Performance and Emission Characteristics of Diesel Engine Fuelled With Diesel-Biodiesel-Ethanol Blends

Nivesh Vijayan

Department of Mechanical Engineering, Kongu Engineering College, Erode, Tamilnadu, India-636052

Abstract: ***For the past few decades, a lot of effort has been made to reduce the dependency on petroleum fuels for power generation and transportation all over the world. Among the proposed alternative fuels, biodiesel and ethanol produced from feedstock were generally considered to be renewable. However biodiesel and ethanol cannot entirely replace petroleum-based fuels, so in order to solve this issue biofuel and diesel blend can be used on existing engines to achieve both environmental and energy benefits. Biodiesel and ethanol added to diesel fuel are known to act as an oxygenated additive, apart from its role as biofuel. In this work, commercial diesel, jatropha biodiesel and various blend of diesel-ethanol-biodiesel in varying proportions ranging from 90-80% of diesel, 0-15% of biodiesel, 0-15% of ethanol, were tested in a single cylinder, four stroke, direct injection diesel engine to investigate the performance and emission characteristics of engine under five different engine loads at a constant speed of 1500 rpm. Engine's performance was evaluated by determining the brake specific fuel consumption and brake thermal efficiency. For pollution evaluation the emissions of carbon monoxide (CO), nitrogen oxides ($NO_{x)}$ and unburned hydrocarbon (UHC) have been measured. In comparison with the commercial diesel fuel, biodiesel and DEB blends, DEB blends has an increase of specific fuel consumption, especially at lower engine loads, with maximum of 34.38%. Brake thermal efficiency of fuel blends is slightly higher than diesel. CO emission for fuel blends having 85% of diesel has shown smaller decrease at higher loads. NO_x emission has increased at higher loads for most of the fuel blends when compared to diesel fuel. Unburned hydrocarbon has reduced considerably at medium loads for most of the fuel blends. Among the various fuel blends D80B5E15 has good performance and emission characteristics when compared to diesel and other fuel blends. D80B5E15 blend would be a better replacement for commercial diesel fuel. Other blends which has good performance, has shown poor emission characteristics and vice versa.***

Keywords: Performance, Emission, Diesel, Biodiesel, Ethanol

1. Introduction

1.1General

Over past few decades there is an increase in depletion of non-renewable resource such as fossil fuels which have been much of concern. World energy consumption is expected to increase to 180,000GWh/year by 2020.Many countries have been focused on the development of alternative fuels since the shortage of fossil fuel resources dating from the global energy crisis in 1970s. In order to overcome this problem many researchers have been going on in the field of biofuels. These researchers are aiming in partial substitution of bio fuels in conventional diesel engine. Some of the biofuels are biodiesel and ethanol which can be produced from feedstocks that are generally considered to be renewable. The main criteria for using these bio fuels are their density and viscosity must be very close to the conventional diesel fuel.

Density is a fuel property which has direct effects on the engine performance characteristics. Many fuel properties such as cetane number and heating value are related to the density. Fuel density influences the efficiency of fuel atomization and combustion characteristics, because diesel fuel injection systems meters the fuel by volume. The change of fuel density will influence the engine output power due to a different mass injected fuel. The ethanol density is lower than diesel fuel density, but higher than biodiesel density.

Viscosity is one of the most important fuel properties, because it affects the operating conditions of injection systems, especially at low temperatures when fuel fluidity is reduced. Alsoviscosity affects fuel lubricating capacity, ensuring fuel pumps and injector's lubrication.

Biodiesel is a form of diesel fuel manufactured from vegetable oils, animal fatswhich consist of long-chain alkyl esters. The biodiesel density at 15^0C is between 860 and 894 kg/$m^{3.}$ The biodiesel viscosity at 40^0C is between 3.3 and 5.2 mm^2/s. When biodiesel is burned in diesel engines, there is substantial reduction in unburned hydrocarbon, carbon monoxide and particulate emissions. Biodiesel has properties similar to those of traditional fossil fuel such that it can be substituted for diesel fuel with little or no engine modification. Studies clearly indicate that the use of biodiesel may potentially reduce the dependence on petroleum diesel fuel. B15 which is a blend of 85% of commercial diesel and 15% of biodiesel has become the most popular biodiesel fuel blend used and this blend level has been studied in different countries.

Biodiesel has various advantages such as it is non toxic, it degrades four times faster than diesel, pure biodiesel degrades 85-88% in water, the higher flash point makes the storage safer, produced in domestic, renewable energy supply, improves air quality and biodiesel produce less green house effect than diesel. It also has some disadvantages which are light decrease in fuel economy on energy basis, density and viscosity is higher but this can be rectified by blending with ethanol and diesel and is highly recommended in cold environment.

Ethanol is an alcohol-based fuel made by fermenting and distilling starch crops, such as sugarcane, cassava, corn. It can also be made from "cellulosic biomass" such as trees and grasses. Ethanol is a low cost oxygenate with high oxygen content (35%) that has been used in ethanol–diesel fuel blends. The weight percent of oxygen content in fuel is the most important factor than the other properties such as chemical structure or volatility.The oxygen content of ethanol is much higher than that of biodiesel. Including ethanol in biodiesel and diesel blends can increase the fuel oxygen level.The use of ethanol in biodiesel-diesel fuel blend can also yield significant reduction of emissions in diesel engines which in turn reduce greenhouse gas effect. It also aids in complete combustion of fuels in engine. The some of the advantages of ethanol are domestically produced, reducing use of imported petroleum, lower emissions of air pollutants, more resistant to engine knock,added vehicle cost is very small. It also has some disadvantages like only can be used in flex-fuel vehicles, lower energy content, resulting in fewer miles per gallon, limited availability, currently expensive to produce.

The main methods of using ethanol in CI engines are described as follows the alcohol-diesel fuel blend, alcohol fumigation, alcohol-diesel fuel emulsion with emulsifier and dual injection. However, there are many technical barriers to the direct use of ethanol in diesel fuel due to their vast difference in their viscosity and density of ethanol, low cetane number of ethanol, low flash point temperature and poor solubility of ethanol in diesel fuel in cold weather. In fact, diesel engines cannot operate normally on ethanol–diesel blend without special additives.Due to huge variance in the properties of ethanol compare to conventional diesel fuel it cannot be directly used in CI engine. So in order to solve this problem, biodiesel and diesel are mixed with ethanol in varying proportions.

On the other hand, biodiesel apart from its role of biofuels it acts as a good emulsifier for ethanol. Solubility and stability of ethanol in diesel-biodiesel fuel blends will be greatly improved without other additives. Additionally, the poor cold flow properties of biodiesel are a barrier to use of biodiesel and diesel fuel blends in cold weather. Ethanol might be expected to improve low temperature flow properties. It is assumed that high cetane number of biodiesel can compensate for the cetane number decrease caused by the presence of ethanol in fuel. Taking these facts into account it was assumed that blends of biodiesel, ethanol, and diesel fuel may improve some properties compared with biodiesel-diesel blends and ethanol-diesel blends.

In the current study, we have investigated the engine performance and emissions characteristics with 10 different blends of petroleum diesel fuel, jatropha biodiesel, ethanol on a diesel engine. Brake specific fuel consumption (BSFC), nitrogenoxygen (NO_x), carbonmonoxide (CO), and total unburned hydrocarbon (TUBHC) were investigated and among the various 10 different fuel blends and the best mixture is identified.

1.2 Jatropha in India

Every country has its own source for alternate fuel. The biodiesel market has already taken shape in the U.S.A and European countries. In these countries, soybean has been the principle source. Using soybean in India was not feasible. Besides being grown in India, jatropha is also being grown in some parts of Africa. There are more 60 known varieties of jatropha out of which only 17 are found in India. Finding an alternative source of fuel was not easy for India until recently when the IOC came up with a suggestion to use jatropha oil as an alternative to the diesel fuel.

The success of jatropha an alternate could be attributed to some important facts like:

- Indian climatic conditions are best for its growth.
- Requires least management
- Can survive long Drought
- It can be a boon for the Indian farmers who are all suffering under severe drought condition.

1.3 Yield Factor

Under normal condition,jatropha cultivation gives a yield of 2 tons per hectare. This yield of seed would yield 25-30% of oil. That is 100kg of jatropha seeds would yield 20-30kg of jatropha oil.

1.4 Cost Factor

The cost of 1 kg of jatropha seed comes up to ₹ 6 .After extracting oil, the cost of one litre of oil comes upto ₹ 22 per litre. After carrying out the trans esterification process, the cost of one litre of biodiesel comes upto ₹ 32 per litre. If mass production is taken up, the cost of the same jatropha biodiesel will comes down to ₹ 25 per litre.

2. Literature Survey

The demand for energy around the world is increasing, specifically the demand for petroleum fuels. Facing the increasing consumption of petroleum fuels and the increasing stringent emission regulations, biofuels such as ethanol and biodiesel, have been explored to reduce fuel consumption and engine emission.

2.1 Biodiesel as a Fuel

JinlinXue, et al.,(2010)[4] have discussed on title “Effect of biodiesel on engine performances and emissions”. In this reports, the effect of biodiesel on engine power, economy, durability and emissions including regulated and non-regulated emissions and the corresponding effect factors were surveyed and analyzed in detail. Biodiesel, as an alternative fuel of diesel, is described as fatty acid methyl or ethyl esters from vegetable oils or animal fats. It is renewable, biodegradable and oxygenated. The use of biodiesel leads to the substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss, the increase in fuel consumption and the increase in NOx emission on conventional diesel engines with no or fewer modification. Higher viscosity of biodiesel, which enhances fuel spray penetration, and thus improves air–fuel mixing, is used to explain the recovery in torque and power for biodiesel related to diesel in some literatures. However, a few authors thought that the higher viscosity results in the power losses, because the high erviscosity decreases combustion efficiency due to bad fuel injection atomization. High lubricity of biodiesel might result in the reduced friction loss and thus improve the brake effective power. An additive used to improve ignition and combustion performances of biodiesel is advantageous to power recovery of biodiesel engine. The result shows that the use of biodiesel will lead to loss in engine power mainly due to the reduction in heating value of biodiesel compared to diesel, but there exists power recovery for biodiesel engine as the result of an increase in biodiesel fuel consumption. And the emission result shows that the NOx emissions will increase when using biodiesel. This increase is mainly due to higher oxygen content for biodiesel. Moreover, the cetane number and different injection characteristics also have an impact on NOx emissions for biodiesel. It is accepted commonly that CO emissions reduce when using biodiesel due to the higher oxygen content and the lower carbon to hydrogen ratio in biodiesel compared to diesel and then the result also shows that HC emissions were reduced when biodiesel is fueled instead of diesel.

2.2 Ethanol –Diesel Blend as a Fuel

MaginLapuerta, et al., (2007) [7] have discussed on title “Stability of diesel- bioethanol blends for use in diesel engines”. Bioethanol is an attractive fuel due to its renewable origin and its oxygen content, but it is unable to be used directly in diesel engines. Although biodiesel can be produced with bio ethanol through ethanolysis, direct blending of ethanol and diesel fuel are called as e-diesel, has at least the same potential to reduce emission, despite their much lower production cost. Bioethanol being a biofuel has various advantages in comparison with biodiesel as a component of diesel blends to be used in diesel engines because its production is simpler and cheaper than biodiesel, it is 100% renewable- with life-cycle renewability efficiency near 50%, while biodiesel is just 89% renewable, its oxygen concentration is higher and its potential for emission reduction is also higher. The main drawback is that ethanol has lower viscosity and lubricity, reduced ignitability, low cetane number, higher volatility, which may lead to increased unburned hydrocarbons emissions, and lower miscibility, which may cause phase separation. In front of these difficulties, the use of cosolvent additives has recovered the potential of these as a promising fuel for automotive diesel engines. Different studies have proved that water free ethanol has good miscibility with diesel fuel at room temperature in warm countries. In this paper the conditions in which the e-diesel blends are stable have been studied. The stability of blends bioethanol-diesel has been studied, aiming to provide essential information previous to their use in diesel engines. In this paper its concluded that presence of water in the blends favours the separation of the ethanol phase, as the water content increase the solubility decrease whereas the presence of additive generate the opposite effect and when the temperature of the blend increase it becomes stable and the solubility of ethanol in diesel fuel increases and use of stability additives may increase either the range of ethanol content in the blends.

