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The Effect of Biodiesel and Bioethanol Blended Diesel Fuel on the Performance and Emission Characteristics of a Direct Injection Diesel Engine

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Abstract: History has seen fuel innovations being driven majorly by transportation needs rather than the overall need to revolutionize the energy needs of the society. Biofuels such as biodiesel and bioethanol are now receiving the impetus required for becoming a fuel source for the future. One of the ways to reduce the dependence on fossil diesel is the blending of bioethanol with conventional diesel. However, an emulsifier or a co-solvent is required to stabilize the blend. The ricebran oil biodiesel offers an alternative application as an emulsifier for diesel-ethanol blends to form diesel-biodiesel-ethanol blends. In the present study the rice bran oil biodiesel was used in different ways such as pure biodiesel, blending with diesel and diesel- ethanol blends. The performance and emission characteristics of a direct injection (DI) diesel engine when fuelled with conventional diesel fuel, pure biodiesel, a blend of diesel and biodiesel and three blends of diesel-biodiesel-ethanol were studied over the entire range of load on the engine. The experimental results showed that the highest brake thermal efficiency was observed with 30% ethanol in diesel-biodiesel-ethanol blends. The exhaust gas temperature and sound reduced with the increase of ethanol percentage in diesel-biodiesel-ethanol blends. The Carbon monoxide, smoke, exhaust gas temperature and sound reduced with the increase of ethanol percentage in diesel-biodiesel-ethanol blends. The minimum values of Carbon monoxides, smoke, exhaust gas temperature and sound intensity were observed with the blend BE30 and were respectively 41.23%, 14.5%, 0.57% and 11.53% lower than that of the diesel fuel. The Oxides of nitrogen and carbon dioxide emissions increased with the increased percentage of ethanol in diesel-biodiesel-ethanol blends. The hydrocarbon emissions increased with ethanol but lower than that of the diesel fuel by a maximum of 35.35% with 10% ethanol in diesel-biodiesel-ethanol blend. The blending of 20% biodiesel into diesel-ethanol blends allowed higher percentage (30%) of ethanol mixing with diesel, increased the brake thermal efficiency and reduced the carbon monoxide, sound, hydrocarbons and smoke than that of the diesel fuel. So the rice bran oil biodiesel can be used as an emulsifier to mix higher percentage of ethanol with fossil diesel to improve the performance and reduce the emissions of a diesel engine.

Key words: Diesel engine % Rice bran oil % Biodiesel % Ethanol % Performance % Emissions

INTRODUCTION

Population growth, increasing needs of current consumers, world wide motorization and global industrialization has stimulated the high increase in energy demand. Energy is very important for life quality, welfare level and social development of people as well as economic growth. Fossil fuels have been an important conventional energy source for years. This growing global energy consumption cannot be covered only by limited conventional fossil sources. Most of the developing countries meet their energy demand by importing fossil fuels. Consequently, these countries have to spend their income earned to buy petroleum products [1]. The climate changes, growing air pollution and depletion of fossil fuels are the major problems in the present century. The researchers have been currently focused on replacing the fossil fuels by biofuels to reduce dependence on fossil fuels. Biofuels provide low green house emissions with the reduction of oil import.

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The role biofuels can play within these economies becomes clearer when their relatively developed agricultural sector is taken into account [2]. Bioethanol, biodiesel and to a lesser extent pure vegetable oils are recently considered as most promising biofuels. Since 19th century, ethanol has been used as a fuel for diesel engines. Ethanol is a low cost oxygenated compound with high oxygen content (34.8%) and most often chosen because of the ease of production, can be obtained from various kinds of biomass such as corn, sugar beet, sugarcane, cassava, maize, red seaweed etc., [3].

Diesel-ethanol blends require little or no change in conventional engines. The use of ethanol combined with diesel can significantly reduce the emission of toxic gases and particulate matters when compared to pure diesel. Ozer Can *et al* [4] investigated the effects of ethanol addition to Diesel No. 2 on the performance and emissions of a four stroke cycle, four cylinder, turbocharged indirect injection Diesel engine with different fuel injection pressures at full load. They showed that the ethanol addition reduces Carbon monoxide (CO), soot and Sulphur Dioxide ($SO_{2)}$ emissions, but caused an increase in Oxides of Nitrogen ($NO_{x)}$ emission. It was also found that increasing the injection pressure reduced CO and smoke emissions with some reduction in power. Andrzej Kowalewicz [5] showed that the injection of ethanol into the inlet port reduces Carbon Dioxide ($CO_{2)}$ emission and smoke at high load and also NO_x and CO emissions with both diesel fuel and rape oil methyl ester. Jincheng Huang *et al* [6] studied the performance and emissions of a diesel engine using ethanol-diesel blends. They showed that the thermal efficiencies of the engine fuelled by the blends were comparable with that fuelled by diesel, with some increase of fuel consumption. They also found reduced smoke emissions, CO emissions above half loads and increased HC emissions with the blends comparing with the diesel fuel

