RICE BRAN OIL BIODIESEL AS AN ADDITIVE IN DIESEL- ETHANOL BLENDS FOR DIESEL ENGINES

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ABSTRACT

A number of studies currently focus on the renewable fuels to reduce the reliance on petroleum fuels. Biofuels such as biodiesel and bioethanol have been studied and tested in many countries including India. One of the methods to reduce the use of fossil fuel is blending ethanol with fossil diesel. However, an emulsifier or a co-solvent is needed to homogenize the diesel-ethanol blends. The rice bran oil biodiesel offers an alternative application as an emulsifier for diesel and ethanol blends. The present research is aimed to investigate experimentally the performance and exhaust emission characteristics of a direct injection (DI) diesel engine when fuelled with conventional diesel fuel, rice bran oil biodiesel, a blend of diesel and rice bran oil biodiesel and three blends of diesel-biodiesel-ethanol over the entire range of load on the engine. The experimental results showed that the highest brake thermal efficiency was observed with 15% ethanol in diesel-biodiesel-ethanol blends. The exhaust gas temperature and the sound intensity from the engine reduced with the increase of ethanol percentage in diesel-biodiesel-ethanol blends. The Carbon monoxide and smoke emissions reduced significantly with higher percentage of ethanol in diesel-biodiesel-ethanol blends. The unused oxygen with 5% ethanol in diesel-biodiesel-ethanol blend was lower than that of diesel fuel. The Hydrocarbons, Oxides of nitrogen and carbon dioxide emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends but the hydrocarbon emissions were still lower than that of diesel fuel. As the brake thermal efficiency increased and carbon monoxide, sound, hydrocarbons and smoke were lower than that of diesel fuel with the diesel-biodiesel-ethanol blends, the rice bran oil biodiesel can be used as an additive to mix higher percentages of ethanol in diesel-ethanol blends to improve the performance and reduce the emissions of a diesel engine.

Key words: *Diesel engine, rice bran oil, biodiesel, ethanol, performance, emissions*

1. INTRODUCTION

Energy is very important for life quality and social development of people as well as economic growth. Fossil fuels have been an important conventional energy source for years. Energy demand around the world is increasing at a faster rate as a result of on going trends in industrialization and modernization. Most of the developing countries import fossil fuels for satisfying their energy demand. Consequently, these countries have to spend their export income to buy petroleum products [1]. The climate changes occurring due to increased Carbon Dioxide ($CO_{2)}$ emissions and global warming, increasing air pollution and depletion of fossil fuels are the major problems in the present century. The present researchers have been focused on the biofuels as environment friendly energy source to reduce dependence on fossil fuels and to reduce air pollution. The biofuels can play an important role towards the transition to a lower carbon economy and also combine the benefits of low green house emissions with the reduction of oil import. 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 19^{th} century, ethanol has been used as a fuel for diesel engines. Ethanol is a low cost oxygenated compound with high oxygen content (34.8%). Ethanol is an alcohol most often chosen because of the ease of production, can be obtained from various kinds of biomass such as maize, sugarcane, sugar beet, corn, cassava, red seaweed etc., relatively low-cost and low toxicity [3].

Diesel-ethanol blends are a more viable alternative and require little or no change in diesel engines. The use of diesel-ethanol blends 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 increases Oxides of nitrogen ($NO_{x)}$ emissions. It was also found that increased injection pressure, reduced the CO and smoke emissions with some reduction in power. Andrzej Kowalewicz [5] showed that the injection of ethanol into the inlet port reduced $CO_{2,}$ NO_x and CO emissions and smoke at higher loads 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, ethanol and diesel fuel are inherently immiscible because of their difference in chemical structures and characteristics. The addition of ethanol to diesel affects properties such as viscosity, lubricity, Cetane number, energy content and mainly, volatility and stability. Phase separation occurs at relatively low temperatures, which are still used in the blending of anhydrous ethanol. The phase separation can be prevented in two ways. First is the addition of an emulsifier, which acts by lowering the surface tension of two or more substances and the second is the addition of a co-solvent, which acts by modifying the power of solvency for the pure solvent. [7]. Diesel and ethanol fuels can be efficiently emulsified into a heterogeneous mixture of one micro-particle liquid phase dispersed into another liquid phase by mechanical with suitable emulsifiers. The emulsifier would reduce the interfacial tension force and increase the affinity between the two liquid phases, leading to emulsion stability [8]. 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 diesel and alcohol. Such chemical structures can be found in biodiesel. [9].

