The effect of Exhaust gas recirculation on Zirconia coated piston of diesel engine fuelled with rape seed oil methyl ester

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Abstract

Increasing global population in present years means more vehicle ownership which leads to the increasing of oxides of nitrogen (NOx) and greenhouse gas emission. Oxides of nitrogen (NOx) are produced from the fuels which burned at high temperatures; contributes to the formation of ozone smog, harmful unseen particles, acid rain, and oxygen depletion that reduced the water quality. The use of higher oxygenated nature biodiesel as an alternative fuel also contributes to the increasing formation levels of NOx emission. In respond to the matters arise, exhaust gas recirculation (EGR) has been introduced to control NOx emissions from diesel engines effectively which lowers the oxygen concentration in the combustion chamber. In this paper, an experimental study was conducted on a four stroke, water cooled DI diesel engine fuelled with neat Rape seed oil-biodiesel operating with exhaust gas recirculation (EGR) along with YSZ coated piston. Both biodiesel fuel and EGR are employed together to evaluate the engine performance and exhaust emission particularly NOx content. Tests were performed under a steady state condition where conventional diesel fuel was used as a baseline fuel. According to the experimental results, diesel engine operating with Rape seed biodiesel and EGR reduced the brake power output, by 2.5%, decreased the engine torque, increased fuel consumption, decreased NOx and absolute slight increment in other emissions include CO_2, CO, and particulate matters.

Keywords: Rape see oil- EGR-Ceramic coated piston- Performance and emission study

1.Introduction

Walke et al. [1] reported that there is vast reduction in NOx emission but slight increasing in bsfc and smoke density concentration corresponding to the higher EGR rate One of the considerable alternative renewable fuel sources is vegetable oils which have similar combustion characteristics and psychochemical properties to the petroleum diesel [2,3]. Many researchers had well-documented their reports on the study of the vegetable oils on their properties and their effects to the engine performances and exhaust emissions [4-9]. According to Knothe et al. [5], the selection of vegetable oils mainly based on geography and climate condition where such as corn, soybean, peanut, rapeseed, canola and olive mostly planted in Europe and United States, while in Asia, South America and Africa preferred for palm oil, coconut, jathropa as well as rubber seed. These vegetable oils have several advantages include low level of sulfur, higher oxygenated nature, higher cetane number and produce less toxic emission when they are burned [2]. Moreover, these crop oils have a better lubrication and a higher ignition temperature which not very flammable (LR).

There were great potentials for the vegetable oils to be discovered in terms of engine performance and exhaust emission. Song et al. [10] reported that both intake oxygen enrichment and biodiesel fuel which higher oxygenated nature increase NOx emissions. They also concluded that the increase was higher when more oxygen is used during combustion rather than oxygenated fuels were used. According to Lapuerta et al. [7], the oxygen content of biodiesel could not cause any increase in NOx formation because the combustion flow occurs in the oxygen-fuel ratio region around the stoichiometric one, which is normally around 3.58 for a standard diesel fuel and 2.81 for typical biodiesel fuels. Exhaust gas recirculation is the effective way to control the NOx formation; where reducing the exhaust temperature during combustion [11, 12].. Rajan et al. [13] investigated the effect of biodiesel on a four stroke DI diesel engine fueled with sunflower methyl ester (SFME) employing the EGR technique. They reported that there is a reduction on 25% less NOx emission at the same level smoke emissions with 15% EGR rate.

2.Materials and Methods

2.1.Production of Biodiesel

The process of preparation of biodiesel from vegetable oil is called transesterification. The method of preparation of biodiesel from vegetable oil varies based on the content of Free Fatty Acid present in the vegetable oil. The Rape seed oil was used for making Rape seed oil methyl ester in this study. The Rape seed oil contains high free fatty acid of 4.9%. It is difficult to transesterify the high FFA vegetable oils using the commercially available alkaline catalyst process. Hence a two stage process namely acid esterification and alkaline esterification has to be followed to esterify the vegetable oil containing high FFA.

2.1.1 Acid Esterification

The one litre of rape seed oil is poured into the flask and heated to about 50ºC. Then 250ml of methanol is added with the preheated rape seed oil and stirred for few minutes. Then 0.5% of sulphuric acid is added with the mixture. Heating and stirring is continued for 20-30 minutes at atmospheric pressure. On completion of this reaction the product is poured into a separating funnel for separating the excess alcohol. The excess alcohol with sulphuric acid and impurities moves to the top surface and is removed. The lower layer is separated for further processing. The first step reduces the FFA value of raw rape seed oil to about 2% using acid catalyst.

2.1.2 Alkaline Esterification

The product of acid catalyzed esterification are preheated to the required reaction temperature of 45 ± 5ºC in the flask. Meanwhile 5 gm of KOH is dissolved in 300ml of methanol and is poured into the flask. The mixture is heated and stirred for 30 minutes and the reaction is stopped and the products are allowed to separate into two layers. The two layers which contained impurities and glycerol is drawn off. The ester remains in the upper layer. Methyl esters are washed to remove the entrained impurities and glycerol. Hot distilled water is sprayed over the surface of the ester and stirred gently. Lower layer is discarded and the upper layer is separated.