De-gang Li, et al., (2007) [1] have discussed on the title “Physico-chemical properties of ethanol–diesel blend fuel and its effect on performance and emissions of diesel engines”. The purpose of this project is to find the optimum percentage of ethanol that gives simultaneously better performance and lower emissions. Ethanol is a renewable energy, it can be made from many raw materials such as sugarcane, molasses, cassava, waste biomass materials, sorghum, corn, barley, sugar beets, etc., by using already improved and demonstrated technologies. The objective of this work was to find the maximum possible and optimum replacement of diesel fuel by ethanol and compare the performance of diesel engine fueled with ethanol–diesel blended fuels. The ethanol used in the tests was limited to essentially anhydrous ethanol because other kinds of ethanol are not soluble or have very limited solubility in the vast majority of diesel fuels. The solubility of ethanol in diesel fuel is dependent on the hydrocarbon composition, wax content and ambient temperature of the diesel fuel. This solubility is also dependent on the water content of the blend fuels. To overcome this problem, a solubilizer is indispensable in ethanol–diesel blended fuel. The experiments were conducted using 0% (neat diesel fuel), 5% (E5–D), 10% (E10–D), 15% (E15–D), and 20% (E20–D) ethanol–diesel blended fuels. The results indicate that the brake specific fuel consumption and brake thermal efficiency increased with an increase of ethanol contents in the blended fuel at overall operating conditions, smoke emissions decreased with ethanol–diesel blended fuel, especially with E10–D and E15–D. CO emissions increased at low and medium loads, but decreased at large and full loads when the engine is fueled with ethanol–diesel blend fuel. On the contrary, NOx emission decreased at low and medium loads, but increased at large and full loads when the engine is fueled with ethanol–diesel blend fuel. THC increased at various loads at different speed for ethanol–diesel blend fuel.

2.3 Biodiesel-Ethanol Blend as Fuel

Lei Zhu, et al., (2011)[6] have discussed onthe title “Combustion, performance and emission characteristics of a DI diesel engine fueled with ethanol–biodiesel blends”. In this study, Euro V diesel fuel, biodiesel, and ethanol–biodiesel blends (BE) were tested in a 4-cylinderdirect-injection diesel engine to investigate the combustion, performance and emission characteristics ofthe engine. In this literature it is stated that biodiesel which is an alternative diesel fuel consisting of alkyl monoesters of fatty acids derived from vegetable oil or animal fats. Because of its reproducibility, nontoxicity, and sulfur-free property, a considerable amount of recent research has focused on the use of biodiesel on diesel engines. Furthermore, due to its similar physical properties to diesel fuel, there is no need to modify the engine when the engine is fueled with its blends. In comparison with conventional diesel fuels, the fuel-borne oxygen in biodiesel may promote more complete combustion and thus reduce particulate matter (PM), carbon monoxide (CO)and total hydrocarbons (THC) in compression-ignition engine, while increase nitrogen oxides

(NOx). According to a review on emission data for heavy-duty engines published by EPA (Environmental Protection Agency of USA), from diesel to B20 (20%biodiesel by volume), CO, HC, and PM decreased by 13%, 20% and20% respectively, while NOx emission increased by 4% on average. The result shows that BSFC decreases with an increase in engine load. For biodiesel and the BE blends, the BSFC are higher than that of Euro V diesel fuel. For each engine load, the BSFC increases with the proportion of ethanol in the blended fuel. The increase of BSFC is mainly due to the lower calorific values of biodiesel and ethanol compared with that of Euro V diesel fuel. It is concluded that the BE blends have lower BSNOx and higher$BSNO_2$ emissions, compared with biodiesel. With the increase of ethanol in the blended fuel, the BSNOx emissions decrease and the BSNO2 emissions increase at low engine loads, while there isno significant difference among the BE blends at medium and high engine loads. The BSPM emissions of the BE blends decrease obviously, compared with Euro V diesel fuel and biodiesel. Compared with the diesel fuel, biodiesel gives lower particulate emission but higher NOx emissions. However, the BE blends give slower particulate emission as well as lower NOx emission.

2.4 Biodiesel-Diesel-Ethanol Blend as a Fuel

Istvan Barabas, et al., (2010)[3] have discussed on the title “Performance and emission characteristics of a CI engine fueled with diesel–biodiesel–bioethanol blends”. The paper presents the experimental results obtained concerning performances and pollution of a diesel engine fueled with diesel–biodiesel–ethanol blends compared with diesel fuel in laboratory tests. The main properties of the researched fuels are presented within this paper, in comparison with classical dieselfuel (chemical composition, density, kinematic viscosity, cold filter plugging point, flash point). Engine performance was evaluated by determining the brake specific fuel consumption and brake thermal efficiency. For pollution evaluation the emissions of CO, CO_2,NO_x, and HC have been evaluated. The main oxygenated organic compounds are biodiesel, alcohols and ester. The use of biodiesel for partial or total diesel fuel substitution does not constitute a novelty, because the vegetable oils have been proposed as compression ignition (CI) engine’s fuel since 1895.The main advantages of using biodiesel for CI engines are as follows biodiesel is non-toxic, biodiesel degrades four times faster than diesel, pure biodiesel degrades 85–88% in water, the higher flash point makes the storage safer, provides a domestic, renewable energy supply, biodiesel does not produce greenhouse effects, because the balance between the amount of CO_2emissionsand the amount of CO2 absorbed by the plants producing vegetable oil is equal, biodiesel can be used directly in compression ignition engines with no substantial modifications of the engine. Nevertheless, biodiesel use has also a number of disadvantages like light decrease in fuel economy on energy basics (about 10%for pure biodiesel), density is higher than that of diesel fuel in cold weather, but may need to use blends in sub-freezing conditions, more expensive due to less production of vegetable oil. The use of biodiesel can be considered as an alternative for CI engines, but some of its properties, as density and viscosity, are higher than those of classic diesel fuel. These properties can be ameliorated by adding bioethanol which on one hand allows the biofuel’s level-increase in the whole blend, and on the other hand brings the mentioned properties in standard diesel fuel prescribed limits. The main methods of using ethanol in CI enginesare described inthe alcohol–diesel fuel blend; alcohol fumigation; alcohol–diesel fuel emulsion with emulsifier; and dualinjection.

Density is a fuel-property which has direct effects on the engine performance characteristics. Many fuel properties such as cetane number and heating value are related to the density. Fuel density influences the efficiency of fuel atomization and combustion characteristics. Viscosity is one of the most important fuel properties, because it affects the operating conditions of injection systems, especially at low temperatures when fuel fluidity is reduced. Also, viscosity affects fuel lubricating capacity, ensuring fuel pumps and injectors lubrication. The fuel blends have been chosen taking into consideration the previous research recommendations from the specialized literature and on the basis of some researches of a grant‘‘ Researches aiming partial substitution of diesel fuels for diesel engine with diesel–biodiesel–ethanol mixtures” the main criteria being that their density and viscosity should be very close to that of classical diesel fuel, having a corresponding lubricating capacity at the same time. Due to the used biofuels’ lower heating value compared to that of diesel fuel, the engine’s performances decrease, especially at low engine loads.CO emission decrease especially at high loads with maximum of 59%.NO_x emission is slightly increased especially at partial and high loads. HC and Smoke emission decrease at all engine loads. The presented experimental results demonstrate the viability of diesel–biodiesel–ethanol blends use for CI engines’ fueling.

Hu Chen, et al., (2006)[2] have discussed on the title “Study on combustion characteristics and PM emission of diesel engines using ester–ethanol–diesel blended fuels”. In this study, one kind of vegetable methyl ester was added to ethanol–diesel fuel to prevent the separation of ethanol from diesel thus the ethanol percentage can be up to 30% in volume. The solubility of the ethanol and diesel mixture is dependent on the hydrocarbon composition of the diesel fuel, wax content, and ambient temperature. The water content of the blended fuels also affects the solubility. It is difficult to dissolve much ethanol into diesel directly. In addition, ester had a higher cetane number and viscosity than ethanol and diesel, so it could partly restore the properties of the ester–ethanol– diesel blended fuels to meet the diesel engine requirement. More attention was paid to smoke emission, PM emission, and the effects of ethanol on the PM component Dry soot (DS), soluble organic fraction (SOF), and sulfate through engine tests using ester–ethanol–diesel fuels. Also,to understand the effects of ethanol on combustion, flame development and soot formation in diesel engines, the combustion process was observed and recorded in an optical engine bydirect photography. On the other hand, the evaporation latent heat of the ethanol is much higher than that of diesel, thus reducing the temperature in the chamber during the mixture formation, in this case it has no benefit for HC reduction. It is concluded Using the ester–ethanol–diesel blend, smoke can be reduced significantly. The more ethanol added to the fuel, the more smoke reduction achieved. PM also can be reduced with the ethanol in the blended fuels, but the PM reduction is not as efficient as the smoke. And with increasing ethanol in the blends, the ignition time is delayed, the combustion duration is shortened, and flame luminosity is decreased and ethanol can also suppress soot formation in fuel rich regions.

Prommes Kwanchareon, et al.,(2006)[8] have discussed on the title "Solubility of a diesel–biodiesel–ethanol blend, its fuel properties, and its emission characteristics from diesel engine".In this work, the phase diagram of diesel–biodiesel–ethanol blends at different purities of ethanol and different temperatures are studied. Fuel properties (such as density, heat of combustion, cetane number, flash point and pour point) of the selected blends and their emissions performance in a diesel engine were examined and compared to those of base diesel. It was found that the fuel properties were close to the standard limit for diesel fuel however the flash point of blends containing ethanol was quite different from that of conventional diesel. The high cetane value of biodiesel could compensate for the decrease of the cetane number of the blends caused by the presence of ethanol. The heating value of the blends containing lower than 10% ethanol was not significantly different from that of diesel. The result shows that the effect of ethanol concentration on phase stability was studied by using three purities of ethanol (95%, 99.5%, and 99.9%) at room temperature. And the results are represented in the three phase diagrams of diesel, biodiesel, and ethanol components. The phase behavior of the diesel–biodiesel and95% ethanol system at room temperature were shown. In case of the 95% ethanol, the diesel and the ethanol with 95% purity were insoluble because 95% ethanol, also called hydrousethanol, has 5% water in its mixture. Due to the high polarity of water, this amount of water enhances the polar part in anethanol molecule. Consequently, diesel, which is a non-pola rmolecule, cannot be compatible with ethanol 95% purity. In the case of 99.5% ethanol, the inter solubility of the three-components was not limited. They could be mixed into a homogeneous solution at any ratio. Because 99.5% ethanol has lower water content than that of 95% ethanol, it is more soluble in diesel fuel than 95% ethanol. The same result was shown for the 99.9% ethanol as for the 99.5% ethanol. It is stated that 99.9% ethanol and diesel could be mixed to a homogeneous solution at any ratio. However, since 99.5% ethanol is much cheaper than99.9% ethanol and is produced in our country, it was there forechosen to blend with diesel and biodiesel in order to study further fuel properties. As for the emissions of the blends, it was found that CO and HC reduced significantly at high engine load, whereas NOx increased, when compared to those of diesel. Taking these facts into account, a blend of 80% diesel, 15% biodiesel and 5% ethanol was the most suitable ratio for diesohol production because of the acceptable fuel properties (except flash point) and the reduction of emissions.

