# STUDY OF PERFORMANCE AND EMISSION CHARACTERISTICS OF A DIRECT INJECTION DIESEL ENGINE USING RICE BRAN OIL ETHANOL AND PETROL BLENDS

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## ABSTRACT

In this study, influence on the engine performance and exhaust emissions of a naturally aspirated, single cylinder direct injection diesel engine has been experimentally investigated using pure rice bran oil (RBO), and its 2.5%, 5% and 7.5% blends with ethanol (ERBO) and petrol (PRBO). The influence on the viscosity of the RBO with the addition of the ethanol and petrol from 20$^0$C to 70$^0$C has also been studied. The tests conducted from no load to full load of the engine with an increment of 20%of the load. The experimental test results showed that the kinematic viscosity reduced maximum by 28.3% and 31.7% with addition of ethanol and petrol respectively. The maximum brake thermal efficiency of 26.83% with ERBO2.5 and 27% with PRBO7.5 was obtained. Among the ethanol blends the minimum brake specific fuel consumption of 0.312 is observed with ERBO7.5 and among the petrol blends the minimum brake specific fuel consumption of 0.299 is observed with PRBO2.5 at full load of the engine. Lower CO emissions of 0.021 with ERBO2.5 and higher CO emissions of 0.032 observed with ERBO7.5. The CO emissions of petrol blends observed between the values of ethanol blends. The unburnt hydrocarbons increased with load in both the ethanol and petrol blends. The lower $NO_x$ emissions of 920 with ERBO2.5 and higher $NO_x$ emissions of 1045 measured with PRBO7.5. The $CO_2$ increased to 3.72 with PRBO7.5 and reduced to 2.45 with ERBO7.5. The unused $O_2$ increased 17.2%with ethanol blends and reduced to 13.1% with petrol blends. The smoke reduced with both the blends and lower value of 34.0% observed with PRBO7.5.

**Keywords**: rice bran oil, ethanol, petrol, diesel engine, emissions.

## INTRODUCTION

The fossil fuels play a very important role in the development of industries, transportation, agriculture and to meet many other basic needs of the human beings. The fossil fuels are limited resources and depleting day by day as the energy consumption is increasing very rapidly. India imports 70% of the oil it uses. Dependence on foreign sources of energy has always been a bane for the Indian economy. It is the single biggest drain on the foreign exchange reserves of the country and the uncertainty in the prices of international crude has always kept Indian government and planners on tenser hooks. An increase of $1 per barrel of crude oil prices adds $425 million to our oil import bill. Compression ignition engines are employed particularly in the field of heavy transportation and agriculture on account of their higher thermal efficiency and durability. The diesel engines are the major contributors of oxides of nitrogen and particulate emissions. Hence more stringent norms are imposed on exhaust emissions. So, the search for alternative renewable fuels is required.

Most suitable alternative kinds of fuel for diesel engines may be considered vegetable oil or fuel obtained from the animal fat, because their characteristics are similar to those of common diesel oil. There are number of plants producing oils which can be used in internal combustion engines. Use of straight vegetable oil (SVO) in Diesel engines is not a new idea. Rudolf Diesel first used peanut oil as a fuel for demonstration of CI engine developed by him in the year 1910 [1]. During the period of world war -II vegetable oils were again used as fuel in emergency situations when fuel availability became scarce. In recent years the efforts have been made by several researchers for the compatibility of straight vegetable oils in diesel engines such as oils from jatropha, karanja, palm, soybean, sunflower, Rice bran etc. [2-8]. Use of vegetable oils as fuel in diesel engines causes problems such as poor fuel atomization, and low volatility due to their high viscosity, high molecular weight and density. Over a long period of use of vegetable oils, these problems may lead to engine failure [9-10]. Viscosity of the vegetable oils must be reduced in order to improve its engine performance. Heating, blending with diesel and transesterification are some of the methods used to reduce viscosity of vegetable oils. Transesterification is a relatively expensive chemical process as it involves the use of chemicals, catalysts and process heat.

The analysis of the test results [11-14] show that the diesel fuel oxygenated with ethanol up to 10% volume and more can be used to improve the performance and reduce the emissions. Alcohols and alcohol esters provide completely dissolved rapeseed oil mixtures with the inclusion rate up to 29% and 33%, but ethanol mixes properly only up to 9% [15]. The above analyses reveal that the mixing of ethanol reduces the viscosity of the vegetable oils. Gvidonas Labeckas, Stasys Slavinskas [16] mixed mineral petrol with the rapeseed oil and observed that the brake specific fuel consumption increases slightly, $NO_x$ emissions increases and CO, $CO_2$ and smoke opacity reduces .The above investigation reveals that the mineral petrol can be mixed with vegetable oils to reduce their viscosity and emissions like CO, $CO_2$ and smoke opacity. Kouremenos DA, Rakopoulos CD, Kotsiopoulos PN [17] used gasoline as supplements in swirl- chamber diesel engines and it reveals that the emissions can be reduced. From the above literature survey, it is concluded that the ethanol and petrol can be used to improve the performance and to reduce the emissions of the diesel engine.