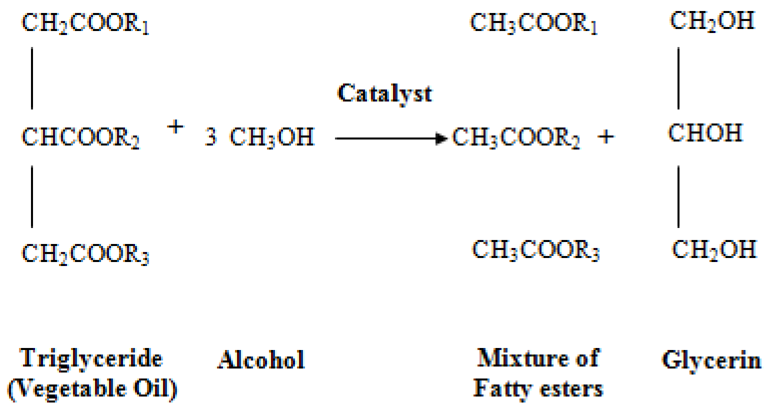

Fig.1. Transesterification process

Table 1 Comparison of properties of diesel and RME

Properties	Diesel	RME
Heating value(kJ/kg)	43,000	39,500
Fire point° C	65	72
Viscosity Cst	2.7	4.7
Specific gravity	0.85	0.872
Flash point °C	52	80
Density(kg/m^3)	850	860

3.Experimental apparatus and procedure

The Experimental work involves observing and taking safety precautions, observations and noting down the engine performance, emissions and combustion parameters using appropriate Instruments. It includes intake air measurement, fuel measurement, power measurement, cylinder pressure measurement and emission measurements. The schematic and photographic view of the experimental set up is shown in Figure 1(a) and Figure 1(b). Two separate fuel-measuring systems were provided to measure both conventional fuel and rape seed oil methyl ester. If the present quantity was not enough to maintain the rated speed then the period was adjusted to maintain the speed and the corresponding fuel consumption was calculated from Figure 1(a) and Figure 1(b). The electrical dynamometer was used for measuring power output of the engine. The detailed specification of the engine shown in Table 4. The electrical power created by the dynamometer is usually released as heat through set of electrical resistances. The load and speed of the engine can be enhanced or decreased on the dynamometer and thereby on the engine, by switching on or off the load resistances and by varying the field strength.

Exhaust emission from the engine was measured with the help of AVL DI Gas 444 analyzer and smoke intensity was measured with the help of Bosch AVL 437 smoke meter. Two separate sampling probes were used to receive sample exhaust gases from the engine for measuring emission and smoke intensity, respectively. An AVL smoke meter was used to measure smoke samples from the engine. A K-type thermocouple and a temperature indicator were used to measure the exhaust gas temperature. A Kistler (601A) water cooled pressure transducer was used to measure cylinder. A Kistler crank angle encoder on the crankshaft (7200 points per cycle) was used to measure pressure data acquisition. For each measured point, the pressure data of 100 cycles were recorded. The analysis software AVL indicom to determine the Heat release rate, cumulative heat release rate, etc. At the beginning engine was started at no load for engine to warm up and the engine was gradually loaded from zero load to full load and all the necessary reading are taken.

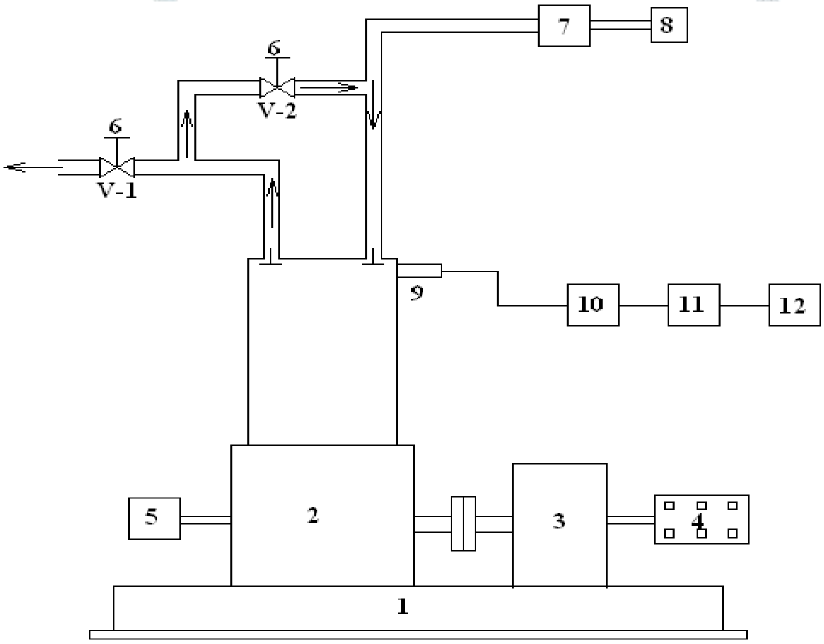

Fig.2. Experimental setup with EGR

1.Engine test bed **2.Test engine** **3.Electrical dynamometer**
4.Dynamo meter control unit **5.Crank angle encoder** **6.Valves**
7 .Air tank **8.Air filter** **9.Pressure sensor** **10.Charge amplifier** **11.Cathode ray oscilloscope** **12.Printer**