However, the addition of ethanol leads to considerable modifications in the physicochemical properties of fossil fuel, causing a significant reduction in the cetane number, viscosity and combustion heat. Depending on the composition of the base diesel, anhydrous ethanol displays little solubility in the diesel. When the water content in ethanol exceeds 1%, the mixture becomes instable and phase separation occurs at relatively low temperatures [7] The phase separation can be prevented in two ways: through the addition of an emulsifier, which acts by lowering the surface tension of two or more substances, or by adding a co-solvent, which acts by modifying the power of solvency for the pure solvent. [8]. Ethanol and diesel fuels can be efficiently emulsified into a heterogeneous mixture of one micro-particle liquid phase dispersed into another liquid phase by mechanical blending in cooperation with suitable emulsifiers. The emulsifier would reduce the interfacial tension force and increase the affinity between the two liquid phases, leading to emulsion stability [9]. A suitable emulsifier for ethanol and diesel fuel is suggested to contain both lipophilic part and hydrophilic part, in order to obtain an emulsion of diesohol. Such chemical structures can be found in biodiesel. [10].

Biodiesels are used mainly because of their similarity to diesel oil, which allows the use of biodiesel-diesel blends in any proportion. The biodiesel allows the addition of more ethanol blended fuel, improves the tolerance of the blend to water and keeps the mixture stable, so that it can be stored for a long period. The large cetane number of the biodiesel offsets the reduction of cetane number from addition of ethanol to diesel, thus improving the engine ignition. Moreover, the addition of biodiesel increases the oxygen level in the blend. In addition, biodiesel have lubricating properties that benefit the engine and are obtained from renewable energy sources such as vegetable oils and animal fats. Similar to ethanol, biodiesel have a great potential for reducing emissions, especially particulate materials. [11].

The above studies reveal that the diesel-biodiesel-ethanol blends can be used as alternative fuels for diesel engines. Recent research has shown that the use of diesel- biodiesel-ethanol blends can substantially reduce emissions of CO, total hydrocarbons (HC) and particulate materials [12]. The mixing of biodiesel and bioethanol with diesel significantly reduces the emission of particulate matter (PM) because the blended biofuel contains oxygen [13]. Hadi rahimi *et al* showed that the bioethanol and sunflower methyl ester can improve low temperature flow properties of diesel-biodiesel-ethanol blends due to very low freezing point of bioethanol and low pour point of sunflower methyl ester. The power and torque produced by the engine using diesel-biodiesel-ethanol blends and conventional fuel was found to be very comparable. The CO and HC emission concentration of these blends decrease compared to the conventional diesel fuel and even diesel-biodiesel blends [14]. Hwanam Kim *et al.* [15] investigated the exhaust gas characteristics and particulate size distribution of PM on a CRDI diesel engine using diesel, biodiesel and ethanol blends. They observed the reduced CO, HC, smoke emissions and total number of particles emitted, but increased NOx emissions. Xiaobing Pang *et al* [16] reported that the use of biodiesel-ethanol- diesel blend could slightly increase the emissions of carbonyls and NO_x but significantly reduce the emissions of PM and THC. Prommes Kwanchareon, Apanee Luengnaruemitchai and Samai Jai[17] studied solubility of a diesel-biodiesel ethanol blend, its properties and its emission characteristics from diesel engine. They examined the solubility of a diesel-biodiesel ethanol blend, its properties and emission characteristics from diesel engine. They found that the blended fuel properties were close to the standard diesel except flash point. As for the emissions of the blends, it was found that CO and HC reduced significantly at high engine load, whereas NO_x emissions increased compared to those of diesel.

The above studies reveal that the diesel-ethanol-biodiesel blends reduce CO, HC, PM, Smoke emissions and increase NO_x emissions compared with the diesel fuel. There is little research on the use of rice bran oil biodiesel in diesel-ethanol-biodiesel blends for diesel engines. Rice is the main cultivation in subtropical southern Asia and it is a staple food for a large part of the world's human population especially in east, south and south-east Asia, making it the most consumed cereal grain. Rice Bran Oil (RBO) is extracted from the germ and inner husk (called bran) of the rice. Rice bran is mostly oily inner layer of rice grain which is heated to produce RBO [18]. RBO is not a common source of edible oil compared to other traditional cereal or seed sources such as corn, cotton, sunflower or soybean. . Until recently, rice bran was used mostly as animal feed and the most of the oil production is used for industrial applications. One of the best ways for the potential utilization of RBO is the production of biodiesel [19]. Biodiesel can be directly used in diesel engines, or mixed with any proportion of diesel fuel in diesel engines. The performance and emission characteristics of the biodiesel blended up to 20% were close to that of diesel fuel [20, 21].

