An Experimental Study on Blending of Ethanol and Biodiesel with Diesel in a C. I. Engine

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation entitled "**An Experimental Study on Blending of Ethanol and Biodiesel with Diesel in a C. I. Engine**" in the partial fulfillment of the requirements for the award of the **degree of Master of Technology with specialization in Thermal Engineering**, submitted to the Department of Mechanical Engineering, Delhi Technological University, is an authentic record of my own work carried out under the supervision of **Dr. Amit Pal, Associate Professor**, Mechanical Engineering Department, Delhi technological university, Delhi.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

During last decades, a substantial effort to develop alternative fuel sources, most notably biofuels, has been in progress worldwide, motivated by both economic and environmental issues. Considerable attention was focused on the development of alternative fuel sources, with particular reference to the alcohols. Blends of ethanol and biodiesel wit diesel fuel were investigated and found to be technically feasible. In the last two decades of the 20^{th} century, major advances in engine technology have occurred, leading to greater fuel economy in vehicles. The reduction of emissions from engines has become a major factor in the development of new engines. As a result the use of alternative fuels as a means of meeting these requirements has generated much attention.

In this work an experimental study on performance and emissions analysis of the various blends of biodiesel and ethanol with diesel on a diesel engine was carried out. The performance of these blends have been tested by evaluating the performance parameters like torque, brake power, brake thermal efficiency, brake specific fuel consumption and emission characteristics. Performance testing has been performed on 4-stroke, single cylinder, water cooled Kirloskar C. I. engine. Performance parameters have been obtained from the computer software “EngineSoft” which is incorporated with the engine panel box.

The test results show that the thermal efficiencies of the engine fuelled by these blends were comparable with that fuelled by diesel. However fuel consumption is increased slightly. The emissions characteristics were also studied and it is found that the smoke opacity from the engine fuelled by the blends were all lower than diesel.

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LIST OF ABBREVIATIONS

BP	Brake power
BSFC	Brake specific fuel consumption
BThE	Brake thermal efficiency
CR	Compression ratio
BD10D90	10% Biodiesel & 90% Diesel
BD20D80	20% Biodiesel & 80% Diesel
FP	Frictional power
IP	Indicated power
IThE	Indicated thermal efficiency
MechE	Mechanical efficiency
PPM	Parts per million
WCO	Waste cooking oil
Z5E5D90	5% Butanol, 5% Ethanol & 90% Diesel
Z5E10D85	5% Butanol, 10% Ethanol & 85% Diesel
Z5E15D80	5% Butanol, 15% Ethanol & 80% Diesel
Z5E5BD10D80	5% Butanol, 5% Ethanol, 10% Biodiesel & 80% Diesel
Z5E5BD20D70	5% Butanol, 5% Ethanol, 20% Biodiesel & 70% Diesel

1. Introduction

The increase on energy demand, environmental apprehension of the global warming and climate change and globally escalating petroleum price has considerably increased the benefit of the application study of alternative fuels to internal combustion engines. Biodiesel and Diesohol (diesel – ethanol blends) have received much attention in recent years for Compression Ignition (CI) diesel engines. Ethanol is regards as a renewable fuel because it can be made from many types of raw materials such as corn, sugar cane, sugar beets, molasses, cassava, waste biomass materials, sorghum, barley, maize, etc. [1]. Ethanol has been successfully used to blend with gasoline fuel as part of the alternative to reduce the consumption of conventional gasoline [2]. However, it has not been commercially used to substitute wholly the diesel fuel in diesel engines, because the barriers for this application have not been overcome yet, due to the difference in chemical and physical properties between ethanol and diesel fuel.

During last decades, a substantial effort to develop alternative fuel sources, most notably biofuels, has been in progress worldwide, motivated by both economic and environmental issues. Diminishing petroleum reserves and increasing prices, as well as continuously rising concern over energy security, environmental degradation and global warming have been identified as the most influential environmental ones [3].

1.1 General

Biodiesel is a clean burning alternative fuel produced from domestic renewable sources. The main commodity sources for biodiesel in India are edible and non-edible oils obtained from plant species (such as, corn oil, peanut oil, olive oil, cotton seed oil, rape seed oil, linseed oil, sunflower oil, coconut oil, palm oil, jatropha seed oil etc.) it can also be produced by algae, animal fat etc.[4]

Edible vegetable oils such as rapeseed, soybean, and corn have been used for biodiesel production and are proven diesel substitutes. However, a major obstacle in the commercialization of biodiesel production from edible vegetable oils is their high production cost which is due to their heavy demand for human consumption. Reducing the cost of the feedstock is necessary for biodiesel's long-term commercial viability. One way to reduce the cost of this fuel is to use less expensive feed stocks including waste cooking oils and vegetable oils that are non-edible or require low harvesting costs. Waste cooking oil (WCO), which is much less expensive than edible vegetable oil, could be a promising alternative to edible vegetable oil. [5]

Waste cooking oil and fats set forth significant disposal problems in many parts of the world. This environmentally-threatening problem could be turned into both economical and environmental benefit by proper utilization and management of waste cooking oil as a fuel substitute.

Many developed countries have set policies that penalize the disposal of waste cooking oil into waste drainage [6]. The Energy Information Administration (EIA) in the United States (USA) estimated that around 100 million gallons of waste cooking oil is produced per day in USA, where about 9 pounds of waste cooking oil are generated per person per year [7]. The estimated amount of waste cooking oil collected in Europe is about 0.49 - 0.7 million gallons/day [8].

1.2 Use of Vegetable Oils as Diesel Engine Fuels

The concept of using vegetable oil as a fuel dates back to 1893 when Dr. Rudolf Diesel developed the first diesel engine to run on vegetable oil. However, diesel engines were adapted to burn petroleum distillate, which was cheap and plentiful. In the late 20th century the cost of petroleum distillate rose, and by the late 1970s there was renewed interest in biodiesel. Commercial production of biodiesel in the United States began in the 1990s.Vegetable oils have become more attractive recently because of its environmental benefits and the fact that it is made from renewable resources. Vegetable oils have potential to substitute a fraction of petroleum distillates and petroleum-based petro chemicals in the near future.

1.3 Ethanol

Alcohols are defined by the presence of a hydroxyl group (–OH) attached to one of the carbon atoms. Ethanol, in particular, (or ethyl alcohol) is a biomass based renewable fuel (bio-ethanol), which can be produced, relatively easily and with low cost, by alcoholic fermentation of sugar from vegetable materials, such as corn, sugar cane, sugar beets, barley, and from (non-food) agricultural residues such as straw, feedstock and waste woods [10-11].

Because of its high octane number, ethanol is considered primarily a good spark-ignition engine fuel. Nonetheless, it has been considered also a suitable fuel for compression ignition engines, mainly in the form of blends with diesel fuel [9-11, 12-13], although investigations with pure ethanol (or methanol) have been conducted too [14-15]. For the latter case, cetane improvers and/or glow plugs were implemented combined with an increase in the engine compression ratio to facilitate ignition, particularly during cold starting.

In any case, there are several critical issues to consider with the use of ethanol in the diesel fuel. While anhydrous ethanol is soluble in gasoline, its miscibility in diesel fuel is problematic. This is one the most important drawbacks since, if unattended, it may cause phase separation between diesel fuel and ethanol, with serious consequences on the engine operation. This is why additives in the form of emulsifiers or co-solvents are usually applied in order to ensure solubility of anhydrous ethanol in the diesel fuel, especially at low temperatures (below 10^oC). Moreover, ethanol possesses lower flash point and lower viscosity than diesel fuel. Ethanol addition in the diesel fuel reduces the lubricity of the blend and creates potential wear problems in fuel pumps, particularly during starting, primarily in rotary and distributor-type pumps and also in modern common-rail systems that employ a fuel-based lubrication. Ethanol, apart from having a lower calorific value than diesel fuel, is also characterized by corrosiveness and a much lower cetane number that reduces the cetane level of the diesel/ethanol blend, thus requiring the use of cetane enhancing additives for improving ignition delay and mitigating cyclic irregularity [16−17].

In view of the previously mentioned disadvantages, another alternative has gained interest recently, namely simultaneous use of diesel, biodiesel and ethanol (or n-butanol). This three-component blend combines the benefits from the two biofuels and also aids in the better solubility of ethanol in the fuel blend using the biodiesel as the co-solvent. Moreover, since biodiesel is characterized by higher viscosity, lubricity, cetane number and flash point relative to ethanol, all the above-mentioned 'obstacles' of using ethanol alone in the diesel blend seem to be, at least partially, overcome [18].

1.4 Ethanol as an Automobile Fuel

Ethanol is a clear, colorless liquid. In dilute aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions it has a burning taste. Ethanol (CH3CH2OH) is made up of a group of chemical compounds whose molecules contain a hydroxyl group, -OH, bonded to a carbon atom. Ethanol made from cellulosic biomass materials instead of traditional feed stocks (starch crops) is called bioethanol.

There has been strong demand for ethanol as an oxygenate blended with gasoline. In the United States each year, approximately 2 billion gallons are added to gasoline to increase octane and improve the emissions quality of gasoline.

Blends of at least 85% ethanol are considered alternative fuels under the Energy Policy Act of 1992 (EPAct) in U.S. E85, a blend of 85% ethanol and 15% gasoline, is used in flexible fuel vehicles (FFVs) that are currently offered by most major auto manufacturers. FFVs can run on gasoline, E85, or any combination of the two and qualify as alternative fuel vehicles under EPAct regulations.

Ethanol is used as an automotive fuel by itself and can be mixed with gasoline to form what has been called "gasohol" or can be mixed with diesel to form "diesohol or "E-diesel". Because the ethanol molecule contains oxygen, it allows the engine to more completely combust the fuel, resulting in fewer emissions. Since ethanol is produced from plants that harness the power of the sun, ethanol is also considered a renewable fuel.

The principal interest in ethanol as motor vehicle fuel lies in its use as blends with gasoline. Its very high octane rating makes it an effective knock suppressor like TEL with an additional, advantage of being a fuel in itself with no hazardous component in like lead TEL, which causes lead pollution.

Its blends can permit higher compression operation of the engine without knock. Its higher latent heat of vaporization, uniform composition, stoichiometric air requirements, higher flash point etc. impart to its blends certain useful properties which not only improve engine performance but also reduce engine emissions and make the blends safer as compared to gasoline.

Its lower calorific value, higher surface tension, greater solvent power etc. restrict its use as a complete motor vehicle fuel. It can be best utilized as a blend constituent with up to around 30% ethanol -gasoline blends useable in the resent day automobiles without requiring any major engine modifications; and giving reduced levels of exhaust CO and HC emissions.

Merits

- It is not a fossil fuel thus, manufacturing it and burning it does not increase the greenhouse effect.
- It reduces dependence on imported fuels.
- Refueling is similar to that of gasoline or diesel.
- It can be used in both light and heavy duty vehicles.
- Ethanol is biodegradable without harmful effects on the environment.
- It significantly reduces harmful exhaust emissions, thereby reduces air pollution.
- More energy density compared to gasoline with optimized compression ratio.
- Ethanol's high oxygen content reduces carbon monoxide levels more than any other oxygenate by 25-30%.
- Ethanol reduces nitrogen oxide, sulphur dioxide, hydrocarbon and CO_2 emissions.
- It provides high octane at low cost as an alternative to harmful fuel additives.
- As an octane-enhancer, ethanol can cut emissions of cancer-causing benzene and butadiene by more than 50%.

Demerits

- The relatively low boiling point and high vapor pressure of ethanol indicate that vapor lock could be a serious problem, particularly at high altitudes on warm summer days.

- The relatively high latent heat of ethanol causes problems in its mixing with air and transporting it 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.

- Although ethanol. When used near its stoichiomctric air-fuel ratio, produces 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.
- Ethanol has strong affinity for water. Less engine power is produced as the water content of an ethanol increases. Further, vapor lock, fuel mixing and starting problems increase with water.
- Corrosiveness: Ethanol is corrosive to certain materials used in engines and thus can dissolve them. It can also cause injury or physical harm if not used properly. People who use in motor. Fuels should observe warning labels and follow precautions to avoid problems.

1.5 Other Requirements of the Fuel

- It should be produced locally to cut transport cost and supply difficulty, to free foreign currency for other uses, and to reduce local under-employment.
- It should need only simple production process to require low capital and cheap Maintenance.
- It should require the minimum alteration to the engine to keep initial cost down and to enable a return to diesel use if the alternative supply fails.
- It should have minimum harmful effect on the engine to ensure reliability and to reduce the need for skilled maintenance.

From above discussion, it can be concluded that, when checked for above requirements as well as engine compatibility, ethanol provides better option than other alternative fuels. Moreover, in Indian context, as Indian economy is an agricultural economy, use of ethanol as an automotive fuel will not only save precious foreign currency but also give boost to agriculture. Keeping this in mind, Ministry of Petroleum and Natural Gas Launched three pilot projects. Based on the experience of these pilot projects. Government of India on 29-11-2001 has taken a decision to introduce petrol blended with 5% ethanol for use in motor vehicles all over the country in a phased manner. Later, it will be increased to 10%. However, it will take some time to introduce ethanol in diesel engines, owing to constraints imposed by properties of ethanol and requirements of diesel engine.

1.6 Properties of Ethanol and Diesel

Table 1: Properties of biodiesel, diesel and ethanol

Fuels	Biodiesel	Diesel	Ethanol
Heating value (MJ/kg)	38.5	44.3	29.7
Density @20°C (gm/cc)	896	840	790
Flash Point (°C)	196	76	13
Viscosity @ 40°C (cst)	6.5	3.2	1.2
Cetane number	56	51	6

1.7 Biodiesel

In the most general sense, biodiesel refers to any diesel fuel substitute derived from renewable biomass. More specifically, biodiesel is defined as an oxygenated, sulphur free, biodegradable, non-toxic, and eco-friendly alternative diesel oil. Chemically, it can be defined as a fuel composed of mono-alkyl esters of long chain fatty acids derived from renewable sources, such as vegetable oil, animal fat, and used cooking oil designated as B100, and also it must meet the special requirements such as the ASTM and the European Standards. One popular process for producing biodiesel is Transesterification. [19]

According to ASTM, biodiesel is made of "mono-alkyl esters of long chain fatty acid derived from vegetable oils or animals fats."

In layman's terms, it is clean-burning alternative fuel made from fat or oil (such as soybean or palm oil) that has been chemically processed to remove glycerin. The term biodiesel refers to the pure diesel called B100 which has been designed as an alternative fuel by the U.S. Department of Energy and Transportation.

The injection and atomization characteristics of the vegetable oils are significantly different than those of petroleum derived diesel fuels, mainly as the result of their high viscosities. Modern diesel engines have fuel-injection system that is sensitive to viscosity change. One way to avoid these problems is to reduce fuel viscosity of vegetable oil in order to improve its performance. The conversion of vegetable oils into biodiesel is an effective way to overcome all the problems associated with the vegetable oils. Dilution, micro emulsification, pyrolysis, and transesterification are the four techniques applied to solve the problems encountered with the high fuel viscosity.

Transesterification is the most common method and leads conversion of vegetable oils and fats into mono alkyl esters, called biodiesel .The methyl ester produced by transesterification of vegetable oil has a high cetane number, low viscosity and improved heating value compared to those of pure vegetable oil which results in shorter ignition delay and longer combustion duration and hence low particulate emissions.