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]. Though India is the second largest producer of rice, hardly 50% of the bran is utilized for producing RBO and only 19% of edible grade RBO is consumed as a cooking media [19]. Ethanol having 4 times lower molecular weight and viscosity 20 times lower at $40^0$C comparing with RBO, which along with low pour point of $-40^0$C may reduce oil viscosity, improve its cold flow properties and its injection, fuel spray penetration and atomization quality. In order to maintain the same amounts of fuel energy and power output the volumetric biofuel delivery per stroke must be increased proportionally. Higher viscosity of the biofuels increases the volumetric fuel delivery per stroke by nearly 2.6% in case of in line fuel injection pump because of the reduced internal leakages of the pump [20]. The higher volumetric rate of delivery and poor miscibility of ethanol with RBO may affect injection pump performance and fuel spray characteristics. Besides, the Cetane number of ethanol is 6.25 times lower comparing with RBO, which may aggravate flammability of blends ERBO and provoke auto-ignition problems at light load operation. However, oxygen present in the ethanol is considerably bigger (34.8%) amounts than in RBO (11.26%). The proportion in the mass between carbons and hydrogens of ethanol is also lower [4], therefore it may improve combustion of a big fuel portions injected at well timed advances and ensure better performance of the loaded engine.

The main purpose of this investigation is to determine the effect of addition of ethanol and petrol into pure RBO as well as preheating temperature on blends kinematic viscosity and to analyze the performance and emission characteristics when operating alternatively on RBO, and its blends with ethanol and mineral petrol at the constant rated speed of the engine.

## MATERIALS AND METHODS

In this study, tests have been conducted on a direct injection diesel engine. The specifications of the diesel engine are given in Table-1.

**Table-1.** Specifications of the 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 ethanol (99.5% pure) used was kindly supplied by Nandi Agro products, Nandyal, Andhra Pradesh, India. The commercial diesel oil, petrol and pure rice bran oil were purchased from the local market. 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, pure RBO, ethanol and petrol are determined and are shown in the Table-2.

**Table-2.** Properties of diesel, RBO, bio ethanol and petrol.

| Property parameters | Diesel fuel | Rice bran oil | Ethanol | Petrol |
|---|---|---|---|---|
| Density at 20 $^0$C, g/cm$^3$ | 0.82 | 0.945 | 0.78 | 0.75 |
| Viscosity at $40^0$ C, mm$^2$/s | 3.4 | 28.8 | 1.35 | 0.65 |
| Flash point, $^0$C | 71 | 202 | 22 | 42 |
| Auto-ignition temperature, $^0$C | 225 | 305 | 415 | 310 |
| Pour point, $^0$C | 1 | 14 | <-35 | <-48 |
| Cetane number | 40-55 | 31 | 10 | 24 |
| Iodine number, J2 g/100 g | 6 | 102 | -- | <5 |
| Acid value, mg KOH/g | 0.07 | 3 | -- | 0.03 |
| Oxygen content, max wt % | 0.4 | 11.25 | 34.8 | 0 |
| Net heating value, MJ/kg | 43.5 | 39.123 | 26.8 | 42.5 |

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The viscosity of the pure RBO and its ethanol and petrol blends were determined at $20^0$C, $30^0$C, $40^0$C, $50^0$C, $60^0$C, and $70^0$C by heating them.

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 Figure-1.