In the present investigation the performance and emission characteristics of a diesel engine were studied by using 20% ricebran oil biodiesel in the diesel-ethanol-biodiesel blends and compared with that of the diesel fuel.

MATERIALS AND METHODS

In the present investigation the fuels used were conventional diesel fuel, ricebran oil biodiesel and bioethanol. The bioethanol (95% pure) used in these tests was kindly supplied by Nandi Agro products, Nandyal andhra Pradesh, India. The rice bran oil biodiesel was supplied by Gaiatech Fuels Pvt Ltd; Hyderabad, India. The diesel fuel was purchased from the Bharat Petroleum pump outlet, Nandyal andhra Pradesh, India. Fuel properties that are important from engine performance and emission point of view such as density, viscosity, net heating value, acid value, flash point, Cetane number, iodine number of diesel, ricebran oil biodiesel and bioethanol were determined and shown in the Table 1.

The specifications of the diesel engine are given in Table 2.

The engine was first operated on diesel fuel with no load for few minutes at rated speed of 1500 rpm until the cooling water and lubricating oil temperatures comes to 85° C. The same temperatures were maintained throughout the experiments with all the fuel modes. The baseline parameters were obtained at the rated speed by varying 0 to 100% of load on the engine with an increment of 20% with the diesel fuel (DF). The diesel fuel was replaced with

Table 1: properties of diesel, ricebran oil biediesel and bioethanol.

Property parameters	Dieselfuel	Rice bran oil biodiesel	Bioethanol
Density at 20°C, g/cm3	0.82	0.8742	0.78
Viscosity at 40° C, mm2/s	3.4	4.63	1.35
Flash point, °C	71	165	22
Auto-ignition temperature, °C	225	320	415
Pour point, °C	1	3	<-35
Cetane number	45	56.2	10
Iodine number, J2 g/100 g	6	102	--
Acid value, mg KOH/g	0.07	0.25	--
Oxygen content, max wt%	0.4	11.25	34.8
Net heating value, MJ/kg	43.5	38.725	26.8

The experimental set up consists of a diesel engine, engine test bed, fuel and air consumption metering equipments, gas analyzer and smoke meter. The schematic diagram of the engine test rig is shown in Fig. 1.

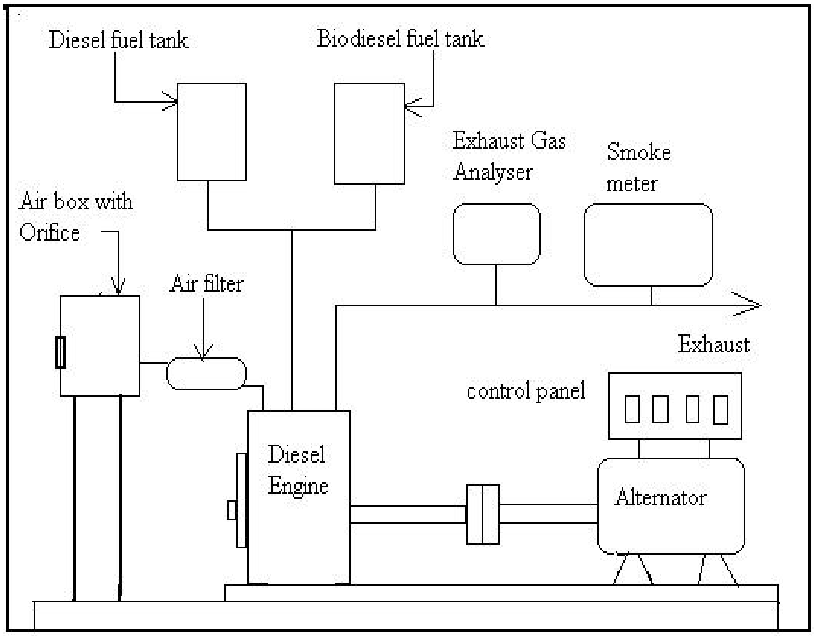

Fig. 1: Schematic diagram of engine test rig

Table 2: Specifications of the diesel engine.

Make	Kirloskar model AV1
No. of Strokes per cycle	4
No. of Cylinders	single
Combustion chamber position	vertical
Cooling method	Water cooled
Starting condition	Cold start
Ignition technique	Compression ignition
Bore (D)	80 mm
Stroke (L)	110 mm
Rated speed	1500 rpm
Rated power	5 hp (3.72 kW)
Compression ratio	16.5 : 1

the rice bran oil biodiesel (B100) and test was conducted by varying 0 to 100% of load on the engine with an increment of 20%. After the rice bran oil biodiesel, the test was conducted with the blend of 80% diesel and 20% biodiesel (B20). Three diesel-biodiesel-ethanol blends were prepared consisting of 70%diesel, 20%biodiesel and 10% bioethanol (BE10), 60% diesel, 20%biodiesel and 20% bioethanol (BE20) and 50%diesel, 20% biodiesel and 30% bioethanol (BE30). Different methods are there for using ethanol in diesel engines such as direct blending, online blending and dual-fuel system. Online blending and dual-fuel systems can more easily adjust the ethanol percentage in the diesel, but they need modified fuel injection systems, especially for the dual-fuel injection method which required an additional fuel injection system on the engine. The directly blended fuel does not require any modifications to diesel engines. Hence direct blending method was used in this test. The tests were conducted with these three blends by varying the load on the engine.

