EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE FUELLED WITH ETHANOL, DIESEL AND JATROPHA BASED BIODIESEL BLENDS

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ABSTRACT

Increasingly stringent emissions regulations and environmental concerns have caused interest in the development of alternative fuels for internal combustion engines. Recently biobutanol, bioethanol and biodiesel emerged as an alternative fuels due to their oxygenated nature. This paper investigates the physical stability of ethanol-diesel blends using Jatropha oil methyl esters and enerdiesel emulsifier as additives, subsequently analysis of physico-chemical properties. Furthermore, experimental tests were carried out to study the performance (fuel consumption, thermal efficiency, exhaust gas temperature) and emissions (CO, NOx, HC and smoke) of Direct Injection (DI) engine fuelled with the various blends compared with those fuelled by diesel. The blends used for this study were B0D95E5, B0D90E10, B15D70E15 and B20D60E20. It is revealed from the observations that the test fuel blends are physically and thermally stable upto 17 days at room temperature. The physico-chemical properties of the all blends show good resemblance with that of diesel except the flash point. The performance results show that B0D95E5 fuel blend has maximum brake thermal efficiency and minimum Brake Specific Fuel Consumption (bsfc) at higher loads. Similarly, the overall emission characteristics are found to be best for the case of B0D90E10 over the entire range of engine operations.

KEYWORDS: *Ethanol, Biodiesel, Jatropha oil.*

I. INTRODUCTION

Energy crisis and environmental degradation are two major challenges on which considerable efforts has given recently. Fossil fuels are being used as a major source of energy now days. Combustion of fossil fuels also contributes in higher environmental pollution. Therefore, urgent attention has given to search alternate fuels and transportation. Promising alternate fuels for Internal Combustion (I.C.) engines are biodiesel, bio-ethanol, methanol, biogas, producer gas etc.

Experimental research has been done on various blends of gasoline and ethanol, and results have shown that 7.5% addition of ethanol was the best suitable for SI engine with reduced CO emission [1]. Recently Environmental Protection Agency (EPA), USA, came out with legal mandate for 15% ethanol in diesel, however no single engine manufacturer approve more than 10 % ethanol. Nevertheless, at the end of last quarter of nineteenth century, possibility of ethanol –diesel blending also initiated and researcher start putting efforts to come out with technical acceptance of E-diesel. Using E-diesel has so many advantages, it reduces pollutants emission from the tail of automobiles, creates employment opportunity, eases burden of importing crude oil.

Long term endurance and durability (500 hrs) tests were conducted with Cummins 5.9 liters engine [2] of using fossil diesel and a diesel/ethanol blend (15% ethanol, PEC additive). Power loss was less than 10% was reported. Moreover, henceforth researcher examined [3] on the same engine reported that the torque output from two blends containing 10% and 15% ethanol results in an approximate 8% reduction for both fuel blends. Some problems, like poor engine performance, may arise at higher blending ratios e.g. if ethanol content exceeds 10%. At the same time the stability of blends decreases if ethanol exceeds more than 10%, therefore in the present investigation biodiesel is used as a solvent to keep emulsion stable at different temperature. Biodiesel is prepared in our biodiesel research laboratory at University of Petroleum & Energy Studies. Biodiesel alone have some concern like the large molecular size of the component triglycerides leading to viscosity than that of mineral diesel. Viscosity affects the handling of the fuels by pump and injector system, and the shape of fuel spray. The high jet penetration and poor atomization results in larger droplets. The fuel jet tends to be a solid stream instead of spray of small droplets hence the fuel does not get mixed with air required for burning. Larger droplets have poor combustion leading to loss of engine power and fuel economy. In small engines, the fuel spray may even impinge upon the cylinder walls, washing away the lubricating oil film and causing the dilution of crank case oil leading to excessive wear of moving parts.

Butanol was used as an additive to evaluate the performance and emission characteristics of diesel ethanol blend in Compression Ignition engine [4]. It has been reported that the thermal efficiencies of the engine fuelled by the blends were comparable when fuelled by diesel ethanol and their blends. It was observed that the smoke emissions from the engine fuelled by the blends were all lower than that fuelled by diesel. The carbon monoxide (CO) were reduced to 50% at above loads, the hydrocarbon (HC) emissions were all higher except at high loads; the nitrogen oxides (NOx) emissions were different for different loads and blends.

T. Krishnaswamy and his co-workers [5] studied with three oxygenated blend fuel designs containing volumes of 15% ethanol with cetane improver additive, 10% ethanol with 10% biodiesel and 15% ethanol with 20% biodiesel. The phase separation of blends is prevented by adding co solvents like Tetrahydrafuran and bio diesel.

An experimental work was conducted to investigate the phase stability of ethanol- diesel and ethanol-diesel-biodiesel blends [6]. The results revealed that the E-Diesel blends containing 20%, 15%, 10% and 5% ethanol are not stable and phase separation were take place after 2, 5, 24 and 80 hours respectively. Whereas for ethanol –biodiesel- diesel blends the separation time is longer than E-diesel and it is found that phase separation was delayed upto 1, 3 and 9 days for 20%, 15%, 10% ethanol concentration, respectively .

