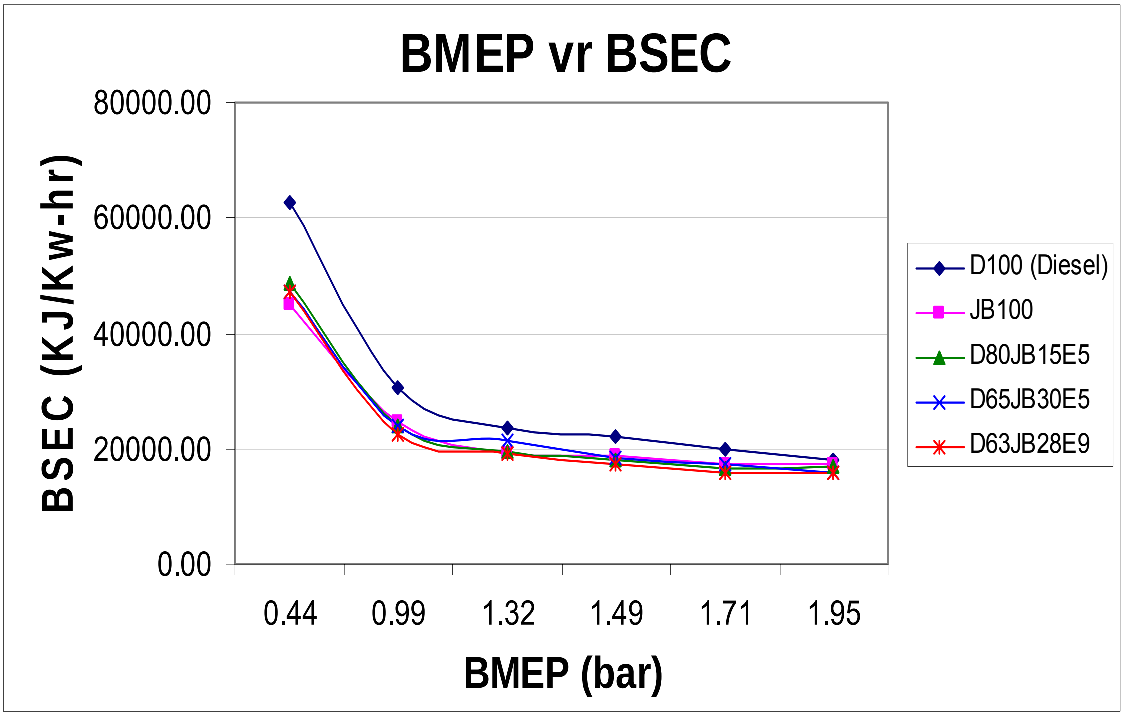


Chart 7

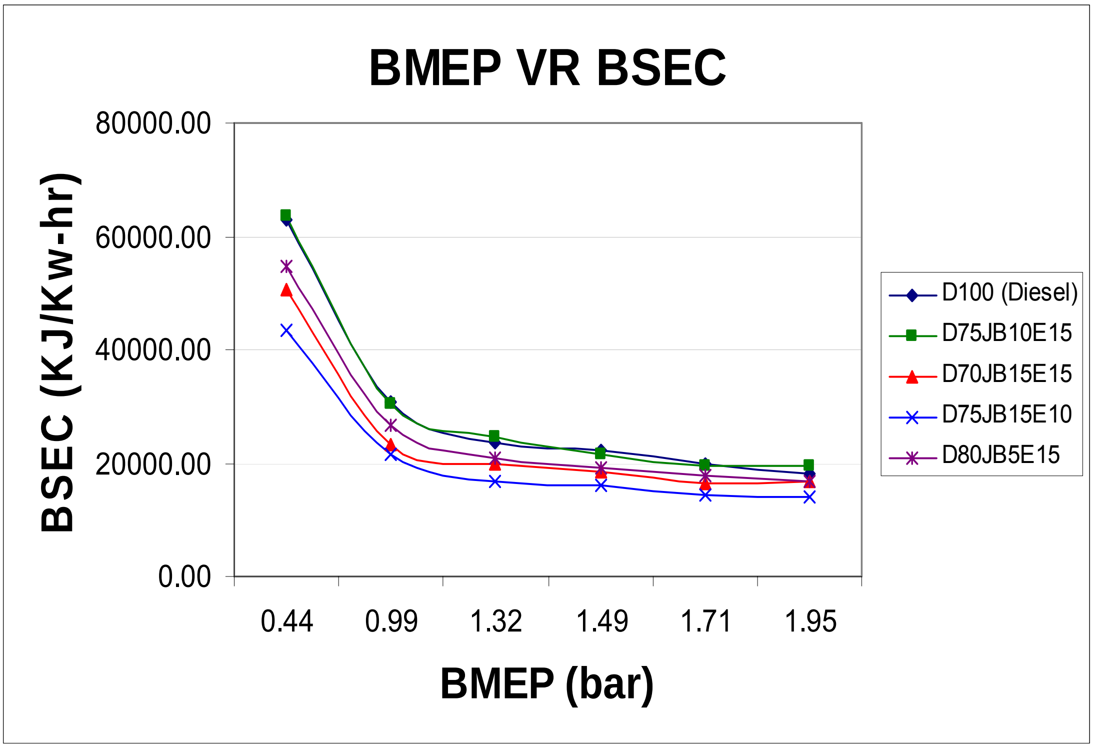


Chart 8

Discussion on Brake Mean Effective Pressure (BMEP) versus Brake Specific Energy Consumption (BSEC) Charts

Similar to the brake specific fuel consumption charts these charts also show that as the load increases the brake specific energy consumption decreases. In addition to this the brake specific fuel consumption of conventional diesel fuel (D100) and that of D75JB10E15 are higher than all samples. At low load the gap between the conventional diesel fuel (B100)'s BSEC and other samples' is greater and at the full load the difference becomes so smaller.