1.8 Biodiesel Production Cycle

Figure 1 shows the Biodiesel production Cycle, solar energy and carbon dioxide along with other inputs are used to grow crops that are in turn harvested and processed. As an example, soybeans are crushed to produce oil that is the basic material to be turned into biodiesel. The production process forces the vegetable oil to react with a catalyst to produce fatty acid esters, the chemical name for biodiesel. The fuel is then used in existing vehicles which also produce carbon dioxide.

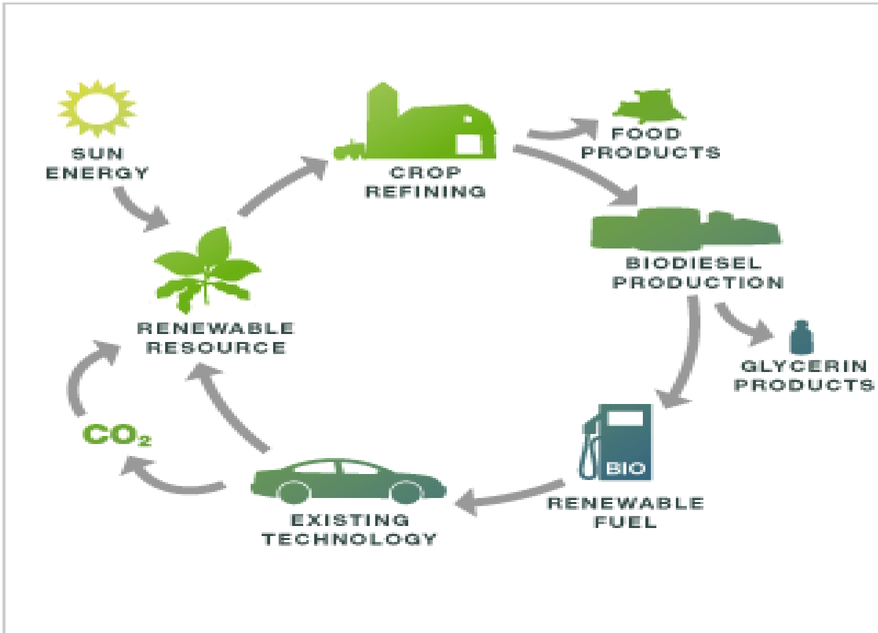

Figure1. Biodiesel production cycle

[http://www.sonicbiodiesel.com/about/full%20cycle.gif]

1.9 Chemistry of Biodiesel: Tranesterification

Transesterification is the process of separating the fatty acids from glycerol to form fatty acid esters and free glycerol. Fatty acid esters commonly known as biodiesel can be produced in batches or continuously by transesterifying triglycerides such as animal fat or vegetable oil with lower molecular weight alcohols in the presence of a base or an acid catalyst. This reaction occurs stepwise, with monoglycerides and diglycerides as intermediate products. The "R" groups are the fatty acids, which are usually 12 to 22 carbons in length. The large vegetable oil molecule is reduced to about 1/3 of its original size, lowering the viscosity making it similar to diesel fuel. The resulting fuel operates similar to diesel fuel in an engine. [20]

CH2-OOC-R1			**R1-COO-R’**	**CH2-OH**
|		**Catalyst**	**|**	**|**
CH-OOC-R2	**+ 3R’OH**	⇄	**R2-COO-R’ +**	**CH-OH**
|			**|**	**|**
CH2-OOC-R3			**R3-COO-R’**	**CH2-OH**
Glyceride	**Alcohol**		**Ester**	**Glycerine**

Where, term R’ represents different alkyl groups.

The process of transesterification brings about drastic change in viscosity of vegetable oil. The biodiesel thus produced by this process is totally miscible with mineral diesel in any proportion. Biodiesel viscosity comes very close to that of mineral diesel hence no problems in the existing fuel handling system. Flash point of the biodiesel gets lowered after esterification and the cetane number gets improved. Even lower concentrations of biodiesel act as cetane number improver for biodiesel blend. Calorific value of biodiesel is also found to be very close to mineral diesel

The overall process is normally a sequence of three consecutive steps, which are reversible reactions. In the first step from triglycerides, diglycerides are obtained. From diglyceride, monoglyceride is produced and in the last step from monoglycerides, glycerine is obtained. In all these reactions esters are produced. The stoichiometric relation between alcohol and the oil is 3:1. However, an excess of alcohol is usually more appropriate to improve the reaction towards the desired product.

1.10 Position of India

India is the world's fifth largest primary energy consumer and fourth largest petroleum consumer after United States, China and Japan. Despite the recent global economic slowdown, India's economy is expected to continue to grow at 6 to 8 percent per year in the near term. With an outlook for moderate to strong economic growth and a rising population, growing infrastructural and socio-economic development will stimulate an increase in energy consumption across all major sectors of the Indian. In Indian fiscal year (IFY) 2009/10, an import of gasoline and petroleum products has outgrown total domestic consumption by more than 14 percent. While India's domestic energy base is substantial, the country continues to rely on imports for a considerable amount of its energy use, consequently escalating India's oil import expenditure to over $135 billion in IFY 2011/12, up 22 percent over the previous year (Figure 2) [21].

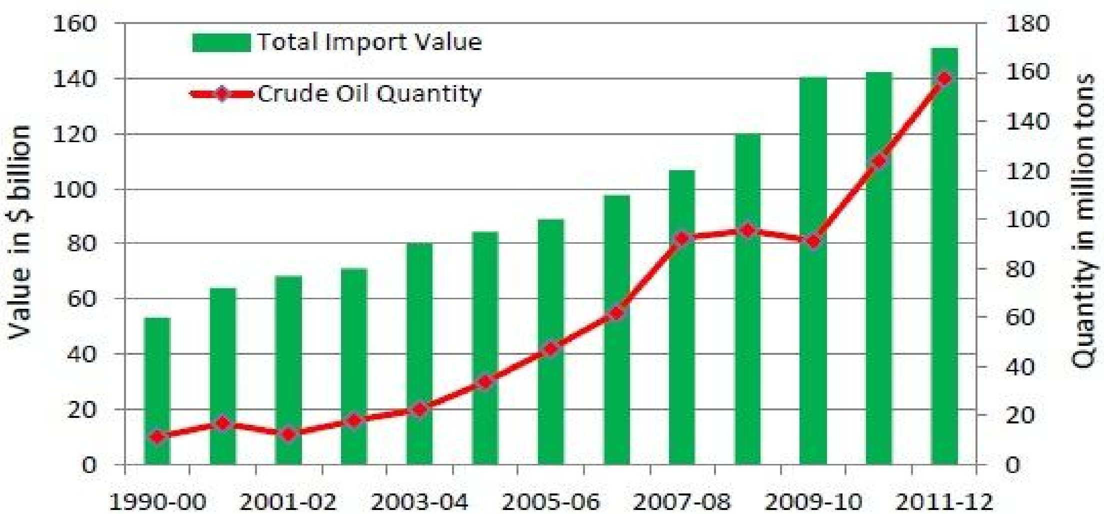

Figure 2. India: Import of crude oil and value of petroleum

(source: Petroleum Planning and Analysis Cell, GOI)

The petroleum industry now looks very committed to the use of ethanol as fuel, as it is expected to benefit sugarcane farmers as well as the oil industry in the long run. Ethanol (FUEL ETHANOL) can also be produced from wheat, corn, beet, sweet sorghum etc. Ethanol is one of the best tools to fight vehicular pollution, contains 35% oxygen that helps complete combustion of fuel and thus reduces harmful tailpipe emissions. It also reduces particulate emissions that pose a health hazard.

Most industrial ethanol is denatured to prevent its use as a beverage. Denatured ethanol contains small amounts, 1 or 2 percent each, of several different unpleasant or poisonous substances. The removal of all these substances would involve a series of treatments more expensive than the federal excise tax on alcoholic beverages (currently about $20 per gallon). These denaturants render ethanol unfit for some industrial uses. In such industries un-denatured ethanol is used under close federal supervision.

2. Literature Review

Researchers did many testing programs to evaluate performance and emission characteristic of the engine running on blends of biodiesel and ethanol with diesel. Result of these studies indicated that the changes in bsfc, torque, BTHE, pressure and also variation in emission as HC, CO, NO_X as compare to diesel fuel.

This literature review mainly deals with study of performance and emission characteristics of blends of biodiesel and ethanol with diesel fuel.

2.1 Performance and Emission Characteristic of Blends with Diesel

Mevada et al. (2013) [22] investigated the effect of ethanol and biodiesel blended diesel fuels von performance from a single cylinder direct injection engine. In this work it is showed that D80B10E10fuel blend gives minimum smoke density compared to the all fuel/fuel blends. At medium load, CO emission for D80B10E10 fuel blend is observed lower than the other fuel blends. Due to higher density, lower calorific value of biodiesel & lower density, lower calorific value of ethanol brake thermal efficiency of these fuel blends in sequence of D80B10E10, D75B20E5, & D85B10E5 are observed slightly lower compared to diesel & B.S.F.C. and B.S.E.C. are slightly higher for these blends in same sequence.

Arun et al. (2014) [23] studied performance analysis of a single cylinder diesel engine (3.2 kW, 1500rpm, Engine coupled with an eddy current dynamometer) using diesel with ethanol and castor seed oil blends. The C15E5 have lower value of NOx and Unburnt hydrocarbon than diesel. This is due to better combustion of fuel inside the cylinder than diesel. The Exhaust gas temp and Brake thermal efficiency for C15E5 is less comparing to C10E5 and pure diesel. C15E5 with 80% diesel, 15% castor oil and 5%

methanol gives us optimum values of performance and emission characteristics comparing to C15E5 and pure diesel. The gas emissions of NOx, carbon monoxide (CO), carbon dioxide (CO2), hydrocarbons (HC), are being measured by the use of AVL smoke meter.

Chasos et al. (2013) [24] studied diesel internal combustion engine emissions measurements for methanol-based and ethanol-based biodiesel blends. Ethanol-based blends have higher smoke than the pure diesel while smoke is less for methanol based blends as compare to diesel fuel. When engine is running at maximum speed and cold, the highest amount of smoke is emitted for increasing percentage of blending of methanol than diesel, and the lowest amount of smoke is emitted when the engine is hot and operating at low engine speed when the fuel blend has the maximum blending percentage of methanol-based biodiesel.

Prasad et al. (2012) [25] studied effect of oxygenated additives on control of emissions in a single cylinder water-cooled direct injection diesel engine using jatropha based biodiesel and diesel blends. There is improvement in performance and reduction in emissions with small nozzle hole injector and high injection pressure. For B20 with addition of DEE5 having better performance and lower emission. The higher cetane rating of DEE is advantageous for obtaining lower smoke opacity and also lower NOx emission. For B40 with DEE10 having better performance in terms of brake specific fuel consumption with low HC and NO_X.

Yilmaz et al. (2012) [26] studied comparative analysis of biodiesel- ethanol-diesel and biodiesel-methanol-diesel blends in a diesel engine. Biodiesel alcohol diesel blends show a higher brake specific fuel consumption than diesel. As alcohol concentrations in blends increase, CO and HC emissions increase, while NO emissions are reduced. Also, methanol blends are more effective than ethanol blends for reducing CO and HC emissions, while NO reduction is achieved by ethanol blends. Biodiesel-ethanol-diesel blends, as compared to standard diesel, increase CO and HC emissions while reducing NO emissions. Interestingly, biodiesel methanol diesel blends have opposite effects on the emissions.

Kleinová et al. (2011) [27] studied properties of fossil diesel oil blends with ethanol and FAME as fuels for diesel engines. The performed study showed that EtOH is an efficient oxygenate of diesel fuel blends decreasing the PM in emissions. The presence of oxygenates of ester type (FAME) ensures excellent lubricity of the blend. Performance characteristics of testing engines with oxygenate – FDO blends are not significantly different from the characteristics for the FDO itself. Slightly lower power output and higher BSFC of blended fuels are the result of lower energetic content of these fuels. Opacity of blended fuels is significantly lower in comparison to standard FDO. Regulated emissions (CO, HC, and NOx) depend on the engine regime.

Keerthi et al. (2013) [28] studied performance characteristics of four stroke single cylinder diesel engine with 10% isobutanol at different injection pressures**.** Higher fuel injection pressure is an effective way to improve the performance and reduce Particulate Matter (PM) emissions. Brake thermal efficiency increased with all blends when compared to the conventional diesel fuel. Maximum Brake thermal efficiency obtained was 33.5% with B40 blend with 10% isobutanol against 28% with conventional diesel. Brake specific fuel consumption decreased with the blends with isobutanol when compared with diesel fuel. Cylinder pressure of the blends increase with increase in injection pressure.CO emissions and smoke density decrease significantly with the blends and isobutanol and further decrease with the increasing injection pressure when compared with diesel. NOx emissions decrease marginally with the blends and isobutanol which however increase with injection pressure.

Shia et al. (2006) [29] studied Emission reduction potential of using ethanol–biodiesel–diesel fuel blend on a heavy-duty diesel engine. The blend ratio used in this study was 5:20:75 (ethanol: methyl soyate: diesel fuel) by volume. Total hydrocarbon (THC) from BE-diesel was lower than that from diesel fuel under most tested conditions. The application of BE-diesel can reduced 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 small amount of ethanol (2–12 mg m^{-3}) was observed in the exhaust using BE-diesel which was not in the exhaust from diesel fuel.

Jagadish et al. (2011) [30] studied performance and emissions from a constant speed single cylinder diesel engine was observed with different kinds of fuels blends like diesel-ethanol, and diesel-palm stearin methyl ester. Brake thermal efficiency of the engine is improved with little amounts of blends like B10, E10B. However, higher quantities of blending leads to increase in fuel consumption. Supercharging operation resulted in reduction in fuel consumption. The NOx emissions seem to reduce with ethanol blending to diesel. E10B showed reduced amount of NO formation when compared with diesel. A little rise in NO emissions was observed with B10 in comparison to diesel with considerable fuel economy. B20 gives a little reduction in HC emissions (10.53%) with a little rise in NO emissions (13.07%). Smoke emissions are considerably reduced with biofuels owing to its higher Cetane number and nature of combustion. PM emissions are considerably reduced with blends of ethanol-diesel, biodiesel-diesel in comparison to pure diesel operation.

Patil et al. (2010) [31] experimented on 3.75 kW diesel engine AV1 Single Cylinder water cooled, Kirloskar Make was used to test blends of diesel with kerosene and Ethanol. The engine performance studies were conducted with rope break dynamometer setup. Parameters like speed of engine, fuel consumption and torque were measured at different loads for pure diesel and various combination of dual fuel. For 20 % mixture of ethanol blend with diesel has a very good efficiency compared with pure diesel and blend of kerosene. Also it is observed that the 20 % ethanol blend is having higher volumetric efficiency compare with diesel and kerosene blend. Exhaust gas temperature for ethanol blend has not shown any substantial increase compare with pure diesel. Hence blending of ethanol at about 20 % can lead to a better performance of engine compare with pure diesel.

Hansen et al. (2001) [32] The properties of ethanol-diesel blends have a significant effect on safety, engine performance and durability, and emissions. An increase in fuel consumption approximately equivalent to the reduction in energy content of the fuel can be expected when using ethanol-diesel blends. With ethanol percentages of 10% or less, operators have reported no noticeable differences in performance compared to running on diesel fuel. It is accepted that the addition of ethanol to diesel fuel will have a beneficial effect in reducing the PM emissions at least. The amount of improvement varies from engine to engine and also within the working range of the engine itself. The flammability of ethanol-diesel blends indicates that they should be treated as Class I liquids as they have flashpoints below 37.8°C, in contrast to diesel fuel, which is a Class II liquid. Hence, appropriate measures when using ethanol-diesel blends need to be implemented to meet the storage, handling and dispensing requirements that are stipulated for Class I liquids.