Biodiesels are used 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, keeps the mixture stable and improves the tolerance of the blend to water, 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. The addition of biodiesel increases the oxygen level in the blend. Also 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 [10].

The above studies reveal that the diesel-ethanol-biodiesel blends can be used as alternative fuels for diesel engines. Recent research has shown that the use of diesel-ethanol-biodiesel blends can substantially reduce emissions of CO, total hydrocarbons (HC), and particulate matters (PM) [11]. The mixing of biodiesel and bioethanol with diesel significantly reduces the emission of particulate matter because the blended biofuel contains more oxygen [12]. Hadi rahimi et al [13] showed that the bioethanol and sunflower methyl ester can improve low temperature flow properties of diesel-ethanol-biodiesel 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-ethanol-biodiesel blends and conventional fuel were found to be very comparable. The CO and HC emission concentration of diesel-ethanol-biodiesel blends decreased compared to the conventional diesel fuel and even diesel– biodiesel blends. Hwanam Kim, Btungchul Choi. [14] 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 [15] 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 et al; [16] studied solubility of a diesel-biodiesel- ethanol blend, its properties and its emission characteristics from diesel engine. They found that the blended fuel properties were close to the standard diesel except flash point. It was also found that CO and HC emissions reduced significantly at high engine load, whereas NO_x emissions increased compared to those of diesel.

The above studies reveal that the diesel-biodiesel-ethanol blends reduce CO, HC, PM, Smoke emissions and increase NO_x emissions compared with the diesel fuel. There is a little research on the use of rice bran oil biodiesel in diesel-biodiesel-ethanol blends for diesel engines. The performance and emission characteristics of the biodiesel blended up to 20% were close to that of diesel fuel [17, 18]. In the present investigation the performance and emission characteristics of a diesel engine were studied by using 10% rice bran oil biodiesel as an additive in the diesel-biodiesel-ethanol blends and compared with that of the diesel fuel.

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 [19]. 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 [20].

2. MATERIALS & METHODS

In the present investigation the fuels used were conventional diesel fuel, rice bran oil biodiesel and 99.5% bioethanol. These fuels were purchased from the local markets. Fuel properties such as density, viscosity, net heating value, acid value, flash point, Cetane number, iodine number of diesel, rice bran oil biodiesel and bioethanol were determined and shown in the table 1.

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

Property parameters	Diesel fuel	Rice bran oil biodiesel	Bioethanol
Density at 20 ^{0}C, g/cm3	0.82	0.8742	0.78
Viscosity at 40^0 C, mm2/s	3.4	4.63	1.35
Flash point, ^{0}C	71	165	22
Auto-ignition temperature, ^{0}C	225	320	415
Pour point, ^{0}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, Exhaust gas analyzer and smoke meter. The schematic diagram of the engine test rig is shown in Fig1.

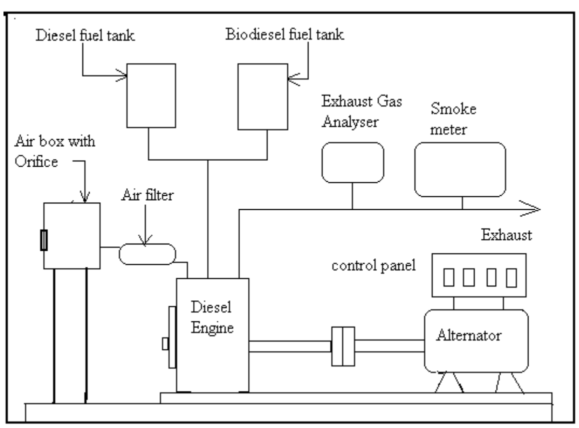

Figure-1. *Schematic diagram of engine test rig*.

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

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 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 reaches to 85^0 C. The same temperatures were maintained throughout the experiment with all the fuel modes. The baseline parameters were obtained at 0%, 20%, 40%, 60%, 80% and 100% of load on the engine with the diesel fuel (DF). The diesel fuel was replaced with the rice bran oil biodiesel (B100) and test was conducted by varying the loads in the same manner. After the rice bran oil biodiesel, the same test was conducted with the blend of 90% diesel and 10% biodiesel (B10). Three diesel- biodiesel-ethanol blends were prepared consisting of 85%diesel, 10%biodiesel and 5% bioethanol (B10E5), 80%diesel, 10%biodiesel and 10% bioethanol (B10E10), and 75%diesel, 10%biodiesel and 15% bioethanol (B10E15). 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 performance parameters such as 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.