10.7.5. Brake Mean Effective Pressure (BMEP) versus Brake Thermal Efficiency (η_{Th}) Charts

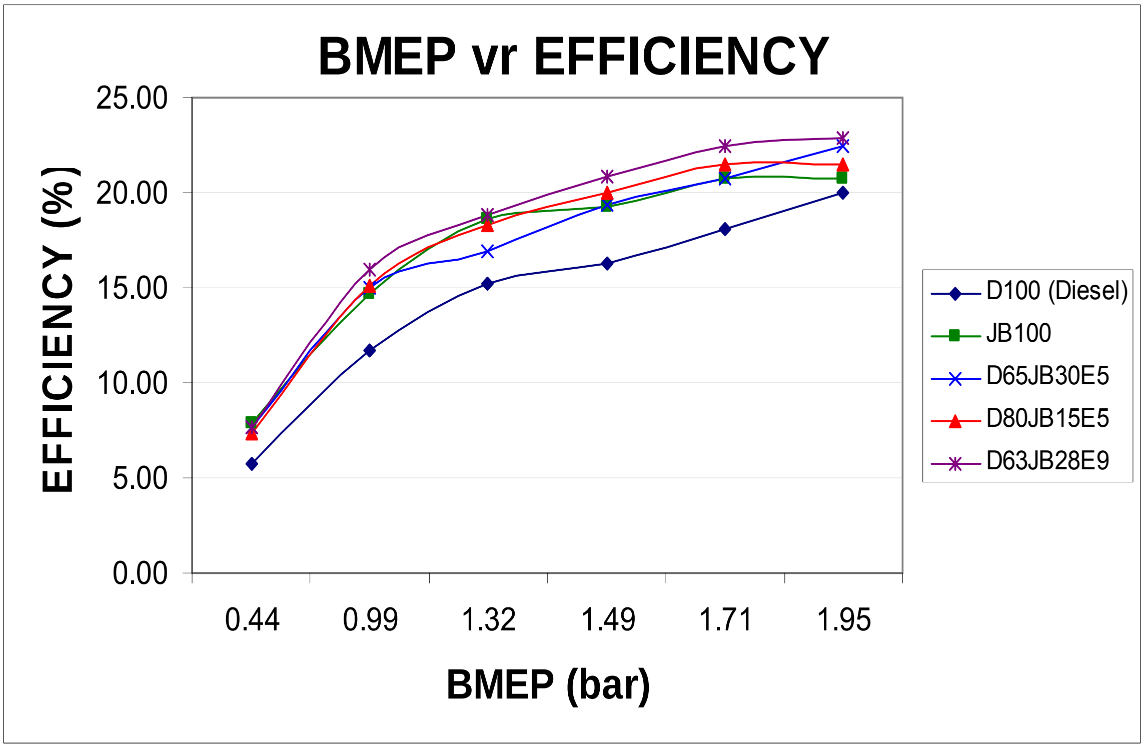


Chart 9

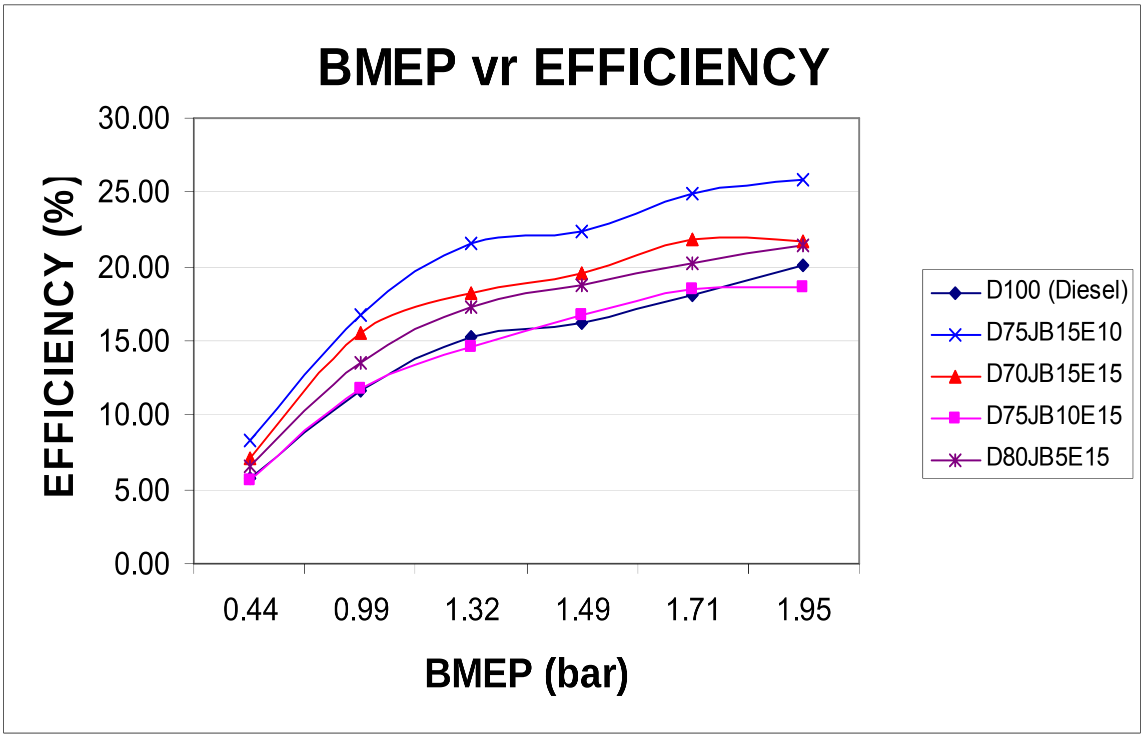


Chart 10

Discussion on Brake Mean Effective Pressure (BMEP) versus Brake Thermal Efficiency (η_{Th}) Charts

Here both charts exhibit the same patterns. The efficiency of all samples increases while the load increases to full load. This is because at low load the Brake Mean Fuel Consumption (BSFC) is higher but the power out put is lower. Therefore efficiency is lower at the low load. As it has been seen in charts 1 and 2, the brake power out put increase as the load increase, as a result there is a definite increase in efficiency for all samples as the load increases. When we come to the individual samples, the fuels D100 and D75JB10E15 exhibit lower efficiency than all samples in all load conditions. Sample D75JB15E10 exhibit wide gap in the full load condition and comparatively all other samples exhibit same mode.

