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Experimental Investigation of the Effect of Compression Ratio in a Direct Injection Diesel Engine Running on Different Blends of Rice Bran Oil and Ethanol

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Abstract**—**The performance, emission and combustion characteristics of a single cylinder four stroke variable compression ratio multi fuel engine when fueled with different blends of rice bran oil methyl ester and ethanol are investigated and compared with the results of standard diesel. Bio diesel produced from Rice bran oil by transesterification process has been used in this study. Experiment has been conducted at a fixed engine speed of 1500 rpm, 50% load and at compression ratios of 16.5:1, 17:1, 17.5:1 and 18:1. The impact of compression ratio on fuel consumption, brake thermal efficiency and exhaust gas emissions has been investigated and presented. Optimum compression ratio which gives best performance has been identified. The results indicate longer ignition delay, maximum rate of pressure rise, lower heat release rate and higher mass fraction burnt at higher compression ratio for waste cooking oil methyl ester when compared to that of diesel. The brake thermal efficiency at 50% load for Rice bran oil methyl ester blends and diesel has been calculated and the blend B40 is found to give maximum thermal efficiency. The blends when used as fuel results in reduction of carbon monoxide, hydrocarbon and increase in nitrogen oxides emissions.

Keywords**—**Biodiesel, Rice bran oil, Transesterification, Ethanol, Compression Ratio.

I. Introduction

INCREASED environmental awareness and depletion of resources are driving industry to develop viable alternative fuels from renewable resources that are environmentally more acceptable. Vegetable oil is a potential alternative fuel. The most detrimental properties of vegetable oils are its high viscosity and low volatility, and these cause several problems during their long duration usage in compression ignition (CI) engines. The most commonly used method to make vegetable oil suitable for use in CI engines is to convert it into biodiesel, i.e. vegetable oil esters using process of transesterification. Rice bran oil is an underutilized non-edible vegetable oil, which is available in large quantities in rice cultivating countries like India, and very little research has been done to utilize this oil as a replacement for mineral Diesel. In the present work, the transesterification process for production of rice bran oil methyl ester has been investigated. The various process variables like temperature, catalyst concentration, amount of methanol and reaction time were optimized with the objective of producing high quality rice bran oil biodiesel with maximum yield.

Most of the research studies concluded that in the existing design of engine and parameters at which engines are operating, a 20% blend of bio-diesel with diesel works well. Many researchers indicated the need of research in the areas of engine modifications so as to suit to higher blends without severe drop in performance so that the renewability advantages along with emission reduction can be harnessed to a greater extent. Effect of variations in these parameters has been studied taking one or more parameters at a time .These studies were carried out in different types of engines (stationary/ mobile; single cylinder/ multi cylinder; constant speed/variable speed) with bio-diesel prepared from different oil origin. To sum up the results of these studies, a cumulative study taking some or all the parameters at a time in one type of engine is still missing. To fill this gap, the study was done with an objective of finding the optimum engine design parameters viz. compression ratio and injection pressure (taken together in a single setup), for better performance of pure bio-diesel (B100) obtained from rice bran oil. The aim was to establish the modifications required in small, constant speed, direct injection diesel engines used extensively for agricultural applications so that these can be made to run on pure bio-diesel with better performance and at the same time improve the emissions.

The optimum conditions for transesterification of rice bran oil with methanol and NaOH as catalyst were found to be 55°C reaction temperature, 1h reaction time, 9:1 molar ratio of rice bran oil to methanol and 0.75% catalyst (w/w). Rice bran oil methyl ester thus produced was characterized to find its suitability to be used as a fuel in engines. Results showed that biodiesel obtained under the optimum conditions has comparable properties to substitute mineral Diesel, hence, rice bran oil methyl ester biodiesel could be recommended as a mineral Diesel fuel substitute for compression ignition (CI) engines in transportation as well as in the agriculture sector.This study targets at finding the effects of the engine design parameters viz. compression ratio (CR) on the performance with regard to fuel consumption(BSFC), brake thermal efficiency (BTHE) and brake power emissions of CO,