Table 2 Specification of the test engine

Make & Model	Kirloskar & TV1
Rated Power	5.2 kW @ 1500 rpm
Number of Cylinders	Single
Combustion chamber	Hemispherical
Piston bowl	Shllow bowl

Compression ratio	17:5:1
Rated Speed	1500 rpm
Bore Diameter	87.5 mm
Stroke Length	110 mm
Injection Pressure	220 bar
Injection Timing	23 deg CA BTDC
Fuel Injection type	Direct
Number of holes in nozzle	3
Spray hole diameter	0.25mm
Spray cone angle	110
Cubic Capacity	661.45 cc
Type of loading	Electrical Load
Type of cooling	Water cooling
Type of ignition	Compression Ignition

A schematic diagram of the EGR arrangement is shown in Figure 2. Metal pipes were installed between the exhaust pipe and the intake pipe, to route the exhaust gases back to the engine inlet system, where the hot gases were inducted into the succeeding cycles. Two gate valves were provided, one in the exhaust pipe and other in the intake pipe to divert a fixed quantity of the exhaust gases into the intake manifold so as to mix with the incoming air before being inducted into the combustion chamber. The photographic view of the experiment is shown in Figure 2.

The EGR ratio was obtained from the measured mass flow rate of air with and without EGR and the EGR percentage was calculated using the formula given by Deepak Agarwal et al (2006), Yasufumi Yoshimoto et al (2001):

$$EGR\% = \frac{[M_a]\text{ without EGR} - [M_a]\text{ with EGR}}{[M_a]\text{ without EGR}}$$

where, = $[M_a]$ Mass flow rate of air, kg/s

With the knowledge of the intake air flow without EGR, the mass flow rates and the manometer heads for the required quantities of EGR are predetermined and the EGR control valve is opened until the required head is achieved. For the EGR, uncooled recirculated exhaust gas was directly inducted into the intake pipe and the gas flow was regulated with an EGR control valve and inlet/outlet gas temperatures were measured with a digital thermocouples. During the experiment, the engine was operated at a constant speed of 1500 rpm.

Tests were carried out for constant speed with various loads from 0 to 100% with varying EGR quantity admitted in to the cylinder. Inlet gas temperature which was recirculated can be kept close to exhaust temperature to reduce ignition delay which reduce the quantity of fuel burned in the premixed burning zone which reduce NOx emission. The temperature of the intake gas, exhaust gas and outlet cooling water were measured using thermocouples. The experiments were repeated from no load to full load while the EGR quantity varies in the values of 10%,15% and 20 %. Since 5% EGR does not show significant difference on the performance and emission characteristics. At these three different EGR flow rates the combustion, performance and emission characteristics were analysed for the 30% Water emulsified biodiesel fuel and compared with the 30% water-biodiesel emulsion without EGR.

3.1 Yitria stabilized Zorconia coating

A bond coat of 150 µm and a yttria stabilized zirconia (YSZ) coat of 350 µm were then applied onto the piston crown by plasma spraying using a robot arm. The application of a TBC is only restricted to the piston crowns in this context because the surface constitutes a major part of the combustion chamber surfaces exposed to high-temperature gases. The authors report that when thermal insulation is applied only to a certain part of the combustion chamber, it would surely increase the thermal loading of the others due to the increase in gas temperature. Extension of surface coating to other parts of the engine components is under exploration.

Fig. 3. Yitriya stabilized Zirconia coated piston

3.2 Estimation of uncertainty

Ambiguities and uncertainties are to be estimated while conducting an experimental analysis. These inaccuracies may arise due to environmental factors, errors in calibration of instruments, human errors while observation and reading. The uncertainty values of measured parameters were estimated from the range and accuracy of instruments and are given below. In order to get more accurate uncertainty limits for computed parameters the principle of root sum square method was used and it is given by equation -1.

$$R= \sum X_i^2 \quad -- \quad (1)$$

where R is the total percentage of uncertainty and Xi is the individual uncertainty of computed parameters. The total percentage uncertainty of computed parameters were calculated and given below