Xiaoyan Shi, et al., (2005) [9] have discussed on the title "Emission reduction potential of using ethanol–biodiesel–diesel fuel blend on a heavy-duty diesel engine". This paper describes the emission characteristics of a three compounds oxygenated diesel fuel blend (BE-diesel), on a diesel engine. Biodiesel and ethanol can be produced from feedstocks that are generally considered to be renewable. The vegetable oil ester-based biodiesel has long been used as fuel for diesel engines. Biodiesel has properties similar to those of traditional fossil diesel fuel such that it can be substituted for diesel fuel with little or no engine modification. Studies clearly indicate that the use of biodiesel may potentially reduce the dependence on petroleum diesel fuel and improve air quality. Substantial reduction in particulate emissions can be obtained through the addition of biodiesel to diesel fuel. Ethanol is a low cost oxygenate with high oxygen content (35%) that has been used in ethanol–diesel fuel blends. The use of ethanol in diesel fuel can yield significant reduction of particulate matter(PM) emissions for motor vehicles. Biodiesel is known to act as an emulsifier forethanol. Blending biodiesel and ethanol into a conventional diesel fuel dramatically improved the solubility of ethanol in diesel fuel over a wide range of temperature. It was concluded that the emission characteristics of a Cummins-4Bdiesel engine using biodiesel–ethanol–diesel fuel blends were investigated and compared with those using diesel fuel. The application of BE-diesel can reduce PM emissions by 30% in average. However, BE-diesel did lead to a slight increase of NOx emissions in a range of 5.6–11.4% at tested conditions. The impact of BE-diesel on CO emissions varies with engine operating conditions and was not conclusive. A general reduction in THC was obtained under the operation conditions.

X. Shi, et al., (2005)[10] have discussed on the title "Emission characteristics using methyl soyate–ethanol–diesel fuel blends on a diesel engine". In this study a blend of 20%(v/v) ethanol/methylsoyate was prepared and added to diesel fuel a an oxygenate additive at volume percent levels of 15 and 20% (denoted as BE15 and BE20) and also prepared a blend containing 20% methyl soyate in diesel fuel (denoted as B20).The fuel blends that did not have any other additive were stable for up to 3 months. Oxygenated fuels are known to reduce PM emissions for motor vehicles and have been evaluated as potential sources of renewable fuels. Among the alternative fuels, biodiesel and ethanol are the most widely used biofuels for diesel engines and have received considerable attention in recent years. Biodiesel has properties similar to those of traditional diesel such that it can be substituted for diesel fuel with little or no engine modification. Biodiesel has been recognized as an environment friendly alternative fuel for diesel engines. They found that the lubricity of these fuels was superior to conventional diesel fuel, and this property was imparted to blends at levels above 20 vol% by volume. Emissions of PM can be reduced dramatically through the use of biodiesel in engines. Emissions of NOx increased significantly for both neat and blended fuels in both two and four-stroke engines. It is suggested that for PM reduction, the weight percent of oxygen content in the fuel is the most important factor, it is more important than other properties such as chemical structure or volatility. The oxygen content of ethanol is much higher than that of methyl soyate. Including ethanol in biodiesel and diesel blends can increase the fuel oxygen level. On the other hand, biodiesel is known to act as an emulsifier for ethanol. Ethanol might be expected to improve low temperature flow properties. It is assumed that the high cetane number of biodiesel can compensate for the cetane number decrease caused by the presence of ethanol in fuel. Taking these facts into account, it was assumed that blends of biodiesel, ethanol, and diesel fuel may improve some properties compared with biodiesel–diesel blends and ethanol–diesel blends. The result shows that the BSFC should increase with an increase inthe oxygenate content in the fuel blends because of the reduced energy content. In the current study, the fuel blends showed very slight change in BSFC compared with diesel fuel. The engine performance was little affected by the lower gross heat value of the oxygenate fuels. All the oxygenate fuels produced moderately lower CO emissions relative to diesel fuel. The B20 blend emitted less total hydrocarbon (THC) emissions compared with base diesel fuel. This was opposite to the fuel blends containing ethanol (BE15, BE20), which produced much higher THC emission.

2.5 Biodiesel as an Additive

Kraipat Cheenkachorn, et al., (2009) [5] have discussed on title "Biodiesel as an Additive for Diesohol". This article discusses the use of biodiesel as an additive for diesohol a mixture of regular diesel and ethanol. Among the proposed alternatives, biodiesel and ethanol have received much attention because they are renewable and readily produced from a variety of feedstocks using proven technology. When biodiesel is burned in diesel engines, there is substantial reduction in unburned hydrocarbons, carbon monoxide, and particulate matter. As substitutes for petroleum fuel, biodiesel is normally blended with diesel while ethanol is mixed with gasoline. Ethanol and diesel fuel are, however, inherently immiscible because of their difference in chemical structures and characteristics. Therefore, an effective emulsifier is needed. These two liquid fuels can be effectively emulsified into a heterogeneous mixture of one micro-particle liquid phase dispersed into another liquid phase by mechanical blending in conjunction with suitable emulsifiers. The emulsifier would reduce the interfacial tension force and increase the affinity between the two liquid phases, leading to emulsion stability. This study showed that the characteristic fuel properties and the power-producing capability of the engine were similar to those of petroleum diesel. Physical and chemical properties of the diesohol blends were obtained and compared with those of regular diesel. The results showed that, in general, the fuel properties of diesohol with biodiesel as an emulsifier satisfy the requirement of regular diesel, although there is a tendency that increasing fraction of biodiesel results in more carbon residue. Engine performance and emissions of a selected blend (5%vol. biodiesel in the 95:5 diesel: ethanol mixture)were tested on a direct injection diesel engine. The result showed that the presence of biodiesel shows the surfactant property by developing a micro emulsion between conventional diesel and ethanol phases, Palm oil-derived biodiesel can be used as an effective emulsifier for diesohol emulsions, fuel properties of diesohol emulsions are within standard limits for high speed diesel, except the flash point, some of disadvantages of using biodiesel as a diesohol emulsifier are the tendency to increase the amount of carbon residue, reduction in cetane index, and slight decrease in heating value, the range of diesohol composition tested, it appears that the optimum blend consists of 5%(vol.) Biodiesel in the 95:5 diesel: ethanol mixture, as the percent of carbon residue is within the standard limit of No. 2 diesel; the average THC and PM are, respectively, about 30% and 52% lower for the diesoho lthan for regular diesel; the emissions of CO and NOx vary from phase to phase. But on the average, the emissions for diesohol are slightly higher than those of regular diesel; there is insignificant difference in fuel consumption between diesel and diesohol for the driving cycle were tested.

3. Problem Identification

3.1problem Description

Negative environmental consequences such as increase in emission level due to fossil fuel and depletion of fossil fuel resources makes energy scarcity all over the world are considered to be the main problem in current situation.

3.2 Reapply of Sir Rudolf Diesel's Idea

Rudolf diesel, the inventor of the diesel engine, used plant oil to run his first diesel engine in 1895.Rudolf diesel demonstrated his new engine with peanut oil at the world exhibition (1900) in Paris .Diesel had said that - "The use of vegetable oils for engine fuels may seem insignificant today, but such oil may become in course of time as important as petroleum and coal tar products of the present time"

3.3 Proposed Idea

To research an alternative fuels for the conventional diesel engines in order to decrease the dependency of fossil fuel and to reduce the fossil fuel pollutants such as Carbon Monoxide (CO), Nitrogen Oxides (NO_x) and Unburned Hydrocarbons(UBHC).Among the alternative fuels biofuels such as biodiesel and ethanol produced from feedstocks are generally considered to be renewable. However biodiesel and ethanol cannot entirely replace petroleum-based fuels,so in order to solve this issue biofuel and diesel blend can be used on existing engines to achieve both environmental and energy benefits.

3.4problem in Using Jatropha Biodiesel as Direct fuel

- Biodiesel are generally not suitable to use in low temperature areas
- Density and viscosity is higher than that of diesel so it cannot be used directly in diesel engine

3.5 Problem in Using Ethanol as Direct Fuel

- Low cetane number of ethanol
- Poor solubility of ethanol
- Low flash point temperature
- Ethanol is instable due to phase separation

3.6 Objective

The main objectives of this study were as follows
- To evaluate the performance characteristics of various fuel blends at different engine loads.
- To evaluate the emission characteristics of various fuel blends at different engine loads.

- To identify the best mixture among the fuel blends that can be used as an alternative fuels which is best in terms of both performance and emission characteristics when compared to conventional diesel fuel.

4. Experimental Investigation

The project is carried out in thermal engineering laboratory of mechanical engineering department. In order to achieve our objective three main processes must be carried out. One is chemical processing which is obviously transesterification process and finding fuel properties, second one is performance testing of standard diesel engine for various blends and finally emission testing is done using flue gas analyser. Transesterification process is not carried out in our college due to lack of equipments at the time of carrying out our project. So transesterified biodiesel was purchased which is readily available in the market. Fuel properties like flash point, viscosity, etc. at various temperatures were found. Then the fuel blends was used for finding engine performance and emission testing was also done simultaneously.

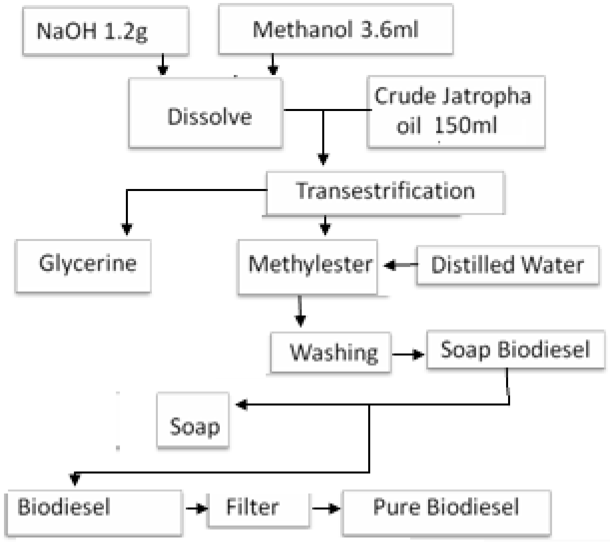
4.1 The Trans-Esterification Process

Though transesterification process was not carried out by us, Knowledge of transesterification process was essential to know how the fuel react to the environment and alcohol.

4.1.1 Materials Required

- The raw oil to be used
- Catalyst (generally NaOH)
- Alcohol (Methanol)
- A washing agent (generally distilled water)

4.1.2 Flow Chart of Transesterification Process



4.1.3 Procedure for Transesterification Process

- The catalyst, NaOH (1.2 gram) is first added to the alcohol. Methanol (36 ml) and dissolved by shaking vigorously. The solution is then mixed with crude oil (150 ml) to be used.
- The contents after mixing thoroughly are heated with water-bath heater with constant stirring at regular intervals for 1-2 hours. The contents are allowed to settle down for 10-12 hours.
- The contents are separated into two parts- methyl ester (less dense) and glycerine (thicker) by gravitational separation. After that methyl ester is washed with equal amount of distilled water. This washed solution is allowed to settle down for another 24 hours. This settling process will separate the biodiesel and the soaps. Finally, the biodiesel is filtered using whatman filter to get pure biodiesel.

4.2 Fuel Properties

The various properties of diesel, jatropha oil, esterified jatropha biodiesel and ethanol is given in the below Table-4.1.