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CO_2, HC, NOx and Smoke opacity with blends of rice bran oil as fuel. Comparison of performance and emission was done for different values of compression ratio to find best possible combination for operating engine with different blends. It is found that the increase of compression ratio increases the BTHE and reduces BSFC while having lower emissions. For small sized direct injection constant speed engines used for agricultural applications (3.5 kW), the optimum combination was found as CR of 18

G. Venkata Subbaiah, et al. [1] experimented on the performance and emission characteristics of a direct injection (DI) diesel engine fuelled with conventional diesel fuel, pure biodiesel, a blend of diesel and biodiesel and three blends of diesel biodiesel-ethanol. They showed that ethanol blended fuel has the highest brake thermal efficiency. The carbon monoxides, smoke, exhaust gas temperature and sound intensity were observed to be minimum with the blend BE30 compared to diesel fuel. The oxides of nitrogen, hydrocarbon and carbon dioxide emissions increased with the increased percentage of ethanol in the blends. Gvidonas Labeckas et al. [2] studied on the diesel engine operated on the blend of diesel fuel, rapeseed methyl ester and anhydrous ethanol. They revealed that the *bsfc* of a fully loaded engine operating on ethanol-diesel-biodiesel increases. The NOx emissions and smoke opacity diminishes.CO amounts from oxygenated blend are lower and emissions of HC are higher than diesel fuel. S. Fernando and M. Hanna [3] revealed that ethanol is immiscible in diesel over a wide range of temperatures, so biodiesel can be used as an amphiphile, to stabilize ethanol and diesel. The ethanol-biodiesel-diesel (EB-diesel) fuel blend micro emulsions are stable below sub-zero temperatures and show superior fuel properties to regular diesel fuel, like increased lubricity, the heat of combustion and cetane numbers of the EB-diesel blends remained same as diesel. Alan C. Hansen et al. [4] studied on the blends of ethanol and diesel fuel and found to be technically feasible with the purpose to review with particular reference on safety and distribution, integrity of the fuel being delivered to the engine, emissions, engine performance and durability. Jaydeep Mevada et al. [5] experimented on the performance & emission characteristics of the C.I. Engine using ethanol, biodiesel, diesel fuel blends and studied on the fuel properties like density, pour point, heat of combustion of all the blends. G. Venkata Subbaiah et al. [6] investigated the performance and exhaust emission fuelled with different blends of diesel-biodiesel-ethanol. The exhaust gas temperature, sound intensity, carbon monoxide and smoke emissions reduced significantly with higher percentage of ethanol. The hydrocarbons, NOx and CO_2 emissions increased with the increase of ethanol. P. Suresh Kumar et al.[7] studied on an IDI diesel engine was tested by diesel, biodiesel, with varying fuel injection pressures and observed that at 100% load the brake thermal efficiency of the biodiesel improves as the fuel injection pressure is increased. Xiaoyan Shi et al. [8] studied on oxygenated diesel fuel consisted of blend ratio 5:20:75 (ethanol: methyl soyate: diesel fuel) by volume. The results showed a significant reduction in PM emissions and increase of NOx emissions. Total hydrocarbon (THC) from BE-diesel was lower but with a slight increase of acetaldehyde, propionaldehyde and acetone emissions. Hassana et al. [9] conducted an experimental study on the phase stability of DE and revealed that the DE blends is not stable and separated after few hours whereas for DBE blends the separation time is longer than of the first system and reached for days. In conclusion, among the different fuel blends, the blends containing 5 and 10% ethanol concentration are the most suited for CI engines due to its acceptable engine performance and to the fuels solubility. Shia et al. [10] studied on a blend of 20% (v/v) ethanol/methyl soyate was prepared and added to diesel fuel as an oxygenated additive at volume percent levels of 15 and 20%. Observations showed that particulate matter (PM) emission decreased with increasing oxygenate content in the fuels but nitrogen oxides (NOx) emissions increased. The diesel engine fueled by BE20 emitted significantly less PM and a lower Bosch smoke number but the highest NOx among the fuel blends tested. All the oxygenate fuels produced moderately lower CO emissions relative to diesel fuel. The B20 blend emitted less total hydrocarbon (THC) emissions. K. Muralidharan and D. Vasudevan [11] conducted a comparative study of the performance, emission and combustion characteristics when fueled with waste cooking at a fixed engine speed, load and at varying compression ratios. The results indicate longer ignition delay, maximum rate of pressure rise, lower heat release rate and higher mass fraction burnt at higher compression ratio for waste cooking oil methyl ester. The blends when used as fuel results in reduction of carbon monoxide, hydrocarbon and increase in nitrogen oxides emissions. K. Muralidharan et al. [12] estimate the performance, emission and combustion characteristics fuelled with waste cooking oil methyl ester and its blends used as fuel results in the reduction of carbonmonoxide, hydrocarbon, carbon dioxide at the expense of nitrogen oxides emissions. S. Jindal et al. [13] studied the effects of the engine design parameters viz. compression ratio (CR) and fuel injection pressure (IP) jointly on the performance with regard to fuel consumption (BSFC), brake thermal efficiency (BTHE) and emissions of CO, CO_2, HC, NOx and Smoke opacity with Jatropha methyl ester as fuel. They have concluded that the increase in compression ratio associated with increase in injection pressure improves the performance of the engine used in study with regard to the engine performance measured in terms of BSFC and BTHE.M. Gumus [14] conducted an experimental investigation of combustion and heat release characteristics of a biodiesel (hazelnut kernel oil methyl ester) fueled direct injection compression ignition engine and results show that the modifications such as increasing of injection timing, compression ratio, and injection pressure provided significant improvement in combustion and heat release characteristics. Sukumar Puhan et al. [15] studied on the effect of biodiesel unsaturated fatty acid on combustion characteristics of a DI compression ignition engine and revealed that Linseed oil methyl ester with high linolenic (unsaturated fatty acid ester) does not suit best for diesel engine due to high oxides of nitrogen emission and low thermal efficiency. P.K. Sahoo and L.M. Das [16] examined the combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine and revealed that neat Polanga biodiesel that results in maximum peak cylinder pressure was the optimum fuel blend as far as the peak cylinder pressure was concerned. Ignition delays were shorter for neat Karanja and Polanga biodiesel when compared with diesel. Hanbey Hazar [17] analyzed the characterization and effect of using cotton methyl ester as fuel in a LHR diesel engine Performance (6.0% for specific fuel consumption) and emission values (up to 18.0% for CO, 8.0% for smoke density) of the test fuel were improved in the coated engine compared with the uncoated engine. NOx increase (4.5%) with the increased temperatures is expected in the coated engine.