Al-Hassan et al. (2012) [33] study on the solubility of a diesel-ethanol blend and on the performance of a diesel engine fueled with diesel- biodiesel - ethanol blends. The experimental results of the phase stability revealed that the DE blends is not stable and separated after 2, 5, 24 and 80 hours, for 20%, 15%, 10% and 5% ethanol concentration, respectively. Whereas for DBE blends the separation time is longer than of the first system and reached 1, 3 and 9 days for 20%, 15%, 10% ethanol concentration, respectively. The blend of DBE5 was of the best stability with very little separation. The experimental results of the engine performance indicated that the equivalence air-fuel ratio and the brake specific fuel consumption for the fuel blends are higher than that of diesel fuel and increases with the increase of the ethanol concentration in the blends. The brake power for the fuel blend of 5% ethanol concentration is close to that of diesel fuel and decreases with higher concentrations.

The brake thermal efficiency was increased with fuel blends of 5 and 10% ethanol concentration and decreases with a higher ethanol proportion in the blends. In conclusion, among the different fuel blends, the blends containing 5 and 10% ethanol concentration are the most suited for CI engines. Waste frying oil-derived biodiesel could be used as an effective additive for diesel-ethanol mixture. The addition of biodiesel to diesel-ethanol mixture permits a higher ethanol concentration and contributes to more stable fuel blends than a mixture of only diesel ethanol blends.

Lapuerta et al. (2007) [34] The stability of blends bioethanol–diesel has been studied, aiming to provide essential information previous to their use in diesel engines. The presence of water in the blends favors the separation of the ethanol phase. As the water content increases, the separation occurs with lower initial ethanol content. When the temperature of the blend increases it becomes more stable and the solubility of ethanol in the diesel fuel increases. This effect is also observed for different water and ethanol contents. The sensitivity of the effect of water content, as well as that of the effect of additive content, become higher as the temperature of the blend increases. Blends with bioethanol contents up to 10% v/v can be used in diesel engines in countries where winter temperatures rarely fall to –5°C, such as Spain, if care is taken about water contamination. Blends with 7% bioethanol, such as those commercially used, can be used in even colder countries, although further experimentation at lower temperatures is needed for confirmation.

Wanchareon et al. (2006) [35] The stability and fuel properties of diesohol blend were investigated in order to evaluate the potential for using biodiesel as an effective agent for diesohol and making diesohol an alternative fuel for diesel engines. The diesohol blends containing 5% ethanol had very close fuel properties compared to diesel fuel. In this study, the blend of 90% diesel, 5% biodiesel and 5% ethanol had a heating value very close to that of diesel fuel. And the blend of 80% diesel, 15% biodiesel and 5% ethanol had the highest cetane index.

It was found that CO and HC were reduced significantly at high engine load, whereas NOx increased, when compared to that of diesel. Taking these facts into account, a blend ratio of 80% diesel, 15% biodiesel and 5% ethanol was the most suitable for diesohol production because of the acceptable fuel properties and the reduction of emissions.

Hira et al. (2012) [36] studied performance and emission characteristic of CI engine using blends of ethanol and biodiesel with diesel. The experimental results show that the BE20 fuel gives the best performance in comparison to conventional diesel fuel along with fairly reduced exhaust emission. They founded that fuel consumption of BE20 is lower than other fuel mainly B20, E- diesel, diesel. BSFC was lower for BE20 than any other fuels especially lower than E diesel and B20 and was same than that of diesel fuel. Brake thermal efficiency of BE20 is higher than any other fuels. Diesel has lower BTE than any other fuels. The highest percentage of exhaust temperature was obtained with blend of BE20 which is helpful in proper combustion. The CO and HC percentage of BE20, B20& E-diesel is lower than that of diesel. The smoke density of BE20, B20 is lower than E diesel & diesel due to the lower HC emission.

Ali et al. (2013) [37] studied improvement of blended biodiesel fuel properties with ethanol additive. The density and kinematic viscosity of the B50-E blend significantly decreased with the increase of E concentration in the blended fuel and displayed satisfactory fuel properties for all blending ranges. Similarly, the acid value of B50-E blends slightly improved with increasing E content. Likewise, increasing E content in the blended fuel B50 resulted in a significant difference in low temperature performance, with a maximum decrease in pour point by 2°C for B50-E3 compare to B50. On the other hand, there was a slight difference in the cloud point of the blends by 1°C. In general, the heating value decreases slightly with increasing E portion in the blends. B-E4 has the minimum heating value 4.3% less than the heating value of the blended fuel B50. B50-E blends exhibited slightly superior low temperature performance, acid value, viscosity and density with slight lower energy continent in comparison to B50.

Kiran et al. (2013) [38] studied performance and emission analysis of diesel engine using fish oil and biodiesel blends with isobutanol as an additive. Brake thermal efficiency is observed as the BP increases there is considerable increase in the BTE. Maximum BTE is 35.14% which is obtained for F30D69.5I5. The BTE of fish oil is increases up to 0.364% and 0.823% as compared with to fuels of optimum blend and diesel at full load condition. As the load increases the fuel consumption decreases, the minimum fuel consumption is for F30D69.5I5 is 0.25 kg/kW-hr as to that of F30 is 0.258 kg/kW-hr at full load condition. It is observed that smoke is increases for fish oil blends at full load conditions as compared to optimum blend. The engine emits more CO for diesel as compared to fish oil blends under all loading conditions. The CO concentration is increases for the blends of F30D69.I5 and same as the diesel for F30D69I10. The unburned hydrocarbons after adding ignition improver of Fish oil decreases up to 24.44% as compared to diesel at full load condition. The NOx emission for all the fuels tested followed a decreasing trend with respect to load.

Karunanithi et al. (2012) [39] attempted to produce biodiesel from waste vegetable oils and the properties of the produced biodiesel have been studied including its emission characteristics. A four stroke, single cylinder is used to study the emission and performance characteristics. The large scale production of Biodiesel and its economic aspects have also been discussed in brief. High temperature of 85 0C is considered to be the optimum temperature for conversion. Increasing the methanol concentration up to 100 % excess than the stoichiometric proportion yields an optimum conversion. It has been found that the biodiesel yield increases and then reaches the optimum conversion at 5-6% of the weight of the catalyst.

Ridvan (2011) [40] investigated the use of waste cooking oil (WCO) methyl ester as an alternative fuel in a four-stroke turbo diesel engine with four cylinders, direct injection and 85 HP. A test was applied in which an engine was fuelled with diesel and three different blends of diesel/biodiesel (B25, B50 and B75) made from WCO. The test engine was run at 18 different speeds with a full load, and the results were analyzed. The biodiesel fuels produced slightly less smoke than the conventional diesel fuel, which could be attributed to better combustion efficiency. The use of biodiesel resulted in lower emissions of total hydrocarbon and CO, and increased emissions of NOx.

This study showed that the exhaust emissions of diesel/biodiesel blends were lower than those of the diesel fuels, which indicates that biodiesel has more favourable effects on air quality.

Singh et al. (2010) [41] studied hybrid fuels consisting of coconut oil, aqueous ethanol and a surfactant. The engine performance and exhaust emission were investigated and compared with that if diesel. The experimental results show that the efficiency of the hybrid fuels is comparable with to that of diesel. The exhaust emission was lower than those for diesel, except carbon monoxide emissions, which increased. As the percentage of ethanol in the hybrid fuels increases, the CO emission level decreases due to higher air –fuel ratio of the fuel. NO emission Values were 459,454,442 ppm for 87CCO 10E 3B, 70CCO 17E 13B, 54CCO 23E 23B respectively, compared to 852 ppm for diesel at 86% load.

Hence it is concluded that these hybrid fuels can be used as an alternatives fuel in diesel engines without any modifications. Their completely renewable nature ensures that they are environment friendly with regard to their emission characteristic

Çetinkaya et al. (2007) [42] investigated the engine performance of biodiesel fuel originated from used cooking oil in a Renault automobile and four stroke, four cylinder, and 75 kW Renault Diesel engine in winter conditions for 7500 km road tests in urban and long distance traffic.

The results showed that the torque and brake power output obtained during the used cooking oil originated biodiesel application were 3-5% less than those of diesel fuel. The engine exhaust gas temperature at each engine speed of biodiesel was less than that of diesel fuel. Higher values of exhaust pressures were found for diesel fuel at each engine speed. The injection pressures of both fuels were similar. Based on the experimental results of this study, the authors concluded that used cooking oil originated biodiesel could be recommended as diesel fuel alternative for winter conditions.

Mei et al. (2008) [43] studied the combustion and heat release of engines using diesel and bio-diesel blends. In this paper, the comparative experiments were carried out with diesel engine using diesel fuel, B20, and B100. The combustion and emissions of engine were analyzed. When the engine uses bio-diesel, the combustion timing occurs in advance, and the ignition delay decreases. At 50% and 100% load at a rated speed, the combustion also happens in advance, the maximal heat release rates are reduced by 11.4% and 25.3%, respectively, and the related point occurs in advance. The specific fuel consumption is raised by about 12% because of the lower calorific value. Total pollution decreases, only NOx emission increases by 5.6%, and CO, HC, and PM emissions are reduced by 41.4%, 38.3% and 38.7%, respectively.

Ozkan et al. (2005) [44] tested waste cooking oil biodiesel fuels in a single-cylinder DI Diesel engine. It was found that Compared diesel fuel, 25% power loss occurred with biodiesel. The performance characteristics of biodiesel were closer to those of diesel fuel. The selling price of waste cooking oil biodiesel fuel is lower than that of diesel fuel as a result of the recycling of raw materials. Based on these results, it may be concluded that the biodiesel fuels can be used as fuel in diesel engines with some modifications. Fuel systems should be optimized for biodiesel fuels, because of the high density and gumming properties. The problems include coking carbon deposits on the injectors to such an extent that fuel atomization does not occur properly , oil ring sticking and thickening and gelling of the lubricating oil as a result of contamination by the vegetable oils.

Pathak et al. (2007) [45] experimented that a multi cylinder naturally aspirated diesel genset (DG) was operated successfully with renewable fuels (bio-diesel of non-edible plant oil such as Jatropha oil, karanja oil, rice bran oil & producer gas) and its performance was verified through extensive, short and long duration trials. Study reveals that mixture of bio-diesel and producer gas offer better break thermal efficiency compared to mixture of fossil-diesel and producer gas. Maximum replacement of biodiesel by producer gas was 86% at 63% engine load with minor losses in engine output compared to fossil-diesel. In general, exhaust gas temperature and specific energy consumption increased with renewable fuel compared to fossil-diesel. It was due to lower calorific value of bio-diesel and producer gas. In compression ignition (CI) engine having 18.4:1 simulated compression ratio, at 84% engine load and with renewable fuel concentration of pollutants like carbon monoxide (CO),hydrocarbon (HC), nitric oxide (NO), nitrogen dioxide (NO2) were reduced, in general compared to fossil-diesel. However concentration of pollutants were more while compared to fossil-diesel – producer gas mixture.

2.2 Conclusion from Literature Review and Objective of Present Work

Biodiesel and ethanol with diesel fuel blends have been tested in compression ignition engine by many researchers. It is suitable for compression ignition engine and performance is enhanced. They founded better thermal efficiency and lower emission like carbon mono-oxide and unburned hydrocarbon with slight increase in NO_X emission. However, there is still need to find out optimum blending of biodiesel and ethanol with diesel.

The objective of the present project work is to study of performance testing of blending of biodiesel and ethanol with diesel fuel in a compression ignition engine without making any modification in the existing engine to check the performance parameter like torque, brake thermal efficiency, specific fuel consumption and emission characteristic. Performance testing will be performed in 4-stroke, single-cylinder, water cooled C.I. engine which is attached by eddy current dynamometer for loading purpose and computer panel to analyze the performance data.

3. Engine Performance Studies

3.1 Engine Test Setup

The setup consists of single cylinder, four stroke, diesel engine connected to eddy current type dynamometer for Brake powering. Setup is equipped another fuel tank to supply alternate fuel and with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for Pθ−PV diagrams. The setup has stand-alone panel box consisting of air box, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. The setup can be used to measure engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Lab view based Engine Performance Analysis software package “Engine soft LV” is available for on line performance evaluation.

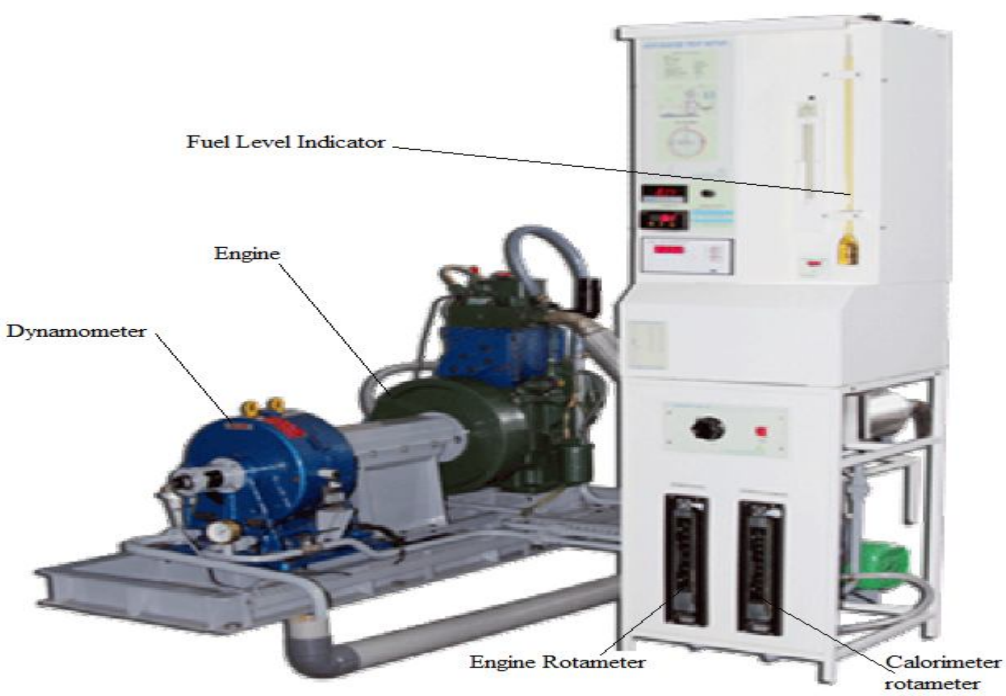

Figure 3: Experimental setup

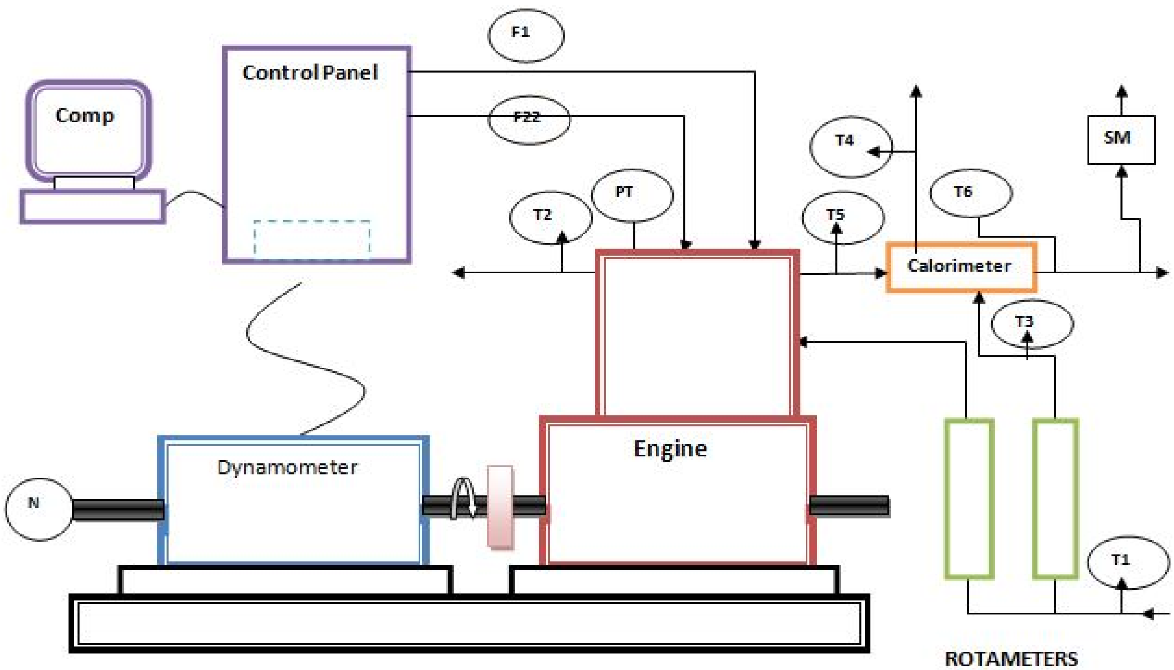

Figure 4: Line diagram of experimental set up

F1	Fuel flow dp (differential pressure) unit
F2	Air flow dp (differential pressure) unit
F4	Calorimeter water flow kg/hr
T1,T3	Inlet water temperature ^{0}K water
T2	Outlet engine jacket water temperature ^{0}K
T4	Calorimeter water outlet temperature ^{0}K
T5	Exhaust gas to calorimeter inlet temp. ^{0}K
T6	Exhaust gas from calorimeter outlet temp. ^{0}K