10.7.6. Brake Mean Effective Pressure (BMEP) versus Smoke Opacity (%) Charts

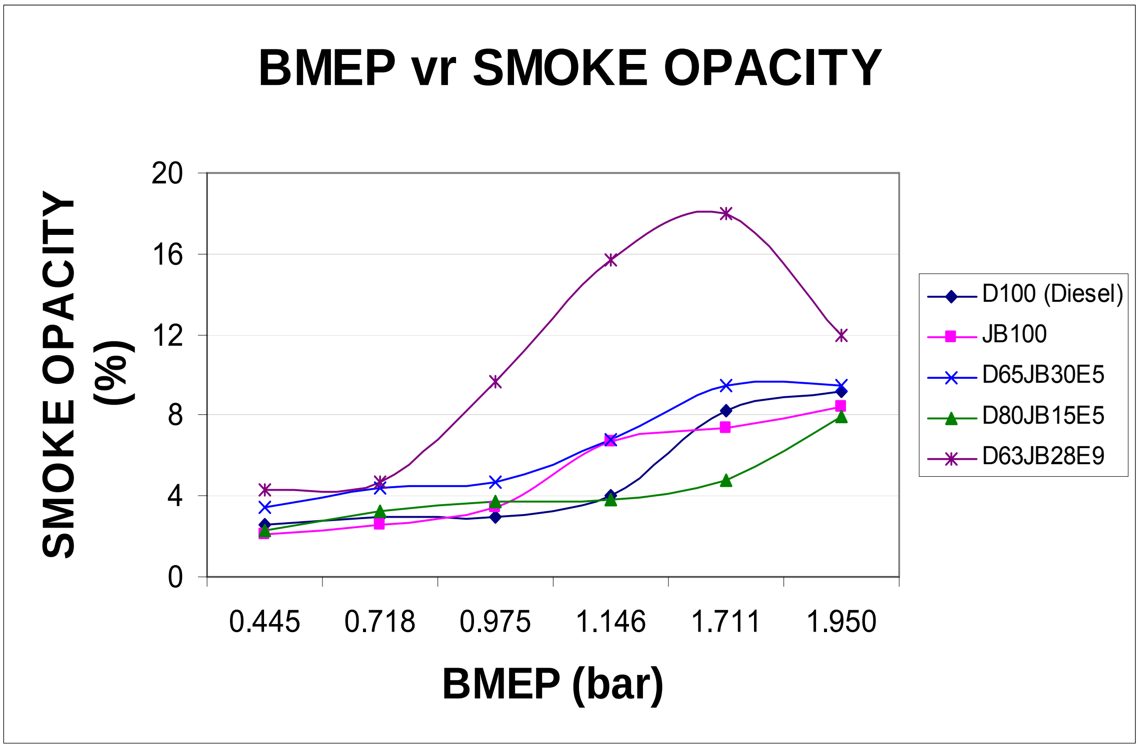


Chart 11

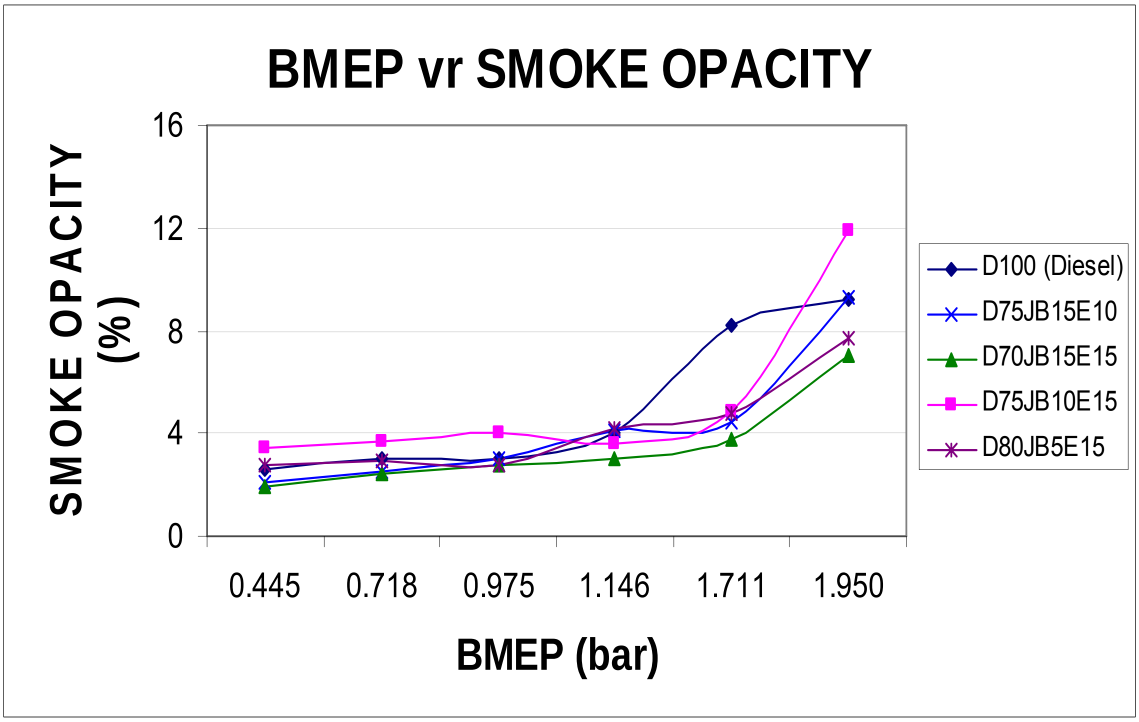


Chart 12

Discussion on Brake Mean Effective Pressure (BMEP) versus Smoke Opacity (%) Charts