Table 4.1: Properties of various fuels

Parameters	*Diesel*	*Jatropha Oil*	*Biodiesel*	*Ethanol*
Density (kg/m^3)	830	918.6	880	794
Viscosity at 45^0 C (cst)	3.509	49.873	5.425	0.527
Flash Point $(^0$ c$)$	62	240	170	13
Calorific value(kj/kg)	45625	39774	38450	27000
Cetane number	45-55	40-45	50	8

Kinematic viscosity was found using say bolt apparatus and flash point was found with the help open cup apparatus. Calorific value was found using bomb calorimeter. Using the calorific values and densities of the given fuels values of the same can be found for various different blends. The various fuel blends used for our experiment are given in the below table. Volumetric percentages of each fuel are chosen in accordance to the study on ‘solubility of a diesel-biodiesel-ethanol blend’ by Prommes Kwanchareon et al[8], in which research was done on the phase diagram of diesel-biodiesel-ethanol blends at different purities of ethanol and at different temperatures. In their research the percentage of fuel blends chosen has shown positive inferences.

Table-4.2 Specific gravities and calorific values of various blends and fuels

Sample No.	*Diesel (%)*	*Biodiesel (%)*	*Ethanol (%)*	*Specific Gravity*	*Calorific Value (Mj/Kg)*
1	90	10	0	0.825	43.258
2	90	5	5	0.835	44.908
3	90	0	10	0.826	43.763
4	85	15	0	0.836	44.548
5	85	10	5	0.830	44.335
6	85	5	10	0.827	43.403
7	85	0	15	0.880	38.450
8	80	15	5	0.835	43.618
9	80	10	10	0.833	43.976
10	80	5	15	0.831	43.045
11	100	0	0	0.830	45.625
12	0	100	0	0.827	42.473

4.3 Experimental Setup

A Schematic diagram of the experimental setup with the required arrangement is shown in Figure-4.2.

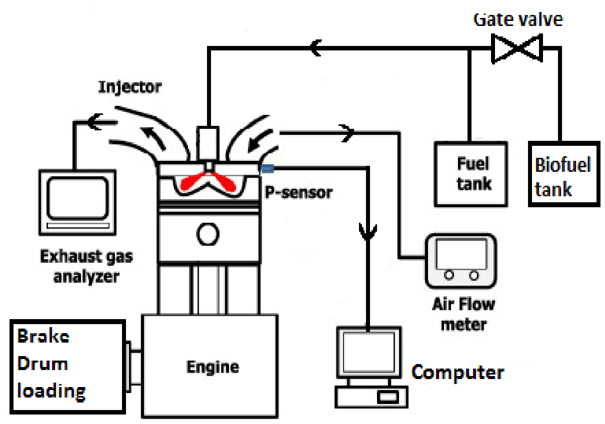


Figure 4.2: ASchematic diagram of experimental setup

The main processes carried out in the thermal engineering laboratory where the performance tests and exhaust emission tests were carried out. The performance tests indicate the various parameters such as specific fuel consumption, thermal efficiency etc., which will enable the fuel to be compared with the conventional diesel. The exhaust emissions indicated the percentages of the various gases present in the exhaust and thus helped in comparing the pollution levels biodiesel with conventional diesel.

4.3.1 Engine

A single cylinder, water cooled, direct injection, kirloskar made engine is used for this project work the water at room temperature is allowed to pass through the water jacket in the engine. The engine is coupled with the break drum for loading. The specifications of the engine are given below in the table.

Table 4.3 Specifications of IC engine

Make	Kirloskar
Engine Type	Diesel engine
Number Of Cylinder	Single cylinder
Number Of Stroke	Four Stroke
Coolant Type	Water cooled
Speed	1500 rpm
Bore	87.5 mm
Stroke	110 mm
Capacity	661 cc
Compression Ratio	17.5:1

4.3.2 Loading Arrangement

The load is applied to the engine with the help of rope and weight mechanism. The rope is wound over the brake drum. One end of the rope is connected to a spring balance and to the other end the weights are attached. The power developed by this engine can be calculated by knowing the applied load.

4.3.3 Fuel Measurement

To measure the fuel, a burette is used. A provision for cut out from the fuel tank and allow the fuel flow from the burette is made for easy and accurate measurement. Using a stop watch, the amount of fuel consumed for one minute is noted down.

4.3.4 Temperature Measurement

While conducting the experiment various temperatures are required they are
1) Inlet water temperature
2) Outlet water temperature
3) Exhaust gas temperature

In order to find these temperatures, numbers of temperature sensors are fitted to the test which shows the reading in a digital display.

4.4 Emission Testing

4.4.1 Flue Gas Analyser

For measuring various emissions like Nitrogen oxide (NO_x), carbon monoxide (CO), unburnedhydrocarbon (UHC or HC) KM9106 flue gas analyser was used. The specification of the equipment is shown in Table-4.4.

Table 4.4: Specifications of KM9106 flue gas analyser

Temperature Measurement		
Parameters	*Accuracy*	*Range*
Fuel Temperature	1.0 °C ± 0.3% of reading	0-1100°C, 32-2140°F
Inlet Temperature	1.0 °C ± 0.3% of reading	0-600°C, 0-999°F
GAS MEASUREMENT		
Oxygen (O_2)	-0.1% + 0.2%	0-25%
Carbon Monoxide (CO)	±20 ppm < 400 ppm 5% of reading < 2000 ppm ±10% of reading > 2000 ppm	0-10000 ppm
Nitric Oxide (NO)	±5 ppm < 100 ppm ±5% of reading < 100 ppm	0-5000 ppm
Nitrogen Dioxide (NO_2)	±5 ppm < 100 ppm ±10 ppm < 500 ppm ±5% of reading > 500 ppm	0-500 ppm
Sulphur Dioxide (SO_2)	±5 ppm < 100 ppm ±5% of reading > 100 ppm	0-5000 ppm
Pressure	±0.5% full scale	0-150 mbar
Carbon Dioxide (CO_2)	±0.3%	0-Fuel Value
Efficiency	±1%	0-100%

4.5 Test Procedure

1) The room temperature was noted down
2) Required quantities of blends were prepared according to their ratios by volume
3) The fuel in the fuel tank, the supply of cooling water, cooling water on the engine were checked before starting the engine.
4) The engine was started and allowed to run at no load for about 10 minutes to warm up and attain the steady state. The speed of the engine was measured using a tachometer and it was adjusted to the rated speed of 1500 rpm
5) The fuel was then supplied from the burette by opening the metering valve. By noting the change in the level of fuel in the burette, the time taken for fuel consumption was noted using a stop watch.
6) The desired cooling water flow rate was obtained by adjusting the valve and was kept constant throughout the experiment.

7) The inlet and outlet temperature of the cooling water are noted from the digital display which is connected to the sensors.
8) The temperature of the exhaust gas is also noted down from the display by adjusting the knob.
9) The full load of the engine was distributing equally so as to run at least five trials during the test from zero load to full load. The set of readings were taken and tabulated.
10) The emissions are measured using the flue gas analyser for all the combinations of diesel-biodiesel-ethanol by using following steps as follows:
    - Clean the hollow probe with proper agent both inside and outside
    - Connect the probe gas water connections to water trap and connect the thermocouple connection from probe to the inlet socket for optional air temperature probe.
    - Connect the water trap outlet tube to the port.
    - Connect the handset to the RS232 data capture connector (25 pin D) using a lead.
    - Turn ON the analyser by pressing ON button in the handset.
    - After turning ON the handset starts calibrating for 5 minutes
    - After calibrating the probe can be inserted into the exhaust outlet and desired parameters can be viewed by pressing the button.
11) The manometer readings are also noted.
12) All the above readings were taken for various loads.

The observed and calculated values of the engine performance are given in the table. After, the experimental part of the project was completed, the calculations were carried out and various graphs were drawn so as to discuss and arrive at specified result. From the analysis of graph the conclusions were made. The various graphs are as follows:
1) Brake power Vs Specific Fuel Consumption
2) Brake power Vs Brake thermal efficiency
3) Brake power Vs Indicated thermal efficiency
4) Brake power Vs Mechanical efficiency
5) Brake power Vs Indicated Mean Effective Pressure

5. Results and Discussion

All the parameters relating to the engine performance and emissioncharacteristics were evaluated from the observed readings. The various parameters being
1. Brake power (BP)
2. Specific fuel consumption (SFC)
3. Brake thermal efficiency (η_{BTH})
4. Indicated thermal efficiency (η_{ITH})
5. Mechanical efficiency (η_{Mech})
6. Brake Mean Effective Pressure(BMEP)
7. Indicated Mean Effective Pressure(IMEP)
8. Carbon Monoxide (CO)
9. Nitrogen Oxides (NO_x)
10. Unburned Hydrocarbon (UHC)

5.1 Performance Characteristics of Fuels

Performance characteristics of various fuels have been calculated using various formulae and tabulated.

5.1.1 FORMULAE USED

1. Fuel Consumption (FC) = (Sp.gravity*vol.of fuel consumed (cc))/ (Tavg*1000)(5.1)
2. Fuel power (FuP) = FC * CV (5.2)
3. Brake power (BP) = (Cb * N*L)/(60 * 1000) (5.3)
 Where Cb= Circumference of brake drum = 0.94
 L = Load in N
4. Specific Fuel Consumption (SFC) = FC / BP (5.4)
5. Frictional Power (FP) = Calculate from William's method (BP Vs FC)
6. Indicated Power (IP) = BP + FP (5.5)
7. MechanicalEfficiency (η_{Mech}) = (BP / IP) * 100 (5.6)
8. Brake Thermal Efficiency (η_{BTH}) = (BP / FuP) * 100 (5.7)
9. Indicated Thermal Efficiency (η_{ITH})=(IP / FuP) * 100 (5.8)
10. BrakeMean Effective Pressure (BMEP) = (BP*60)/ (100* area of cylinder (A)*stroke (SL)*speed (N_1)) (5.9)
11. Indicated Mean Effective Pressure (IMEP) = (BP*60)/ (100* area of cylinder (A)*stroke (SL)*speed (N1) (5.10)
 N_1 = N/2 for 4 stroke engine
12. Torque = Load (L) * 9.81* radius of brake drum (5.11)

5.1.2 Diesel

Various parameters have been calculated using the available data and the readings have been tabulated as shown in Table-5.1.

Table 5.1: Performance characteristics of diesel fuel

LOAD (%)	FC ($*10^{-4}$kg/s)	BP (kW)	SFC ($*10^{-4}$ kg/s.kW)	IP (kW)	η_{Mech} (%)	FuP (kW)	η_{BTH} (%)	η_{ITH} (%)	BMEP (bar)	IMEP (bar)	TORQUE (N-m)
0	1.167	0	-	2	0	5.324	0	37.56	0	2.419	0
25	1.521	0.902	1.686	2.902	31.08	6.939	13	41.82	1.090	3.509	5.886
50	2.805	1.805	1.110	3.805	47.43	9.147	19.73	41.59	2.183	4.602	11.762
75	2.282	2.707	0.843	4.707	57.51	10.411	26.00	45.21	3.274	5.693	17.658
100	2.766	3.610	0.766	5.610	64.35	12.619	28.60	44.45	4.366	6.785	22.072

5.1.3 Biodiesel

Table-5.2, given below shows the performance characteristics of biodiesel which are as follows.

Table 5.2: Performance characteristics of biodiesel

LOAD (%)	FC (*10^{-4}kg/s)	BP (kW)	SFC (*10^{-4} kg/s.kW)	IP (kW)	η_{Mech} (%)	FuP (kW)	η_{BTH} (%)	η_{ITH} (%)	BMEP (bar)	IMEP (bar)	TORQUE (N-m)
0	1.804	0	-	2.46	0	6.936	0	35.46	0	2.977	0
25	1.936	0.902	2.146	3.362	26.82	7.444	12.11	45.16	1.090	4.066	5.886
50	2.464	1.805	1.365	4.265	42.32	9.474	19.05	45.01	2.183	5.158	11.762
75	2.904	2.707	1.072	5.167	52.39	11.166	24.24	41.31	3.274	6.249	17.658
100	3.226	3.610	0.893	6.07	59.47	12.404	21.10	48.93	4.366	7.342	22.072

5.1.4 D90B10E0

Table-5.3, given below shows the performance characteristics of D90B10E0 which are as follows.