Rodrigo C. Costa, José R. Sodré [18] studied on the compression ratio effects on an ethanol/gasoline fuelled engine performance and investigates the influence of compression ratio on the performance of a spark ignition engine fuelled by a blend of 78% gasoline-22% ethanol (E22) or hydrous ethanol (E100). The results showed that higher compression ratios improved engine performance for both fuels throughout all the speed range investigated, with major effects being observed when hydrous ethanol was used. M. Bahattin Celik et al. [19] used methanol at high CR to increase performance and decrease emissions of a single-cylinder engine. The results showed that some decreases were obtained in CO, CO_2 and NOx emissions without any noticeable power loss when using methanol at the CR of 6/1. By increasing the CR from 6/1 to 10/1 with methanol, the engine power and brake thermal efficiency increased by up to 14% and 36%, respectively. Moreover, CO, CO2 and NOx emissions were reduced by about 37%, 30% and 22%, respectively. Mohammed EL_Kassaby, Medhat A. Nemit_allah [20] studied the effect of compression ratio on an engine fueledwith waste oil produced biodiesel/diesel fuel Wasted cooking oil from restaurants was used to produce neat (pure) biodiesel through transesterification, and then used to prepare biodiesel/diesel blends. The effect of blending ratio and compression ratio on a diesel engine performance has been investigated. Emission and combustion characteristics was studded when the engine operated using the different blends (B10, B20, B30, andB50) and normal diesel fuel (B0) as well as when varying the compression ratio from 14 to 16 to 18.Souvik Bhattacharyya[21]optimized the cycle for power output as well as for thermal efficiency with respect to compression ratio and cut-off ratio. The optimum values of these ratios compare well with standard values used in real Diesel engines [22]. The cycle also demonstrates a loop-shaped power vs. efficiency curve as is exhibited by real heat engines [23].