$$R= X_1^2+X^2+X_3^2+X^2+X_5^2$$

$$R= (1)^2+(.4)^2+(1)^2+(.1)^2+(.2)^2$$

$$R= \pm 1.48\%$$

4.Results and discussion

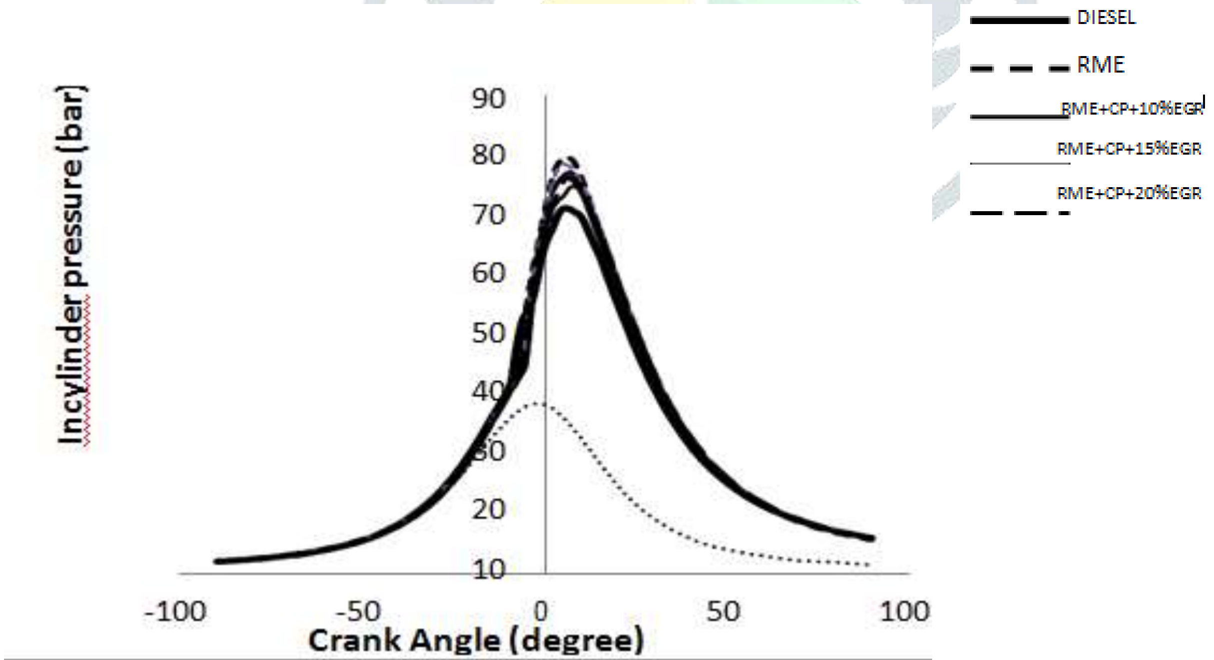

Fig.4 Variation of cylinder pressure with crank angle

Figure 4 shows the variation of cylinder pressure with crank angle for diesel, Rape seed oil methyl ester, rape seed oil methyl ester with various proportions of EGR in a ceramic coated piston engine. The combustion characteristics were analyzed based on the measured in-cylinder pressure. From the figures, it can be seen that the occurrence of peak pressure advances with respect to the top dead centre with an increase in load. Also, the occurrence of peak pressure retards with an increase in EGR levels. This leads to an increased rate of pressure rise and engine noise, whereas the cylinder pressure reduces for EGR and the occurrence of peak pressure is maximum in RME biodiesel. The ignition delay has been increased in increasing the EGR concentration in both diesel and biodiesel and the engine knock increases at higher load with these blends. The B100 also has variable increase in peak pressure compared to diesel. In general, peak pressure varies from about 69 to 70 bars for the entire load range considered. For diesel the cylinder peak pressure was 69 bar , for rape seed oil methyl ester the peak cylinder pressure was 73 bar, for ceramic coated piston with RME and with 10% EGR the peak cylinder pressure was 74.5 bar, for RME with ceramic coated piston with 15%EGR the peak cylinder pressure was 76 bar , for ceramic coated piston with RME and 20%EGR the cylinder peak pressure was 76.6 bar. This increase in pressure with the increase in EGR quantity was to rise in delay period due to the presence of exhaust gas in to the cylinder.