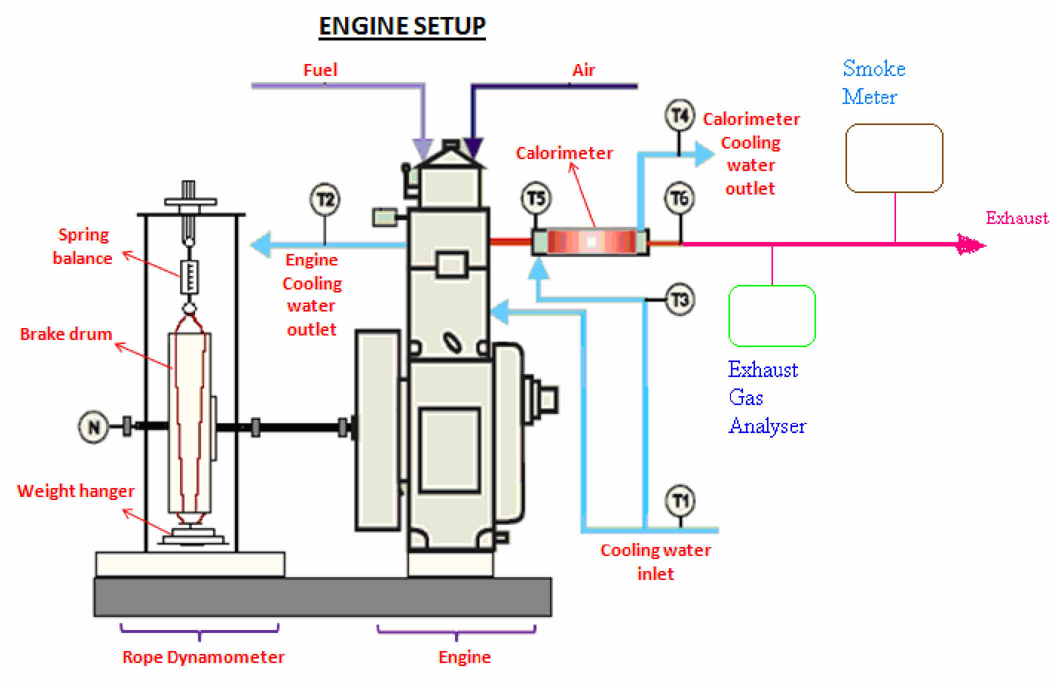


**Figure-1.** Schematic diagram of engine test rig.

The engine was operated with cooling water and lubricating oil temperatures of 85-90 deg C. The engine was first operated on petroleum diesel with no load for few minutes at rated speed of 1500 rpm until it comes to the steady state conditions. Then the pure RBO is used instead of diesel to obtain the baseline parameters at the rated speed by varying 0 to 100% of load on the engine with an increment of 20%. After using pure rice bran oil as a basic fuel, three RBO and ethanol (E) blends were prepared by pouring ethanol into a rice bran oil container in the following proportions by volume: 97.5% RBO and 2.5% ethanol (ERBO2.5), 95% RBO and 5% ethanol (ERBO5), 92.5% RBO and 7.5% ethanol (ERBO7.5) mixing them by hand-splash. After conducting the tests with ERBO blends, three rice bran oil and petrol (P) blends were prepared by the same splash mixing technique by pouring petrol into a rice bran oil container in the following proportions by volume: 97.5% RBO and 2.5% petrol (PRBO2.5), 95% RBO and 5% petrol (PBRO5), and 92.5% RBO and 7.5% petrol (PBRO7.5)), and similar experiments were conducted again over the same range of engine loads at rated speed. The brake power is measured by a rope brake dynamometer. The exhaust emissions such as carbon monoxide, $CO_2$, $NO_x$, hydrocarbons and unused $O_2$ are measured by AVL DiGas 444 exhaust analyzer and the smoke opacity by AVL smoke meter 437C for pure RBO and all its blends with ethanol and petrol separately under all load conditions. The results of the engine operating on various ERBO and PRBO blends are compared with the baseline parameters obtained during engine fuelling with pure RBO at rated speed of 1500 rpm.

## RESULTS AND DISCUSSIONS

The kinematic viscosity of the diesel, ethanol, petrol, pure RBO and its blends with ethanol and petrol are measured by using HAAKE Viscometer VT500. The variation of kinematical viscosity with temperature for rice bran oil and its blends with ethanol and petrol are shown in Figures 2 and 3, respectively.

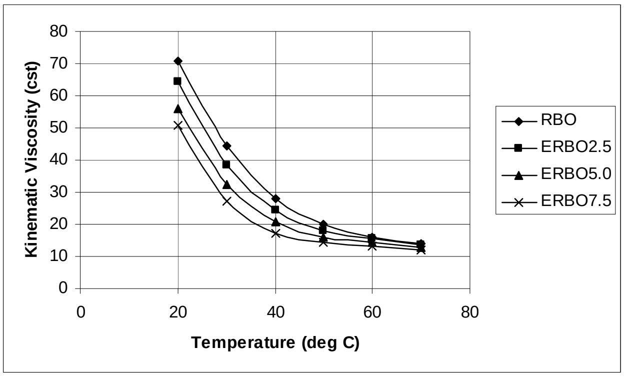


**Figure-2.** Kinematic viscosity Vs temperature for RBO and ERBO blends.

The kinematic viscosity decreases with temperature for RBO and its blends with ethanol and

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petrol as shown in the above figures. The viscosity of RBO is reduced greatly by 9.2%, 21.3% and 28.3% at $20^0$C in the case of ERBO2.5, ERBO5.0, and ERBO7.5 respectively. At $70^0$C, the viscosity is reduced by 2.14%, 8.7% and 15.12% respectively for the same blends. The viscosity of RBO is reduced greatly by 14.08%, 24.8% and 31.7% at $20^0$C in the case of PRBO2.5, PRBO5.0, and PRBO7.5, respectively. At $70^0$C, the viscosity reduction is by 3.7%, 8.7% and 13.7% respectively for the same blends.

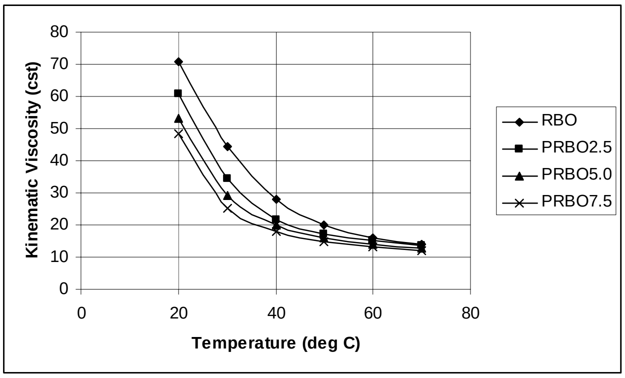


**Figure-3.** kinematic viscosity Vs temperature for RBO and PRBO blends.

The variation of brake thermal efficiency with the load for rice bran oil and its blends with ethanol and petrol are shown in Figures 4 and 5, respectively.