Since biodiesel is derived from vegetable oils or animal fats made up of esters, these vegetable oils are renewable biological sources. It has been reported that they emit substantially lower quantity of harmful pollutants compare to conventional diesel, Researchers also found that comparable engine performance with diesel was achieved at relatively lower emission [7,8]. The merits of using biodiesel instead of conventional diesel are has comparable energy density, cetane number, heat of vapourization, and stoichiometirc air /fuel ratio [9]. Biodiesel is also non-toxic and rate of biodegradation is much faster than conventional diesel. Green house gases effects were least in case of biodiesel [10,11].

Experimental work done on four strokes DI diesel engine fuelled with blends of diesel-rapeseed methyl ester-ethanol and base fuel diesel. Tests were conducted on different speeds (1400, 1800 and 2200 rev/min) and loads. It was found that, for all the blends the thermal efficiency was improved and emissions were reduced except HC compared with diesel [**12].**

Dhandapani Kannan and his co-workers examined phase stability and performance and emissions of ethanol- diesel- biodiesel blends at various proportions in constant speed four stroke single cylinder DI engine. The volumetric proportions of ethanol –diesel –biodiesel (E:D:B) studied were 5:95:0, 5:75:20, 5:55:40, 5:35:60, 5:15:80 and 5:0:95. Results revealed that maximum in-cylinder peak pressure, cumulative heat release (CHR), rate of heat release (ROHR), in-cylinder peak temperature and combustion duration was increased as compared to base fuel diesel. Regarding emission characteristics they observed significant reduction in smoke, carbon monoxide (CO) and total hydrocarbon (THC) emissions with extended oxygen mass percentage in the fuel at higher engine loads. However, oxides of nitrogen (NOx) emissions is found to increase at high loads [13].

The objectives of this research work to examine phase stability of various blends of E-diesel fuel using Jatropha oil methyl ester and enerdiesel emulsifier as additives. Henceforth, the physico-chemical analysis of various blends was carried out in the laboratory. Secondly, to investigate the performance and emissions of four stroke single cylinder DI engine fuelled with blends (B0D95E5, B0D90E10, B15D70E15 and B20D60E20) at varying loads. The engine which is used for the study was constant speed water cooled DI engine has rated power 5 hp. To improve the repeatability same blends were tested 3 to 4 times and average of all the results recorded for reporting.

II. METHODOLOGY

2.1 EXPERIMENTAL TEST SET-UP

Kirloskar make single cylinder four stroke water cooled engine was used in the present study. The detailed specification of the engine is shown in table 1. The schematic diagram of the experimental set up is shown in Fig.1. The experimental set up consists of engine, dynamometer, load cell and temperature sensors etc. Eddy current-dynamometer was used for engine loading. A fuel Consumption meter, DP transmitter, Range 0-500 mm WC, is used for measuring the specific fuel consumptions of the engine. Combustion pressure sensor, Piezoelectric Pressure transducer is used, Range 5000 PSI, with low noise cable, make from kistler, power unit is Make-Cuadra, Model AX-409. Real time data acquisition is done with the help of EngineSoftLV is Labview based software package developed Lucidbit technology Pvt. Ltd

Exhaust gas analyser was used for measuring the emissions of CO, HC, and NO_x from the engine; the model is AVL DiGas 444, made by Austria AVL Company. A Smoke meter, model 437C, made by AVL Gurgaon, is used for measuring the smoke emission from engine. Exhaust gas emissions recorded were: CO in % vol, unburned hydrocarbons (UBHC) in parts per million (PPM), and oxides of nitrogen (NO_X) in PPM by using gas analyzer. Opacity of the smoke in the exhaust was measured in % by using smoke meter.

Table 1: Specifications of the variable compression ratio engine.

General details	4-Stroke, water cooled, variable compression ratio engine, CI engine
Rated power	3 .7 kW
Speed	1500 rpm (constant)
Number of cylinder	Single cylinder
Compression ratio	12:1–18:1 (variable)
Bore	80 mm
Stroke	110 mm

Table 2: Test Fuel Nomenclature

BOD95E5	5% ethanol + 95% diesel+ 0.7 % additive
BOD90E10	10% ethanol + 90% diesel+1 % additive
B15D70E15	15% Biodiesel +15 % Ethanol + 70% diesel+1 % additive
B20D60E20	20% Biodiesel + 20 % Ethanol + 60% Diesel+1 % additive