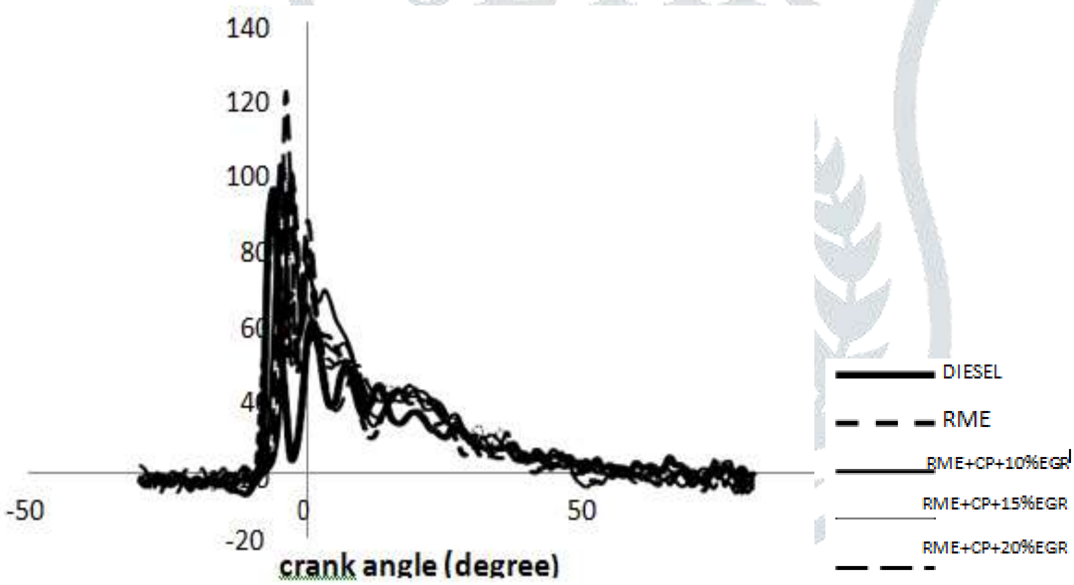

Fig. 5 Variation of heat release with crank angle

The Figure 5 shows the variation of net heat release rate with crank angle for diesel, RME, RME with ceramic coated piston and with different % of EGR. It is seen from the figure that the heat release was found to be high for RME and with the addition of EGR the heat release decreases. This may be due to the fact that with the addition of EGR the quantity of oxygen available for combustion reduces which makes incomplete combustion and also due to hot EGR the ignition lag reduces and the amount of fuel burned in the premixed combustion zone also reduces and hence the heat release decreases. For diesel the heat release rate was found to be 89 J/deg CA, for RME the heat release was found to be 85 J/deg CA, for RME with coated piston and 10% EGR the heat release rate was found to be 80J/deg CA, for RME with coated piston and 15% EGR the heat release rate was found to be 72 J/deg CA, for RME with coated piston and 20 % EGR the heat release rate was found to be 70 J/deg CA. The heat release rate decrease with the addition of EGR in to the cylinder because the amount of oxygen available for combustion got reduced and the cylinder temperature reduces which in turn reduces the combustion chamber temperature and the NOx formation.

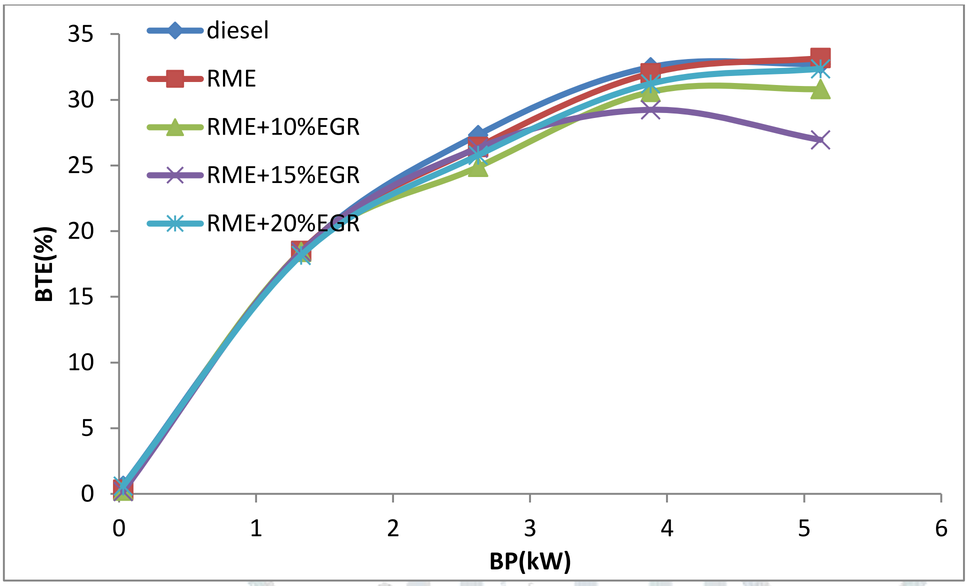

Fig. 6. Variation of BTE with BP

Figure 6 shows the variation of BTE with respect to BP for the engine running with palm methyl ester at different operating conditions. It was found that the engine has lower brake power compared to conventional diesel when using RME as duel with and without EGR. Lower heating value and higher density as well as higher viscosity of Rape seed biodiesel were found to be the major factors for the results. EGR employment on diesel engine for the fuel tests also establishes profound results. Biodiesel with EGR has produced lower power compared to the condition without EGR with the reduction rate of nearly of 4.1% due to different combustion efficiency of the engine. This result shows that when diesel engine operating with EGR, engine power dropped rapidly due to lower oxygen burned in the chamber and leads to incomplete fuel burning as well as lower thermal efficiency. It is illustrated that the brake torque when the engine running with palm-biodiesel has decreased to average 2.8% respectively compared to conventional diesel. Again, biodiesel psychochemical properties include density and viscosity has to be blamed for the existing results. In other section, palm-biodiesel with EGR had lower torque as compared to diesel with EGR over 76.3% respectively. Lack of oxygen during combustion leads to the combustion inefficiency and incomplete burning of the fuels. Results have demonstrated that diesel had the lowest bsfc overall with those two conditions throughout the study. Increase in BSFC was understandable as palm methyl ester have approximately 2.1% less energy than conventional diesel (figure 2(c)). The higher the palm oil contents in the biodiesel, the lower its heating value.