3.2 Eddy Current Dynamometer

It consists of a stator on which a number of electromagnets are fitted and a rotor disc is coupled to the output shaft of the engine. When rotor rotates eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets. These eddy currents oppose the rotor motion, thus loading the engine. These eddy currents are dissipated in producing heat therefore a cooling arrangement is attached. A moment arm measures the torque. Regulating the current in electromagnets controls the load.

Table 2: Specifications of engine test setup

Product	Constant speed CI engine Engine test setup 1 cylinder, 4 stroke, Diesel
Engine	Make Kirloskar, Type 1 cylinder, 4 stroke Diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5, Modified to VCR engine CR range 12 to 18
Dynamometer	Type eddy current, water cooled
Rota meter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Software	“EnginesoftLV” engine performance analysis software
Smoke meter	AVL DIX, for opacity and gas measurement

3.3 Performance Evaluation

A single cylinder Diesel engine is used for the experimental analysis. Fuel was supplied to the engine from an outside tank. All runs started with a 15-min warm-up period prior to data collection. The gap of 5 minutes was provided between the two consecutive runs. The data measured during the tests included, brake power, torque, and fuel consumption, SFC, opacity. During the test Brake power was varied by adjusting the Brake power knob provided on the control panel of the test rig . The tests were performed with pure diesel fuel and blends of biodiesel, diesel and ethanol. The observations were taken at Brake power of 0.5kW, 1.5kW, 2.5kW, 3.5kW, 4.5kW.

Formulation used for calculation of various parameters are described below:

i. Torque (kg m) =Brake power × Arm length

ii. Brake power (kW) = (2 × π × Speed × Torque × 9.81) / (60 × 1000)

iii. Brake Thermal Efficiency (%) = $\frac{\text{Brake power (kW)} \times 3600 \times 100}{\text{Fuelflowin}\frac{\text{kg}}{\text{hr}} \times \text{calorificvalue (kJ/kg)}}$

iv. Specific fuel consumption (Kg/kWh) =$\frac{\text{Fuelflowin}\frac{\text{kg}}{\text{hr}}}{\text{Brake power (kW)}}$

v. Mechanical Efficiency (%) = $\frac{\text{Brake power (kW)} \times 100}{\text{Indicated power (kW)}}$

vi. Heat balance (kJ/h):

a) Heat supplied by fuel (kJ/h) = fuel flow (kg/h) × Calorific value (kJ/kg)

b) Heat equivalent to useful work (kJ/h) = Break power (kW) × 3600

$$\text{Heat Break power (\%)} = \frac{\text{Heat equivalent to useful work} \times 100}{\text{Heat supplied by fuel}}$$

c) Heat carried in jacket cooling water = $F_3 \times C_{p}w \times (T_2 - T_1)$

Heat carried in jacket cooling water (%)

$$= \frac{\text{Heat carried in jacket cooling water} \times 100}{\text{Heat supplied by fuel}}$$

d) Heat in Exhaust (calculate value):

$$Cpex = F4 * CpW * \frac{(T4 - T3)}{(F1 + F4)\ (T5 - T6)}$$

Where,

C_pex = Specific heat of exhaust gas (kJ/kg ^{0}C).

C_pw = Specific heat of water (kJ/kg^{0}C).

F_1 = Fuel consumption (kg/hr).

F_2 = Air consumption (kg/hr).

F_3 = Engine water flow rate (kg/hr).

F_4 = Calorimeter water flow rate (kg/hr).

T_{amb} = ambient temperature (^{0}C).

T_1 = Engine water inlet temperature (^{0}C).

T_2 = Engine water outlet temperature (^{0}C).

T_3 = Calorimeter water inlet temperature (^{0}C).

T_4 = Calorimeter water outlet temperature (^{0}C).

T_5 = Exhaust gas to calorimeter inlet temp(^{0}C).

T_6 = Exhaust gas from calorimeter outlet temp (^0C).

Heat in Exhaust (kJ / h) = $(F_1 + F_2) \times C_p ex \times (T_3 - T_{amb})$

$$\text{Heat in Exhaust}(\%) = \frac{\text{Heat in Exhaust} \times 100}{\text{Heat supplied by fuel}}$$

e) Heat to Radiation and unaccounted (%)

= Heat Supplied By Fuel (%) - {(Heat In Jacket Cooling Water (%)
+ Heat To Exhaust (%)
+ Heat Equivalent To Useful Work (%)}

3.4 Preparation of Blends

3.4.1. Blends of ethanol with diesel

Blends are prepared on the volume percentage base of ethanol and diesel. Ethanol percentage varied from 5 to 15 percent with n-butanol as co-solvent. Blends prepared are as-Z5E5D90, Z5E10D85, Z5E15D80. Z represents the volume percentage of n-butanol, E represents the volume percentage of ethanol and D represents the volume percentage of diesel. Here Z5 represents use of 5% n-butanol as surfactant. Fuel properties for different blends are shown in the Table 4.

Calorific value of diesel = 44300 kJ/kg.

Calorific value of ethanol = 29700 kJ/kg.

Calorific value of n-butanol = 33000 kJ/kg.

Table 3: Calorific values of blends of ethanol and diesel

Type of blend	Amount of Ethanol (ml)	Amount of n-butanol (ml)	Amount of diesel(ml)	Resultant calorific value (kJ/kg)
Pure Diesel	0	0	1000	44300.0
Z5E5D90	50	50	900	43005.0
Z5E10D85	100	50	850	42275.0
Z5E15D80	150	50	800	41545.0

Table 4: Fuel properties for blends of ethanol and diesel

Fuel/ Properties	Diesel	Ethanol	n-butanol	Z5E5D90	Z5E10D85	Z5E15D80
Mole weight	190 -220	46.07	74.12	190.51	182.56	174.61
Density at 20^{o}c (gm/cc)	0.840	0.789	0.810	0.835	0.8334	0.83085
Carbon content (Wt %)	86	52.2	64.82	83.251	81.561	79.871
Viscosity at 40^{o}c (cst)	3.35	1.2	3.0	3.225	3.1175	3.01

3.4.2 Blends of biodiesel and ethanol with diesel

Blends are prepared on the volume percentage base of biodiesel,ethanol and diesel. Ethanol percentage fixed to 5 percent with n-butanol as co-solvent. Blends prepared are as-Z5E5BD10D80, Z5E5BD20D70. Z represents the volume percentage of n-butanol, E represents the volume percentage of ethanol, BD represents volume percentage of biodiesel and D represents the volume percentage of diesel. Here Z5 represents use of 5% n-butanol as surfactant. Fuel properties for different blends are shown in the Table 6.

Calorific value of diesel = 44300 kJ/kg,

Calorific value of ethanol = 29700 kJ/kg.

Calorific value of n-butanol = 33000 kJ/kg,

Calorific value of biodiesel = 38500 kJ/kg.

Table 5: Calorific values of blends of biodiesel and ethanol with diesel

Type of Blend	Amount of Ethanol (ml)	Amount of N-Butanol (ml)	Amount of Biodiesel (ml)	Amount of diesel(ml)	Resultant calorific value (kJ/kg)
Pure Diesel	0	0	0	1000	44300.0
Z5E5BD10D80	50	50	100	800	42425.0
Z5E5BD20D70	50	50	200	700	41845.0
BD10D90	0	0	100	900	43720.0
BD20D80	0	0	200	800	43140.0

Table 6: Fuel properties for blends of biodiesel and ethanol with diesel

Fuel/ Properties	Biodiesel	Diesel	Ethanol	n-butanol	Z5E5BD10D80	Z5E5BD20D70	BD10D90	BD20D80
Mole weight	870	190-220	46.07	74.12	257.01	323.50	271.50	338.00
Density at 20^{o}c (gm/cc)	0.896	0.840	0.789	0.810	0.842	0.847	0.845	0.851
Carbon content (Wt %)	77	86	52.2	64.82	82.35	81.45	85.1	84.2
Viscosity at 40^{o}c (cst)	6.3	3.35	1.2	3.0	2.997	3.797	3.793	4.53

3.5 Performance data for diesel and blends of ethanol with diesel

Experiments have been performed on various brake power for different blends. The experimental data for performance study are given below:

3.5.1 Diesel performance data

Engine performance parameters obtained from performance testing in single cylinder C. I. engine against different loads for diesel are given below in Table 7.

Table 7: Performance parameters for diesel

Torque (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	Sfc (kg/kWh)	Opacity (%)
3.18	0.65	2.15	2.69	13.55	59.16	20.03	0.49	8.2
9.28	1.52	1.94	3.46	26.64	56.04	43.93	0.27	19.2
15.21	2.47	1.81	4.28	32.57	54.96	57.72	0.24	31.1
22.06	3.52	1.62	5.14	35.58	52.37	68.44	0.21	54.6
28.41	4.70	1.49	6.02	36.12	51.10	73.90	0.21	59.62

Table 8: Observation data for diesel

LOAD (kg)	CR	T1 deg C	T2 deg C	T3 deg C	T4 deg C	T5 deg C	T6 deg C
1.75	18	18.20	25.46	18.20	20.34	140.00	109.87
5.11	18	18.30	25.96	18.30	20.36	160.56	130.04
8.38	18	18.53	32.17	18.53	23.52	205.67	169.53
12.16	18	18.58	36.08	18.58	25.59	260.30	189.60
13.95	18	18.61	37.73	18.61	27.99	305.60	203.26

3.5.2 Blends of Ethanol with diesel performance data

Experiments has been performed by taking ethanol 5%,10%,15% with diesel in proportion of 90%, 85%, 80% respectively with 5% fixed n-butanol, as diesel engine fuel and following parameters has been obtained.

Table 9: Performance parameters for ethanol diesel (Z5E5D90)

Torque (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	Sfc (kg/kWh)	Opacity (%)
3.41	0.58	1.70	2.28	13.75	54.19	25.37	0.64	1.2
9.85	1.64	1.53	3.17	27.13	52.37	51.80	0.32	2.2
16.15	2.64	1.43	4.08	32.62	51.88	64081	0.26	3.5
22.30	3.60	1.35	4.95	35.98	50.22	72.68	0.24	6.2
29.03	4.64	1.19	5.83	36.60	48.01	79.57	0.23	9.6

Table 10: Observation data for ethanol diesel (Z5E5D90)

LOAD (kg)	CR	T1 deg C	T2 deg C	T3 deg C	T4 deg C	T5 deg C	T6 deg C
1.88	18	24.96	31.26	24.96	26.47	170.3	133.96
5.43	18	24.99	31.84	24.99	26.44	188.03	136.1
8.9	18	25.09	32.74	25.05	27.10	233.83	164.41
12.29	18	25.09	33.75	25.09	27.92	285.66	195.41
16.00	18	25.16	35.36	25.16	30.14	342.44	230.26

Table 11: Performance parameters for ethanol diesel (Z5E10D85)

Torque (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	Sfc (kg/kWh)	Opacity (%)
3.75	0.64	1.77	2.41	17.39	65.76	26.44	0.59	2.5
9.77	1.63	1.58	3.21	28.78	62.66	50.73	0.32	4.6
16.14	2.65	1.50	4.15	33.64	60.55	63.82	0.26	9.1
22.45	3.63	1.42	5.05	36.64	58.83	71.81	0.24	13.5
28.64	4.57	1.33	5.90	38.25	57.64	77.45	0.23	16.5

Table 12: Observation data for ethanol diesel (Z5E10D85)

LOAD (kg)	CR	T1 deg C	T2 deg C	T3 deg C	T4 deg C	T5 deg C	T6 deg C
2.07	18	24.64	30.54	24.64	25.92	145.11	109.62
5.38	18	24.71	31.43	24.71	26.42	175.83	125.96
8.89	18	24.75	32.37	24.75	27.58	221.30	154.52
12.37	18	24.80	33.42	24.80	28.62	273.21	187.15
15.78	18	24.83	34.63	24.83	29.49	327.12	221.39

Table 13: Performance parameters for ethanol diesel (Z5E15D80)

Torque (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	Sfc (kg/kWh)	Opacity (%)
3.58	0.60	1.71	2.31	16.48	63.05	26.14	0.62	3.3
9.30	1.55	1.55	3.10	29.69	61.45	49.95	0.33	6.2
15.95	2.61	1.49	4.09	35.15	61.48	63.67	0.26	10.2
22.65	3.64	1.39	5.03	37.81	59.16	72.37	0.24	15.6
28.65	4.56	1.30	5.86	38.64	57.88	77.75	0.23	18.8

Table 14: Observation data for ethanol diesel (Z5E15D80)

LOAD (kg)	CR	T1 deg C	T2 deg C	T3 deg C	T4 deg C	T5 deg C	T6 deg C
1.97	18	25.00	31.47	25.00	27.20	143.83	109.80
5.13	18	25.05	32.14	25.05	27.39	173.13	125.11
8.79	18	25.07	33.02	25.07	28.08	217.46	151.38
12.48	18	25.09	34.23	25.09	30.04	275.51	189.56
15.79	18	25.17	35.39	25.17	32.59	320.89	217.29

3.6 Performance data for blends of biodiesel and ethanol with diesel

Engine performance parameters obtained from performance testing in single cylinder C. I. engine against different loads for different blends of biodiesel and ethanol with diesel and following parameters has been obtained.