3. RESULTS AND DISCUSSIONS

The results obtained pertaining to the performance and emissions of the engine are demonstrated with the help of graphs. The variation of brake thermal efficiency with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 2.

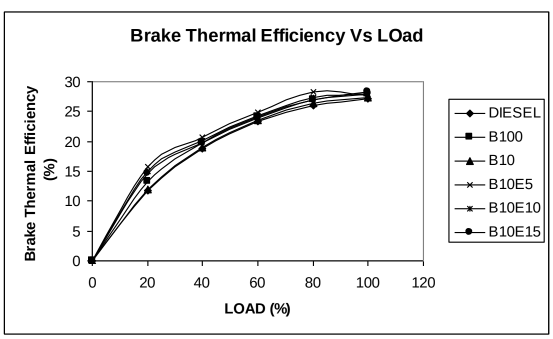

Figure 2.*Variation of brake thermal efficiency with Load*

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 10% biodiesel 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 extended ignition delay and the leaner combustion of biodiesel , resulting in a larger amount of fuel burned in the premixed mode of the ethanol blends. The brake thermal efficiency was increased by 1.5%, 2.2% and 2.91% respectively with 5%, 10% and 15% of bioethanol in diesel-biodiesel-ethanol blends compared with the blend B10. The maximum brake thermal efficiency was observed with B10E15 at all the loading conditions of the diesel engine and it was 3.67%, 0.7% and 2.92% higher than that of diesel fuel, B100 and B10 respectively at full load of the engine. It may be due to the reduction in the density and viscosity 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.

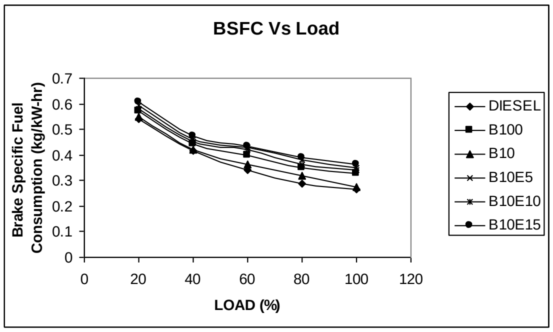

Figure 3. *Variation of brake specific fuel consumption with Load*

The BSFC reduced with load for all the fuel modes. The BSFC of B100 and B10 were 24.43% and 3.7% higher than that of the diesel fuel at full load of the engine. The BSFC increased by 23.27%, 27.63% and 31.63% respectively with the blends B10E5, B10E10 and B10E15 compared with the blend B10. 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.

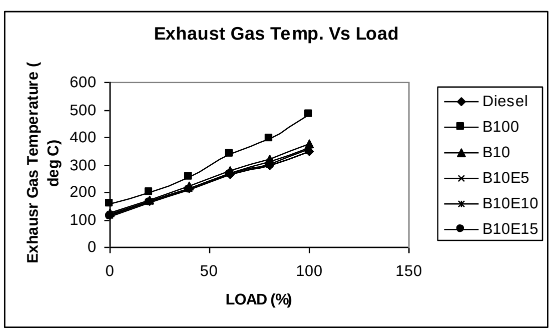

Figure 4. *Variation of exhaust gas temperature with Load*

The exhaust gas temperature increased with the load for all the fuels. The exhaust gas temperature of the blend B10 was 9.56% higher than that of diesel fuel and 22.36% lower than that of the 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 B10 respectively with the blends B10E5, B10E10 and B10E15. 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.

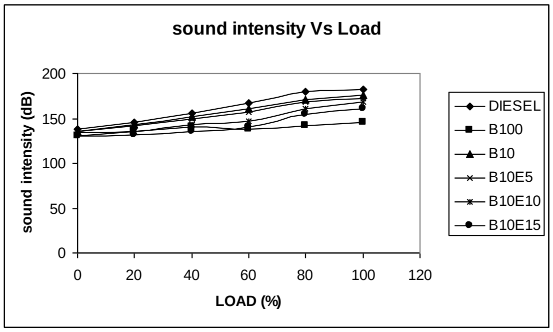

Figure 5. *Variation of sound with Load*

The intensity of sound increased with load for all fuel modes. The intensity of sound with the blend B10 was 3.3% lower than that of diesel fuel at full load of the engine. The intensity of sound for diesel-biodiesel-ethanol blends was lower than that of the diesel and the blend B10. The increase of the ethanol concentration in the blends reduced the sound intensity. The reduction was by 6.6%, 7.69% and11.53% than diesel fuel with the 5%, 10% and 15% of ethanol in diesel-biodiesel-ethanol blends.