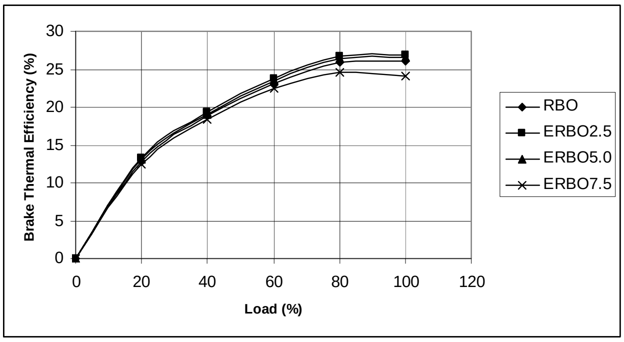


**Figure-4.** Brake thermal efficiency Vs load for RBO and ERBO blends.

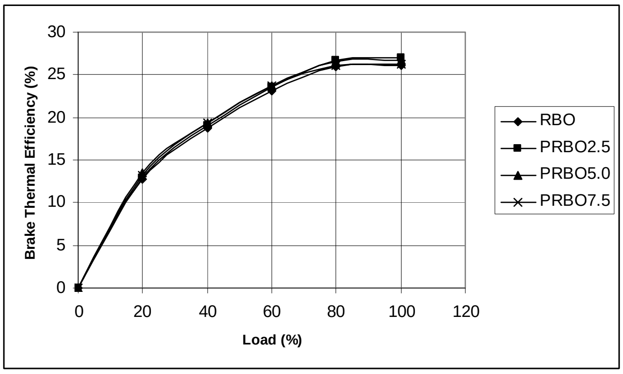


**Figure-5.** Brake thermal efficiency Vs load for RBO and PRBO blends.

The brake thermal efficiency is improved by 3.5% - 2.8% with the blend ERBO2.5 and 0.8%-3.4% with PRBO2.5 from low load to full load. Improved performance of the engine at low loading conditions is due to lower molecular weight and viscosity of ethanol, which may lead to better fuel spray penetration, atomization and evaporation of small RBO droplets injected per cycle, where as efficient combustion of blends ERBO under rated loading conditions can be aggravated by low Cetane number of ethanol accompanied by both its high latent heat for evaporation (910kJ/kg) and auto-ignition temperature of $420^0$ C. In contrast to ethanol, petrol demonstrates advantages linked with its higher Cetane number, lower auto-ignition temperature (300 deg C) and calorific value better by 62.5% that in the case of running the engine on blends PRBO2.5-5 .The addition of petrol does not lead to better performance of the engine in the case of PRBO7.5.

The variation of brake specific fuel consumption (BSFC) with load for RBO and its ethanol and petrol blends are shown in Figures 6 and 7. The oxygen content in blends ERO increases from 11.25% (RBO) to 11.75%, 12.4%, and 13.1% with 2.5, 5, and 7.5 vol% ethanol addition into RBO, whereas when the same amounts of petrol are added, the fuel conserved oxygen diminishes to 10.9%, 10.2%, and 9.8%, respectively. The BSFC increases by 3.5% at lower loads and becomes almost same as pure RBO at full load in the case of using blend ERBO2.5. When running the engine on more concentrated ERBO5-7.5 blends, the BSFC was correspondingly higher by 11.3-21.7% for lower, and 2.4- 4.2% for full load conditions. In the case of fuelling the engine with blend PRBO2.5, the brake specific fuel consumption lower by 2.9% to 3.2% from low to full load, whereas using higher PRBO5 and PRBO7.5 blends, in spite of a better calorific value, resulted into BSFC increase by 4.1-21.2% and 1.2-6.3% with load.

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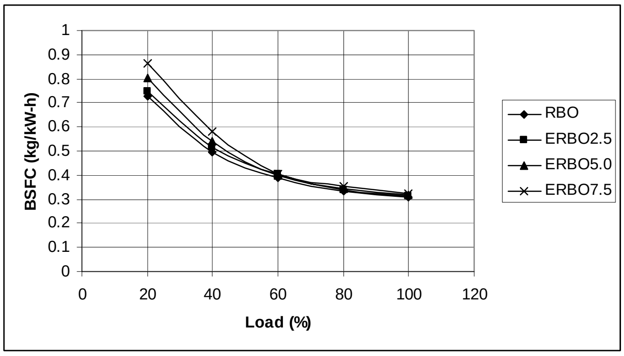