Table 15: Performance parameters for ethanol biodiesel diesel (Z5E5BD10D80)

Torque (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	Sfc (kg/kWh)	Opacity (%)
4.08	0.67	1.67	2.34	15.28	53.33	28.66	0.56	1.7
10.53	1.68	1.56	3.25	27.21	52.48	51.86	0.31	6
17.20	2.70	1.49	4.19	32.97	51.14	64.46	0.26	15.1
24.05	3.72	1.38	5.10	36.18	49.58	72.96	0.23	29.2
30.95	4.73	1.37	6.09	37.55	48.41	77.55	0.23	46.4

Table 16: Observation data for ethanol biodiesel diesel (Z5E5BD10D80)

LOAD (kg)	CR	T1 deg C	T2 deg C	T3 deg C	T4 deg C	T5 deg C	T6 deg C
2.25	18	20.84	24.77	20.84	22.25	153.75	117.97
5.80	18	20.86	25.19	20.86	22.67	183.77	130.36
9.48	18	20.90	25.78	20.90	23.16	224.44	153.50
13.25	18	20.93	26.52	20.93	23.82	274.22	184.61
17.06	18	20.95	27.34	20.95	24.56	330.87	216.81

Table 17: Performance parameters for ethanol biodiesel diesel (Z5E5BD20D70)

Torque (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	Sfc (kg/kWh)	Opacity (%)
4.10	0.66	1.55	2.21	16.04	53.80	29.81	0.54	2.4
10.72	1.70	1.47	3.17	28.72	53.44	53.74	0.30	9.2
17.28	2.70	1.38	4.08	33.74	50.98	66.17	0.26	23.5
23.95	3.69	1.40	5.09	37.06	51.11	72.51	0.23	36.5
30.99	4.72	1.32	6.04	38.60	49.36	78.20	0.22	48

Table 18: Observation data for ethanol biodiesel diesel (Z5E5BD20D70)

LOAD (kg)	CR	T1 deg C	T2 deg C	T3 deg C	T4 deg C	T5 deg C	T6 deg C
2.26	18	21.23	29.26	21.23	22.34	142.01	106.43
5.91	18	21.22	30.21	21.22	22.67	177.46	124.24
9.52	18	21.23	31.48	21.23	23.13	219.44	148.26
13.19	18	21.22	32.84	21.22	23.81	266.44	176.99
17.07	18	21.26	34.65	21.26	24.40	324.27	210.27

Table 19: Performance parameters for biodiesel diesel (BD10D90)

Torque (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	Sfc (kg/kWh)	Opacity (%)
4.09	0.67	1.65	2.32	15.48	53.42	28.97	0.52	2.3
10.55	1.68	1.40	3.08	27.38	50.19	54.56	0.30	6.7
17.37	2.72	1.25	3.96	32.53	47.48	68.52	0.25	14.5
24.09	3.72	1.13	4.85	35.67	46.54	76.63	0.23	22.3
30.77	4.71	1.06	5.77	36.65	44.91	81.63	0.22	36.6

Table 20: Observation data for biodiesel diesel (BD10D90)

LOAD (kg)	CR	T1 deg C	T2 deg C	T3 deg C	T4 deg C	T5 deg C	T6 deg C
2.25	18	18.69	26.44	18.69	19.83	139.12	104.52
5.82	18	18.73	27.11	18.73	20.28	179.65	126.50
9.57	18	18.74	28.52	18.74	20.80	227.11	155.25
13.28	18	18.78	29.74	18.78	21.58	275.04	186.05
16.96	18	18.81	30.89	18.81	22.58	329.31	216.96

Table 21: Performance parameters for biodiesel diesel (BD20D80)

Torque (Nm)	BP (kW)	FP (kW)	IP (kW)	BThE (%)	IThE (%)	MechE (%)	Sfc (kg/kWh)	Opacity (%)
4.09	0.68	1.38	2.06	16.2	47.14	32.85	0.52	1.9
10.91	1.73	1.21	2.94	29.45	46.67	58.81	0.29	4.8
17.11	2.67	1.26	3.93	34.52	47.69	67.97	0.25	9.1
23.93	3.69	1.18	4.87	36.41	46.64	75.76	0.23	14.8
30.61	4.67	1.04	5.71	37.10	44.42	81.73	0.22	26.3

Table 22: Observation data for biodiesel diesel (BD20D80)

LOAD (kg)	CR	T1 deg C	T2 deg C	T3 deg C	T4 deg C	T5 deg C	T6 deg C
2.26	18	18.93	27.56	18.93	20.91	164.85	130.73
6.01	18	18.97	28.05	18.97	20.98	190.75	136.86
9.43	18	18.99	29.12	18.99	21.48	229.06	158.17
13.19	18	19.01	30.00	19.01	22.20	276.47	187.28
16.87	18	19.03	31.46	19.03	22.93	329.54	218.21

4. Result and Discussions

4.1 Variation of Performance Parameters for Ethanol, Diesel with Diesel

4.1.1 Pressure Angle (P-θ) Curves

Figure 5 show the combustion chamber pressure data with the variation of crank angle. It is found from these curves that for all the blends maximum pressure attained in the combustion chamber is for the Z5E5D90 which is closely followed by Z5E10D85 and Z5E15D80 blends.

Trends for P-theta from all the fuels used are different, addition of ethanol in diesel results in more effective combustion due to its higher oxygen content but its significantly lower calorific value reduces the combustion pressure and thus as a combined effect causes slightly higher combustion pressure. In this experiment highest pressure is observed with blend Z5E5D90, which may be attributed to the oxygenating effect of ethanol, while for higher blends it shows a reducing trend which is due to very low calorific value of the ethanol. For blends lower than Z5E15D80, combustion improvement effect supersedes the effect of lower calorific value of ethanol than diesel and pressure developed increases with increase of ethanol in blend (up to 5%).

4.1.2 Brake Thermal Efficiency v/s Brake Power

Figure 6 shows the results of the thermal efficiencies of engine with the engine power when fuelled by different fuel blends and the pure diesel. The test results show that there is increase in brake thermal efficiencies for different blends compared with diesel fuel. This is due to better combustion efficiency of blends caused by presence of extra amount of oxygen.

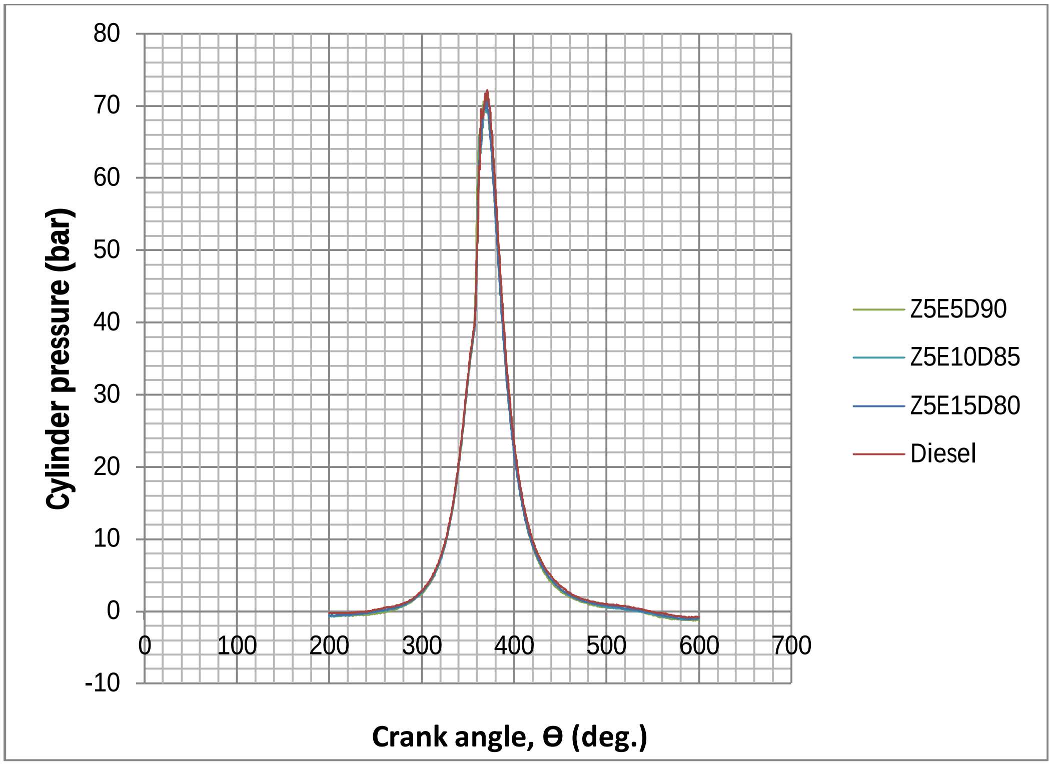

Figure 5: Variation of pressure and crank angle

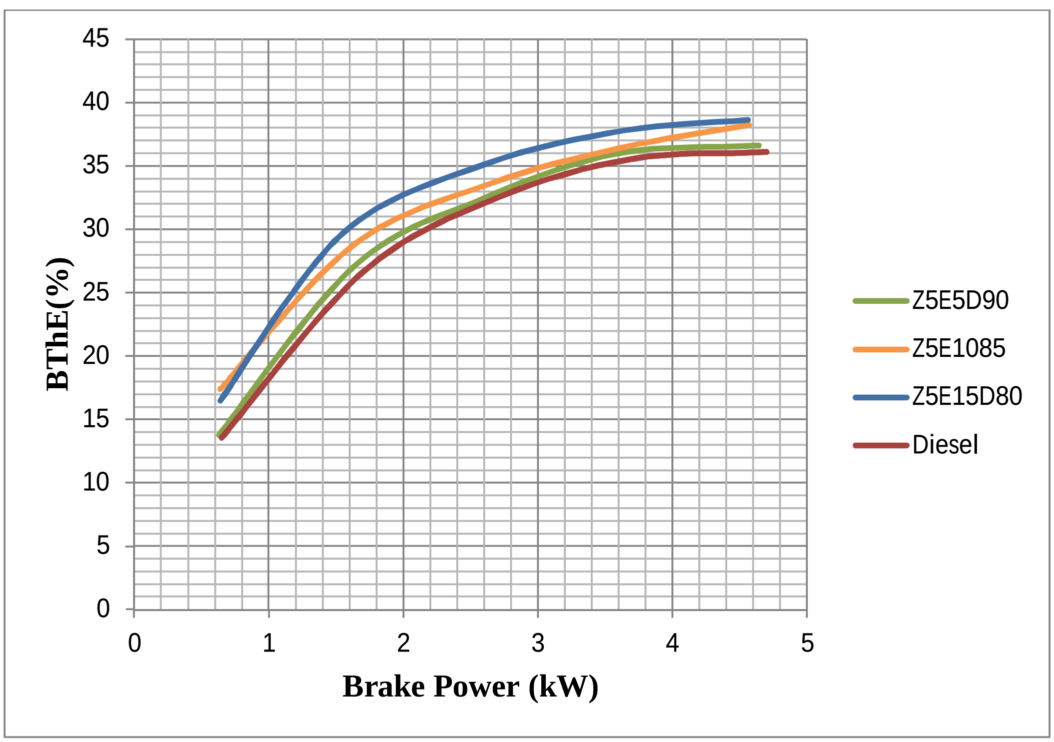

Figure 6: Variation of brake thermal efficiency and brake power

4.1.3 Specific Fuel Consumption v/s Brake Power

Figure 7 shows the test results of the brake specific fuel consumptions with the engine brake power, when the engine fuelled by different fuel blends and diesel. From the results, it can be seen that the engine power could be maintained at the same level when fuelled by different fuel blends with some extent increases of fuel consumption, the more ethanol was added in, the more fuel consumption was found, compared with pure diesel. These increases of fuel consumption are due to the lower heating value of ethanol than that of pure diesel. The results show the trend of the increase of fuel consumption with the increase percentage of ethanol in the blends.

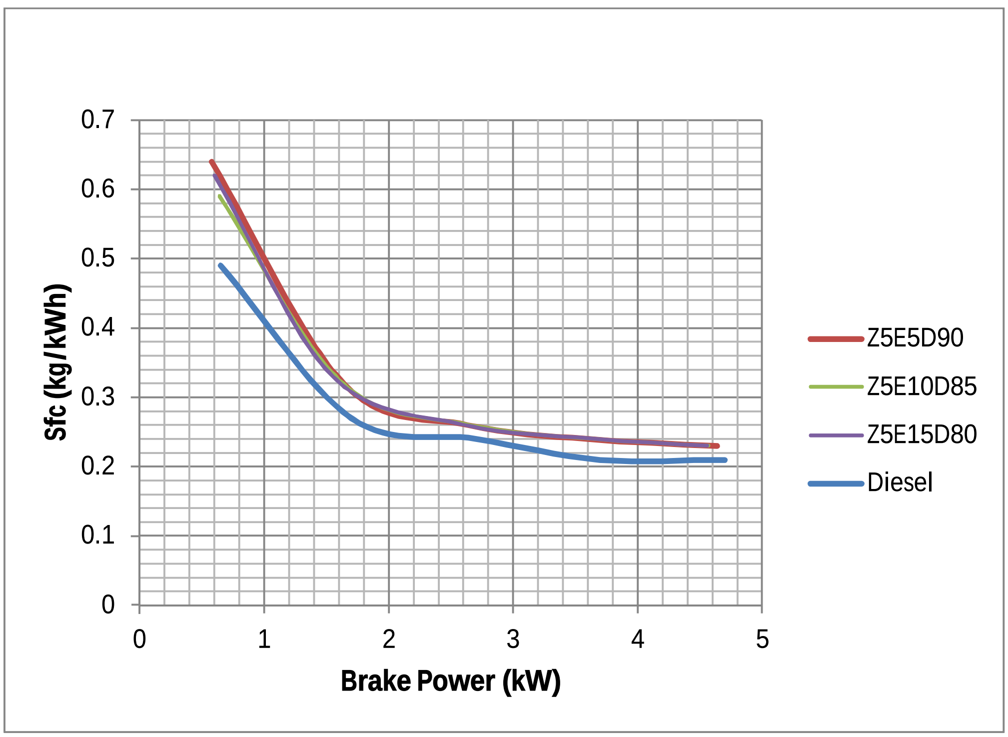

Figure 7: Variation of specific fuel consumption and brake power

4.1.4 Smoke Opacity v/s Brake Power

Figure 8 shows the test results of smoke emissions from the engine when fuelled by different fuels. The results show that the smokes from the engine were all lowered down using blends.