Table 5.3: Performance characteristics of biodiesel

LOAD (%)	FC (*10-4 kg/s)	BP (kW)	SFC (*10-4 kg/s.kW)	IP (kW)	ηMech (%)	FuP (kW)	ηBTH (%)	ηITH (%)	BMEP (bar)	IMEP (bar)	TORQUE (N-m)
0	1.252	0	-	2.42	0	5.622	0	43.04	0	2.926	0
25	1.600	0.902	1.773	3.322	27.15	7.185	12.55	46.23	1.090	4.017	5.886
50	2.338	1.805	1.295	4.225	42.72	10.499	17.20	40.24	2.183	5.109	11.762
75	2.574	2.707	0.950	5.127	52.79	11.559	23.41	44.35	3.274	6.200	17.658
100	2.825	3.610	0.782	6.08	59.37	12.686	28.45	47.92	4.366	7.353	22.07

5.1.5 D90B0E10

Table-5.4, given below shows the performance characteristics of D90B0E10 which are as follows.

Table 5.4: Performance characteristics of D90B0E10

LOAD (%)	FC (*10-4 kg/s)	BP (kW)	SFC (*10-4 kg/s.kW)	IP (kW)	ηMech (%)	FuP (kW)	ηBTH (%)	ηITH (%)	BMEP (bar)	IMEP (bar)	TORQUE (N-m)
0	1.197	0	-	2.45	0	5.238	0	46.77	0	2.963	0
25	1.638	0.902	1.815	3.352	26.90	7.168	12.58	46.76	1.090	4.054	5.886
50	1.886	1.805	1.044	4.255	42.42	8.253	21.87	51.55	2.183	5.146	11.762
75	2.436	2.707	0.899	5.157	52.49	10.660	25.39	48.37	3.274	6.672	17.658
100	3.014	3.610	0.834	6.06	59.57	13.190	27.36	45.94	4.366	7.329	22.072

5.1.6 D90B5E5

Table-5.5, given below shows the performance characteristics of D90B5E5 which are as follows.

Table 5.5: Performance characteristics of D90B5E5

LOAD (%)	FC (*10^{-4} kg/s)	BP (kW)	SFC (*10^{-4} kg/s.kW)	IP (kW)	η_{Mech} (%)	FuP (kW)	η_{BTH} (%)	η_{ITH} (%)	BMEP (bar)	IMEP (bar)	TORQUE (N-m)
0	1.397	0	-	2.55	0	6.193	0	41.17	0	3.084	0
25	1.535	0.902	1.701	3.452	26.13	6.805	13.25	50.72	1.090	4.175	5.886
50	1.964	1.805	1.088	4.355	41.44	8.707	20.73	50.01	2.183	5.267	11.762
75	2.877	2.707	1.062	5.257	51.50	12.755	21.22	41.22	3.274	6.358	17.658
100	2.974	3.610	0.824	6.160	58.60	13.185	27.38	46.72	4.366	7.450	22.072

5.1.7 D85B15E0

Table-5.6, given below shows the performance characteristics of D85B15E0 which are as follows.

Table 5.6: Performance characteristics of D85B15E0

LOAD (%)	FC (*10^{-4} kg/s)	BP (kW)	SFC (*10^{-4} kg/s.kW)	IP (kW)	η_{Mech} (%)	FuP (kW)	η_{BTH} (%)	η_{ITH} (%)	BMEP (bar)	IMEP (bar)	TORQUE (N-m)
0	1.270	0	-	2.52	0	5.657	0	44.54	0	3.048	0
25	1.863	0.902	1.733	3.422	26.35	6.963	12.95	49.14	1.090	4.138	5.886
50	2.163	1.805	1.198	4.325	41.47	9.636	18.73	45.16	2.183	5.231	11.762
75	2.358	2.707	0.871	5.227	51.78	10.505	25.76	49.75	3.274	6.672	17.658
100	2.847	3.610	0.788	6.130	58.89	12.683	28.46	48.33	4.366	7.414	22.072

5.1.8 D85B10E5

Table-5.7, given below shows the performance characteristics of D85B10E5 which are as follows.

Table 5.7: Performance characteristics of D85B10E5.

LOAD (%)	FC (*10^{-4} kg/s)	BP (kW)	SFC (*10^{-4} kg/s.kW)	IP (kW)	η_{Mech} (%)	FuP (kW)	η_{BTH} (%)	η_{ITH} (%)	BMEP (bar)	IMEP (bar)	TORQUE (N-m)
0	1.346	0	-	2.85	0	5.919	0	48.15	0	3.447	0
25	1.550	0.902	1.724	3.752	24.04	6.838	13.19	54.87	1.090	4.538	5.886

50	2.068	1.805	1.145	4.655	38.77	9.094	19.84	51.18	2.183	5.624	11.762
75	2.401	2.707	0.887	5.559	48.71	10.580	25.64	52.63	3.274	6.721	17.658
100	2.915	3.610	0.801	6.460	55.88	12.819	28.16	50.39	4.366	7.813	22.072

5.1.9 D85B5E10

Table-5.8, given below shows the performance characteristics of D85B5E10 which are as follows.

Table 5.8: Performance characteristics of D85B5E10

LOAD (%)	*FC ($*10^{-4}$ kg/s)*	*BP (kW)*	*SFC ($*10^{-4}$ kg/s.kW)*	*IP (kW)*	η_{Mech} *(%)*	*FuP (kW)*	η_{BTH} *(%)*	η_{ITH} *(%)*	*BMEP (bar)*	*IMEP (bar)*	*TORQUE (N-m)*
0	1.352	0	-	2.45	0	5.868	0	41.75	0	2.963	0
25	1.848	0.902	2.048	3.352	26.90	8.021	11.24	40.86	1.090	4.054	5.886
50	2.235	1.805	1.238	4.255	42.42	9.700	18.60	43.86	2.183	5.146	11.762
75	2.607	2.707	0.963	5.157	52.49	11.315	23.92	48.51	3.274	6.237	17.658
100	2.925	3.610	0.810	6.060	59.57	12.69	28.44	47.75	4.360	7.329	22.072

5.1.10 D85B0E15

Table-5.9, given below shows the performance characteristics of D85B0E15 which are as follows.

Table 5.9: Performance characteristics of D85B0E15

LOAD (%)	*FC ($*10^{-4}$ kg/s)*	*BP (kW)*	*SFC ($*10^{-4}$ kg/s.kW)*	*IP (kW)*	η_{Mech} *(%)*	*FuP (kW)*	η_{BTH} *(%)*	η_{ITH} *(%)*	*BMEP (bar)*	*IMEP (bar)*	*TORQUE (N-m)*
0	1.416	0	-	2.75	0	6.065	0	45.34	0	3.326	0
25	1.842	0.902	2.042	3.652	24.69	7.889	11.43	46.29	1.090	4.417	5.886
50	2.227	1.805	1.233	4.555	39.62	9.538	18.92	47.75	2.183	5.509	11.762
75	2.543	2.707	0.939	5.547	45.60	10.892	24.85	50.10	3.274	6.600	17.658
100	2.887	3.610	0.799	6.360	56.76	12.365	29.195	51.43	4.366	7.692	22.072

5.1.11 D80B15E5

Table-5.10, given below shows the performance characteristics of D80B15E5 which are as follows.

Table 5.10: Performance characteristics of D80B15E5

LOAD (%)	*FC ($*10^{-4}$ kg/s)*	*BP (kW)*	*SFC ($*10^{-4}$ kg/s.kW)*	*IP (kW)*	η_{Mech} *(%)*	*FuP (kW)*	η_{BTH} *(%)*	η_{ITH} *(%)*	*BMEP (bar)*	*IMEP (bar)*	*TORQUE (N-m)*
0	1.827	0	-	2.05	0	7.969	0	25.72	0	2.479	0
25	2.044	0.902	2.266	2.952	30.55	8.915	10.11	33.11	1.090	3.570	5.886
50	2.777	1.805	1.538	3.855	46.82	12.113	14.90	31.82	2.183	4.662	11.762
75	3.044	2.707	1.124	4.757	56.90	13.27	20.39	35.84	3.274	5.753	17.658
100	3.427	3.610	0.949	5.66	63.78	14.94	24.16	37.88	4.360	6.845	22.072

5.1.12 D80B10E10

Table-5.11, given below shows the performance characteristics of D80B10E10 which are as follows.

Table 5.11: Performance characteristics of D80B10E10

LOAD (%)	*FC ($*10^{-4}$ kg/s)*	*BP (kW)*	*SFC ($*10^{-4}$ kg/s.kW)*	*IP (kW)*	η_{Mech} *(%)*	*FuP (kW)*	η_{BTH} *(%)*	η_{ITH} *(%)*	*BMEP (bar)*	*IMEP (bar)*	*TORQUE (N-m)*
0	1.288	0	-	2.55	0	5.544	0	45.99	0	3.084	0
25	1.662	0.902	1.842	3.452	26.13	7.154	12.60	48.25	1.090	4.175	5.886
50	2.271	1.805	1.258	4.355	41.44	9.775	18.46	44.55	2.183	5.267	11.762
75	2.479	2.707	0.915	5.257	51.49	10.670	21.37	41.26	3.274	6.358	17.658
100	2.880	3.610	0.797	6.160	58.60	12.396	29.12	49.69	4.366	7.450	22.072

5.1.12 D80B5E15

Table-5.12, given below shows the performance characteristics of D80B5E15 which are as follows.

Table 5.12: Performance characteristics of D80B5E15

LOAD (%)	*FC ($*10^{-4}$ kg/s)*	*BP (kW)*	*SFC ($*10^{-4}$ kg/s.kW)*	*IP (kW)*	η_{Mech} *(%)*	*FuP (kW)*	η_{BTH} *(%)*	η_{ITH} *(%)*	*BMEP (bar)*	*IMEP (bar)*	*TORQUE (N-m)*
0	1.171	0	-	2.45	0	4.973	0	49.26	0	2.963	0
25	1.819	0.902	2.016	3.352	26.90	7.725	11.67	43.39	1.090	4.054	5.886
50	2.315	1.805	1.282	4.255	42.42	9.832	18.35	43.27	2.183	5.146	11.762
75	2.508	2.707	0.926	5.157	52.49	10.652	25.41	48.41	3.274	6.237	17.658
100	2.867	3.610	0.794	6.06	59.57	12.177	29.64	49.76	4.366	7.329	22.072

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5.2 Performance Charcteristic Curves

Performance curves had been drawn for various parameters as mentioned above. For the convenience of easy understanding blends with 90% diesel is denoted as A, 85% diesel as B and 80% diesel as C. 100% diesel and 100% biodiesel is a common curve in all the charts.

5.2.1 Brake Power (BP) Vs Specific Fuel Consumption (SFC)

Comparison has been made between various blends falling under A, B and C category separately for various values specific fuel consumption and brake power as shown in Figure-5.1, Figure-5.2 and Figure-5.3 for various loads (0%, 25%, 50% and 100%).