The brake power was measured by using an electrical dynamometer. The mass of the fuel consumption was measured by using a fuel tank fitted with a burette and a stop watch. The brake thermal efficiency and brake specific fuel consumption were calculated from the observed values. The exhaust gas temperature was measured by using an iron-constantan thermocouple. The exhaust emissions such as carbon monoxide, Carbon Dioxide, Nitrogen Oxides, hydrocarbons and unused Oxygen were measured by AVL DiGas 444 exhaust analyzer and the smoke opacity by AVL smoke meter 437C for diesel fuel, biodiesel, a blend of diesel and biodiesel and three diesel-biodiesel-ethanol blends separately under all load conditions. The results from the engine with rice bran oil biodiesel, a blend of diesel and biodiesel and three diesel-biodiesel-ethanol blends were compared with the baseline parameters obtained during engine fuelled with diesel fuel at rated speed of 1500 rpm.

RESULTS

The performance parameters such as brake thermal efficiency and brake specific fuel consumption were calculated from the observed parameters and shown in the graphs. The other performance parameters such as exhaust gas temperature and sound levels and the exhaust gas emissions such as Carbon monoxide, Hydro Carbons, Oxides of nitrogen, Carbon dioxide, unused Oxygen and smoke were represented in the form of graphs from the measured values. The variation of brake thermal efficiency with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 2.

The brake thermal efficiency increased with load for all fuel modes. The brake thermal efficiency of rice bran oil biodiesel (B100), blend of diesel and 20% biodiesel (B20) and all diesel-biodiesel-ethanol blends was higher than that of the conventional diesel fuel over the entire range of the load. The reason may be the leaner combustion of biodiesel and the extended ignition delay, resulting in a larger amount of fuel burned in the premixed mode of the ethanol blends. The increased brake thermal efficiency of 1.46%, 2.19% and 2.92% was observed respectively with the blends BE10, BE20 and BE30 compared with the blend B20. The maximum brake thermal efficiency was observed with BE30 at all the loading conditions of the diesel engine and it is 3.67%, 0.7% and 2.92% higher than that of diesel fuel, B100 and B20 respectively at full load of the engine. It may be due to the reduction in the viscosity and density of the fuel by the addition of ethanol.

The variation of brake specific fuel consumption (BSFC) with load for different fuels is shown in Fig. 3.

The BSFC reduces with load for all the fuel modes. The BSFC of B100 and B20 were 24.43% and 3.7% higher than that of the diesel at full load of the engine. The BSFC increased by 23.27%, 27.63% and 31.63% respectively with the blends BE10, BE20 and BE30 compared with the blend B20. The BSFC increased with the increase of ethanol percentage in the diesel-biodiesel-ethanol blends at all loading conditions of the engine. It is due to the lower heating values of biodiesel and ethanol compared with diesel fuel. The highly oxygenated ethanol blending into the blends leads to leaner combustion resulting in higher BSFC.

The variation of exhaust gas temperature with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 4.

The exhaust gas temperature increased with the load for all the fuels. The exhaust gas temperature of the blend B20 was 6.83% higher than diesel fuel and 22.36% lower than that of the pure biodiesel (B100). The increase of the ethanol percentage in the diesel-biodiesel-ethanol blends reduced the exhaust gas temperature. The reduction was 2.93%, 4.53% and 6.93% lower than that of the blend B20 with the blends BE10, BE20 and BE30 respectively. It is due to the advanced fuel injection. The decrease in exhaust temperatures with increased ethanol concentration is due to the high evaporative heat and low heating values of ethanol, which takes off the heat from combustion space.

The variation of intensity of sound with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 5.

The intensity of sound increased with load for all fuel modes. The intensity of sound with the blend B20 was 3.3% lower than that of diesel fuel at full load of the engine. The intensity of sound reduced with the higher percentages of ethanol and was lower than that of the diesel fuel and the blend B20 but higher than B100. The reduction was by 5.5%, 7.69% and 11.53% than diesel fuel with the blends BE10, BE20 and BE30.

The variation of Carbon Monoxide (CO) with load for different fuels is shown in Fig. 6.