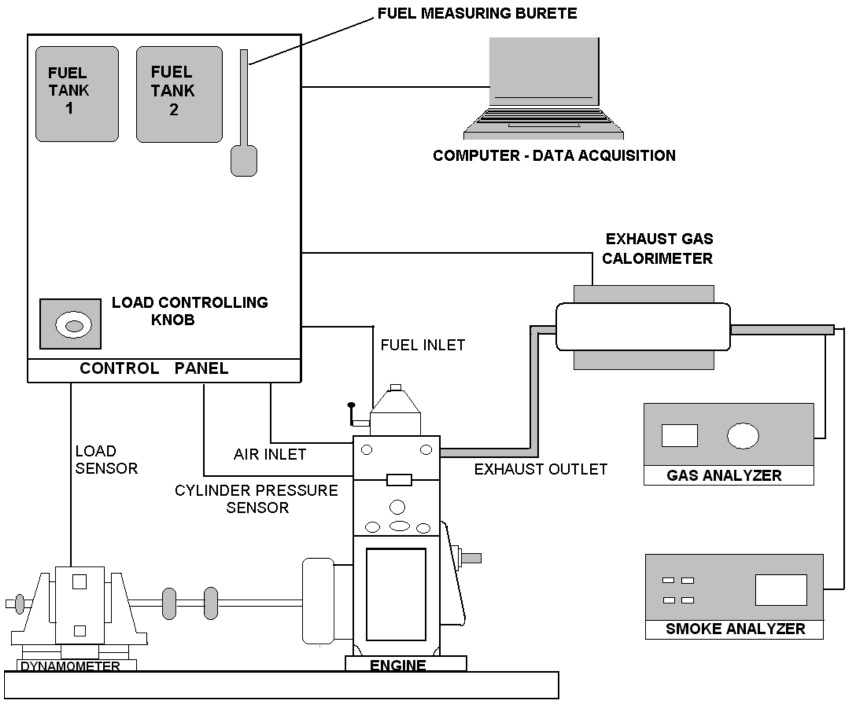

Fig. 1 Schematic of Test Set-up

Fig. 2 Variable compression ratio engine test bench

2.2 THE EXPERIMENTAL PROCEDURE

The experimental procedure includes preparation of biodiesel, study of the stability of blends, measurement of physico-chemical analysis as per ASTM/BIS and engine performance emission studies. The detailed procedure is discussed below.

2.2.1. Preparation of biodiesel

The biodiesel is produced by the transesterification, i.e., the reaction of a triglyceride (Jatropha seed oil) with a alcohol to form esters and glycerol. The reaction was carried out in one liter batch reactor using potassium hydro-oxide as a catalyst and methanol as an alcohol. The alkali KOH 1 % by weight is used for this purpose. The reaction results in monoalkyl esters and glycerol. The glycerol is then removed by gravity separation and remaining ester is washed with hot water for separation of excess catalyst and remaining glycerol. Moreover it leads to increase moisture content in the solution. Moisture was removed using silica gel; the resulting biodiesel was filtered with the help of filter paper of 11 micron.

2.2.2. Tests of the solubility of the blends & Physico-chemical analysis

The properties of diesel, ethanol and biodiesel are shown in Table 3. The purity of the ethanol used is of 99.9%. A series of tests was performed to observe the solubility of ethanol and diesel with the help of additive and biodiesel. Diesel, ethanol and biodiesel were mixed into a homogenous blend in a container by stirring it. The blend was kept in cylindrical glass container to study the solubility and phase stability. The low volume percentage, i.e., 5 and 10 of ethanol is easily miscible and found to be stable as much as 7 to 17 days but higher concentration of ethanol with diesel is not stable for longer period of time. Phase separation was takes place soon after stirring. To overcome this problem biodiesel is added in equal proportion to the ethanol. As shown in fig 3, the test results of the solubility and the physical stability of the blends. Fig 3a shows the condition when diesel, ethanol, biodiesel and additive added into a containers. In case of ethanol and diesel blend, it was clearly visible that they were stratified into two layers, whereas diesel, ethanol and biodiesel were relatively miscible and not had any clearly visible interface. Fig 3b shows the status when the blend were formed after magnetic stirring. The volume percentages tested were 5%, 10%, ethanol with diesel (0.7% and 1% additive respectively) and 15% and 20% of ethanol with equal amount of biodiesel and diesel (1% additive in each). They were named as B0E5D95, B0E10D90, B15D70E15 and B20D60E20. The additive is supplied by Energenics Pte. Ltd. Singapore. The suitability of blends selected was justified by measuring different physico-chemical properties as depicted in table 3. The entire test was carried out as per ASTM standards. However it is worth noting that considerable loss of calorific value due to addition of ethanol in diesel is compensated by using biodiesel.
For comparison, the experimental plan for the engine tests were designed to run at constant speed of 1500 rev/min (rated power speed) at fixed compression ratio of 18.There were no changes for the engine running parameters. The whole experimental plan was realized in two stages: (i) running engine with diesel; and (ii) running engine with the blends. Each test was repeated three times to make sure the data were reliable.

BOD95E5 BOD90E10 B15D70E15 B20D60E20

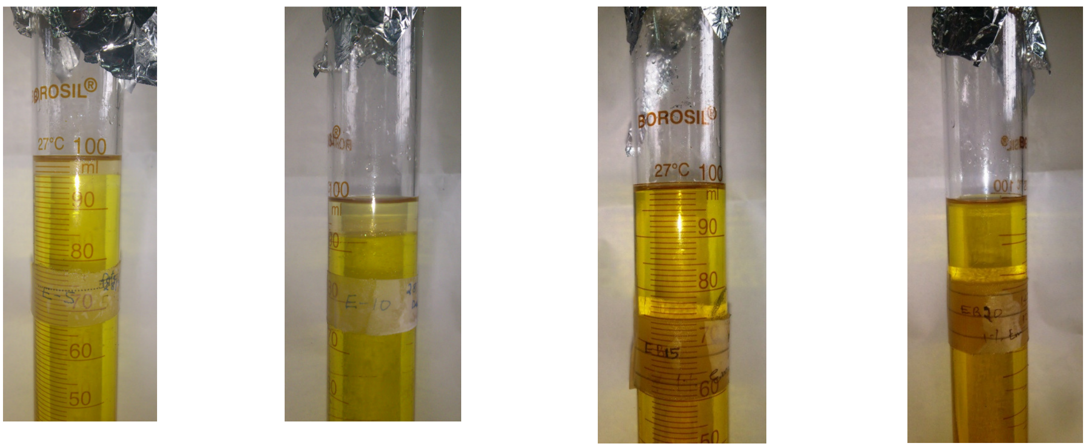

Fig 3a: Shows the stratified blends immediate after adding ethanol, biodiesel with diesel