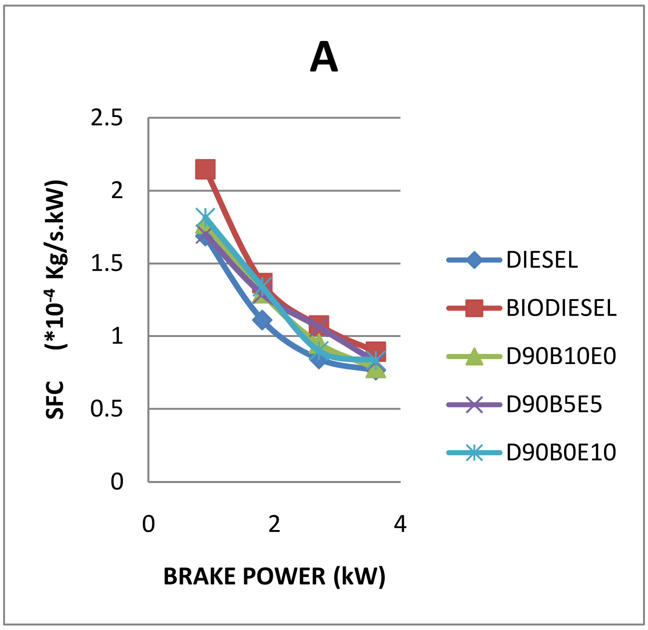


Figure 5.1: Brake power Vs Specific fuel consumption (A)

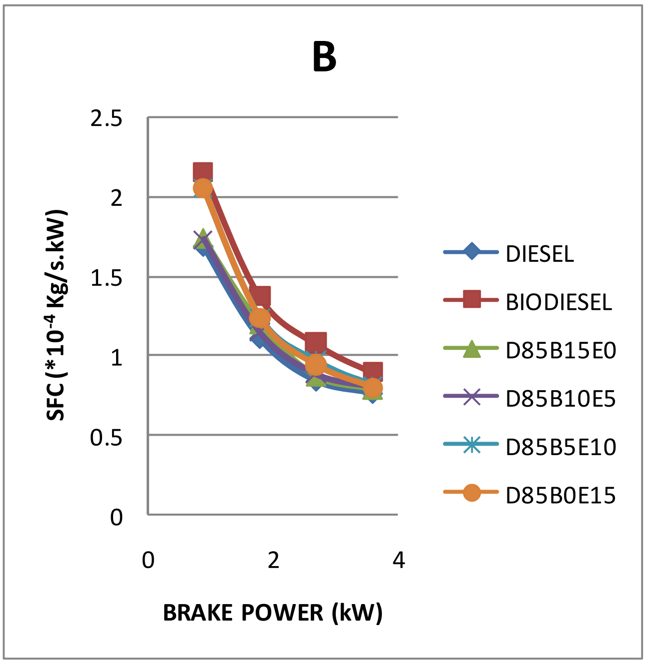


Figure 5.2: Brake power Vs Specific fuel consumption (B)

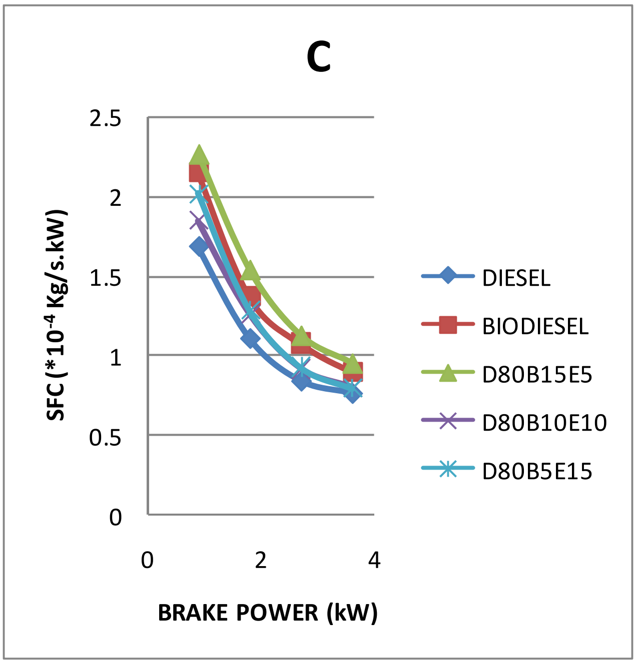


Figure 5.3: Brake power Vs Specific fuel consumption (C)

The specific fuel consumption is greater for all the blends at smaller loads but it decreases at medium and higher loads because of the smaller heating values. Biodiesel and ethanol has high oxygenate contents which results in low heating value and high fuel consumption than diesel fuel. If we examine the curves falling under A category will have slight increase (0.88-7.57%) at minimum load because of higher diesel content eventually those which falls under B category will substantial increase (2.25-21.47%) and greater increase (9.25-34.38%) for fuel blends fall under C category. Hence D80B15E5 has shown much greater increase in SFC compared to other blends and it is nearer to biodiesel. All blends show nearer values at maximum load.

5.2.2 Brake Power (BP) VS Mechanical Efficiency (η_{Mech})

Mechanical efficiency has been found for various blends and the curve was plotted against brake power as shown in Figure-5.4, Figure-5.5 and Figure-5.6.

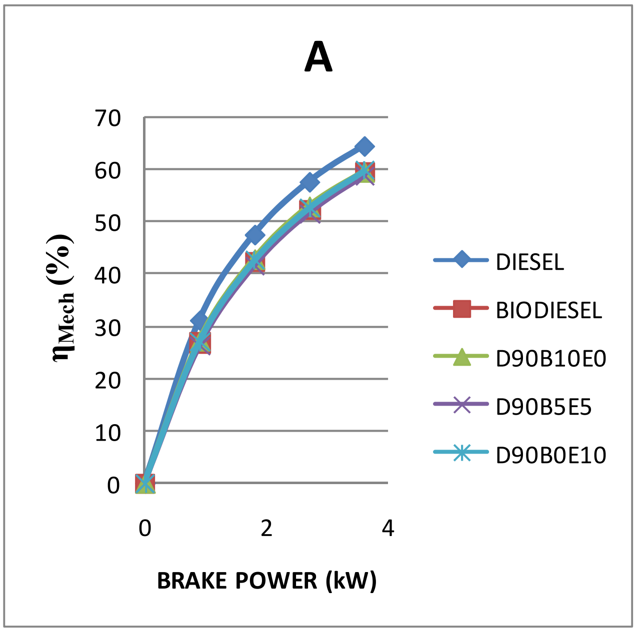


Figure 5.4: Brake power Vs Mechanical efficiency (A)

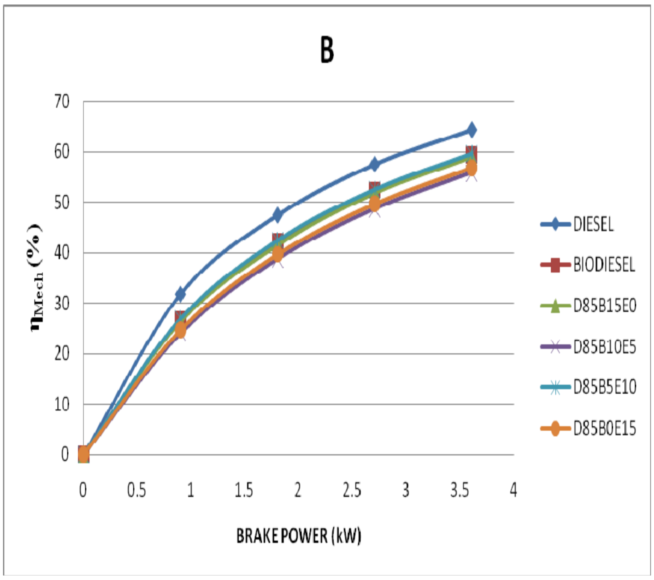


Figure 5.5: Brake power Vs Mechanical efficiency (B)

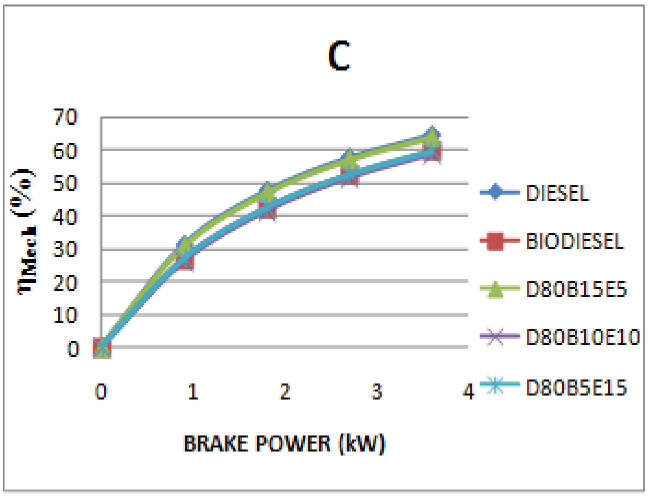


Figure 5.6: Brake power Vs Mechanical efficiency (c)

From the graph it is noted that mechanical efficiency of diesel is higher compared to fuel blends, this may be justified by lower value of frictional losses while using diesel than the other fuel blends. Category with 80% diesel 10% Biodiesel and 5% Ethanol has shown slight decrease (0.88% decrease) compared to other blends.

5.2.3 Brake Power (BP) VS Brake Thermal Efficiency (η_{BTH})

Curve has been plotted for brake thermal efficiency VS brake power for 0, 25, 50 and 75% loads as shown in Figure-5.7, Figure-5.8 and Figure-5.9.

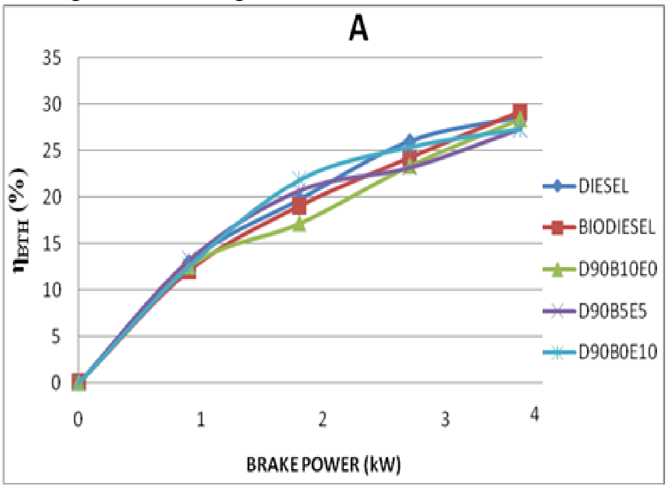


Figure 5.7: Brake power Vs Brake thermal efficiency (A)

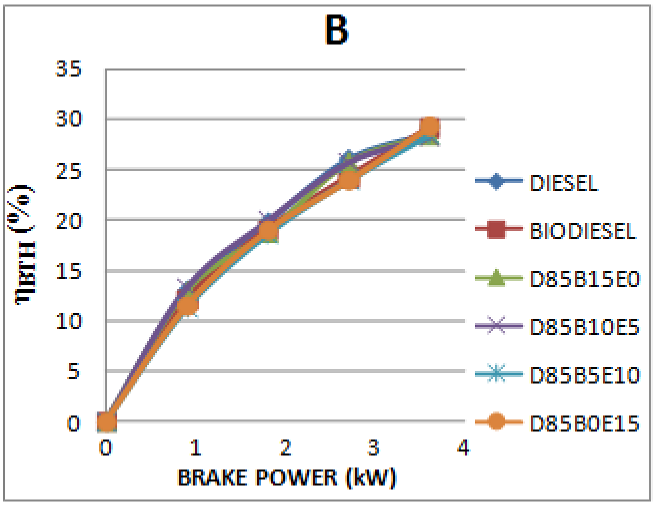


Figure-5.8 Brake power Vs Brake thermal efficiency (B)

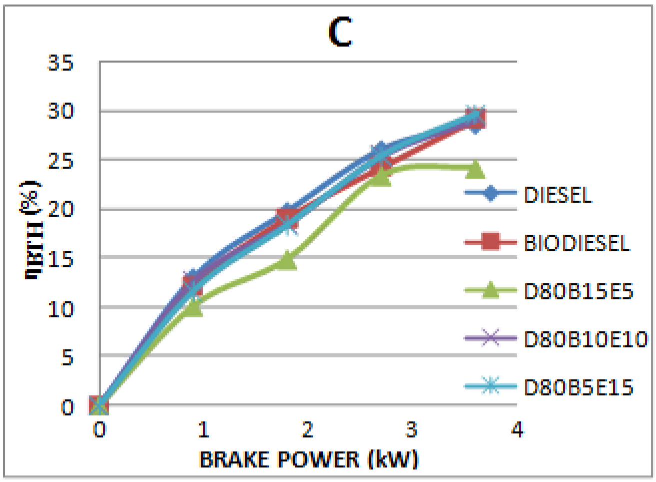


Figure 5.9: Brake power Vs Brake thermal efficiency (C)

From the above curves brake thermal efficiency of fuel blends is slightly higher (up to 3.63%) than diesel this is because of the higher oxygenate content in the biodiesel which enhances the oxidation process therefore it improves the complete combustion process. There is an exception for D80B15E5 because their brake thermal efficiency is lower than diesel this is due to the fact that the fuel power is less sufficient at higher loads.