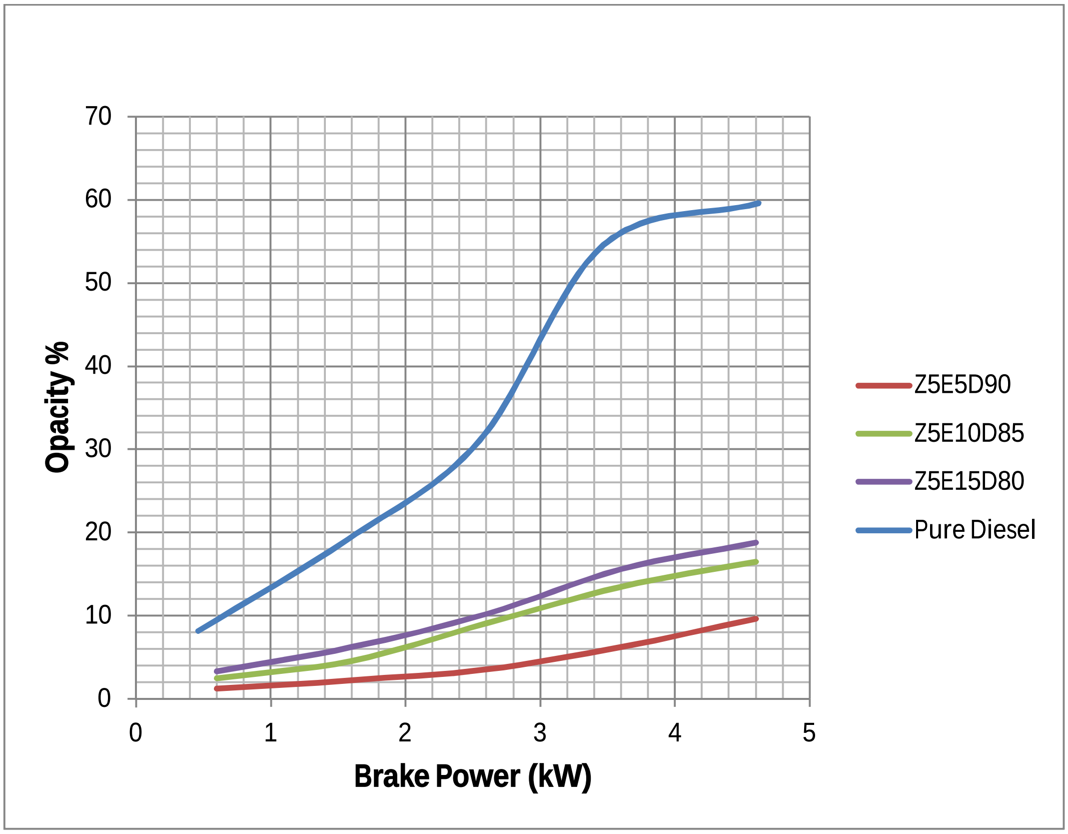

Figure 8: Variation of opacity and brake power

4.1.5 Variation of Torque v/s Brake Power

Figure 9 shows the variation of torque with brake power for diesel and blends of ethanol with diesel. Variations of torque for different blends and diesel at all values of brake powers are within a very slight range. The torque developed for diesel (28.41 Nm) is little less than blends (29.03 Nm, 28.64 Nm and 28.65 Nm respectively for Z5E5D90, Z5E10D85 and Z5E15D80) at 4.5 kW.

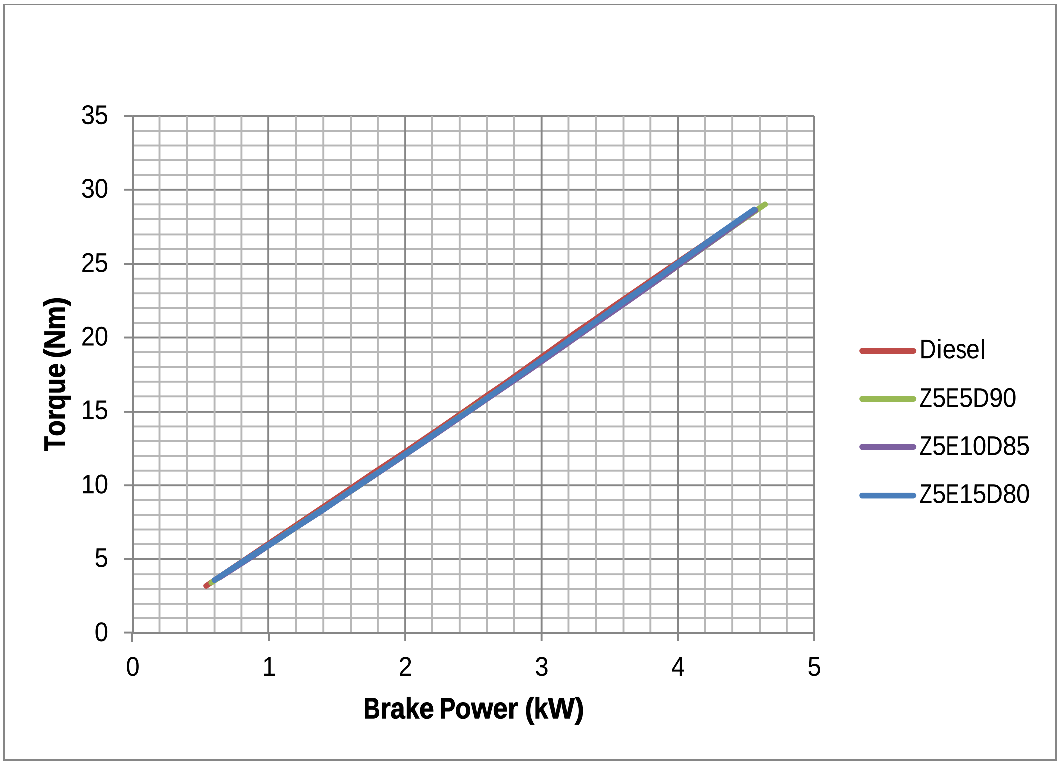

Figure 9: Variation of torque and brake power

4.1.6 Variation of Exhaust Gas Temperature v/s Brake Power

Exhaust Temperature of the blends such as Z5E5D90, Z5E10D85 and Z5E15D80 at various brake powers compared to diesel are shown in the Figure 10. The Exhaust gas temperature values are higher for blends because of better combustion efficiency. This high temperature is also indication of more NOx emission in case of blends.

4.1.7 Variation of NOx Emission v/s Brake Power

As shown in figure 11 NOx concentration increases with increase of bp for all the blends. Compared with diesel, NOx emission of the ethanol blended fuel increases slightly at all tested engine loads and the increase is more obvious at higher engine loads.

The peak concentrations at 4.7 kW bp are 820 ppm, 880 ppm, 855 ppm and 839 ppm respectively, for diesel, Z5E5D90, Z5E10D85 and Z5E15D80.

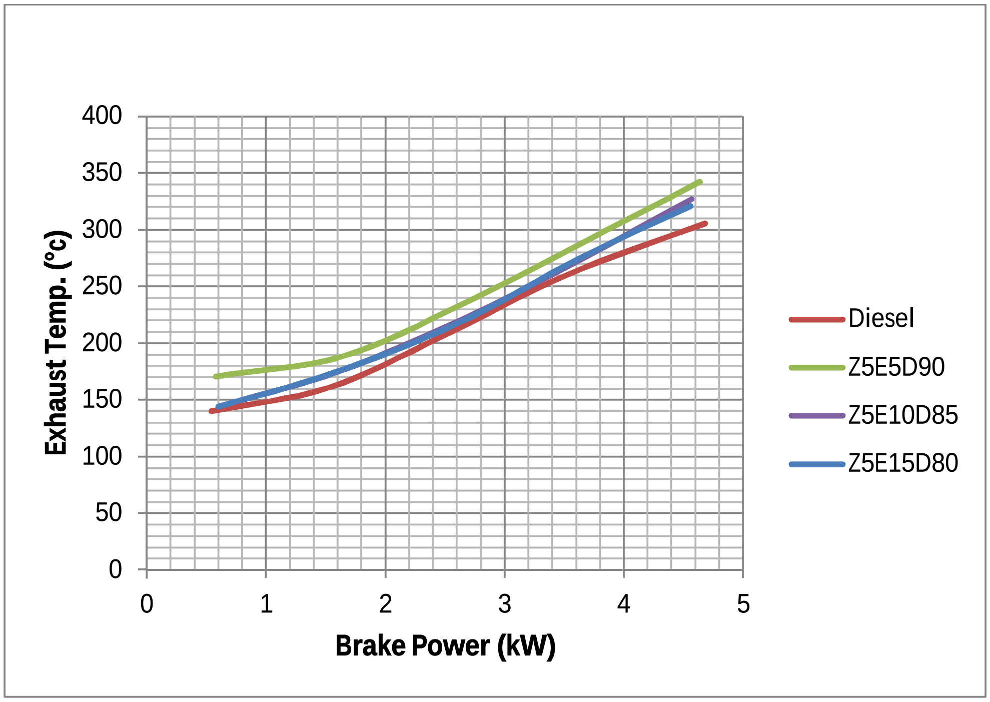

Figure 10: Variation of exhaust gas temperature and brake power

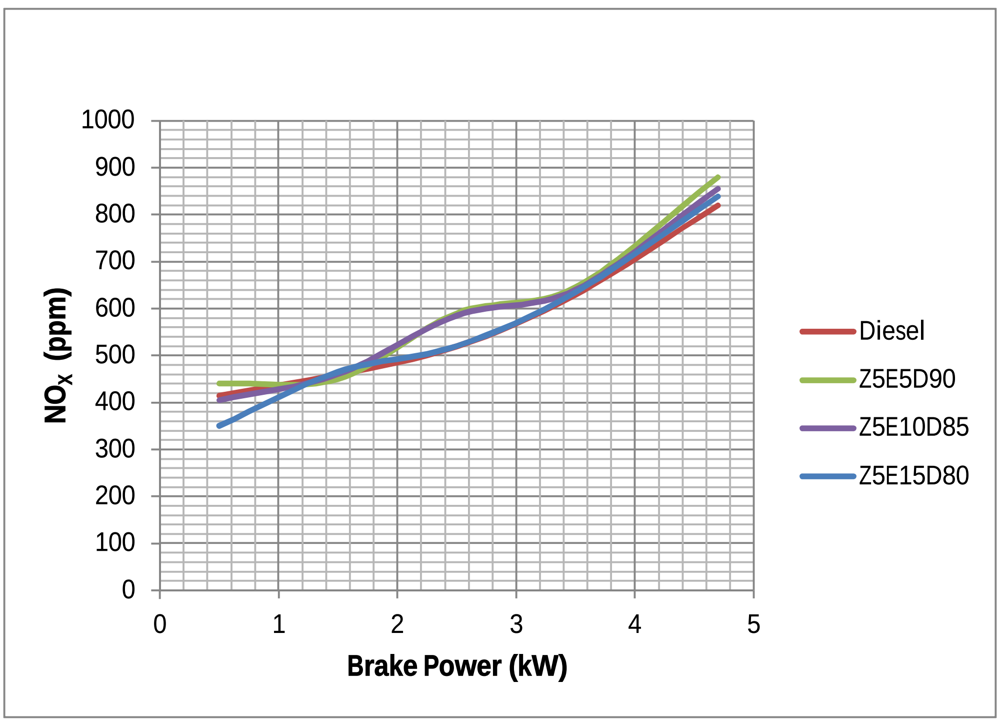

Figure 11: Variation of NO_X emission and brake power

4.1.8 Variation of HC Emission v/s Brake Power

The test results for the unburned HC from the engine is shown in Figure 12. The results showed that the HC emissions from the engine for the blend fuels were all higher and the HC emissions became less as the loads increased. Except at the point of top power output. At this point, the HC emissions for all blends were lower than that fuelled by diesel. This is due to the high temperature in the engine cylinder to make the fuel be easier to react with oxygen when the engine ran on the top load.

4.1.9 Variation of CO Emission v/s Brake Power

Figure 13 shows the CO emissions from the engine exhaust when fuelled by different fuels. At part loads, the CO emissions from the engine fuelled by the ethanol blends were higher than those fuelled by pure diesel. The higher the percentage of the ethanol, the more CO emissions, this may be due to the cooling effect of ethanol evaporation which may retard combustion. But at the engine higher loads which were about above half of the maximum engine load, the CO emissions became lower than that fuelled by diesel for all the blend fuels. This may be attributed to the oxygenating effect of the ethanol.

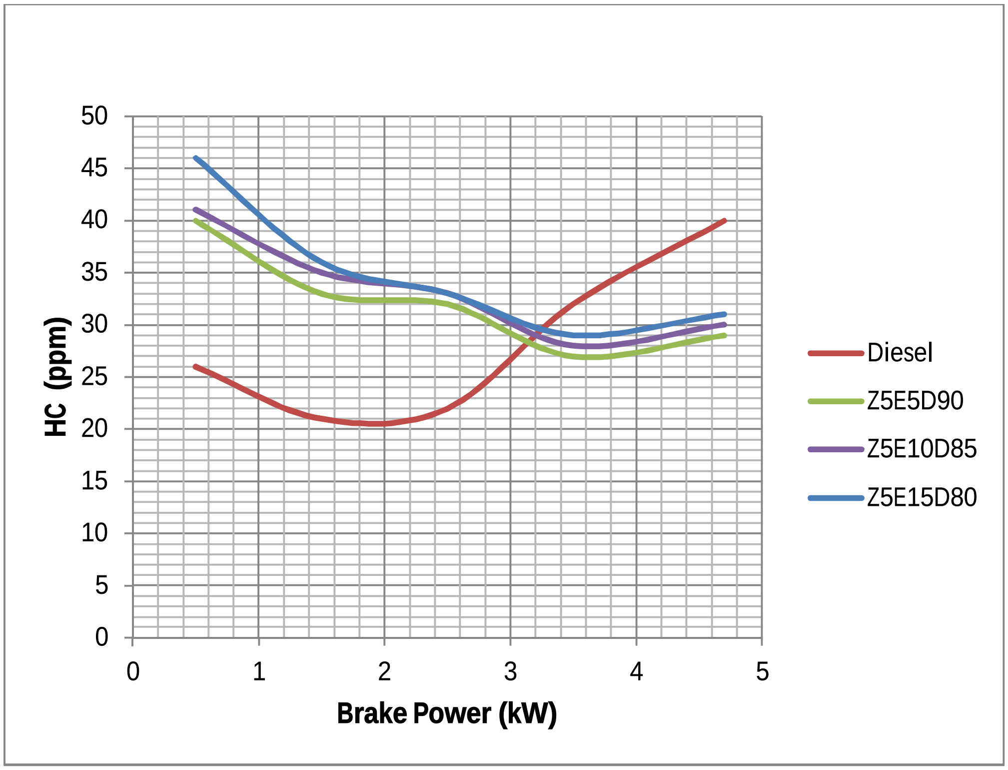

Figure 12: Variation of HC emission and brake power

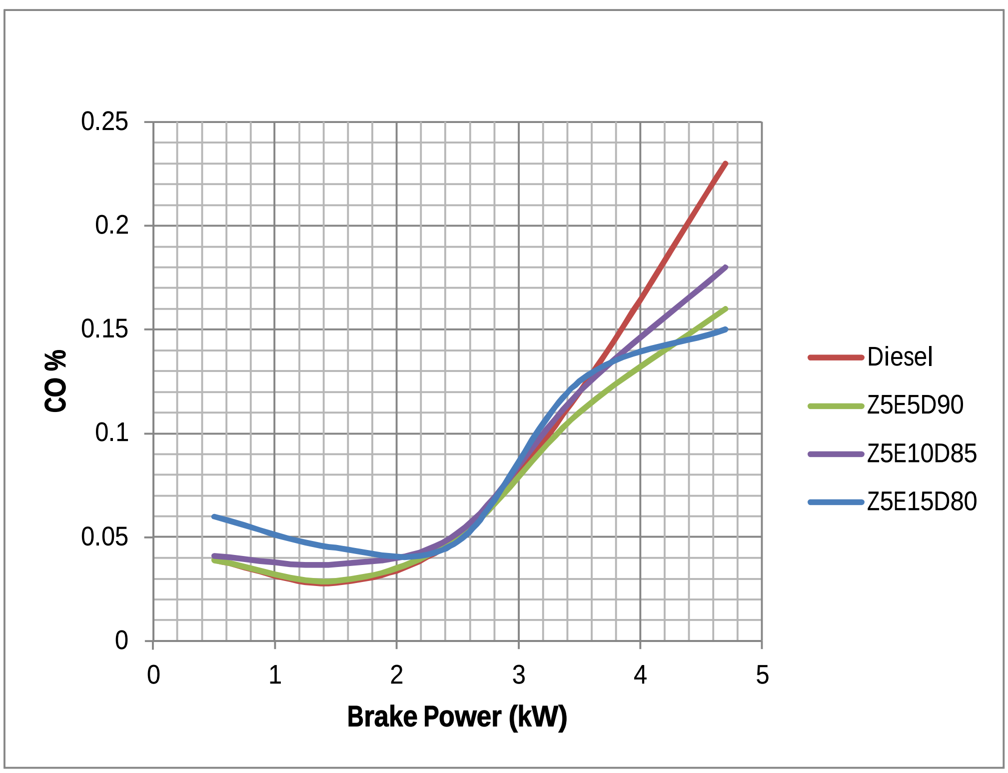

Figure 13: Variation of CO emission and brake power

4.2 Variation of Performance Parameters for Blends of Biodiesel and Ethanol with Diesel

The tests are carried out using the diesel and blends of biodiesel, ethanol and diesel on CI engine. The detailed analyses of these results are discussed in this section.