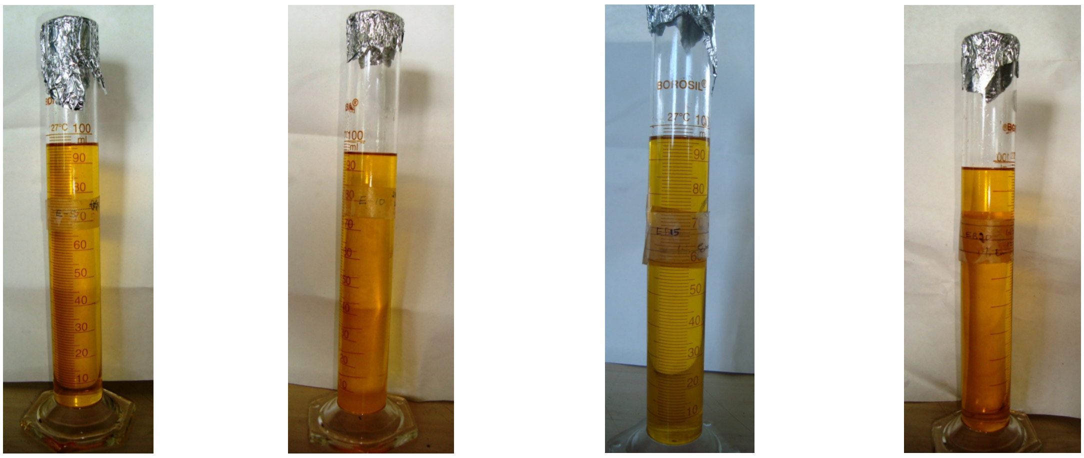

Fig 3b: Homogeneous blend after magnetic stirring

Table 3: Physico-chemical analysis of fuels

Properties	Diesel	Biodiesel	Ethanol	B0D95 -E5	B0D90 -E10	B15D70-E15	B20D60 -E20
Diesel Content (%vol)	100	0	0	95	90	70	60
Biodiesel Content (%vol)	0	100	0	0	0	15	20
Ethanol Content(%vol)	0	0	100	5	10	15	20
Density at 15^0 C (Kg/m^3)	843	890	794.85	836	833	838	838
Viscosity at 40^0C (c P)	2.48	4.45	1.86	2.24	2.47	2.57	2.81
Flash Point (^{0}C)	50	145	13.8	17.3	16.5	15.0	14.2
Calorific Value (kJ/kg)	45000	35400	26400	43580	43053	41263	38840

III. RESULT AND DISCUSSION

3.1 Effect of fuel blends on brake thermal efficiency

The results of the thermal efficiencies of engine with the load are shown in Fig. 4. As it was expected, the engine efficiency decreases for fuel blends, similar trend is being observed in case of brake specific fuel consumption. The engine efficiency decreases between 0.10 % and 13.5 %, highest reduction in efficiency is found in B0D90E10 fuel. However, the reduction in efficiency is more prominent at higher loads; at low and medium loads efficiency is comparable with diesel.

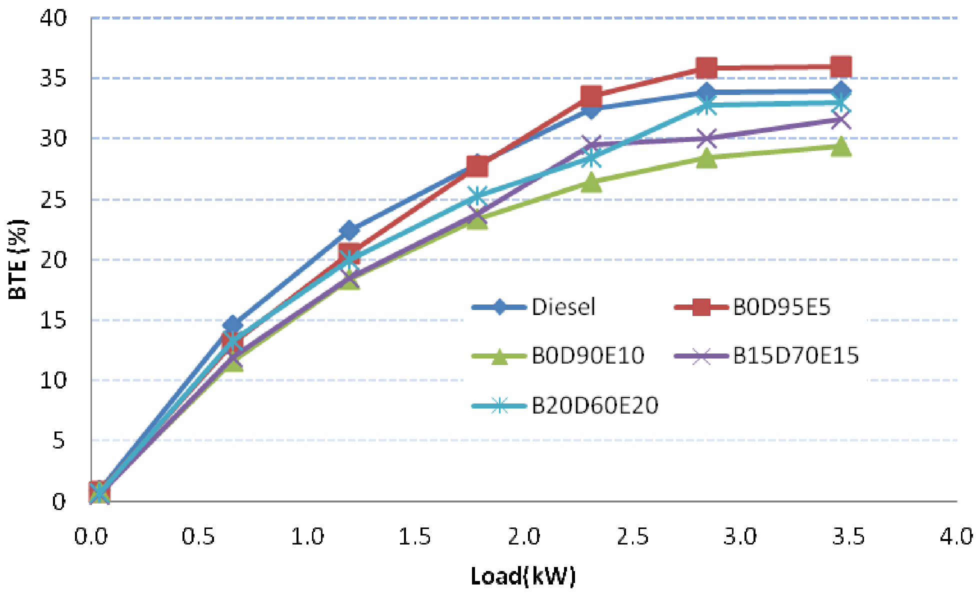

Fig. 4 Variation of brake thermal efficiency with load (brake power)

3.2 Effect of fuel blends on brake specific fuel consumption

The results of brake specific fuel consumption (bsfc) related to engine load are presented in Fig.5 the brake specific fuel consumption is greater at smaller loads, but it decreases at medium and higher loads. It was expected from the heating value of various blends, the bsfc increases with increasing oxygenate content. The sequence is D100, B0D95E5, B0D90E10, B15D70E15 and B20D60E20; being the same at all engine loads, maintain the increasing sequence of biofuel content. The increase is higher at small loads (5.7%, 7.6%, 8.8% and 9.5 %) respectively, the highest variation is found for B20D60E20 (22.2%) at medium load. At high load the values are comparable with that of diesel.