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 higher amount of oxygen with the ethanol and biodiesel addition, which 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 blend. The CO emissions reduced by 46.39%, 51.54% and 54.63% than the conventional diesel with the addition of 5%, 10% and 15% of ethanol in diesel-biodiesel-ethanol blends. Among the diesel-biodiesel-ethanol blends the blend of 75%diesel, 10%biodiesel and 15% ethanol produced the lowest amount (0.44 % volume) of CO emissions at full load of the engine.

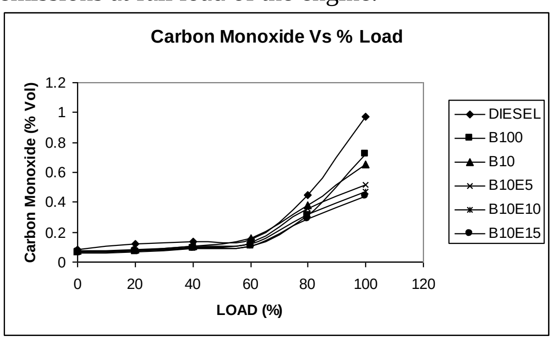

Figure 6. *Variation of carbon monoxide emissions with Load*

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

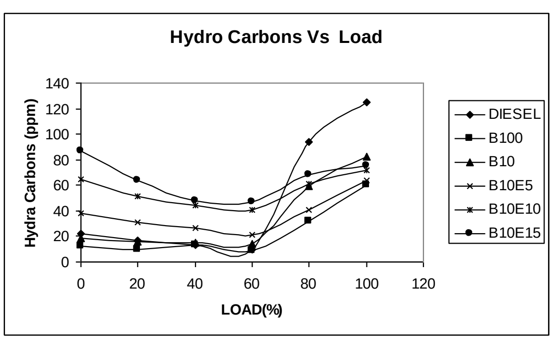

Figure 7. *Variation of hydroCarbons with Load*

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 B10 and diesel-biodiesel-ethanol blends were higher at low and medium loads and significantly lower at higher loads than those of diesel fuel. It is due to the better combustion achieved 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 the exhaust due to the larger ethanol dispersion region in the combustion chamber. The HC emissions were 48.8%, 34.3% and 40.0% lower than those of diesel fuel with 5%, 10% and 15% of ethanol addition at full load of the engine. Among these blends, the blend of 85% diesel, 10% biodiesel and 5%ethanol had the lowest HC emissions at the full load of the engine. The pure biodiesel produced lowest HC emissions among all fuels and were 52% lower than those of diesel fuel. Biodiesel has a higher cetane number 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.

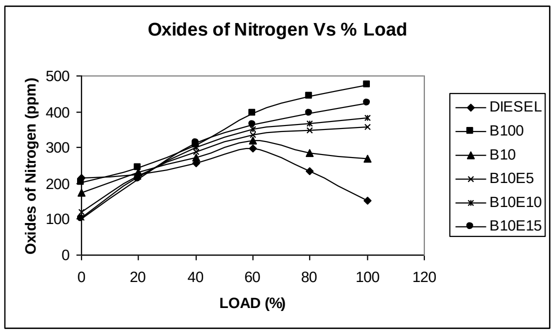

Figure 8. *Variation of oxides of nitrogen with Load.*

The NOx emissions of biodiesel, blend (B10) and diesel-biodiesel-ethanol blends were less at low loads and more at medium and high loads than those of diesel fuel. It is due to the higher oxygen content and combustion temperature of the biodiesel and the ethanol at medium and high loads. The NO_x emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends. The NOx emissions of B10E5, B10E10 and B10E15 were 33.95%, 42.53% and 58.28% higher than those of the blend B10 at full load of the engine.
The variation of Carbon Dioxide (CO_2) emissions with load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends is shown in the Fig. 9.