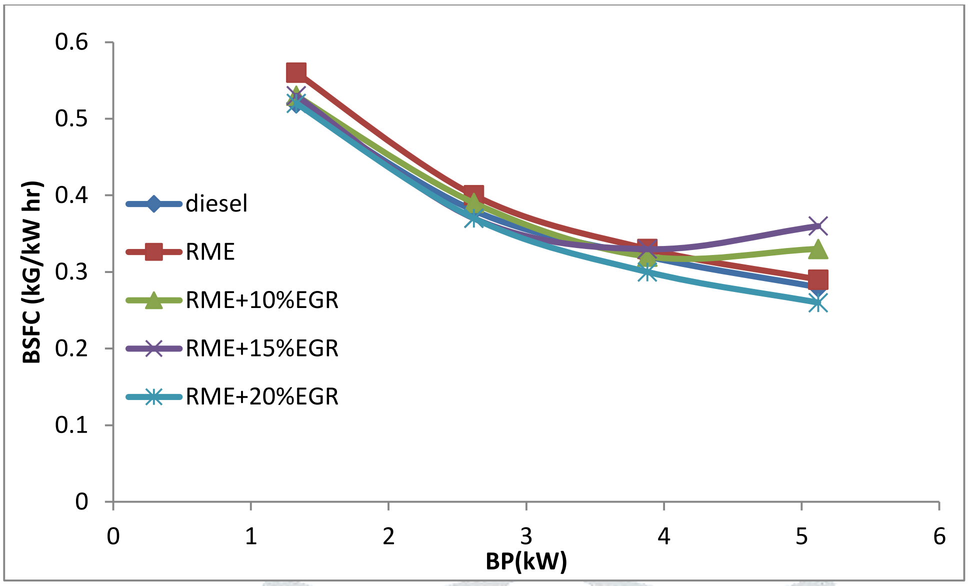

Fig. 7 Variation of BSFC with BP

The Figure 7 shows the variation of brake specific energy consumption with respect to Brake power for Diesel, RME, RME with coated piston and various EGR rates. It can be seen from the figure that increase in EGR rate increases the specific energy consumption of the engine due to reduced intake oxygen concentration which resulted in reduced combustion gas temperature. It is also seen that for RME the BSFC was found to be 0.3 kg/kW-hr, for ceramic coated piston with RME with 10% EGR the BSFC was found to be 0.31 kg/ kW hr, for RME and ceramic coated piston with 15% EGR the BSFC was found to be 0.33 kg/kW hr, for RME and ceramic coated piston with 20% EGR the BSFC was found to be 0.36 kg/kW hr. This increase in specific energy consumption was due to insufficient quantity of oxygen available for combustion.

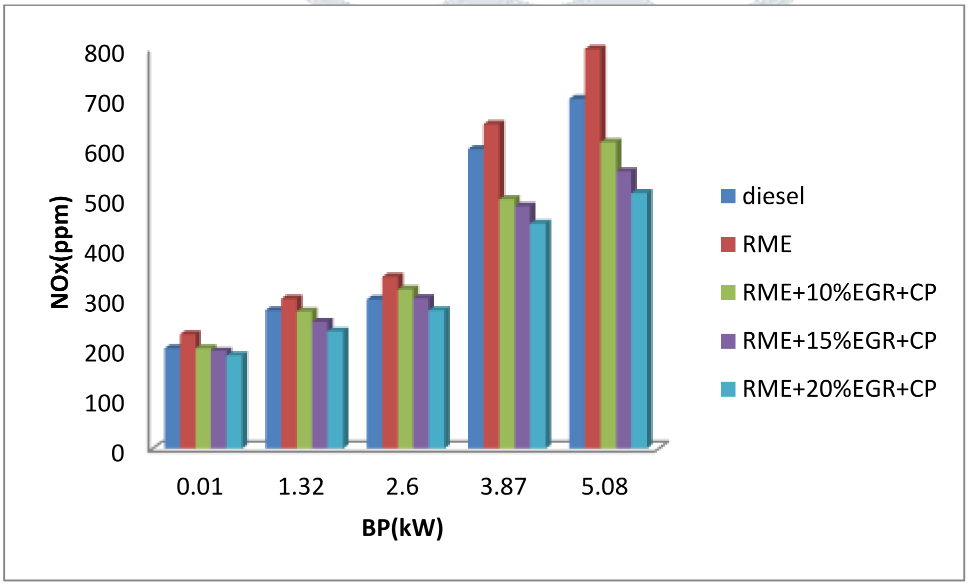

Fig.8 Variation of NOx emission with BP

Figure 8 shows the variation of NOx emission with brake power output for Diesel, RME, RME with coated piston and various EGR rates. It can be seen from the figure that increase in EGR rate reduces the NOx emission due to reduced intake oxygen concentration which resulted in reduced combustion gas temperature. It is also seen that for RME the NOx emission was found to be 2282 ppm , for ceramic coated piston with RME with 10% EGR the NOx emission was found to be 1562ppm, for RME and ceramic coated piston with 15% EGR the NOx emission was found to be 955 ppm, for RME and ceramic coated piston with 20% EGR the NOx emission was found to be 1280 ppm. This increase in NOx emission was due to insufficient quantity of oxygen available for combustion, reduced intake oxygen concentration which reduced flame temperature which reduces the formation of NOx.