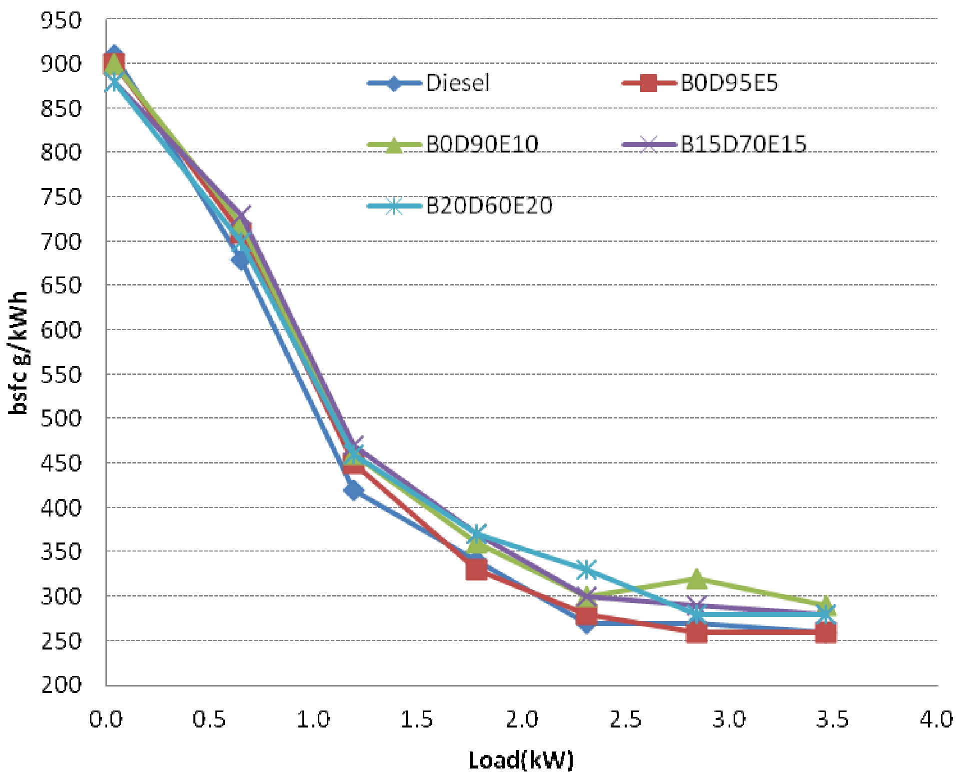

Fig. 5 Variation of bsfc with load (brake power)

3.3 Effect of fuel blends/load on NO_x emissions analysis

The NO_x emissions are the major part of pollutants emitted from the CI engines. Nitric oxide (NO) and nitrogen dioxide (NO_2) are the oxides of nitrogen found in exhaust emissions. The NO_x formation majorly depends upon the in-cylinder temperature, the oxygen concentration and residence time for the reaction to take place [14]

The test results for the NOx emission from the engine are shown in Fig.6. NO_X level increase with increase in engine loads for both diesel and various blends. This is due to more fuel was injected and combusted in the cylinder when engine load increased, which cause higher gas temperature and resulted in more NOx formation in the engine cylinder and then higher NOx emission from the engine. This proves that one of most important factors for the emissions of NOx is combustion temperature in the engine cylinder. It is observed that the presence of oxygenated components and biodiesel in the studied fuels at small loads has a minimal influence on the NOx emission level, very small reduction can be seen very clearly. The NOx emissions were reduced at low loads when fuelled by blended fuels; this is possibly due to two reasons: one is that the evaporation of ethanol in the blends B0D95E5 and B0D90E10, after being injected into the combustion chamber, cause the lower gas temperature in the cylinder (ethanol has higher latent of vaporization 840kJ/kg, compared with that of 270 kJ/kg for diesel and biodiesel of 240kJ/kg), and the temperature was also lower after combusted; this caused less NO_x formation and it has an obvious effect when less fuel was injected into the engine cylinder at low engine loads; anther is that the lower calorific value of ethanol , biodiesel and its blends, which cause lower combustion temperature as can be seen from the Fig.6

The NO_x emissions for diesel fuel are 50% higher than that of B0D90E10 fuel blends lower load range. During medium load range, the NO_x emission of diesel is 84% more than the B0D90E10 fuel blend. For high load range, the NO_x emission of diesel is 34% more than the B0D95E5 fuel blend at higher loads.