The CO emissions slightly increased at low and medium loads and increased significantly at higher loads with all the fuel modes. The CO emissions of the diesel-biodiesel-ethanol blends were not much different from that of conventional diesel at low and medium loads as shown in the figure. However, the CO emissions of these blends decreased significantly, when compared with those of conventional diesel at full load of the engine. This is due to the enrichment of oxygen owing to the ethanol and biodiesel addition, in which an increase in the proportion of oxygen will promote the further oxidation of CO during the engine exhaust process. The results showed that the CO emissions reduced with increase of ethanol percentage in the diesel-biodiesel-ethanol blends. The CO emissions reduced by 32.98%, 38.14% and 41.23% than the conventional diesel respectively with the blends BE10, BE20 and BE30 at full load of the engine. Among the diesel-biodiesel-ethanol blends the blend BE30 produced the lowest amount (0.57 % volume) of CO emissions at full load of the engine.

The variation of Hydrocarbon emissions (HC) with load for different fuels is shown in Fig. 7.

The HC emissions were minimum at medium load and maximum at full load of the engine for all the fuel modes. The HC emissions of the pure biodiesel, blend B20 and diesel-biodiesel-ethanol blends were higher at low and medium loads and lower at higher loads than those of diesel fuel. It is due to better combustion at a medium speed and with a medium sized load. The HC emissions increased with increase of ethanol percentage in the diesel-biodiesel-ethanol blends. Higher HC emission means that there is some unburned ethanol emitted in