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 [24]. Rice bran is mostly oily inner layer of rice grain which is heated to produce RBO [25]. RBO is not a common source of edible oil compared to other traditional cereal or seed sources such as corn, cotton, sunflower or soybean [26]. 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 [27].

II. Materials

A. Rice Bran Methyl Ester

High Free Fatty Acid (FFA) Rice Bran Oil (RBO) was purchased from local market, which was filtered by 10 micron filter cloth. The acid value was determined as per UNE-55001, following washing of the sample with distilled water to remove any residual catalyst and the tested acid value was 24 mg KOH/ g oil, corresponding to a FFA level of 12%, which is far above the 1% limit for satisfactory transesterification reaction using alkaline catalyst. The average molecular weight of RBO is calculated based on its FFA and TG content, assuming a molecular weight 870 for TG and 282 for FFA. Other materials were: methyl alcohol of 99.0% purity and H_2SO_4andKOH of 99 % purity.

B. Reaction Procedure

1. Esterification

The esterification was carried out in a 500 ml water jacketed glass batch reactor working with total reflux (Fig. 1). Due to low solubility of methanol in RBO, an agitator with speed 400 rpm was used. 100 gm of RBO was preheated to the required temperature (varied from 45°C to 60°C). Varying quantities of sulfuric acid as catalyst (0.15 to 1.0 wt %) were mixed in methanol (methanol to oil ratio varying from 5 to 30) and the resulting mixture is allowed to react with pre-heated oil. The reaction was carried out for 2 hours. Samples were collected at different time intervals (5, 15, 30, 50, 70, 90 and 120 min), washed with distilled water to remove residual acid and impurities, dried to remove residual water and tested for acid value.

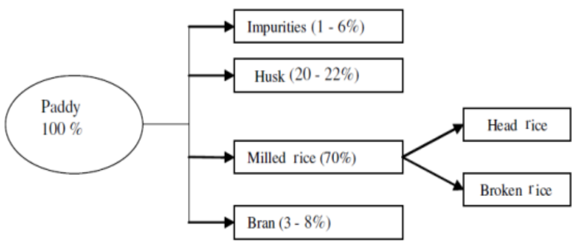

Fig. 1 Reaction Procedure

All experiments were carried out at atmospheric pressure. The standard error obtained in calculation of the acid value was ± 1- 2% for the duplicate set of reactions. The optimum values obtained after esterification are 0.5% sulfuric acid, 1:20 oil to methanol ratio, 60°C and for 2 hours. The acid value obtained after esterification at optimum conditions is 2 mg KOH/g oil. Once the FFA content of oil reaches below 1%, the alkali transesterification ensures a good yield of FAME while facilitating separation of glycerin.

C. Transesterification

Transesterfication of low FFA oil was carried out in same glass batch reactor which was used for esterification. The reaction was carried out with oil to methanol ratio 1:6, 1% KOH at 65°C for 1 hour. The resulting biodiesel is separated from glycerin by separating funnel. The FAME is water washed thrice to remove residual alkali and impurities. Biodiesel is finally heated at 120°C for removal of residual water (Fig. 2).

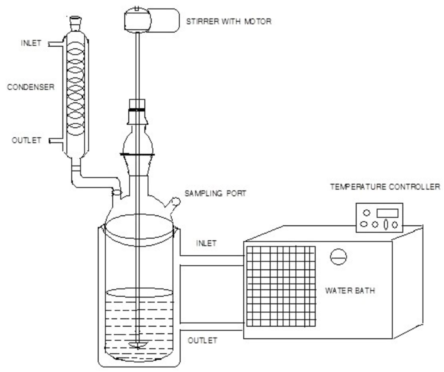

Fig. 2 Transesterfication setup

The properties of so prepared bio-diesel were tested in the laboratory using standard test procedures as per ASTM/BIS and are listed in:

TABLE I
TEST RESULT

Properties	Diesel	B10	B10E2	B15E3
Calorific value	44000	45899	45883	45899
Fuel density	.838	.829	.831	.827

D. Experimental Set-Up

The study was carried out in the laboratory on an advanced fully computerised experimental engine test rig comprising of a single cylinder, water cooled, four stroke, VCR (variable compression ratio) diesel engine connected to eddy current type dynamometer for loading.