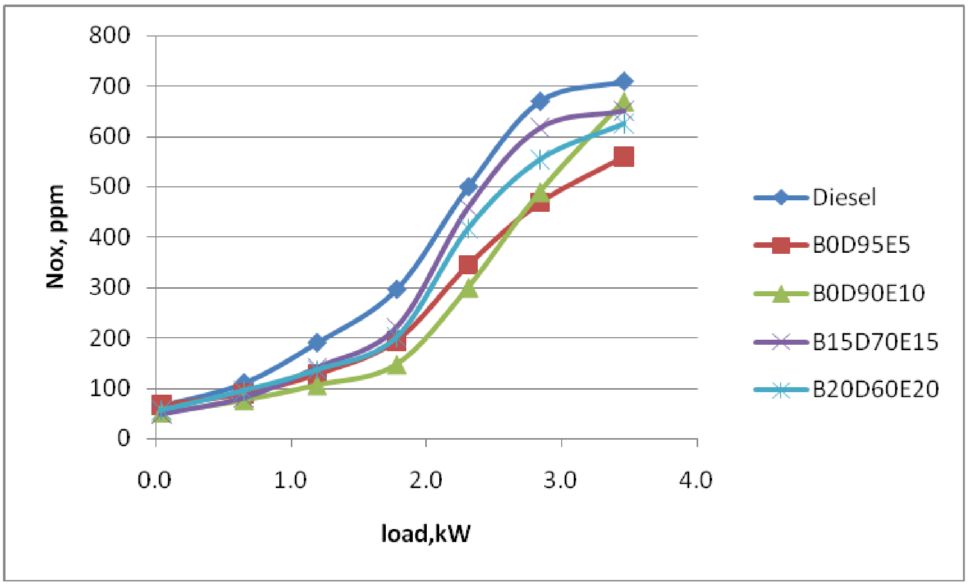

Fig. 6 Variation of NOx emissions with load (brake power)

3.4 Effect of fuel blends/load on CO emissions

CO emission is toxic and must be controlled. It is an intermediate product in the combustion of a HC fuel, so its emission results from incomplete combustion. Emission of CO is therefore greatly dependent on the air-fuel ratio relative to the stoichiometric properties. Rich combustion invariably produces CO and emission increase nearly linearly with the deviation from the stoichiometric [15].

The experimental results of CO emission are shown in Fig.7. It is observed that at higher loads emissions for diesel fuel is highest compared to all the blends and the lowest for B0D90E10. Moreover, compared to all four blends it has maximum ethanol content and it promote better combustion because of ethanol. As per the results the lowest CO emission is from the B0D90E10 fuel which is compared with the diesel fuel represents a reduction of 40 %. At higher load CO emission fluctuates in small range. The high level of oxygen content in the ethanol and biodiesel sustain the oxidation process.

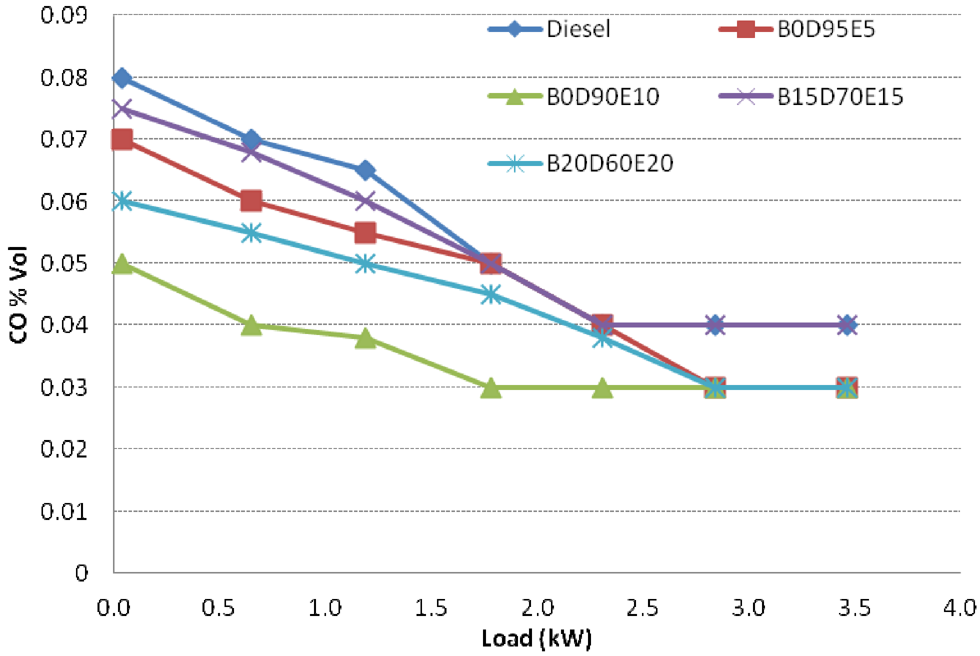

Fig. 7 Variation of CO emission with load (brake power)

3.4. Effect of fuel blends/load on HC emission analysis

The HC emission variation with engine loads for the analysed fuels is shown in Fig. 8. HC emissions showed negative trends with load, all the blends and pure diesel HC emission decreases with increase in loads. It can be noticed that the HC emission for B0D90E10 is showed a drop in the range of 32% to 40%. Also, for B0D95E5 it drops by 20% to 25% as compared to base fuel diesel. During medium and high loads HC emissions increased in the range 45-47 % and 27-32 % for B15D70E15 and B20D60E20 respectively.