5.2.4 Brake Power (BP) VS Indicated Thermal Efficiency (η_{ITH})

Using the available values brake power Vs indicated thermal efficiency curve has been plotted for all loads as shown in Figure-5.10, Figure-5.11 and Figure-5.12.

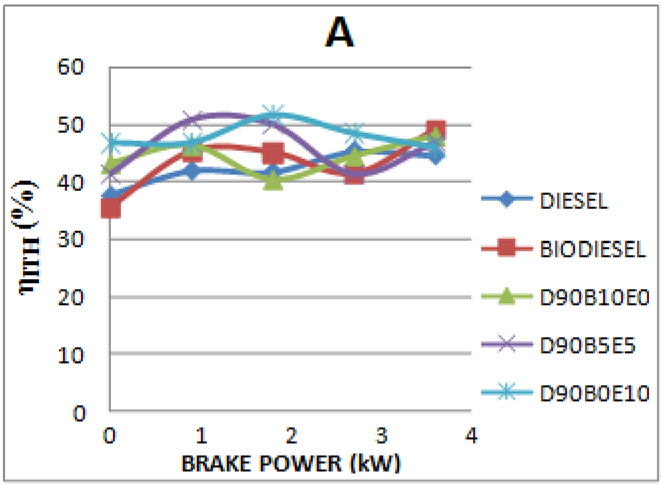


Figure 5.10: Brake power Vs Indicated thermal efficiency (A)

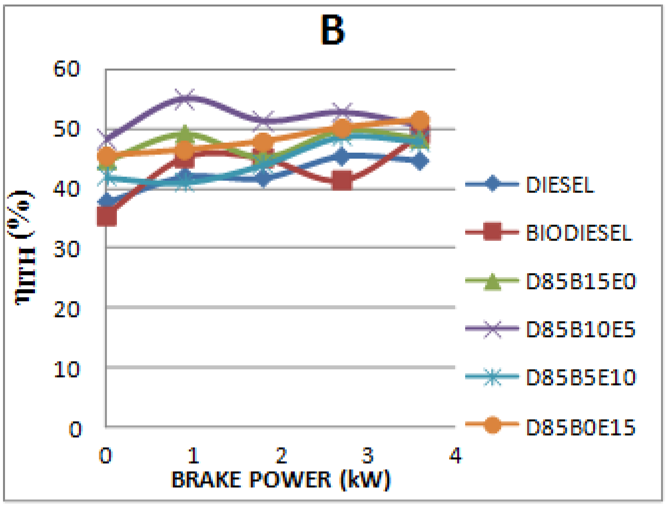


Figure 5.11: Brake power Vs Indicated thermal efficiency (B)

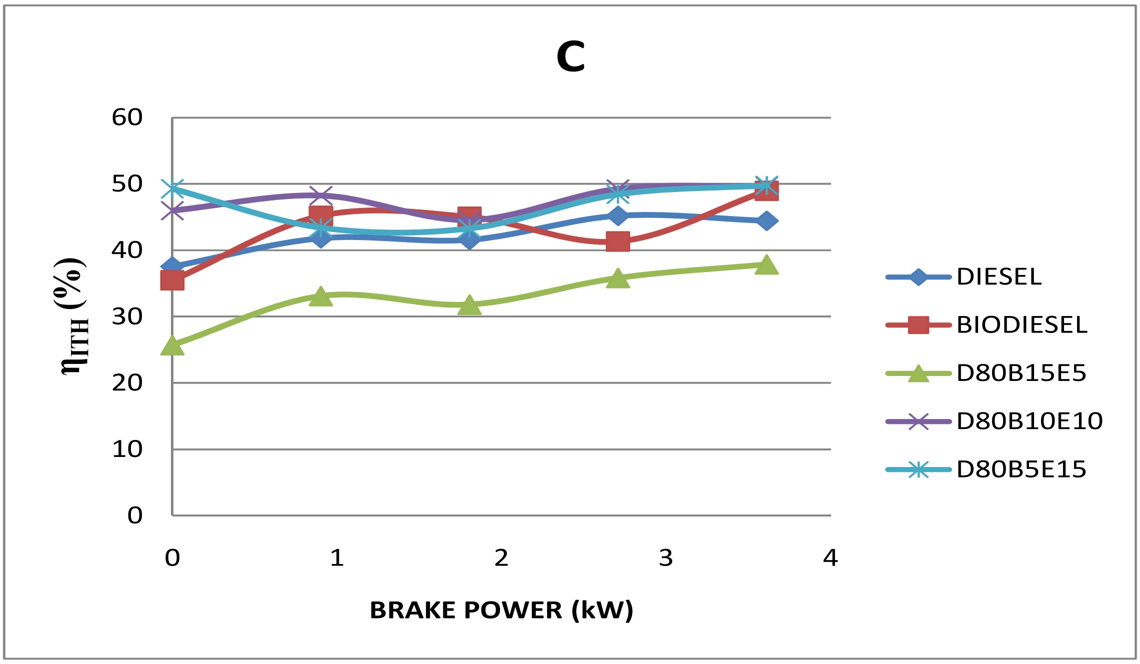


Figure 5.12: Brake power Vs Indicated thermal efficiency (C)

From the above curves we infer that indicated thermal efficiency has increased considerably for fuel blends (up to 15.07%) than diesel except D80B15E5. This increase is because of improvement in complete combustion due to oxidation imparted by the oxygenated fuel blends.

5.2.5 Brake Power (BP) VS Indicated Mean Efective Pressure (IMEP)

Brake power Vs Indicated mean effective pressure has been plotted as shown in Figure-5.13, Figure-5.14 and Figure-5.15, for various loads.

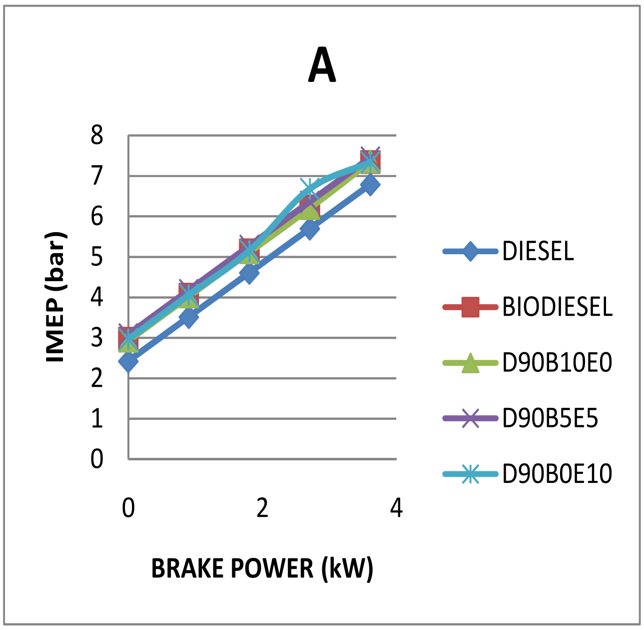


Figure 5.13: Brake power Vs Indicated Mean Effective Pressure (A)

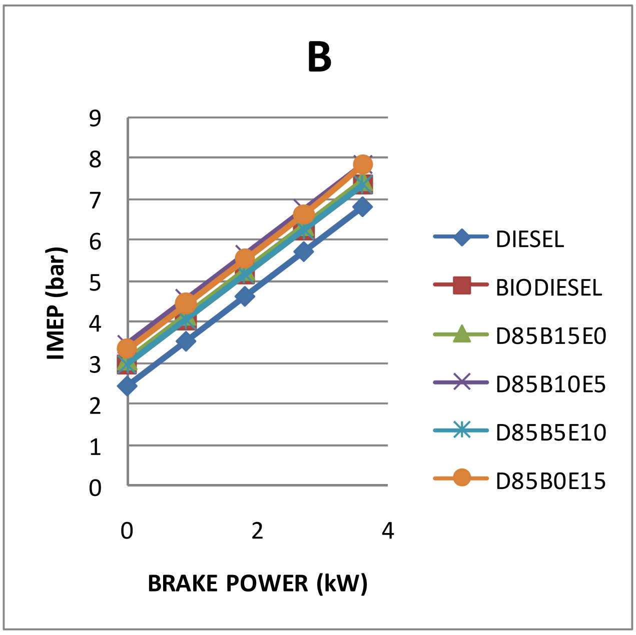


Figure 5.14: Brake power Vs Indicated Mean Effective Pressure (B)

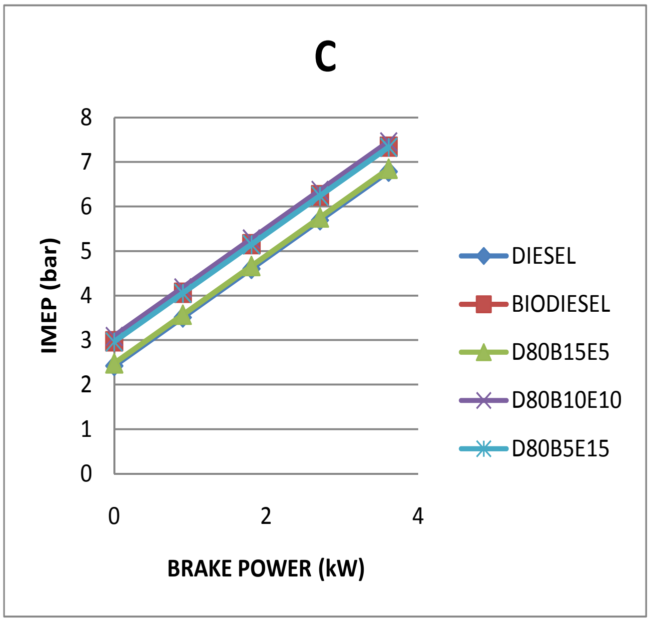


Figure 5.15: Brake power Vs Indicated Mean Effective Pressure (C)

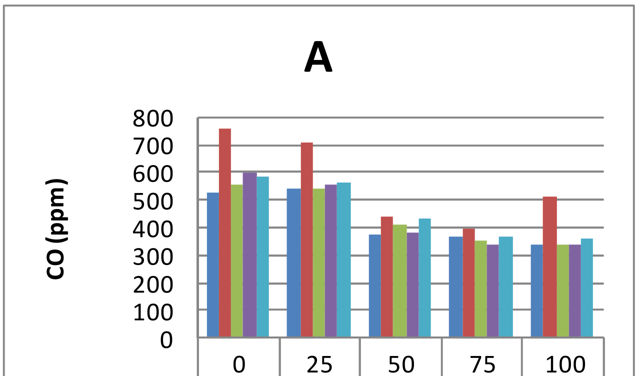
From the graph it is inferred that as the IMEP for fuel blends is greater than diesel this is due to improvement in complete combustion for fuel blends and biodiesel. Due to this improvement in complete combustion pressure exerted on the piston head is more compared to diesel fuel.