4.2.1 Variation of Torque v/s Brake Power

Figure 14 shows the variation of torque with brake power for diesel and blends of biodiesel, ethanol and diesel. Variations of torque for different blends and diesel at all values of brake powers are within a very slight range. The torque developed for diesel (28.41 Nm) is little less than blends (30.95 Nm, 30.99 Nm, 30.77 Nm and 30.61 Nm respectively for Z5E5BD10D80, Z5E5BD20D70, BD10D90 and BD20D80) at 4.5 kW.

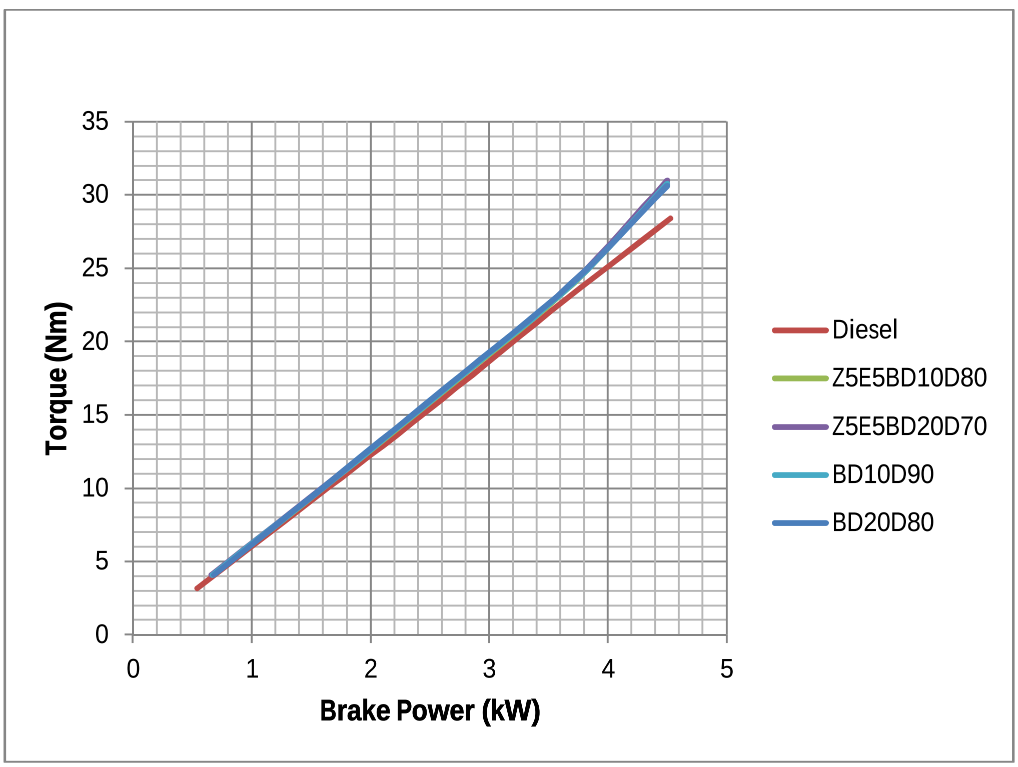

Figure 14: Variation of torque and brake power

4.2.2 Variation of Specific Fuel Consumption v/s Brake Power

The variation of specific fuel consumption vs. brake power is shown in figure 15 for blends and diesel. For all cases the sfc initially decreases sharply with increase in brake power and afterward remains stable. In case of blends sfc values are higher at the beginning because of higher viscosity. Once the required temperature is attained inside the engine cylinder the values are comparable with diesel.

4.2.3 Variation of Brake Thermal Efficiency v/s Brake Power

Figure 16 shows comparison of Brake thermal efficiency v/s brake power for different blends in comparison to diesel. For all blends brake thermal efficiency values are higher as compared to diesel at higher load. This is due to better combustion efficiency of blends caused by presence of extra amount of oxygen. The maximum thermal efficiency achieved by Z5E5BD20D70 is around 38.60 % at 4.7 kW.

4.2.4 Variation of Smoke Opacity v/s Brake Power

The variation of opacity v/s brake power is shown in figure 17 for blends in comparison to diesel. The opacity value for diesel is higher as compared to all type of blends for wide range of Brake power. Maximum value of opacity has obtained at 59.62 at 4.7 kW brake power for diesel and for blends 48.0 at 4.7 kW for Z5E5BD20D70.

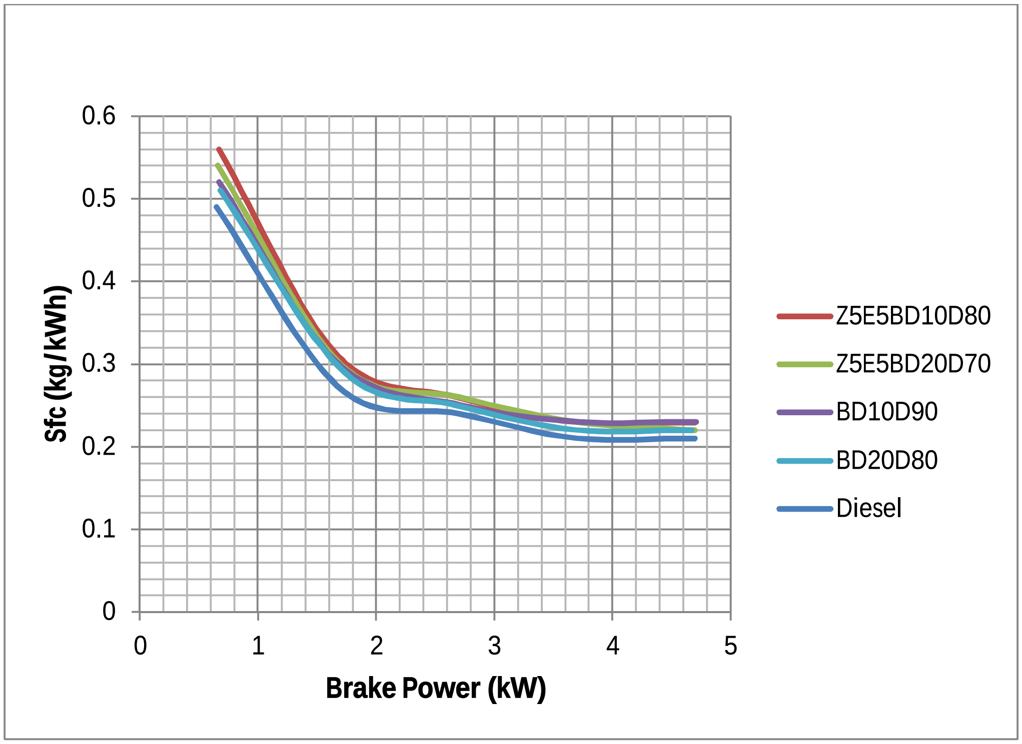

Figure 15: Variation of specific fuel consumption and brake power

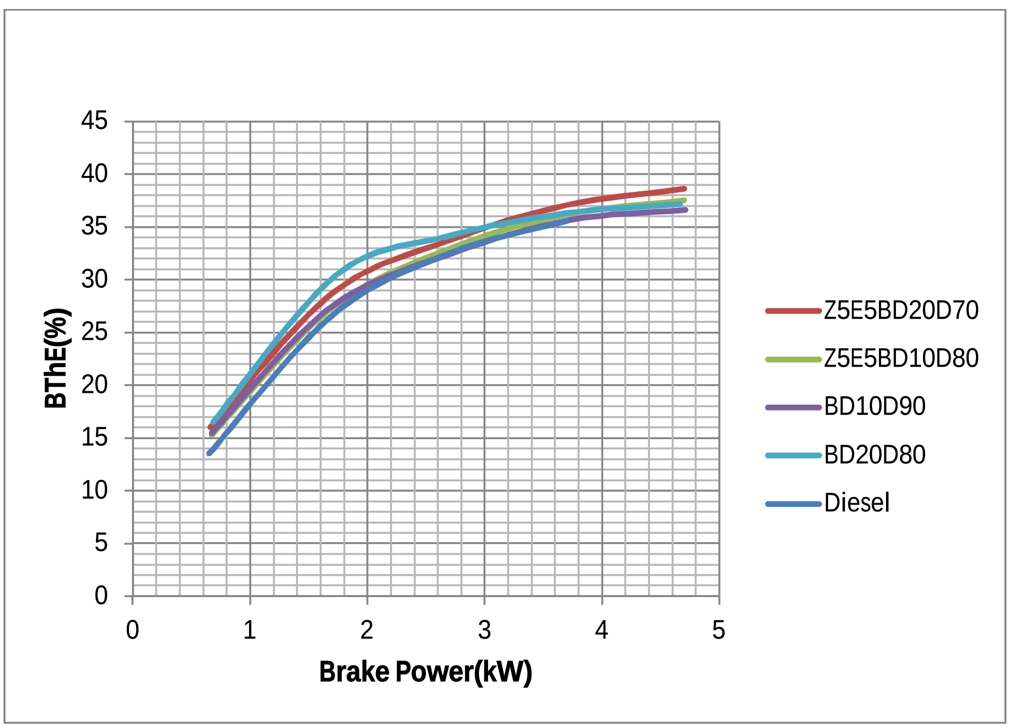

Figure 16: Variation of brake thermal efficiency and brake power

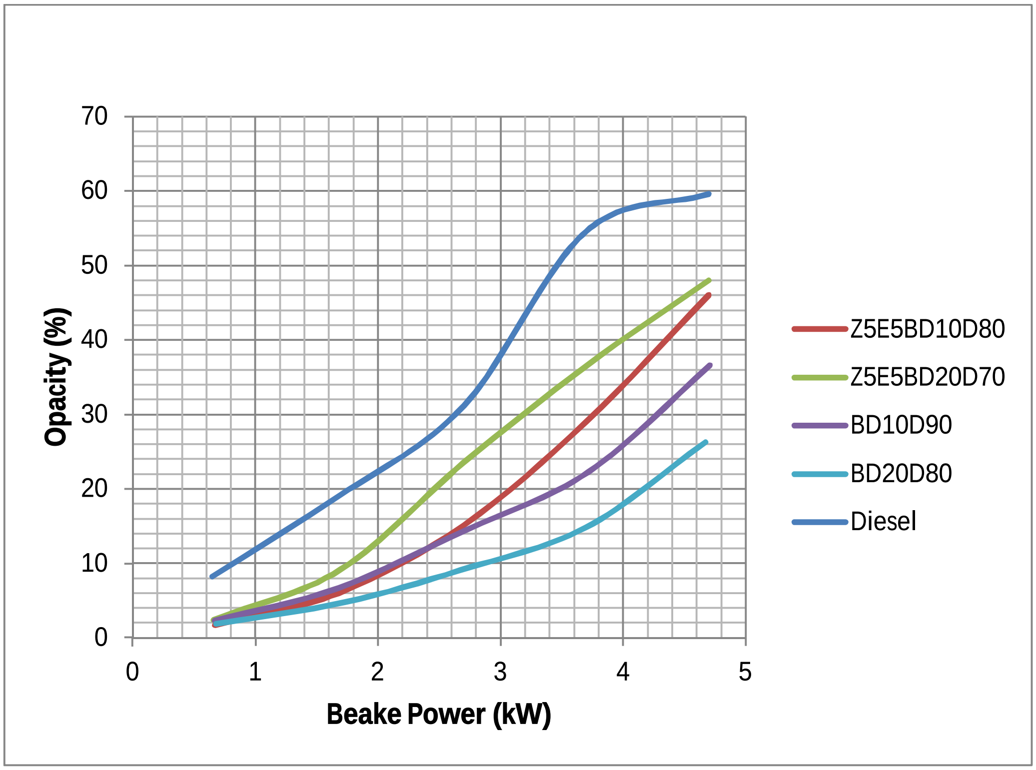

Figure 17: Variation of Opacity and brake power

4.2.5 Variation of Exhaust Gas Temperature v/s Brake Power

Exhaust Temperature of the blends such as Z5E5BD10D80, Z5E5BD20D70, BD10D90 and BD20D80 at various brake powers compared to diesel are shown in the Figure 18. The Exhaust Temperature values are higher for blends because of better combustion efficiency. This high temperature is also indication of more NOx emission in case of blends.

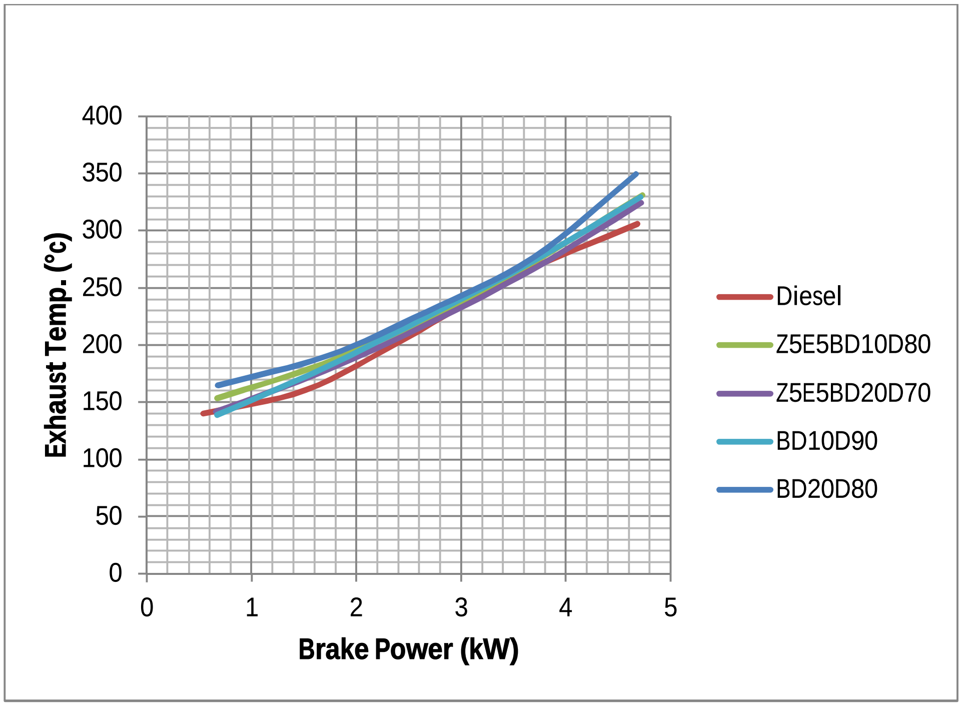

Figure 18: Variation of exhaust gas temperature and brake power

4.2.6 Variation of CO Emission v/s Brake Power

The characteristics of CO emission are shown in figure 19, for each fuel, there is a decrease of CO emission on increase of the engine load or brake power. The peak concentrations at the 4.7 kW brake power are 0.23%, 0.18%, 0.175%, 0.16% and 0.151% respectively, for diesel, Z5E5BD10D80, Z5E5BD20D70, BD10D90 and BD20D80. Then higher combustion temperature at higher engine load contributes to the general increasing trend. With the addition of biodiesel, ethanol, CO emission also decreases as compare to diesel.