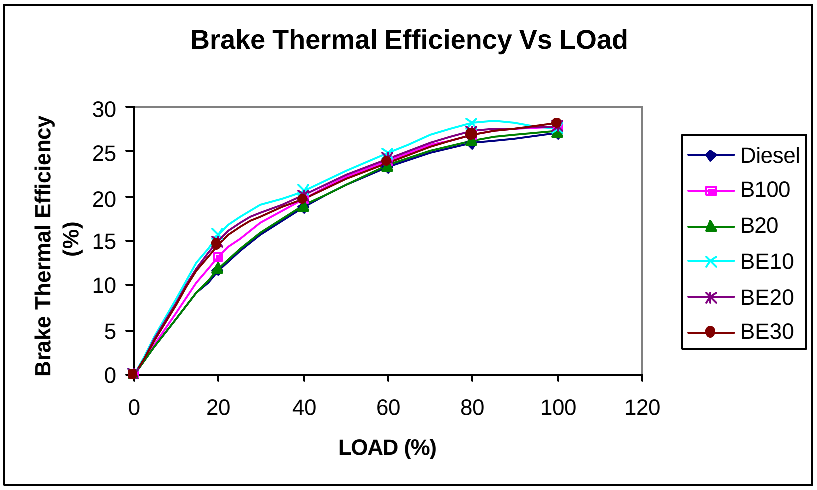

Fig. 2: Variation of brake thermal efficiency with Load

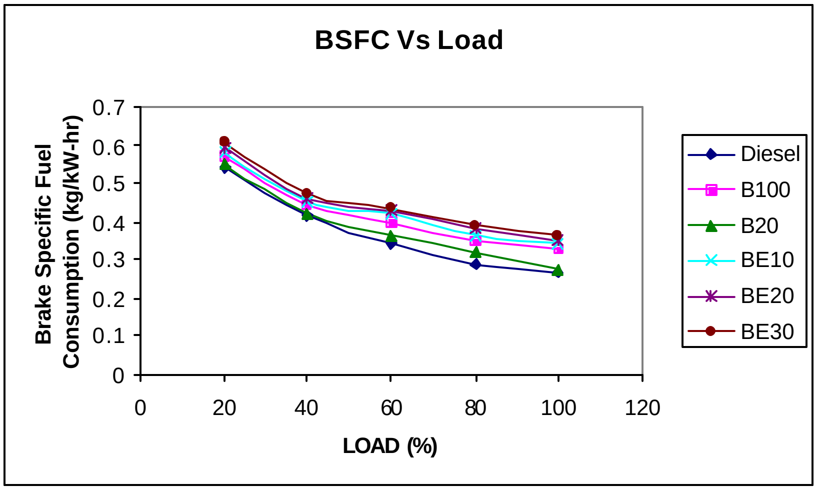

Fig. 3: Variation of brake specific fuel consumption with Load

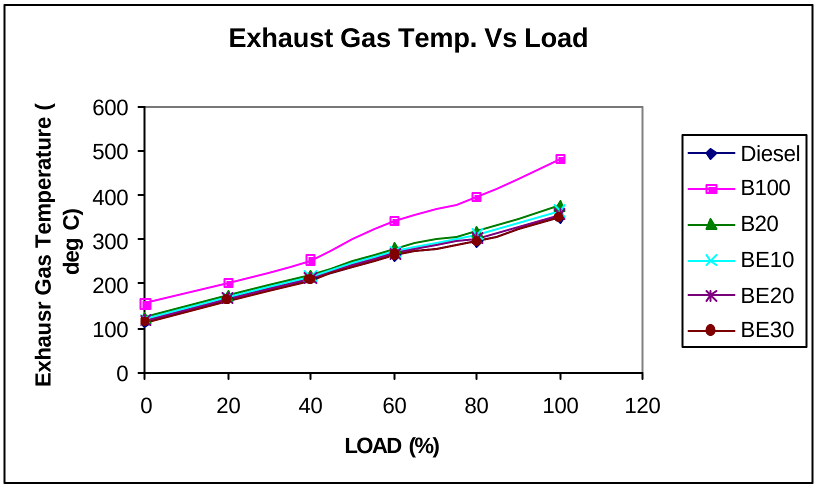

Fig. 4: Variation of Exhaust gas temperature with Load

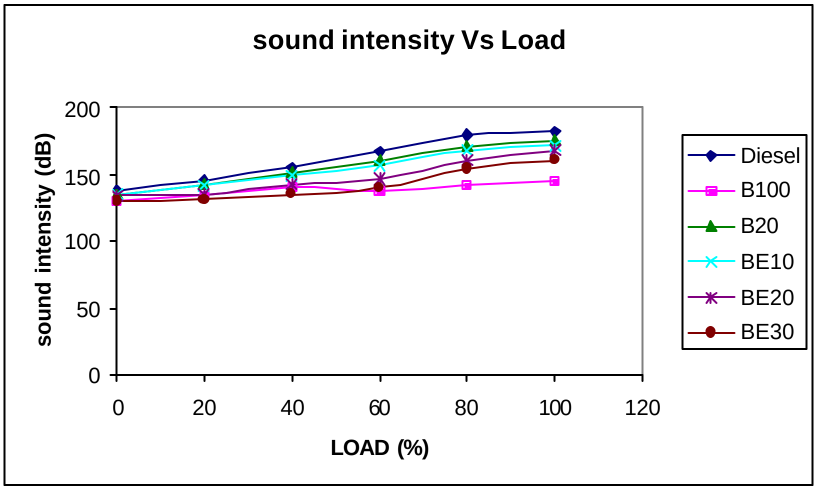

Fig. 5: Variation of sound intensity with load

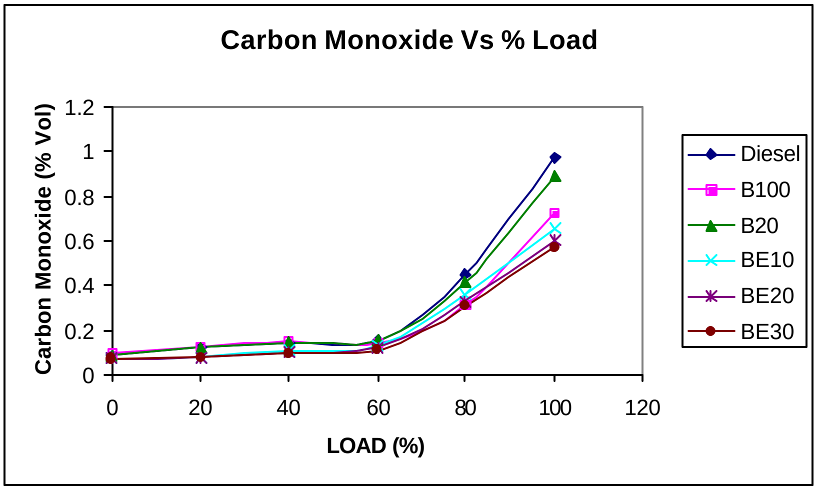

Fig. 6: Variation of Carbon Monoxide emissions with Load

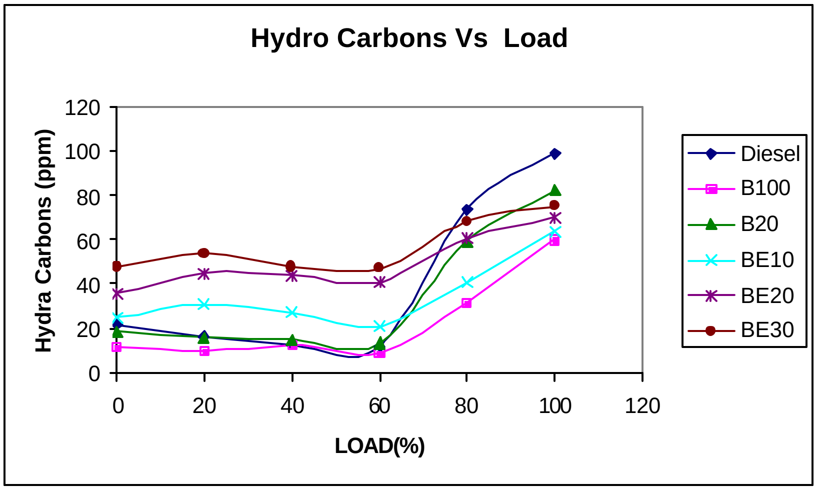

Fig. 7: Variation of Hydro Carbon emissions with Load

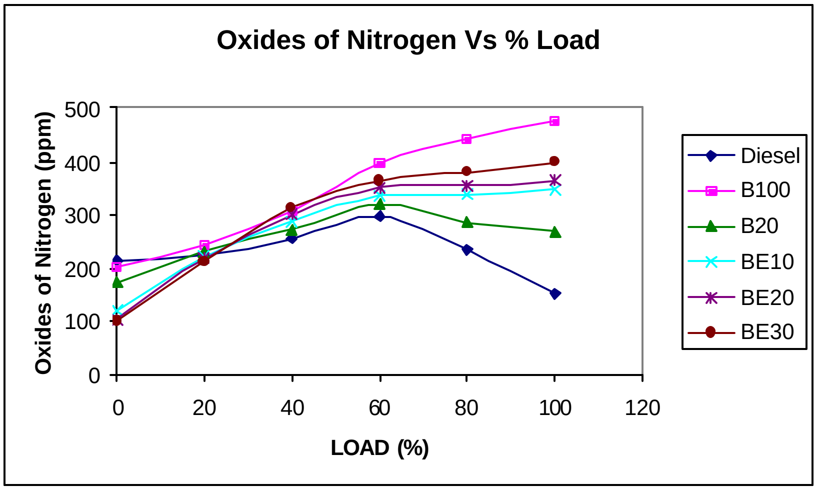

Fig. 8: Variation of Oxides of Nitrogen with Load

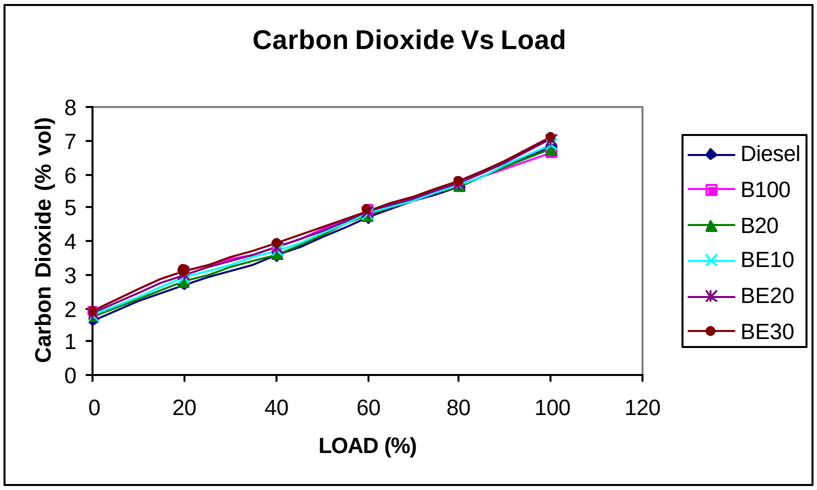

Fig. 9: Variation of Carbon dioxide emissions with Load

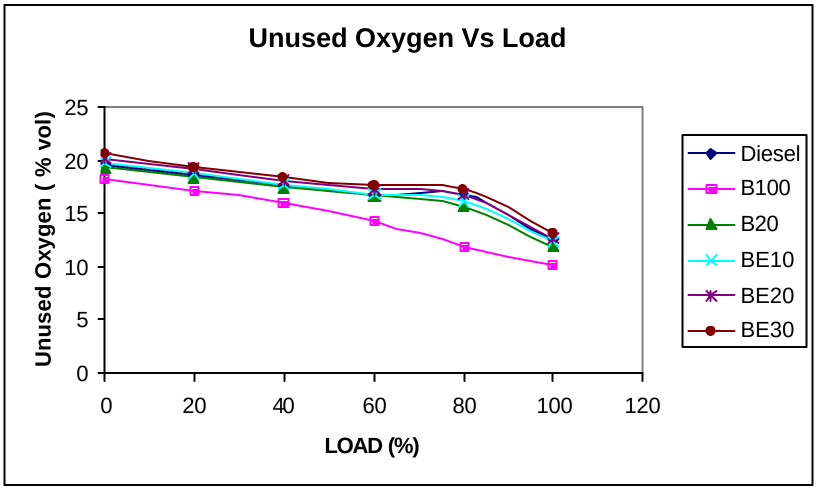

Fig. 10: Variation of Ubused oxy gen emissions with Load

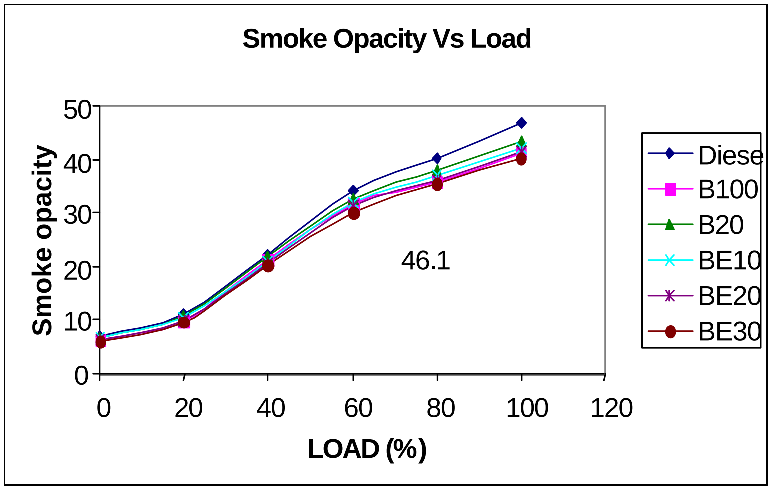

Fig. 11: Variation of Smoke Opacity with Load

the exhaust due to the larger ethanol dispersion region in the combustion chamber. The HC emissions were 35.35%, 29.29% and 24.24% lower than those of diesel fuel respectively with the blends BE10, BE20 and BE30 at full load of the engine. Among these blends, the blend BE10 had the lowest HC emissions at the full load of the engine. The pure biodiesel produced lowest HC emissions among all fuels and were 39.39% lower than those of diesel fuel. It is due to the higher cetane number of the biodiesel than conventional diesel, resulting in more complete combustion in the cylinder.

The variation of Oxides of Nitrogen (NO_x) with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 8.