**Figure-6.** BSFC Vs load for RBO and ERBO blends.

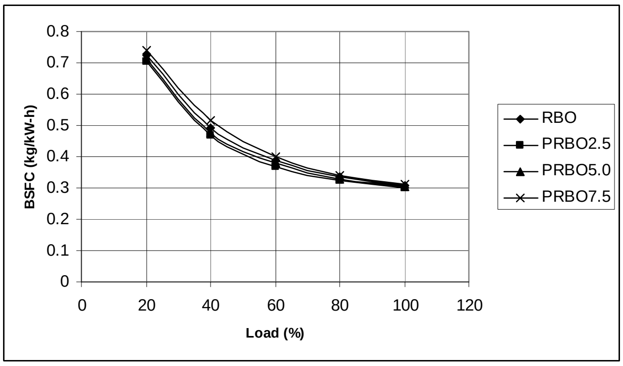


**Figure-7.** BSFC Vs load for RBO and PRBO blends.

In case of ERBO blends higher latent heat for evaporation along with low calorific value of ethanol may create significant cooling effect of the fuel spray patterns leading to longer auto-ignition delay and retarded start of combustion. It may be the reason for the BSFC increase at lower loads in case of ERBO5 and PRBO5, and higher blends. As soon as cylinder gas temperature goes up with load, the engine performance on tested blends becomes better and differences in the BSFC diminish together with overall lower level of the brake specific fuel consumption. The addition of petrol reduces the viscosity of oil more efficiently than ethanol and accelerates start of evaporation of the tested blends, but on the other hand, the Cetane number of petrol is not sufficient for a normal operation of diesel engine and this may increase the amount of fuel premixed for rapid combustion during the first stage of process. Problems with complete burning more likely can arise when a fully loaded engine operates on fuel-rich mixtures, therefore, in spite of a higher (by 16.3%) calorific value of petrol, the BSFC under full load conditions, increases when more than 2.5 vol% of petrol is added into RBO. However, as soon as the percentage of petrol added into RBO increases, BSFC becomes higher again for all loading conditions, reaching the biggest increment rate 2.9% (PRBO7.5). In comparison with the ethanol case, petrol demonstrates advantages related to threefold higher Cetane number and excellent miscibility with RBO that along with its better calorific value results into BSFC of blend PRBO2.5 in load increasing order lower by 11.0%, 10.3% and 5.5%. In the case of running the fully loaded engine on blends PRBO5-7.5, BSFC still remains lower by 3.0% and 1.4%, respectively.

The variation of Carbon Monoxide emissions ($CO_2$) with load are shown in Figures 8 and 9 for RBO and its blends with ethanol and petrol.

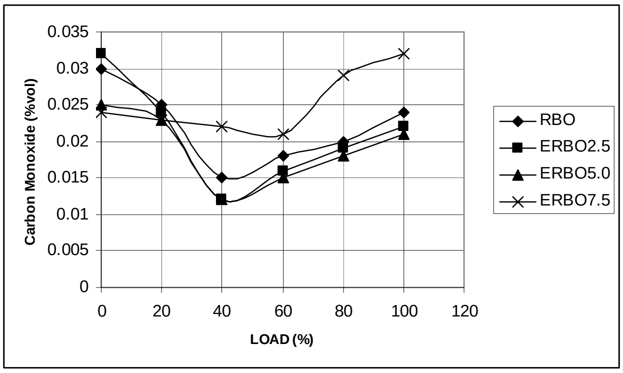


**Figure-8.** CO Vs load for RBO and ERBO blends.

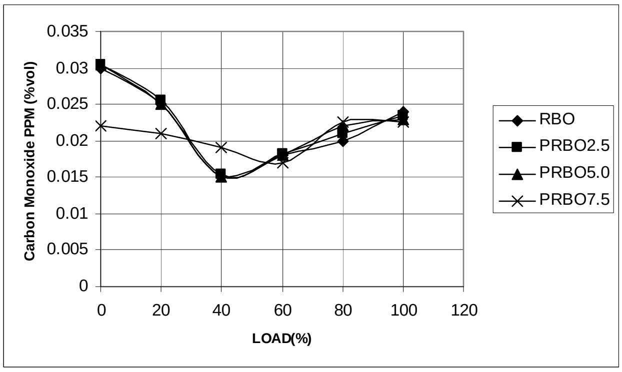


**Figure-9.** CO Vs load for RBO and PRBO blends.

As the chemical properties of ethanol and petrol are different they have different effects on the CO emissions and vary with load and their percentages added into RBO. The CO emissions increase first, slightly decrease and again increase with load. The CO emissions are higher with the higher percentages of ethanol. The maximum CO emissions happened with ERBO7.5 due to their lower energy conversion efficiency. The CO emissions slightly increase at lower loads only in case of PRBO2.5 blend. The CO emissions decrease with all PRBO blends at full load of the engine. PRBO blends produced less CO emissions than ERBO7.5 throughout the range of the load on the engine.

The variation of Unburnt Hydrocarbons (HC) with load is shown in Figure-10 and Figure-11 for RBO and its blends with ethanol and petrol.

