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Performance, emission and combustion characteristics of a diesel engine with the effect of thermal barrier coating on the piston crown using biodiesel

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Abstract: This paper investigates the effect of thermal barrier coated piston on the performance, emission and combustion characteristics of the bio-diesel fuelled diesel engine. Initially, the piston crown was coated with 0.3mm thickness of Partially Stabilized Zirconium (PSZ) material by plasma coating method with the base coat of Y_2O_3 material without affecting the compression ratio of the engine. Then the test was conducted on a base engine and coated diesel engine using diesel and bio-diesel blend at different load conditions. The results revealed that BSFC was decreased by 8.5% and the brake thermal efficiency (BTE) was increased by 6.2% for B20 with coated engine compared with the base engine with biodiesel blend. The smoke, CO and HC emissions were also decreased for biodiesel blend with coated engine compared with base engine. The combustion characteristics such as like peak pressure, maximum rate of pressure rise and heat release rate were increased and the ignition delay was decreased for B20 blend for the coated piston engine compared with biodiesel blend with the base engine.
Keywords: Biodiesel, emissions, diesel engine, partially stabilized zirconia coating, piston.

1. Introduction

Stringent emission norms to reduce the emission have urged the researchers to search for an alternative energy sources like alcohol, vegetable oil for diesel engines. Vegetable oils are easily available and renewable it nature. A number of vegetable oils have been tried in the past to use as fuel in diesel engine. It has been reported that raw vegetable oils can be used as fuel in diesel engines in neat form as well as blended with the diesel fuel. However, the long term operation of the engine problems of injector coking, dilution of engine oil, deposits in various parts of the engine. Higher viscosity of oils is having an adverse effect on the combustion in the existing diesel engines [1-3]. Esterification is one of the methods to convert the vegetable oil into its methyl ester, known as biodiesel. Several researchers have used biodiesel as an alternate fuel in the existing CI engines without any modifications [4-8].

Satyanarayana Murthy et al [9] investigated the effects of steam injection into the intake manifold of a single cylinder, low speed, direct injection diesel engine fuelled with biodiesel palm methyl ester. The addition of steam in to the intake manifold of the engine was carried out by vaporizing the water inside a boiler and heat is supplied by the solar concentrated parabolic dish. They reported that the addition of steam to the combustion chamber decreases the NOx emisions and also there is a significant improvement of engine performance in terms of specific fuel consumption and brake thermal efficiency with steam injection. Hemanandh and

Narayanan [10] studied the exhaust emissions using different blends of diesel, refined Sunflower oil (RSF) and methyl ester diesel blend on direct Injection 4-stroke, single cylinder air-cooled constant speed diesel engine. They experiments were conducted with various blends of diesel (BRS10, BRS30, and BRS40) at different pressures (180 bar, 210 bar, &240 bar) with three hole nozzle and at different loads (0%, 25%, 50%, 75%, 100%). Their results showed that there is an increase in CO, marginal increase in NO_x and decrease in HC emissions.

Pugazhvadivu [11] studied the addition of ethanol with 5% and 10% with B25, B50, B75 and B100 biodiesel diesel blends on a single cylinder diesel engine. They reported that the addition of ethanol to biodiesel diesel blends did not alter the engine performance significantly. The engine produced lower NO_X and smoke emission with ethanol addition. Hanumantha Rao et al [12] studied the performance and emissions of single cylinder water-cooled diesel engine using Multi-DM-32 diesel additive and methyl-ester of Jatropha oil as fuel. Their results indicated that B25 have closer performance to diesel and B100 had lower brake thermal efficiency mainly due to its high viscosity compared to diesel. However, its diesel blends showed reasonable efficiencies, lower smoke, CO_2 and CO emissions. The addition of multi- DM-32 additives with methyl ester of Jatropha offer fuel conservation as well as reduction in exhaust emissions.