TABLE II
SPECIFICATION OF TEST RIG

Make	Legion Brothers
BHP	3 to 5 Hp
Speed	1450 to 1600 Rpm
Number of cylinder	1
Compression ratio	5:1 to 20:1
Bore	80 mm
Stroke	110 mm
Type of ignition	Spark ignition
Method of starting	Manual crank start
Method of cooling	Water

E. Emission Measurement

The exhaust gases were sampled from exhaust line through especially designed arrangement for diverting the exhaust to sampling line without increasing the back pressure and was then analyzed using a portable multi-gas analyzer. It measures carbon monoxide (CO), carbon dioxide (CO2), hydrocarbons (HC) and nitric oxide (NO). For the measurement of smoke intensity of diesel engine's exhaust, a diesel smoke meter was used.

F. Experimental Procedure

In the study, the variable compression ratio engine was run with different blends of RBO at different compression ratios to evaluate the performance with emissions characteristics. The results were compared against the diesel fuel results as well as for different combinations of compression ratio. Initially the engine was run on no load condition and its speed was adjusted to 1500 ± 20 rpm. The engine was then tested at 4kg load and at 16.5, 17, 17.5, and 18 compression ratio. As per the test rig specifications, at rated power, i.e. at full load (100%), the eddy current dynamometer is to be loaded with 10 kg load for given arm length. The engine at the above mentioned loads was tested on all of the fuel types. For each compression ratio condition, the engine was run for at least 3 min after which data were collected. The experiment was replicated three times. For all settings, the emission values were recorded thrice and a mean of these were taken for comparison. The performance of the engine at different compression ratio and different blends was evaluated in terms of brake specific fuel consumption (BSFC), brake thermal efficiency (BTHE) and emissions of carbon monoxide, carbon dioxide, un-burnt hydrocarbon and oxides of nitrogen with exhaust gas opacity and temperature. The BSFC is evaluated by the software on the basis of fuel flow and brake power developed by the engine using the expression BSFC = (volumetric fuel flow in 1h _ fuel density/brake power). Similarly, BTHE is also evaluated by software using the expression

III. RESULTS AND DISCUSSION

The relationships between independent variables (compression ratio and fuel blends) and dependent variables (BSFC, BTHE, and emissions) are shown in the figures and the results are discussed in the following sections.

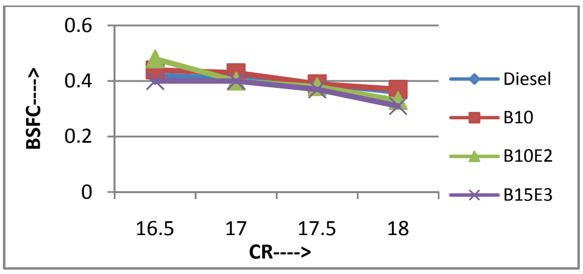

Fig. 3 Brake specific fuel consumption

The bsfc for all blends decreases as the compression ratio increases. This may be due to improved combustion at higher compression ratios. The bsfc of pure diesel and the blendB10 decreased on an average by 14.84% and 15.96%, respectively, when the compression ratio was increased from 16.5 to18. Similar values were obtained for B10E2 and B15E3 blends but with greater decrease. As it is clear from these values that B15E3 gives a better decrease in bsfc than diesel as the compression ratio increase. This behavior may be due to lower volatility and higher cetane number of biodiesel blend compared to diesel fuel which will result in improved combustion at higher compression ratios.