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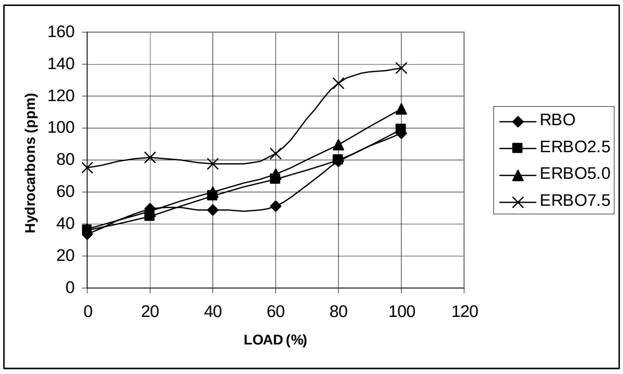


**Figure-10.** Hydrocarbons Vs load for RBO and ERBO blends.

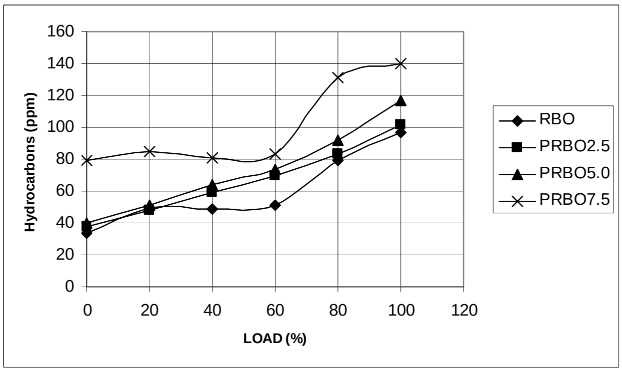


**Figure-11.** Hydrocarbons Vs load for RBO and PRBO blends.

The Unburnt Hydrocarbons varies with load and percentage fuel blend. The HC emissions of ERBO2.5 are almost same as RBO at lower and full load of the engine. The HC emissions of ERBO5.0 and ERBO7.5 are respectively 15% and 40% higher than RBO at full load of the engine. The Hydrocarbon emissions produced by ERBO blends are less than PRBO blends throughout the entire range of load on the engine. It may be due to higher oxygen content and lower C/H ratio in ethanol composition than petrol.

The Oxides of Nitrogen ($NO_x$) variation with the load on the engine is shown in Figure-12 for ERBO blends and in Figure- 13 for PRBO blends.

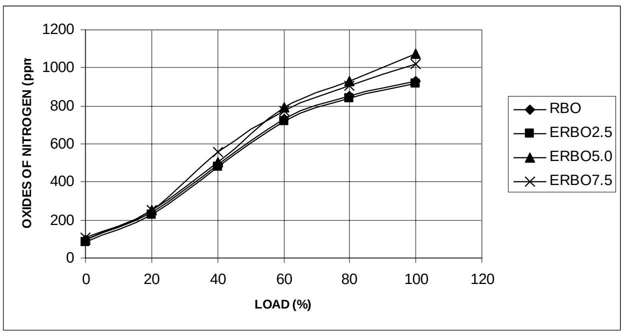


**Figure-12.** $NO_x$ Vs load for RBO and ERBO blends.

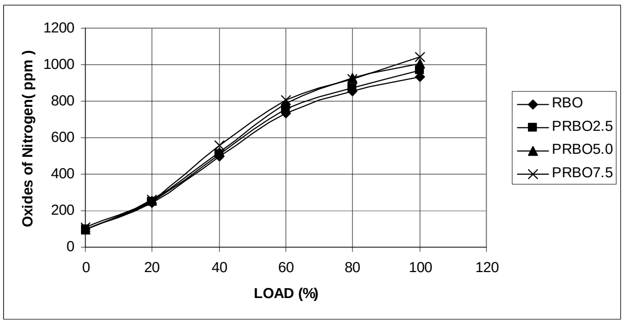


**Figure-13.** $NO_x$ Vs load for RBO and PRBO blends.

$NO_x$ emissions increase gradually with the load and their values depend on the type of biofuel used when the speed is kept constant. The $NO_x$ emissions of ERBO2.5 are lower than that of pure RBO throughout the range of load. RBO has high $O_2$ content and mixing with ethanol reduces heating value of the blend. It may be the reason for the reduced $NO_x$ emissions of ERBO2.5 than pure RBO. The $NO_x$ emissions of ERBO5 increases and reaches maximum value. It is due to the increased mass percentage of fuel oxygen by the addition of ethanol. In the case of ERBO7.5 the excessive addition of ethanol may leads to the unstable performance of the engine resulting in reduced brake thermal efficiency and the temperature related $NO_x$ emissions. The $NO_x$ emissions increases with the engine load and the amount of petrol added into RBO. The increased cylinder gas temperature may be the reason for higher $NO_x$ emissions for PRBO blends. In comparison with pure RBO the $NO_x$ emissions increases by 4.1%. 7.9% and 12.1% at full load for PRBO2.5, PRBO5.0 and PRBO7.5 respectively.

The variation of carbon dioxide ($CO_2$) emissions with load is shown in Figure-14 and Figure-15 for RBO and its blends with ethanol and petrol.