As can be seen from the above two charts, all samples' brake mean effective pressure versus smoke opacity has been compared with that of the conventional diesel fuel (D100). From the result at the beginning the smoke opacity of all samples seems to be similar to that of the conventional diesel fuel. But as the load increases difference become so clear. Again referring to the same charts, D63JB28E9 seems to be exceptional with almost higher smoke opacity all over the test from low load to high load. D70JB15E15, D80JB15E5, and D75JB15E10 show lower smoke opacity all over the test. Similarly for JB100 there is an increase in smoke opacity at the middle load, but lower at the starting and high loads.

10.7.7. Brake Mean Effective Pressure (BMEP) versus Exhaust Gas Temperature (^oC) Charts

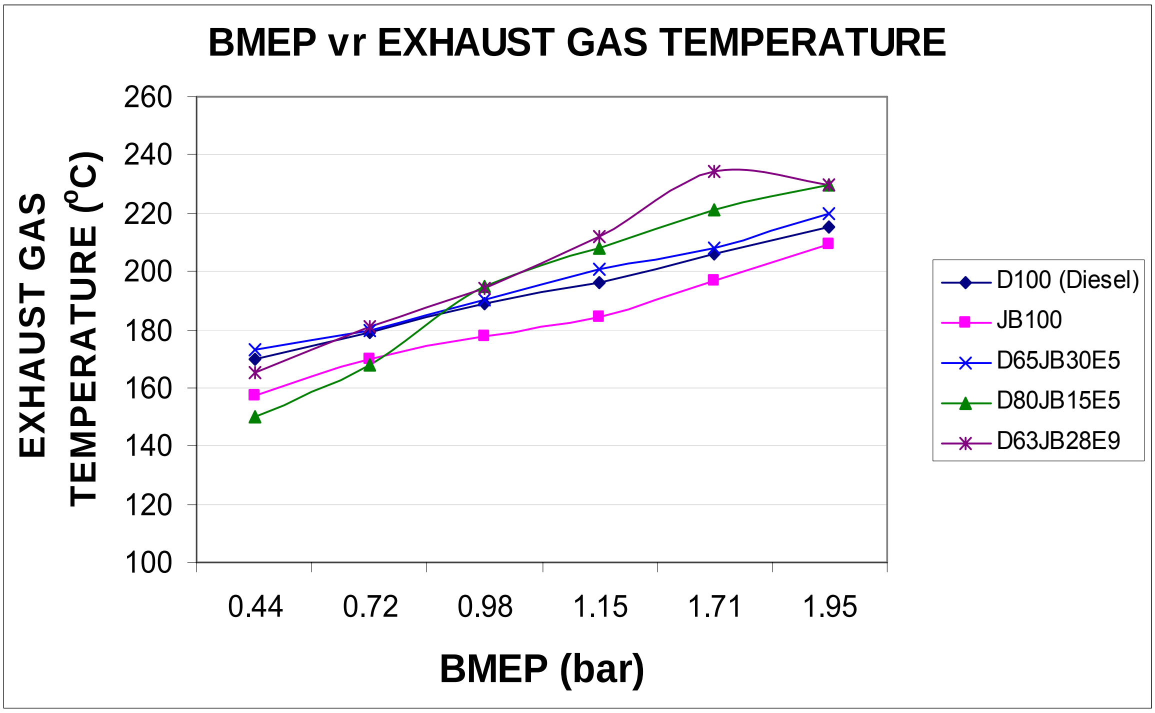


Chart 13

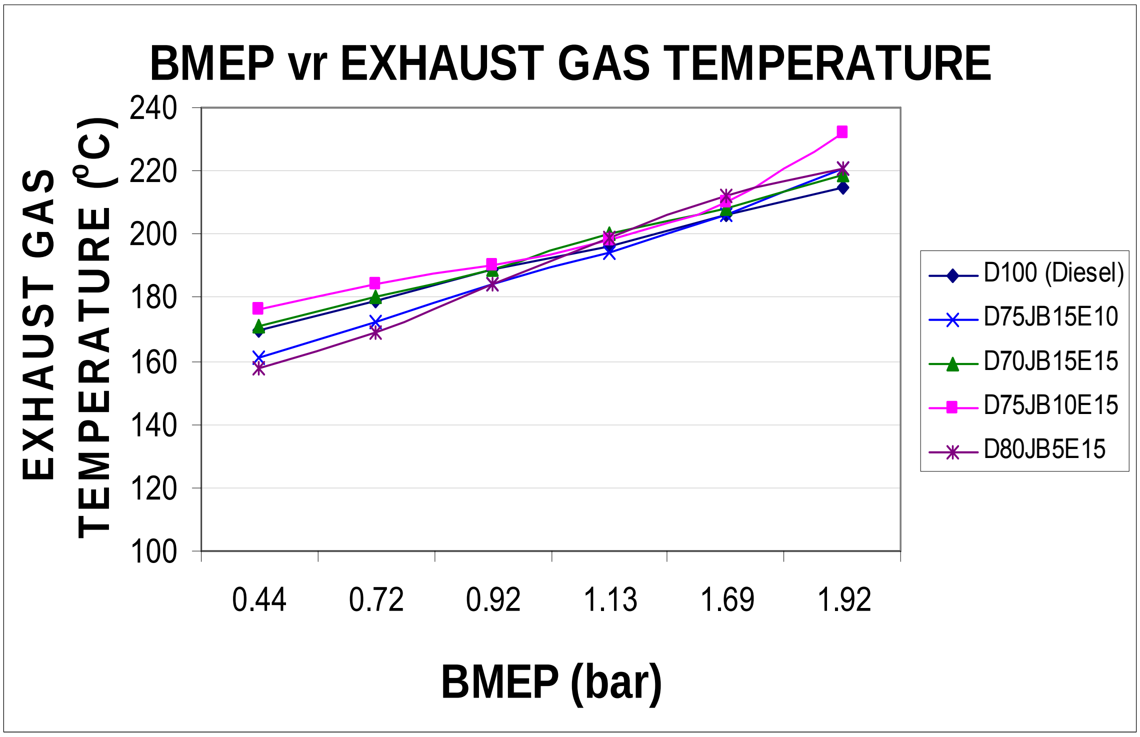


Chart 14

Discussion on Brake Mean Effective Pressure (BMEP) versus Exhaust Gas Temperature (°C) Charts

These charts show the comparison of the exhaust gas temperature of all samples with that of the conventional diesel fuel (D100). As we can see from these two charts, the maximum exhaust gas temperature has been seen with the sample D63JB28E9 and that of the minimum temperature has been seen with the samples D80JB15E5 and JB100. Generally this maximum exhaust gas temperature is associated with that of emission of nitrogen oxides.