The NOx emissions of biodiesel, the blend B20 and diesel-biodiesel-ethanol blends were lower at low loads and higher at medium and high loads than those of diesel fuel. It is due to the higher combustion temperature as well as the oxygen content of the biodiesel and the ethanol at medium and high loads. The NO_x emissions increased with the increased percentage of ethanol in diesel-biodiesel-ethanol blends. The NOx emissions of BE10, BE20 and BE30 were 30.22%, 35.82% and 48.88% higher than those of the blend B20 at full load of the engine.

The variation of Carbon Dioxide (CO_2) with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 9.

The CO_2 emissions increased with load for all the fuel modes. The CO_2 emissions of B100, B20, BE10, BE20 and BE30 were slightly higher than those of diesel fuel. The CO_2 emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends. The CO_2 emissions increased by 3.75%, 5.56% and 6.76% respectively with the blends BE10, BE20 and BE30 compared with diesel fuel at full load of the engine. It is due to the complete combustion caused by the highly oxygenated ethanol supply.

The variation of Unused Oxygen (O_2) emissions with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 10.

The unused oxygen emissions reduced with load for all the fuel modes. The unused O_2 emissions of biodiesel (B100) and blend B20 were 19.2% and 4.8% lower than those of diesel fuel. The O_2 emissions increased with the higher amount of ethanol in diesel-biodiesel-ethanol blends. The O_2 emissions reduced by 0.8% with the blend BE10 and increased by 1.6% and 4.8% respectively with the blends BE20 and BE30 compared with the diesel fuel at the full load of the engine.

The variation of smoke opacity with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 11.