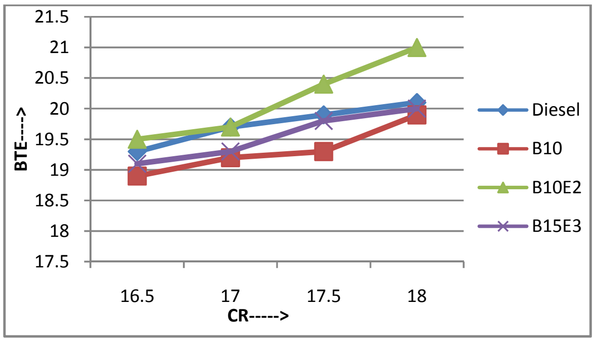

Fig. 4 Brake Thermal Efficiency

In general, increasing the compression ratio improved the efficiency of the engine. The mean brake thermal efficiency increased by more than 5% when the compression ratio was raised from 16.5 to 18. This improved performance of the engine at higher compression may be due to the reduced ignition delay. The compression ratio 18 was found to be the best for all blends tested. The change of compression ratio from 16.5 to 18 resulted in, 4.1%, 5.2%, 7.6%, and 4.7% increase in brake thermal efficiency in case of Diesel, B10, B10E2, and B15E3 respectively. This could be due to the fact that biodiesel blends had lower volatility and therefore the improvement in their combustion characteristics might have been relatively more at higher temperatures resulted from higher compression ratio with the same rise in compression ratio.

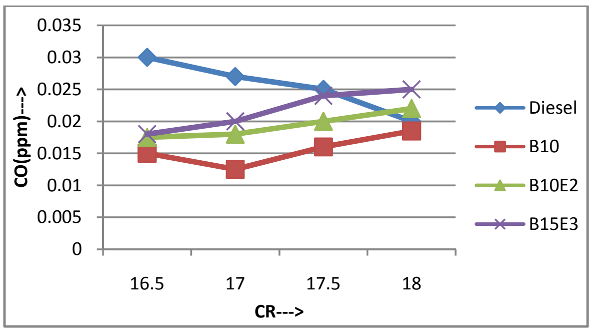

Fig. 5 Carbon Monoxide

The CO emission reduced by 50% when compression ratio was increased from 16.5 to 18 for diesel whereas for the other blends it increases. The CO emission of the blend B10 is less for all the CR whereas the diesel shows the maximum CO emissions for the 16.5 to 17.5 CR. The percentage of CO increases due to rising temperature in the combustion chamber, physical and chemical properties of the fuel, air–fuel ratio, shortage of oxygen at high speed, and lesser amount of time available for complete combustion. The effects of fuel viscosity on fuel spray quality would be expected to make some CO increase with vegetable oil fuels. The effects of fuel viscosity on fuel spray quality would be expected to make some CO increase with vegetable oil fuels at higher CR.

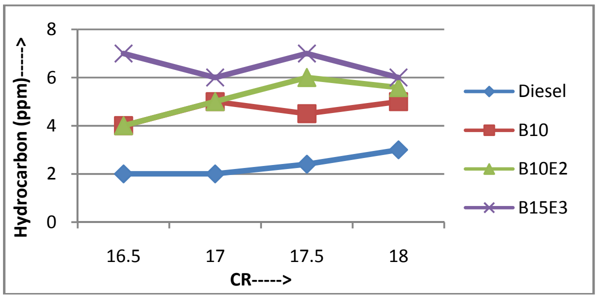

Fig. 6 Hydro Carbon

It shows that the hydrocarbon emission of various blends is higher at higher compression ratios. The effects of fuel viscosity, on the fuel spray quality, are expected to produce some HC increase with vegetable oil fuels. In this research, it shows that the increase in compression ratio increases the HC emission for Blend B15E3. The other blends B10 and B10E2 produce lesser hydrocarbon emissions than B15E3 while more than the standard diesel at all compression ratios. Due to the longer ignition delay, the accumulation of fuel in the combustion chamber may cause the higher hydro carbon emission.

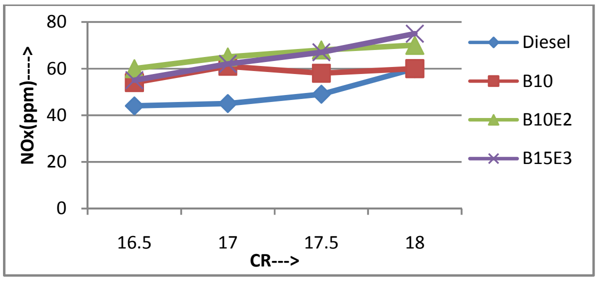

Fig. 7 Nitrogen Oxides

As observed from the figure, the NOx emission for diesel and other blends increase with the increase of compression ratio. From the figure, it is obvious that for all the compression ratio, NOx emission for all the blends is higher than that of diesel. The reason for higher NOx emission for blends is due to higher peak temperature. Hence the most significant factor that causes NOx formation is high combustion temperatures and the combustion temperature increases the compression ratio increase; so as the compression ratio increase, the amount of NOx will increase. The NOx emission for diesel and blend B10for compression ratio 18 is 20% less than B10E2 and 25% less than B15E3.