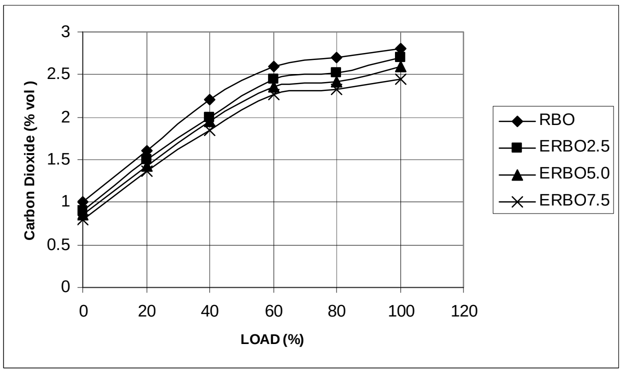


**Figure-14.** $CO_2$ Vs load for RBO and ERBO blends.

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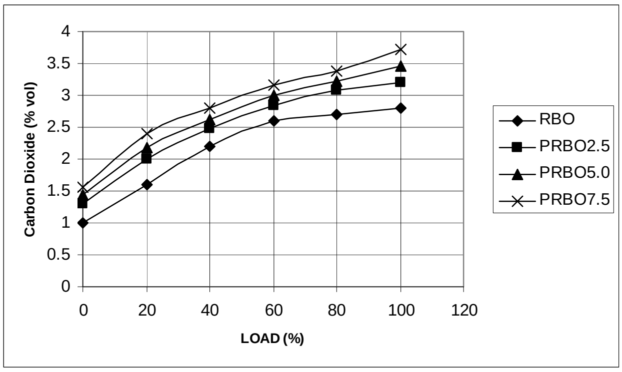


**Figure-15.** $CO_2$ Vs load for RBO and PRBO blends.

The emissions of carbon dioxide ($CO_2$) increase with load and biofuel consumption in mass as shown in the above Figures. The analysis of the data indicates that, in spite of higher consumption of blend ERBO7.5, the $CO_2$ emission and temperature of the exhausts are lower under adequate loads. Moreover, they diminish from 2.8 to 2.45 % after the addition of 7.5% volume of ethanol into RBO when running the fully loaded engine. It happens because of lower C/H ratio and the calorific value of ethanol. In contrast, the $CO_2$ emissions and temperature of the gases exhausted from the engine run under the same loading conditions on blend PRBO7.5 increase to 3.72% volume and $512^0$ C due to the addition of 7.5% volume of petrol.

The unused Oxygen variation with the load on the engine is shown in Figure-16 for ERBO blends and in Figure-17 for PRBO blends.

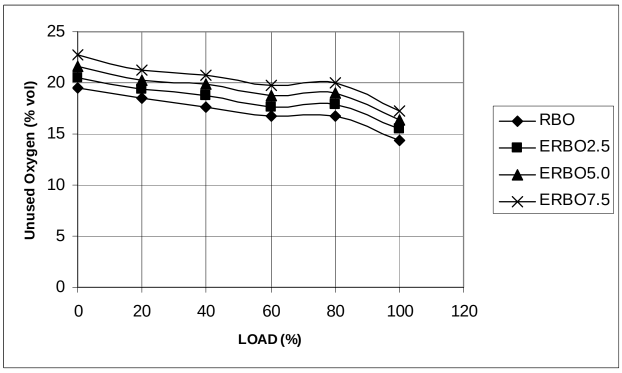


**Figure-16.** Unused $O_2$ Vs load for RBO and ERBO blends.

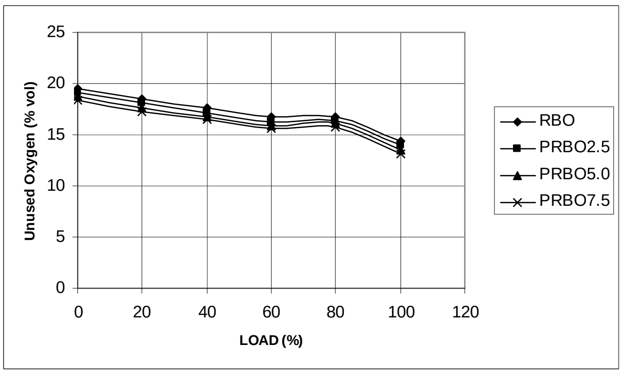


**Figure-17.** Unused $O_2$ Vs load for RBO and PRBO blends.

The unused $O_2$ decreases with load in the case of both ERBO and PRBO blends. In case of the ERBO blends the unused $O_2$ levels increases with the addition of ethanol as ethanol contains higher percentage of oxygen than pure RBO. In case of the PRBO blends the unused $O_2$ levels decreases with the addition of petrol as petrol contains no oxygen.

The smoke variation with the load on the engine is shown in Figure-18 for ERBO blends and in Figure-19 for PRBO blends. The exhausts smoke generated by different origin blends depends on the engine load, speed and cylinder air turbulence velocity. It is obvious from the Figure-18 and Figure-19 that the smoke levels of ERBO and PRBO blends are always less than that of pure RBO under all load conditions and decreases with the increasing percentages of the blends. The minimum smoke levels are observed with ERBO7.5 among ERBO blends and PRBO7.5 among PRBO blends and the maximum smoke levels are observed with ERB5.0 among all ERBO and PRBO blends.