The smoke opacity increased with the load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends. The smoke opacity of the pure biodiesel, the blend B20, BE10, BE20 and BE30 were lower than those of the diesel fuel at all loads on the engine. The smoke opacity of biodiesel was 12.36% lower than that of diesel at full load of the engine. The smoke opacity of the blend B20 was 7.46% lower than that of the diesel fuel. The smoke Opacity reduced with increase of ethanol percentage in diesel-biodiesel-ethanol blends. The smoke opacity of the blends BE10, BE20 and BE30 was respectively 10.23%, 11.72% and 14.5% lower than that of the diesel fuel at the full load of the engine.

CONCLUSIONS

The performance and emission characteristics of conventional diesel, rice bran oil biodiesel, diesel and biodiesel blend and diesel-biodiesel-ethanol blends were investigated on a single cylinder diesel engine. The conclusions of this investigation are as follows:

- The brake thermal efficiency and BSFC increased with the increased percentage of ethanol in diesel-biodiesel-ethanol blends. The maximum brake thermal efficiency (28.2%) was observed with the blend BE30.
- The increased amount of ethanol in diesel-biodiesel-ethanol blends reduced the exhaust gas temperature, sound intensity, Carbon monoxide and smoke. The minimum values of exhaust gas temperature, sound intensity, Carbon monoxides and smoke were observed with the blend BE30 and were respectively 0.57%, 11.53%, 41.23% and 14.5% lower than that of the diesel fuel.
- The increased amount of ethanol in diesel-biodiesel-ethanol blends increased the Oxides of Nitrogen, Carbon dioxide and unused Oxygen.
- The hydrocarbon emissions increased with ethanol but lower than that of the diesel fuel by a maximum of 35.35% with the blend BE10.
- The blending of 20% ricebran oil biodiesel into diesel-ethanol blends allowed higher amounts (30%) of ethanol mixing with diesel, increased the brake thermal efficiency and reduced the carbon monoxide, sound, hydrocarbons and smoke than that of the diesel fuel.

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