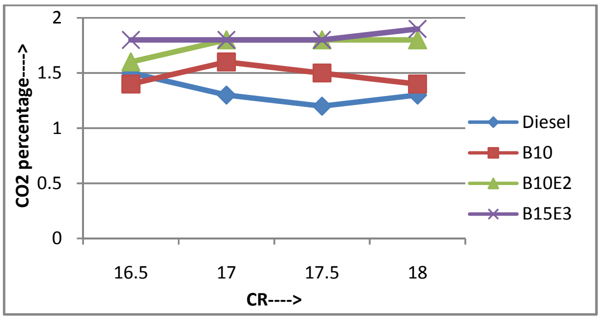

Fig. 8 Carbon Dioxide

The blend emits higher percentage of CO2 than diesel at all compression ratios. More amount of CO_2 is an indication of complete combustion of fuel in the combustion chamber. It also relates to the exhaust as temperature. CO2 emission of the blend B10 for compression ratio 16.5 is lesser due to incomplete combustion and inadequate supply of oxygen. The CO2 emission from the combustion of bio fuels can be absorbed by the plants and the carbon dioxide level and is kept constant in the atmosphere while otherwise the accumulation of CO_2 in the atmosphere leads to many environmental problems like ozone depletion and global warming.

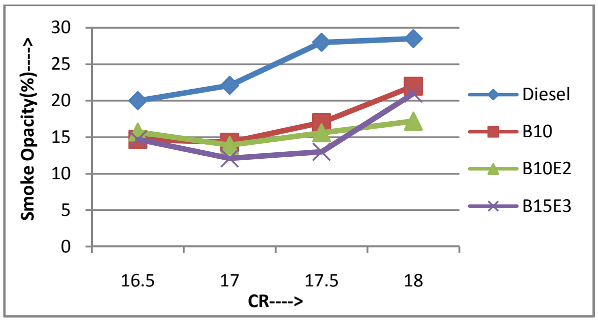

Fig. 9 Smoke opacity

From Fig. 9, it is observed that the smoke opacity better all the blends is far than normal diesel at all compression ratio. The blends show minimum smoke opacity at 17 compression ratio which is almost 25% less than normal diesel.

IV. Conclusions

In the current study, experiments were done to evaluate the effects of engine parameter values while working with rice bran oil and its blends as fuel. Trials with four values of compression ratio (16, 17, 17.5, and 18) as against the standard values set by manufacturer has demonstrated that increase in compression ratio improves the performance of the engine used in study with regard to the engine performance measured in terms of BSFC and BTHE.

- The maximum brake thermal efficiency of 21% was observed with the blend B15E3 which is 5% higher than diesel at 18 compression ratio. The brake thermal efficiency of the diesel and all the other fuel blends improves with increase in the compression ratio.
- The BSFC of the blend B10E2&B15E3 shows minimum value than that of diesel and B10 at higher compression ratio whereas the BSFC decreases with increase in compression ratio from 16.5 to 18.
- The CO emissions of the diesel decrease whereas for all the other fuel blends it increases with increase in compression ratio. The minimum CO emissions were observed with the blend B10 throughout the whole range of testing.
- The diesel produces minimum HC emissions as compare to all the blends at all compression ratio.
- The NOx emissions increase with increase in compression ratio and blending as compare to diesel.
- The CO2 emissions of the biodiesel and all the other fuel blends were higher than that of the diesel fuel.
- The smoke opacity better all the blends is far than normal diesel at all compression ratio. The blends show minimum smoke opacity at 17 compression ratio which is almost 25% less than normal diesel.

Looking to the advantage of improved performance of the engine with higher compression ratio marginal deterioration of some emissions, which are still lower than that with diesel fuel, can be accepted. For fuelling the engine with bio-diesel, one should go for higher compression ratio.

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