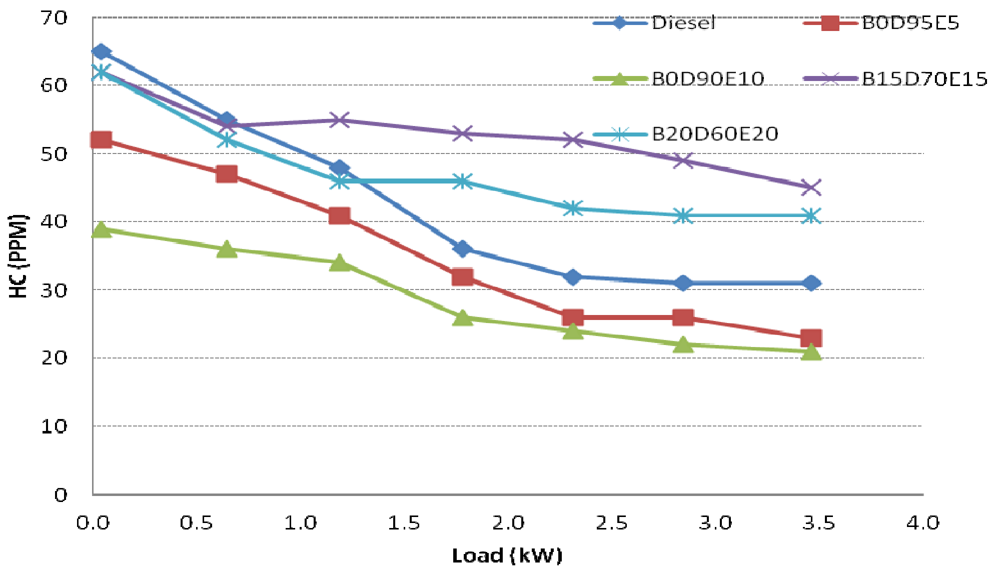

Fig. 8 Variation of HC emissions with load (brake power)

3.5. Effect of fuel blends/load on Smoke opacity

The degree to which the visibility or passage of light is reduced by the smoke is called the smoke opacity. In context of diesel emissions, the more smoke in exhaust will have the more opacity and vice-versa. Opacity is increased due to the increased density of smoke particles in the exhaust. The particles restrict the light passing through them, which causes the opacity.

The variation of smoke opacity with load is shown in Fig. 9. The smoke opacity for the pure diesel fuel is 40% less than the smoke opacity of B15D70E15 fuel blend, for small loads. However at medium loads, the smoke opacity of the B0D95E5 fuel blend is 52.5% less than that of pure diesel fuel. Also, at higher load range, the smoke opacity of B0D95E5 fuel blend is 72% less than that of pure diesel.

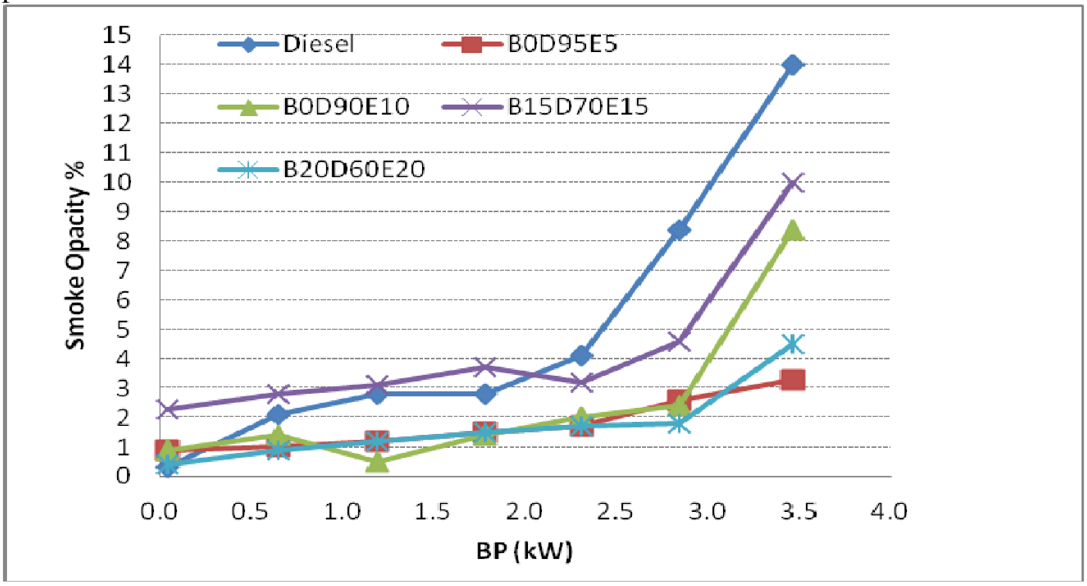

Fig. 9 Variation of smoke opacity with load (brake power)

3.6. Effect of fuel blends/load on Exhaust gas temperature

The exhaust gas temperature affects the NOx emission directly, because the higher temperature facilitates the formation of NOx. Fig10 shows an increasing trend of exhaust gas temperature, which is in line with NOx emission trend and it is shown in Fig.6.

It is seen from Fig. 10 that there is a little difference in the exhaust gas temperature of pure diesel and various blends during higher and medium loads. The exhaust gas temperature of diesel is 14% more than that of the B0D90E10 blends at higher loads.