10.7.8. Maximum Brake Thermal Efficiency versus Samples Chart

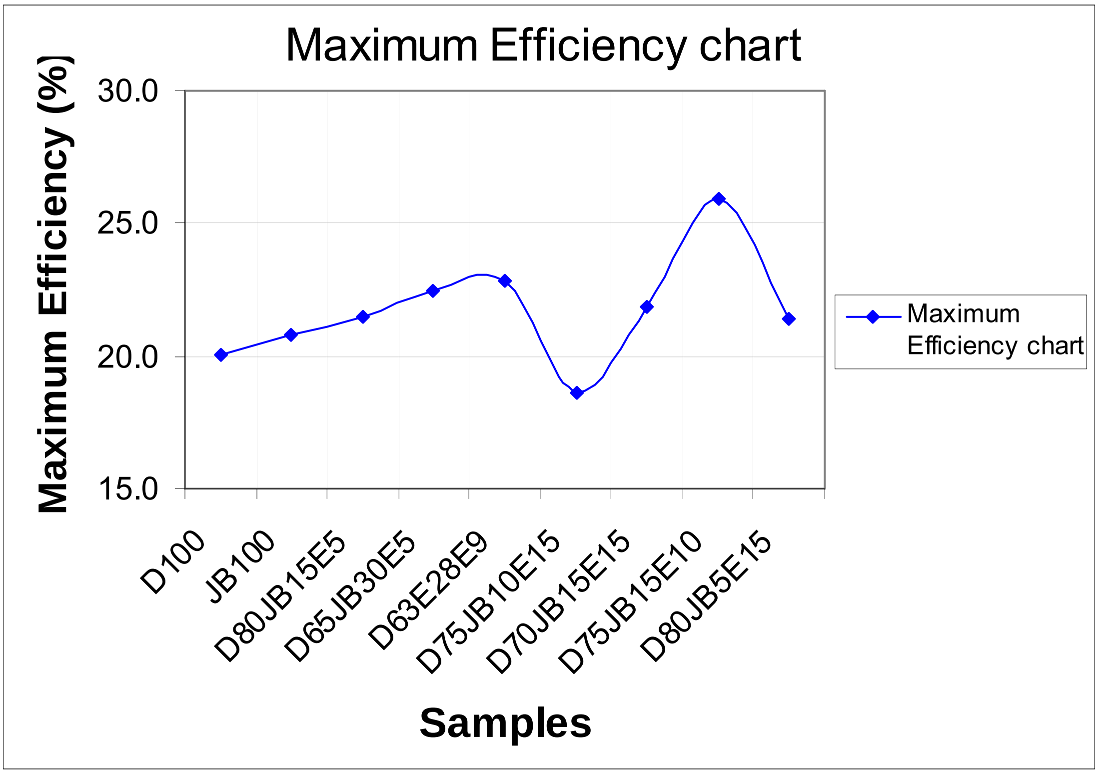


Chart 15

Discussion on the Maximum Brake Thermal Efficiency versus Samples Chart

This chart shows the comparison of maximum brake thermal efficiency of all samples. As it can be seen from the chart, there are new minima and maxima points. These points are maximum brake thermal efficiency of D75JB10E15 and D75JB15E10 respectively. As the result indicates there is an increase in the maximum brake thermal efficiency of D75JB15E10 by 5.86% compared to that of Conventional diesel fuel (D100). In addition to this the difference between the maxima and minima maximum brake thermal efficiency is 7.28%.