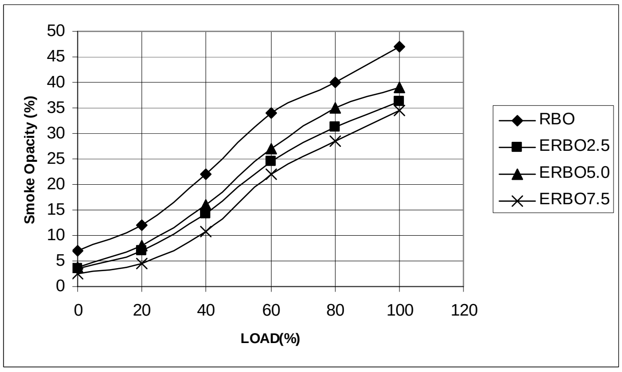


**Figure-18.** Smoke opacity Vs load for RBO and ERBO.

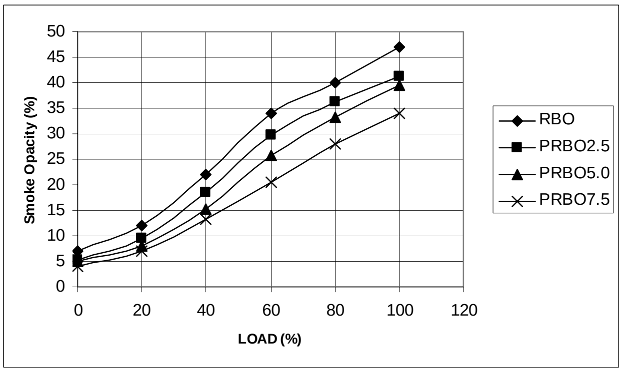


**Figure-19.** Smoke opacity Vs load for RBO and PRBO.

## CONCLUSIONS

a) The kinematic viscosity of pure RBO diminishes with the addition of ethanol and petrol. The maximum reduction is 28.3% with ERBO7.5 and 31.7% with PRBO7.5 at $20^0$C and 15.12% with ERBO 7.5 and

13.7% with PRBO7.5 at 70$^0$C. The kinematic viscosity decreases more at 20$^0$C than at 70$^0$C in case pure RBO and its ethanol and petrol blends;

b) The maximum brake thermal efficiency of both ethanol and petrol blends depends on the engine load. Among the RBO and its ethanol blends the maximum brake thermal efficiency of 26.83% with ERBO2.5 and the minimum brake thermal efficiency of 24.1% with ERBO7.5 is observed at full load of the engine. The brake thermal efficiency of all the petrol blends is higher than pure RBO throughout the range of load on the engine. The maximum brake thermal efficiency of 27% is observed with PRBO7.5 at full load of the engine;

c) The brake specific fuel consumption increases with the increase of ethanol percentage in RBO. The higher values are observed with ERBO 7.5 among the ethanol blends. The brake specific fuel consumption is lower than RBO with PRBO2.5 and is higher than RBO with PRBO5 and PRBO7.5. Among the petrol blends the minimum brake specific fuel consumption of 0.299 is observed with PRBO2.5 at full load of the engine;

d) The lower Carbon monoxide emissions of 0.021 produced with ERBO5.0 at all load conditions. The higher CO emissions of 0.032 observed with ERBO 7.5. All the petrol blends produced higher CO emissions than RBO. The maximum CO emissions of 0.027 observed with PRBO7.5 and minimum of 0.243 with PRBO5.0;

e) Emissions of unburned hydrocarbons, of ERBO2.5 remain almost same as RBO and are increasing with the addition of ethanol in ERBO5.0 and ERBO7.5. Among petrol blends PRBO2.5 produced slightly higher emissions of unburned hydrocarbons than RBO. The PRBO5.0 and PRBO7.5 produced considerable higher amounts of emissions of unburned hydrocarbons than RBO;

f) The NOx emissions of ERBO2.5 are lower than RBO and that of ERBO5.0 and ERBO7.5 are higher than RBO. The NOx emissions of PRBO blends are higher than RBO and increases with the increase of petrol percentage;

g) The $CO_2$ emissions decrease with the addition of ethanol and lowest of 2.5% observed with ERBO7.5. The $CO_2$ emissions increase with the addition of petrol and highest of 3.72% observed with PRBO7.5;

h) The unused oxygen increases with addition of more oxygenated ethanol and the maximum value of 17.2% observed with ERBO7.5. The unused oxygen decreases with addition of non oxygenated petrol and the minimum value of 13.1% observed with PRBO7.5; and

i) The smoke decrease with addition of ethanol and the minimum value of 34.5% observed with ERBO7.5. The smoke decrease with the addition of petrol and the minimum value of 34.0% observed with PRBO7.5.

The ethanol blend ERBO2.5 improves the performance and ERBO5.0 reduces the emissions like CO, $CO_2$. The petrol blend PRBO2.5 improves the performance and reduces the emissions.

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