4.2.7 Variation of HC Emission v/s Brake Power

As shown in figure 20, for Diesel, the HC emission decreases with increase of brake power upto 2 kW and then increases. For biodiesel blended fuel, the HC emission is lower than that of diesel and increases with increase of biodiesel in the fuel. For biodiesel, ethanol and diesel blends, HC emission is less as compare to diesel but for Z5E5BD20D70, HC emission is higher than diesel upto 3 kW. However, the lower volatility of biodiesel compared with diesel contributes to the larger difference in HC emission. The maximum concentrations of HC are 40 ppm, 31 ppm, 22 ppm, 21 ppm and 19 ppm respectively, for diesel, Z5E5BD20D70, Z5E5BD10D80, BD20D80 and BD10D90.

4.2.8 Variation of NOx Emission v/s Brake Power

As shown in figure 21, NOx concentration increases with increase of bp for all the fuels. Compared with diesel, NOx emission of the biodiesel blended fuel increases slightly at all tested engine loads and the increase is more obvious at higher engine loads. The peak concentrations at 4.7 kW bp are 1652 ppm, 1616 ppm, 1016 ppm 866 ppm and 820 ppm respectively, for BD20D80, BD10D90, Z5E5BD10D80, Z5E5BD20D70 and diesel.

4.2.9 Pressure v/s Crank Angle (ϴ)

P-ϴ diagram of Z5E5BD10D80, Z5E5BD20D70, BD10D90, BD20D80 and diesel is shown in figures 22. At various crank angles, pressure observed for Z5E5BD10D80, Z5E5BD20D70, BD10D90, BD20D80 and diesel are 71.84856 bar at 369° , 71.34870 bar at 370°, 71.09877 bar 370°, 70.20131 bar at 370° and 72.13256 bar at 371° . Blends follow the similar pattern of pressure rise to that of diesel at all brake power conditions. Because of higher ignition delay the rate of rise of pressure is more in case of diesel as compared to blends .This higher rate of rise in pressure is main cause of knocking in compression ignition engines.

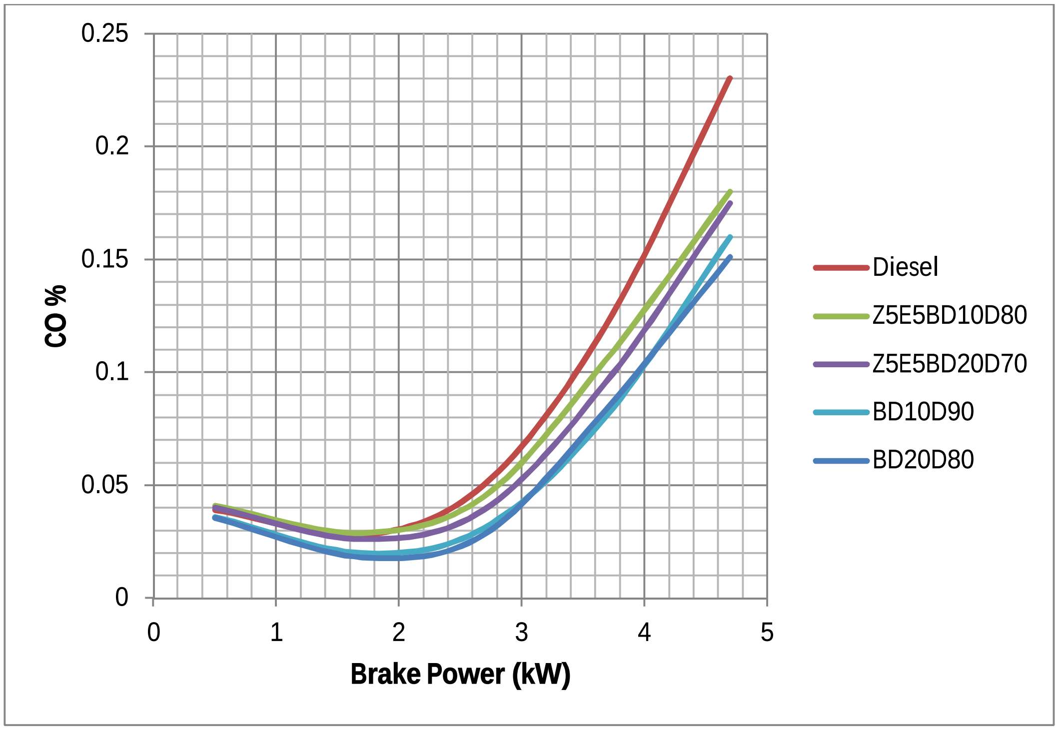

Figure 19: Variation of CO emission and brake power

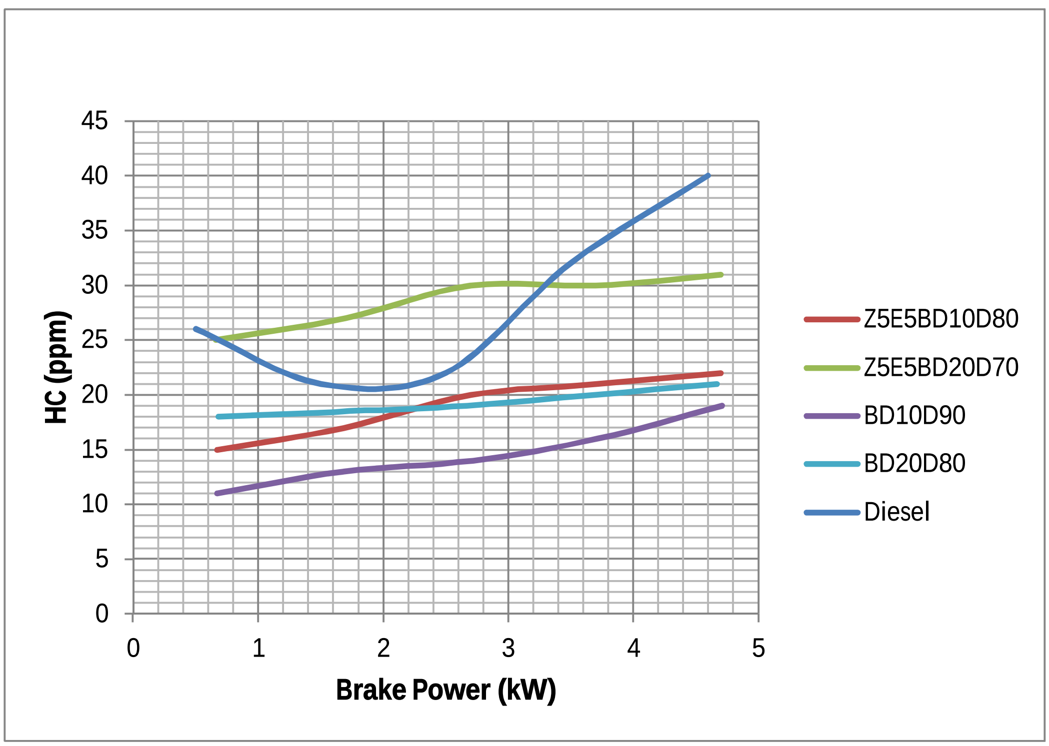

Figure 20: Variation of HC emission and brake power

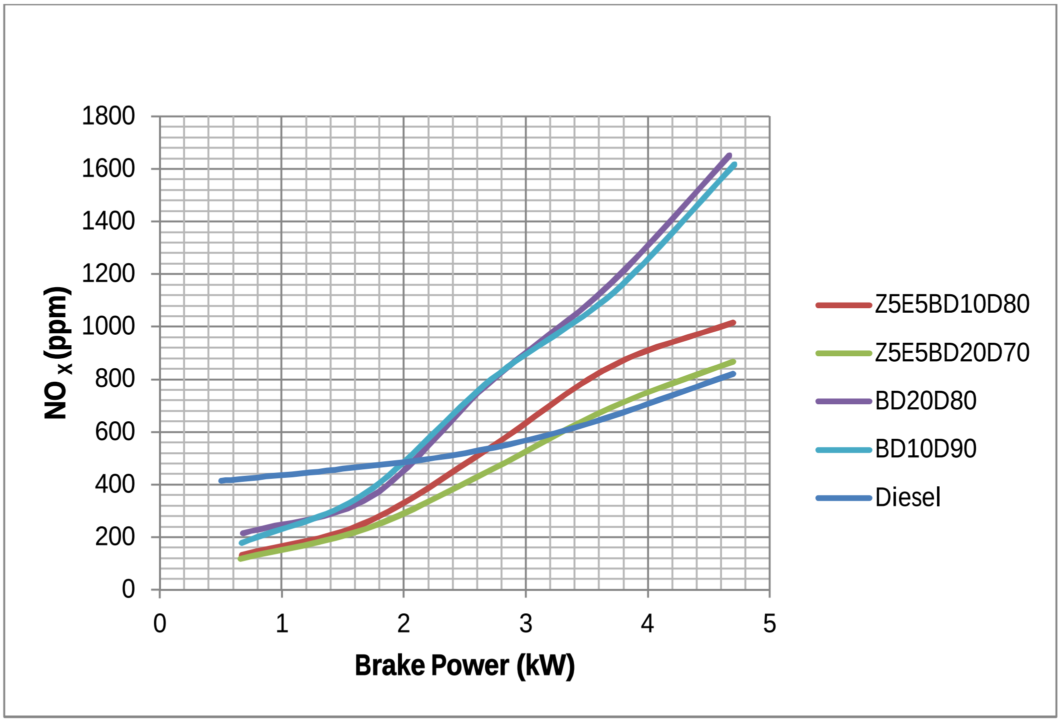

Figure 21: Variation of NO_X emission and brake power

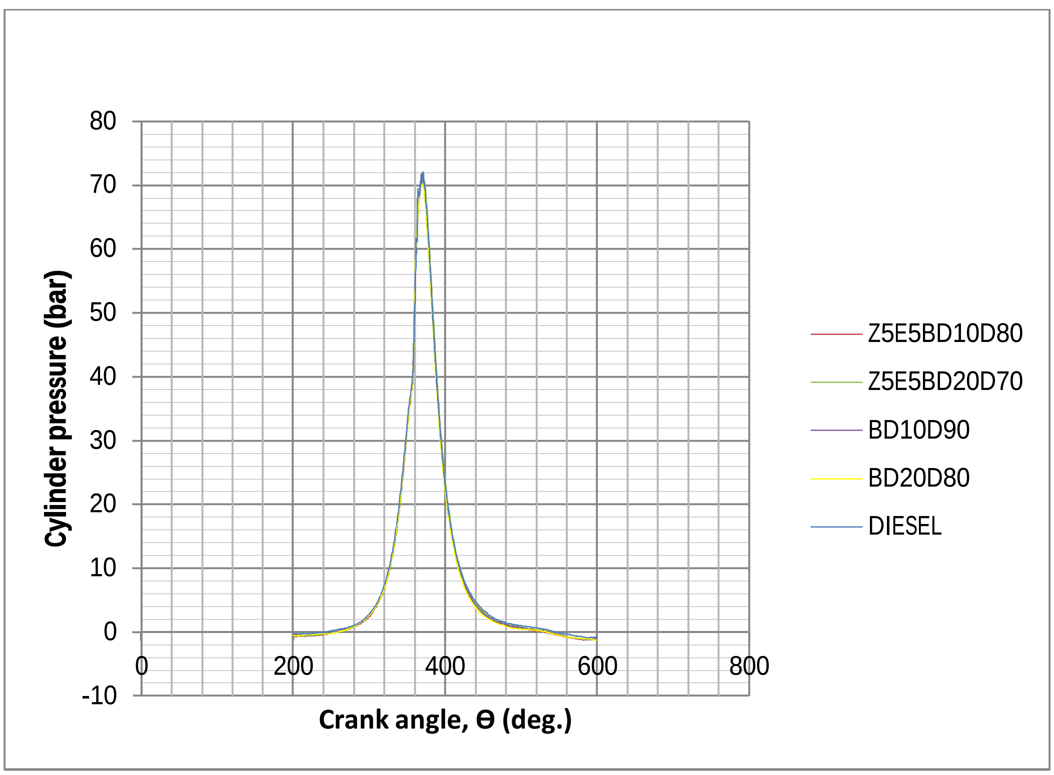

Figure 22: Variation of pressure and crank angle

5. Conclusion and Future Scope of Work

The experimental study is performed on the blending of ethanol and biodiesel with diesel in a CI engine. According to the performance results the blend of ethanol and biodiesel with diesel shows the better thermal efficiency as compare to ethanol with diesel blends and diesel. Also got low environmental effect as compare to diesel fuel.

5.1 Following conclusions are shown from the experimental results

1- The brake thermal efficiency is more than that of diesel for all blends. BTHE is more for Z5E5BD10D80, Z5E5BD20D70 as compare to Z5E5D90, Z5E10D85, Z5E15D80 and BD10D90, BD20D80.

2- The sfc is slightly more for blends than diesel. sfc is more for Z5E5D90, Z5E10D85, Z5E15D80 as compare to Z5E5BD10D80, Z5E5BD20D70 and BD10D90, BD20D80.

3-The HC and CO emission for the ethanol blended diesel fuel is higher than diesel fuel but for ethanol and biodiesel blended diesel fuel, HC and CO emission is lower than that of the diesel fuel. However, the HC and CO emission for ethanol and biodiesel blended diesel fuel is more as compare to biodiesel blended diesel fuel.

4- The NO_X emission for all blends has slight increase as compare to diesel.

However, for ethanol and biodiesel blended diesel fuel has less NO_X emission as compare to biodiesel blended diesel fuel. This is due to calorific value of biodiesel blended diesel fuel is high as compare to ethanol and biodiesel blended diesel fuel which results in higher temperature.

5- For all brake power conditions the opacity of all blends has less value than diesel fuel. Maximum value of opacity has obtained 59.62 at 4.7 kW brake power for diesel fuel and for blends 48 at 4.7 kW for Z5E5BD20D70.

6- At various crank angles, pressure observed for Z5E5BD10D80, Z5E5BD20D70, BD10D90, BD20D80, Z5E5D90, Z5E10D85, Z5E15D80 and diesel are 71.84856 bar at 369°, 71.34870 bar at 370°, 71.09877 bar at 370°, 70.20131 bar at 370°, 70.59892 bar at 367°, 69.67873 at 369°, 71.36006 bar at 370° and 72.13256 bar at 37°. Cylinder pressure for all blends is lower as compare to diesel fuel.

5.2 Future scope

The blends can also be tested in variable speed vehicle engine with double fuel filters and some basic engine modifications like change in injection pressure and variable valve timing for long term uses. Compression ratio of engine can also be changed for further analysis. Testing of preheated blends can be done for cold climate.

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