10.7.9. Minimum Brake Specific Energy Consumption versus Samples Chart

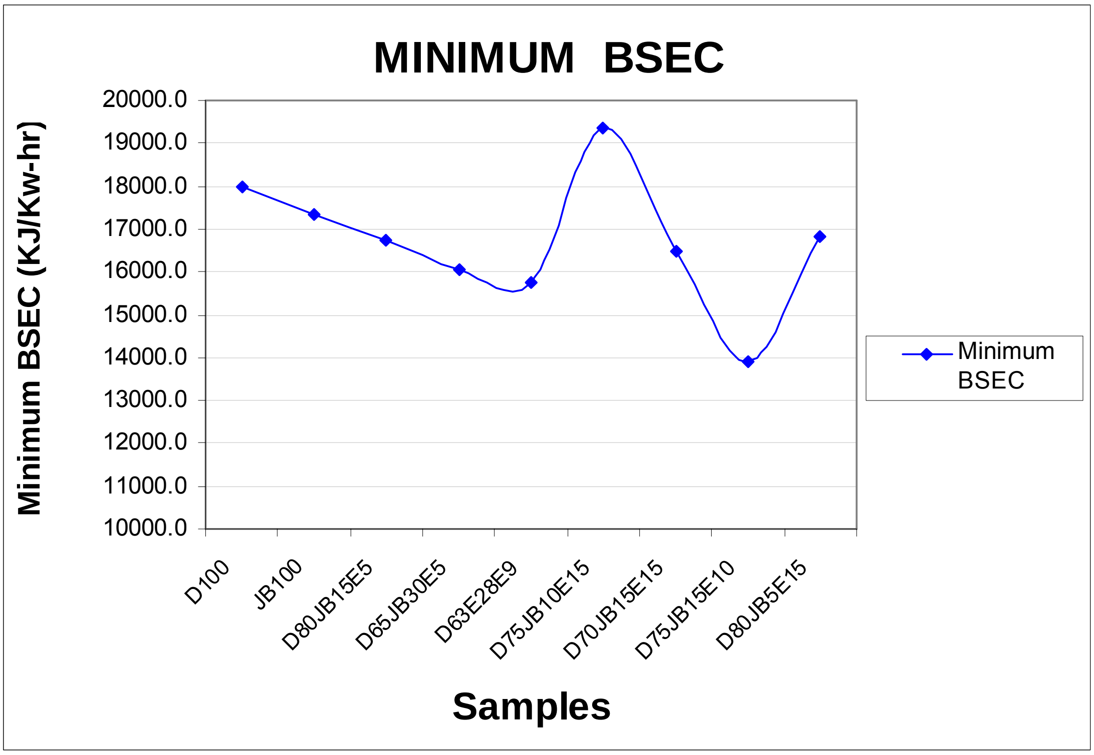


Chart 16

Discussion on the Minimum Brake Specific Energy Consumption versus Samples Chart

This chart shows the comparison of minimum brake specific energy consumption of all samples. As it can be seen from the chart, there is a clear gap between the maxima and the minima of the MBSEC. Though all samples' minimum specific energy consumption are less than conventional diesel fuel's (D100) (17968.13 KJ/Kw-hr) except D75JB10E15 again the minima lies to, similar to the maximum brake thermal efficiency, D75JB15E10 (13899.71 KJ/Kw-hr). Here the minimum brake specific energy consumption difference between the minima and conventional diesel fuel (D100) is 22.64%.