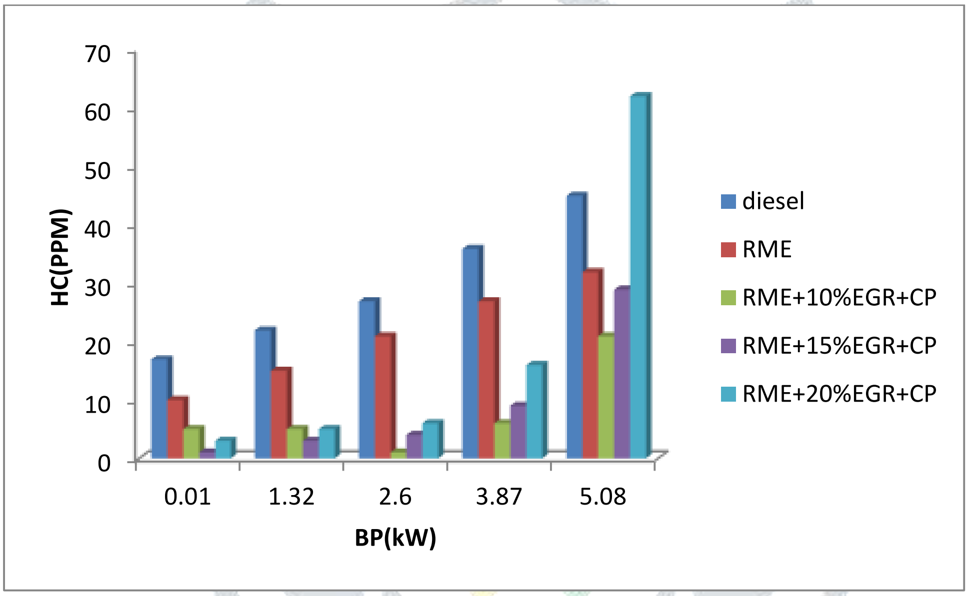

Fig.9. Variation f HC emission with BP

Figure 9 shows the variation of HC emission with brake power output for Diesel, RME, RME with coated piston and various EGR rates. It can be seen from the figure that increase in EGR rate increase the HC emission due to reduced intake oxygen concentration which resulted in reduced combustion gas temperature. It is also seen that for RME the HC emission was found to be 17 ppm, for ceramic coated piston with RME with 10% EGR the HC emission was found to be 21ppm, for RME and ceramic coated piston with 15% EGR the HC emission was found to be 29 ppm, for RME and ceramic coated piston with 20% EGR the HC emission was found to be 62 ppm. This increase in HC emission was due to insufficient quantity of oxygen available for combustion, reduced intake oxygen concentration which reduced flame temperature which increase the formation of HC.