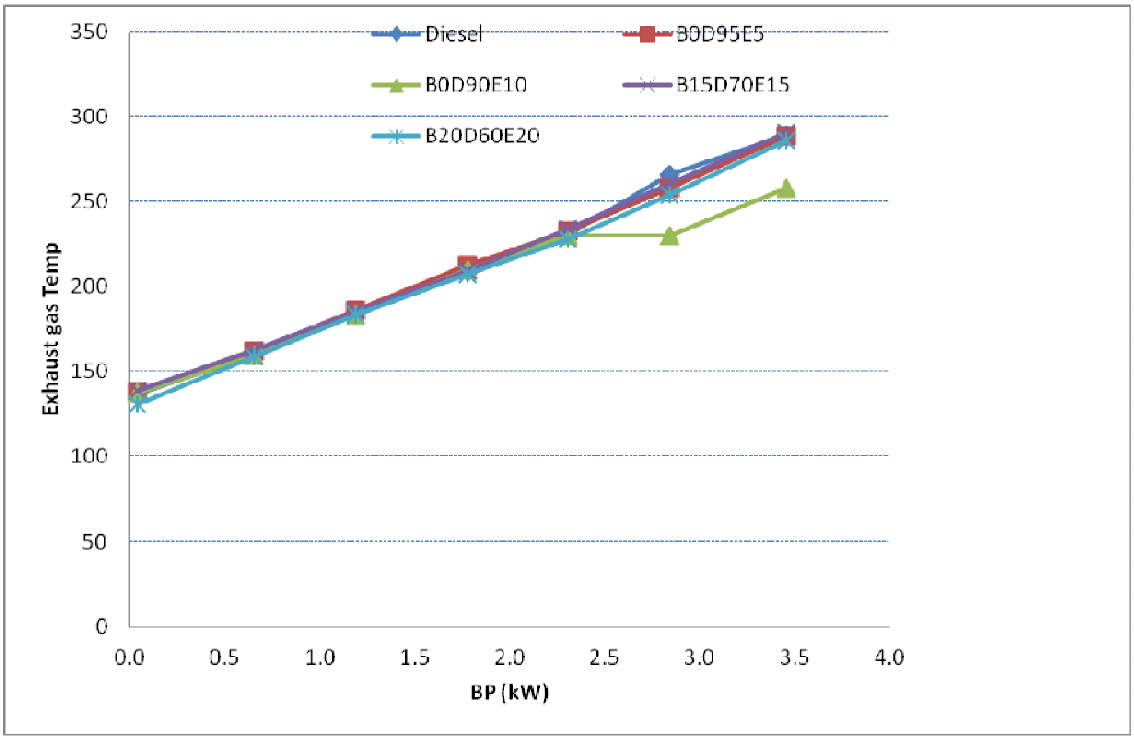

Fig. 10 Variation of exhaust gas temperature with load (brake power)

IV. CONCLUSIONS

The experimental study was conducted concerning phase stability of various blends at room temperature and analysis of their physico-chemical properties. The effects of these fuel blends on the engine performance and emissions were compared with diesel. The tests blends were from 5% -20% Ethanol and 15%-20% Biodiesel by volume. The engine was operated on constant speed at 1500 rev/min and varying loads. From the experimental results following conclusions were drawn

- The fuel blends with lower concentration of ethanol (i.e., 5%-10%) with diesel were found stable after the addition of emulsifier (0.7% and 1%). However, the fuel blends with higher percentage of ethanol (i.e., 15% -20%) separated soon and need co-solvent, i.e., biodiesel to avoid phase separation.
- The physico-chemical analysis of the blends shows that examined fuel blends have less calorific value than those of base fuel diesel. Also, the viscosity of base fuel diesel is less than those of diesel-biodiesel-ethanol blends, but more than those of diesel-ethanol blends.
- Moreover, due to lower heating value of oxygenates biodiesel and ethanol, the break thermal efficiency of ethanol-biodiesel-diesel blends deteriorate significantly as compared to base fuel diesel.
- In addition to decrease in brake thermal efficiency for the blends of ethanol-biodiesel- diesel fuels, brake specific fuel increases with increasing the oxygenates content
- HC emissions are found less in case of E-diesel fuel blends i.e., B0D90E10 and B0D95E5, they showed a reduction of 20% to 40% as compared to base fuel diesel. However, addition of biodiesel exhibits higher HC emissions for blends than that of base fuel diesel.
- CO emissions of ethanol-diesel blends were found less than that of base fuel diesel. CO from fuel blend (B0D90E10) shows a reduction upto 40% at low and medium loads.
  However, for biodiesel added blends, CO emissions were very similar to the neat diesel emissions at medium and high loads.
- Smoke and NO_X emissions are found less for all oxygenated fuel blends in compare to diesel fuels in the entire range of loads. NOx emissions for diesel fuel were 50%, 84% and 34% higher as compared to B0D90E10 fuel blend at low medium and high loads respectively.

- Exhaust gas temperature for the pure diesel fuel and for various fuel blends, vary by a very small fraction for the small and medium load ranges. For the high load range, the exhaust gas temperature of diesel is 14% more than that of the B0D90E10 blend
- The test results revealed that overall emission generation is less in case of B0D90E10 fuel blends.

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