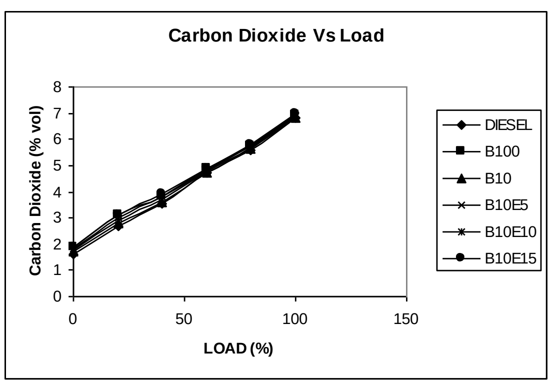

Figure 9. *Variation of carbon dioxide with Load.*

The CO_2 emissions increased with load for all the fuel modes. The CO_2 emissions of B100, B10, B10E5, B10E10 and B10E15 were slightly higher than those of diesel fuel. The CO_2 emissions increased by 1.03%, 1.91% and 2.94% respectively with 5%, 10% and 15% of ethanol in diesel-biodiesel-ethanol blends.
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.

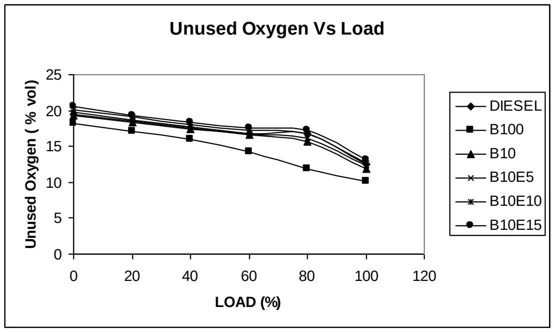

Figure 10. *Variation of unused oxygen with Load*.

The unused oxygen emissions reduced with load for all the fuel modes. The unused O_2 emissions of biodiesel and the blend B10 were 19.2% and 4.8% lower than those of diesel fuel. The O_2 emissions reduced with 5% addition of ethanol and increased with 10% and15% of ethanol in diesel-biodiesel-ethanol blends. The O_2 emissions reduced by 0.8% with the blend B10E5 and increased by 1.6% and 4.8% respectively with the blends B10E10 and B10E15 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.

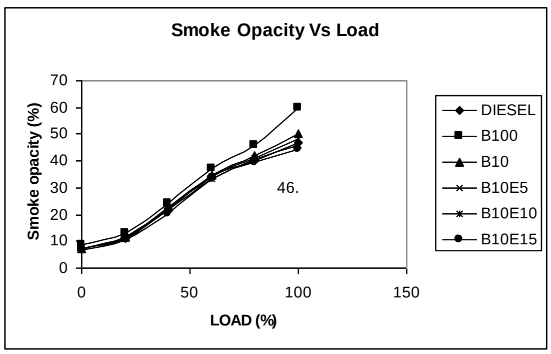

Figure 11. *Variation of smoke opacity with Load*

The smoke opacity increased with the load for diesel fuel, biodiesel and diesel-biodiesel-ethanol blends. The smoke opacity of the pure biodiesel was higher than those of all the other fuels used in this test. The smoke opacity of biodiesel was 27.93% higher than that of diesel fuel at full load of the engine. The smoke opacity of the blend B10 was 6.6% higher than that of the diesel fuel but 16.66% lower than that of the biodiesel at full load of the engine. The smoke Opacity reduced with increase of ethanol percentage in diesel-biodiesel-ethanol blends. The smoke opacity of the blend B10E5 was 2.55% higher but with the blends B10E10 and B10E15 respectively 1.7% and 5.11% lower than that of the diesel fuel at the full load of the engine.

4. 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 maximum brake thermal efficiency of 28.2% was observed with the blend B10E15.The BSFC of the biodiesel and all the other fuel blends was higher than that of the diesel fuel.
- The exhaust gas temperature of the blend B10E15 was slightly lower than that of diesel fuel throughout the range of the load on the engine.
- The CO emissions of the biodiesel and all the other fuel blends were lower than that of the diesel fuel. The minimum CO emissions were observed with the blend B10E15 well below the diesel fuel and the biodiesel.
- The HC emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends, but lower than those of the diesel at higher loads on the engine.
- The NO_x emissions of the biodiesel and all the other fuel blends were low at lower loads and high at higher loads compared with the diesel fuel

- The CO_2 emissions of the biodiesel and all the other fuel blends were higher than that of the diesel fuel.
- The unused oxygen emissions of the biodiesel were lower than all other fuels and the smoke from the blend B10E15 was lower than that of the diesel fuel.

As the brake thermal efficiency increases and carbon monoxide, unused oxygen, hydrocarbons and smoke reduces with the increase of ethanol percentage in diesel-biodiesel-ethanol blends, the ricebran oil biodiesel can be used as an additive to mix higher percentages of ethanol in diesel-biodiesel-ethanol blends for a diesel engine.

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