5.3 Emission Charcteristic Charts

Emission characteristic charts were drawn using the values obtained from emission testing. The variation in the volume of emissions such as CO, $NO_x$and HC is shown for the various loads using the emission characteristic curves.

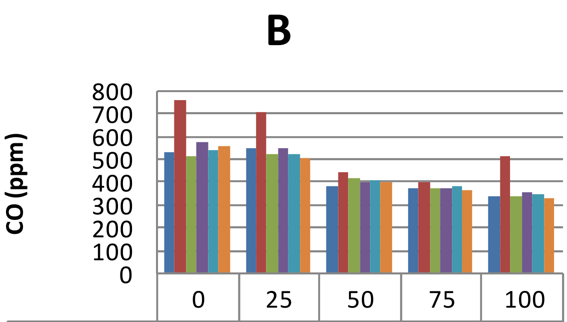
5.3.1 Load Vs Carbon Monoxide (CO)

Variation in carbon monoxide for various loads is shown in below bar charts in Figure-5.16, Figure-5.17 and Figure-5.18.



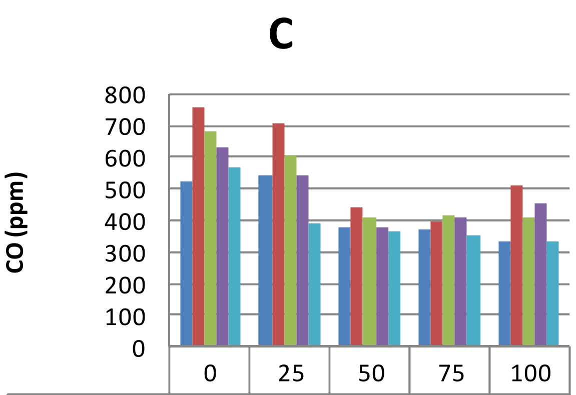
	0	25	50	75	100
DIESEL	525	544	377	371	337
BIODIESEL	757	705	439	394	511
D90B10E0	556	541	409	352	339
D90B5E5	598	555	385	338	341
D90B0E10	583	562	434	371	358

Figure 5.16: Load Vs Carbon Monoxide (A)



	0	25	50	75	100
DIESEL	525	544	377	371	337
BIODIESEL	757	705	439	394	511
D85B15E0	509	515	413	373	332
D85B10E5	571	547	399	366	349
D85B5E10	532	517	408	376	345
D85B0E15	556	499	395	364	328

Figure 5.17: Load Vs Carbon Monoxide (B)



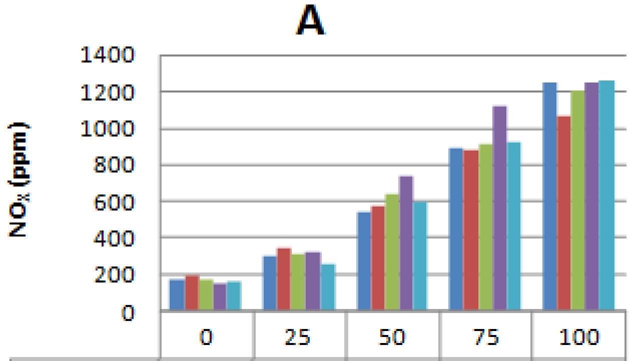
	0	25	50	75	100
DIESEL	525	544	377	371	337
BIODIESEL	757	705	439	394	511
D80B15E5	679	603	412	417	408
D80B10E10	630	541	381	407	456
D80B5E15	565	393	367	351	333

Figure 5.18: Load Vs Carbon Monoxide (C)

From the above bar charts we can infer that CO emissions for diesel is nearer or slightly higher than the other fuel blends and biodiesel show higher CO emission because the amount of exact oxygenate content at medium loads which enhances complete fuel combustion. It was also interesting to observe that CO emission is less for medium loads and slight increase or slight decrease at higher loads.

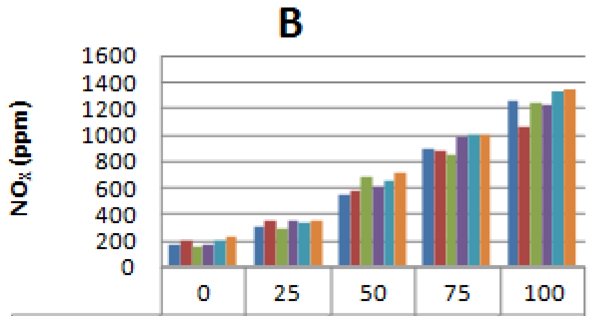
5.3.2 Load Vs Nitrogen Oxides (NO_X)

Load Vs Nitrogen oxides bar chart has been generated with the values obtained from emission testing which is shown in Figure-5.19, Figure-5.20 and Figure-5.21.



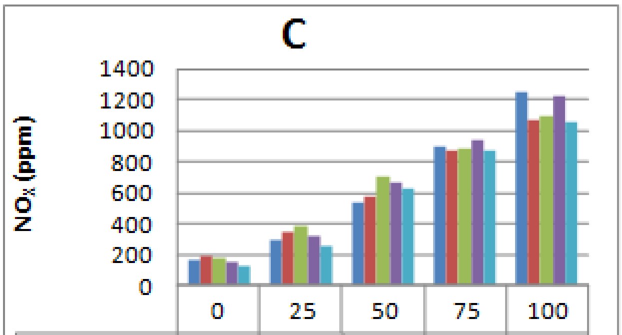
	0	25	50	75	100
DIESEL	169	301	541	893	1249
BIODIESEL	198	345	573	877	1061
D90B10E0	176	313	635	917	1206
D90B5E5	157	329	740	1113	1251
D90B0E10	159	265	600	924	1263

Figure 5.19: Load Vs Nitrogen Oxides (A)



	0	25	50	75	100
DIESEL	169	301	541	894	1249
BIODIESEL	198	345	573	877	1061
D85B15E0	146	283	682	842	1231
D85B10E5	167	351	598	977	1221
D85B5E10	202	337	642	992	1329
D85B0E15	220	352	705	997	1350

Figure 5.20: Load Vs Nitrogen Oxides (B)



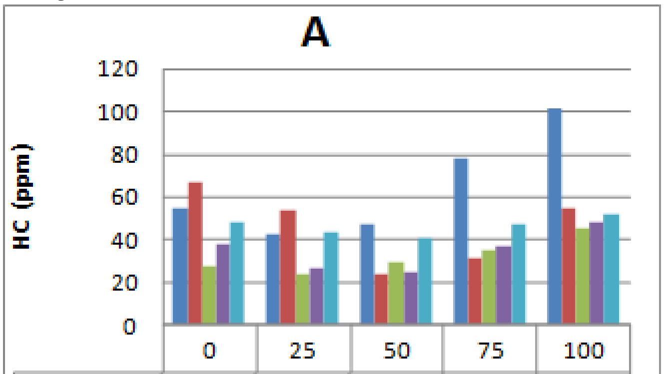
	0	25	50	75	100
DIESEL	169	301	541	893	1249
BIODIESEL	198	345	573	877	1061
D80B15E5	176	380	707	885	1086
D80B10E10	158	319	674	934	1220
D80B5E15	131	263	634	870	1052

Figure 5.21: Load Vs Nitrogen Oxides (B)

The above bar chart is evidence that NO_x emission has increased as the load is increased this is due to improvement in complete combustion due to oxidation at higher loads. And also it was noted that some fuel blends show slight decrease at all loads this is also justified by higher oxygen content. It was also evident that the fuel blends falling under Acategory show lesser NO_x because of less oxygenate contents in fuel blends than those under the category B and C.

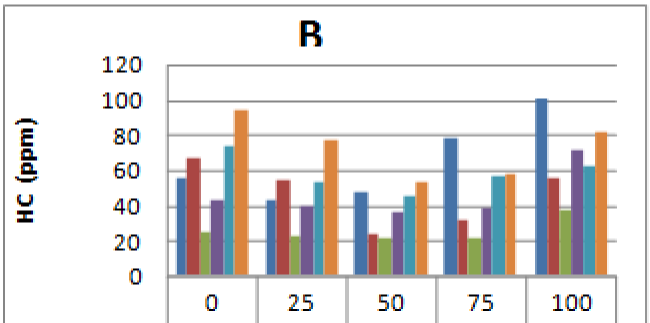
5.3.3 Load Vs Unburned Hydrocarbon (HC)

Bar charts shown in Figure-5.20, Figure-5.21 and Figure-5.22, shows the variation of Hydrocarbon for various loads which is generated using the results obtained from emission testing.



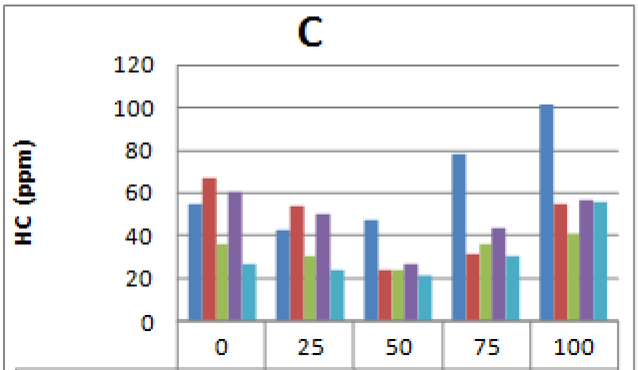
	0	25	50	75	100
DIESEL	55	43	47	78	101
BIODIESEL	67	54	24	32	55
D90B10E0	28	24	30	35	46
D90B5E5	38	27	25	37	48
D90B0E10	48	44	41	47	52

Figure 5.20: Load Vs Hydrocarbon (A)



	0	25	50	75	100
DIESEL	55	43	47	78	101
BIODIESEL	67	54	24	32	55
D85B15E0	25	23	21	21	37
D85B10E5	43	40	36	39	71
D85B5E10	74	53	45	57	62
D85B0E15	94	77	53	58	81

Figure 5.21: Load Vs Hydrocarbon (B)



	0	25	50	75	100
DIESEL	55	43	47	78	101
BIODIESEL	67	54	24	32	55
D80B15E5	36	31	24	36	41
D80B10E10	60	50	27	44	57
D80B5E15	27	24	21	31	56

Figure 5.22: Load Vs Hydrocarbon (C)

From the bar chart we can infer that unburned hydrocarbon emission for fuel blends is lower than that of diesel fuel this is because of enhancement in the combustion of fuel blends due to high oxygenate content. Lower oxygenate content is observed for D85E15E0 for all loads compared to diesel and other fuel blends. The volume of unburned hydrocarbon at medium load is lower compared to minimum and maximum load this is due to exact oxygenate content and proper heating value.

6. Conclusion

Results obtained from the experiment where found to be positive; hence diesel-ethanol-biodiesel fuel blends can be used in conventional diesel engine as an alternative for diesel fuel. Various inferences from the results obtained are as follows.

- The specific fuel consumption for fuel blends has increased when compared to diesel due to the smaller heating value of fuel blends.
- Brake thermal efficiency of fuel blends is slightly higher than diesel this is because of the higher oxygenate content in the biodiesel which enhances the oxidation process.
- Decrease in mechanical efficiency of fuel blends has been observed.
- Indicated thermal efficiency has increased for most of the fuel blends at smaller and higher loads.
- Indicated mean effective pressure has increasedfor most of the fuel blends at all loads when compared to diesel fuel.
- CO emission for fuel blends having 85% of diesel has shown smaller decrease at higher loads this is due to the enhanced oxidation process at higher loads.
- NO_x emission has increased at higher loads for most of the fuel blends when compared to diesel fuelthis is due to improved complete combustion at medium and higher loads.
- Unburned hydrocarbon has reduced considerably at medium loads for most of the fuel blends.

Among various fuel blends, D80B5E15 has shown good performance and emission characteristics when compared to diesel and other fuel blends. Other blends which has good performance, has shown poor emission characteristics and vice versa.

7. Acknowledgement

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