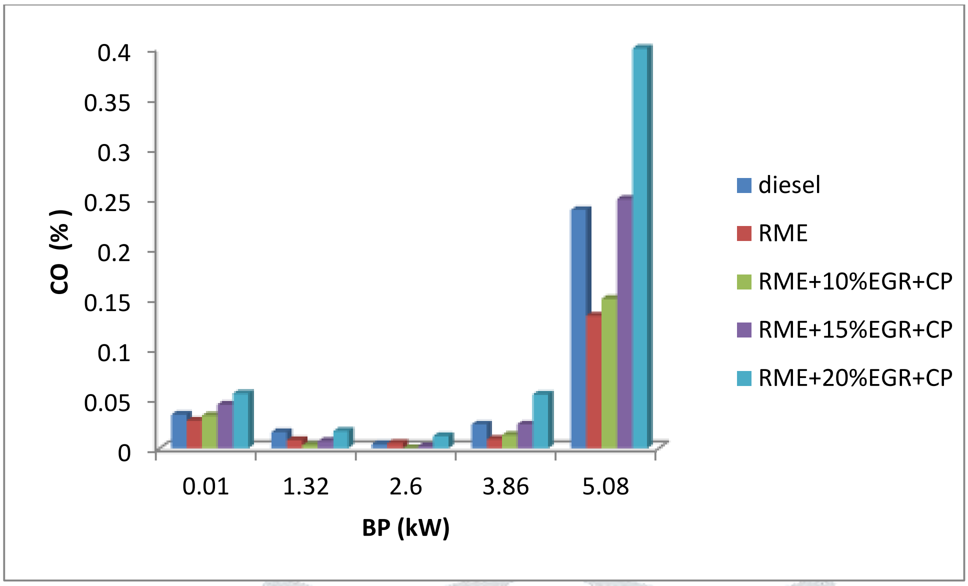

Fig. 10 Variation of CO with BP

Fig. 10 shows the variations of CO emission with respect to the load. The CO emission decreases with increase in load for all the fuel samples except at full load condition. It is observed that CO emissions increases with the addition of EGR. The EGR shortens the ignition delay period, reduces the air-fuel mixing and higher carbon combustion activation leads to complete combustion. Low flame temperature and too rich fuel air ratio are the major causes of CO emissions from diesel engine. CO emissions are due to incomplete combustion of fuel either due to inadequate oxygen or flame quenching. Higher CO emissions results in loss of power in engine. Different factors can be at the origin of its formation like insufficient residence time, too low or too high equivalence ratios are part of those reasons. CO emissions are the products of improper and incomplete combustion resulting from antioxidant addition. The oxidation of CO is directly related to the amount of OH radicals present in the reaction. It is also seen that for RME the CO emission was found to be 0.133 % by volume, for ceramic coated piston with RME with 10% EGR the CO emission was found to be 0.65 % by volume, for RME and ceramic coated piston with 15% EGR the CO emission was found to be 0.79 % by volume, for RME and ceramic coated piston with 20% EGR the CO emission was found to be 0.60 % by volume.

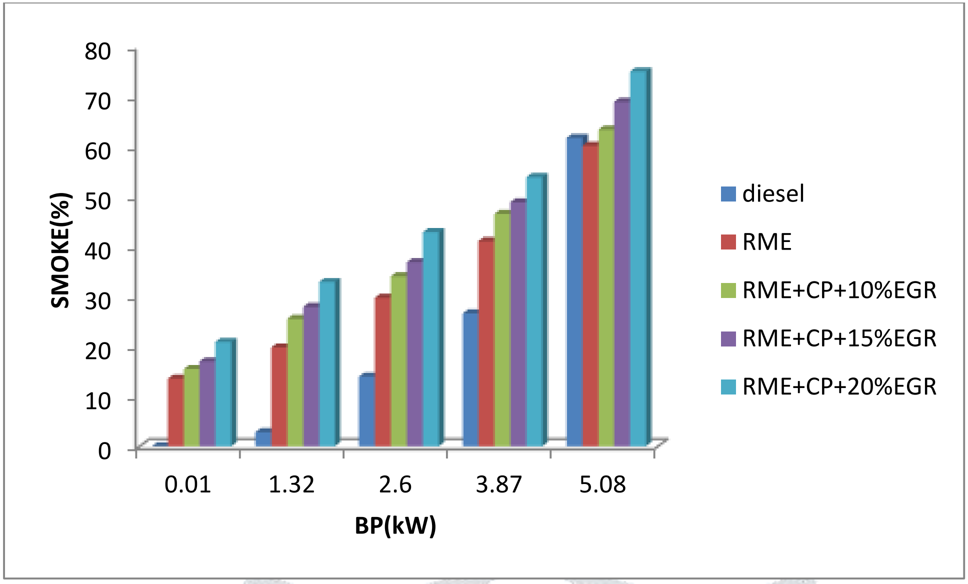

Fig. 11. Variation of smoke opacity with BP

The Fig 11 shows the variation of smoke emission with brake power for Diesel, RME, RME with coated piston and various EGR rates. It is seen that the smoke emission was found to increase with the increase in EGR %. This may be attributed to the absence of lean mixture due to the addition of exhaust gas into the combustion chamber. The smoke emission increases partly because the diffusion combustion is extended by EGR due to slow down of the premixed combustion resulting in longer combustion duration. At high loads the flame engulfing the fuel spray propagates all over the combustion chamber producing a large amount of soot which in turn indicates the lack of oxygen at high loads causes a sharp rise in smoke emission. It is also seen that for diesel the smoke emission was found to be 61.8 opacity %, for RME the smoke emission was found to be 60.2 opacity %, for ceramic coated piston with RME with 10% EGR the smoke emission was found to be 63.5 opacity %, for RME and ceramic coated piston with 15% EGR the smoke emission was found to be 69 opacity %, for RME and ceramic coated piston with 20% EGR the smoke emission was found to be 75 opacity %. This increase in smoke emission was due to insufficient quantity of oxygen available for combustion, reduced intake oxygen concentration which reduced flame temperature which increase the formation of smoke.

4.Conslusion

Based on the experimental test results from the engine testing, it can be concluded as follows:

i.Both EGR and biodiesel have increased the specific fuel consumption (SFC) and reduced the engine performance of the diesel engine include engine power and torque as well as brake thermal efficiency.

ii. Other emissions such as CO and HC also found to have decreased simultaneous with the use of biodiesel fuel.

iii. Biodiesel has higher oxygen-natured which leads to better combustion, produced higher NOx emission in exchange.

iv. This higher NOx emission can be effectively controlled by using EGR.

v. EGR increases the CO and HC emissions due to incomplete combustion and reduced the exhaust temperature in advance.

In summary, engine operation fueled with rape seem-biodiesel while employing EGR results in NOx emission reductions without neglecting engine performance as well as exhaust emissions.

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