Conclusion and Recommendations

CONCLUSION

Due to depletion of fossil fuels and environmental concerns, vegetable oils and alcohols are believed to be the potential replacements of petrodiesel. But due to undesirable combustion features of vegetable oils, and material compatibility, dissolution of lubricant, and less cetane number with alcohols are some which prevented them to go long. Transesterification for vegetable oils this brings about a modification in the molecular structure, thus converting it to biodiesel, was appropriate measure. Even with this, emission of excess NO_x becomes a major problem. Therefore instead of using pure biodiesel or alcohol as substitution, blending of these fuels was taken an alternative solution at present days.

Macro-emulsion of jatropha biodiesel, ethanol and conventional diesel fuel has the potential to substitute the conventional diesel fuel. The economics of the product is controlled by the availability of the raw materials. So, the plantation of the trees and their usage should be properly synchronized to explore the benefits from this neglected plant. The important conclusions are as follows:-

1. All fuels except jatropha biodiesel have a specific gravity almost near to the specific gravity of conventional diesel #2 fuel. Pure jatropha exhibits the largest specific gravity of all the fuels, which is clear evidence that this project is necessary that by macro-emulsification of biodiesel and other fuels we can bring biodiesel to a better engine friendly fuel.
2. The calorific value of all the samples was lower than the diesel fuel. Though this case leads to the increase in brake specific fuel consumption of these fuels, due to the higher specific gravities with these sample fuels compared to D100 (conventional diesel fuel) the brake specific consumption of sample fuel D75JB15E10 is much less than that of the conventional diesel fuel.
3. The presence of oxygen in the molecular structure of ethanol and biodiesel derived from Jatropha intensifies the complete combustion phenomenon with the macro-emulsified samples.

4. As far as flash point is concerned, jatropha biodiesel exhibits the larges flash point of all samples and those samples which contain more percentage of ethanol in their composition has got lower flash point.
5. The fuel characterization tests have highlighted the striking similarity of various physical & chemical properties of macro- emulsion of biodiesel derived from Jatropha, ethanol, and conventional diesel, when compared to diesel.
6. Samples JB100, D80JB15E5, D65JB30E5, D63JB28E9, D75JB15E10, 70JB15E15, D80JB5E15 experience a better higher brake thermal efficiency compared to the conventional diesel fuel. Even there is a 5.86% higher brake thermal efficiency improvement with sample D75JB15E10 compared to D100.
7. all samples' minimum specific energy consumption are less than conventional diesel fuel's (D100) (17968.13 KJ/Kw-hr) except D75JB10E15 again the minima lies to, similar to the maximum brake thermal efficiency, D75JB15E10 (13899.71 KJ/Kw-hr). Here the minimum brake specific energy consumption difference between the minima and conventional diesel fuel (D100) is 22.64%.
8. The smoke opacity of these fuels seems to be comparable with considerably less with samples D70JB15E15, D80JB15E5, and D75JB15E10 due to complete combustion of the fuel.

RECOMMENDATIONS

This work tries to organize the advantages of the core fuels (conventional diesel fuel, jatropha biodiesel and ethanol). As it has been mentioned in the introduction part, blending is believed as a way of getting a best alternative fuel taking best characters from their core fuels. The same is true with this work, macro-emulsion of the above stated fuels. Therefore here are some recommendations in which I believe that this live make this work complete.

1. Due to the material constraint in our laboratory, the emission gases (nitrogen oxide (NO_x), carbon monoxide (CO), carbon dioxide (CO2), surfer oxide (SO_x), and poly cyclic aromatic hydrocarbon (PAH)) could not be measured in present work. Therefore an experimental evaluation of these emission gases is needed and should have to be done in the future.

2. The performance test results are from a short term running, so they can not show the consequence at the engine hardware with these samples. Therefore long term performance and endurance test to evaluate the durability of the engine with prolongs operation on these blends should be conducted so that to see the results.
3. While formulation of the samples from the core fuels, it was done by random in which it was believed that it would give best result. Therefore an extensive research should be conducted near D75JB15E10 by altering the composition of all core fuels.
4. The effect of the sample fuels on the lubricant has not been seen. Therefore a future investigation should be conducted in this regard.

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