An effective way of burning high viscous vegetable oils in diesel engine is by retaining the heat produced from combustion of the fuel in the combustion chamber. This can be achieved by modifying the engine into a semi adiabatic one. If the heat rejected to the coolant is reduced, thermal efficiency could be improved. This semi adiabatic condition can be achieved by providing a ceramic coating on the piston crown [13-14]. Ceramic coating is used in addition to achieve better potential to do more work by reducing losses and reduce in fuel consumption and heat rejection in the coolant by improving the performance [13]. The most effective, economic and reliable approach to increase the performance, emission and combustion is possible if the use of optimum coating thickness of 0.5 mm (500μm). If the coating thickness increases beyond the optimum thickness range the temperature of the combustion chamber wall increases, resulting in decrease in the volumetric efficiency, inadequate lubrication and decreasing the thermal efficiency [14-15]. Ceramic coating allows use of low cetane value and high viscous fuels to reduce the ignition delay of the fuel and increases the thermal efficiency and reduces the smoke, CO and HC emissions [16, 17].

The objective of the present research is to investigate the performance, emission and combustion characteristics of Karanja oil methyl ester diesel blend as fuel in a diesel engine with and without coating on the piston crown. The measured values for the coated engine with biodiesel blend are compared with base engine with diesel and biodiesel blend.

2. Preparation of Karanja oil methyl ester (KOME)

Karanja is considered as feedstock for the biodiesel production. Transesterification is a chemical process of transforming large, branched, triglyceride molecules of vegetable oils and fats into smaller, straight chain molecules, almost similar in size to the molecules of the species present in diesel fuel. The process takes place by the reaction of vegetable oil with alcohol in the presence of a catalyst. Methyl esters are preferred, as methanol is non hygroscopic and is less expensive than other alcohols.

The raw Karanja oil is heated in a reactor to remove the moisture. Potassium methoxide is prepared by dissolving crystal form of potassium in methanol. Methoxide is mixed with preheated oil and the reaction carried out under nominal speed stirring by a mechanized at a constant reaction temperature of 60 ^{o}C for 2 hrs. After 8hrs of settling period, ester separates as an upper layer and glycerol settles at bottom separated by decantation. Then the ester is washed with warm distilled water to remove impurities and separated. The optimum proportions are for one litre of Karanja, the requirement of methanol and KOH are 200 ml and 8 grams respectively. With this proportion from one litre of 830 ml of Karanja oil methyl ester (KOME) was produced. The important properties of diesel, Karanja oil and its methyl ester are given in Table.1.

Table.1.Properties of diesel, Karanja oil and its methyl ester

Properties	Diesel	Karanja oil	KOME
Density (kg/m3)	840	918.6	880
Viscosity(mm^2/s)	3.8	38.23	4.18
C.V (MJ/kg)	42.50	39.77	38.45
Flash Point (^oC)	50	240	170
Fire Point (^oC)	20	26	14
Cetane Number	47	40-45	45

3. Experimental setup and procedure

Experiments were conducted in a direct injection diesel engine at a constant speed of 1500 rpm with varying load conditions, from no load to full load in the steps of 25%. The specifications of the test engine are listed in Table.2. The engine was coupled with swinging field electrical dynamometer to provide the brake load. Two separate fuel tanks were used for the diesel fuel and Karanja oil methyl ester. The volumetric fuel flow rate was measured using a 50 cm^3 burette/stop and the volumetric air flow rate was measured using a U-tube manometer. The fuel consumption was determined by measuring the time taken for a fixed volume of fuel to flow into the engine. The test was conducted with diesel and biodiesel blend with standard engine and coated piston engine. The performance of the engine was evaluated in terms of the brake thermal efficiency, brake power, specific energy consumption, emission characteristics such as HC, CO, NO, and smoke and the combustion parameters such as peak cylinder pressure, heat release rate, maximum rate of pressure rise and ignition delay. The exhaust emissions were measured by the AVL 444 five gas analyzer and the smoke opacity was measured by AVL- 437 smoke meter. The combustion parameters were measured by using pressure sensor, TDC encoder and data acquisition chord with the help of computer. The schematic of the experimental set up as shown in Figure 1. The uncertainties of the measured parameters are shown in Table 3.

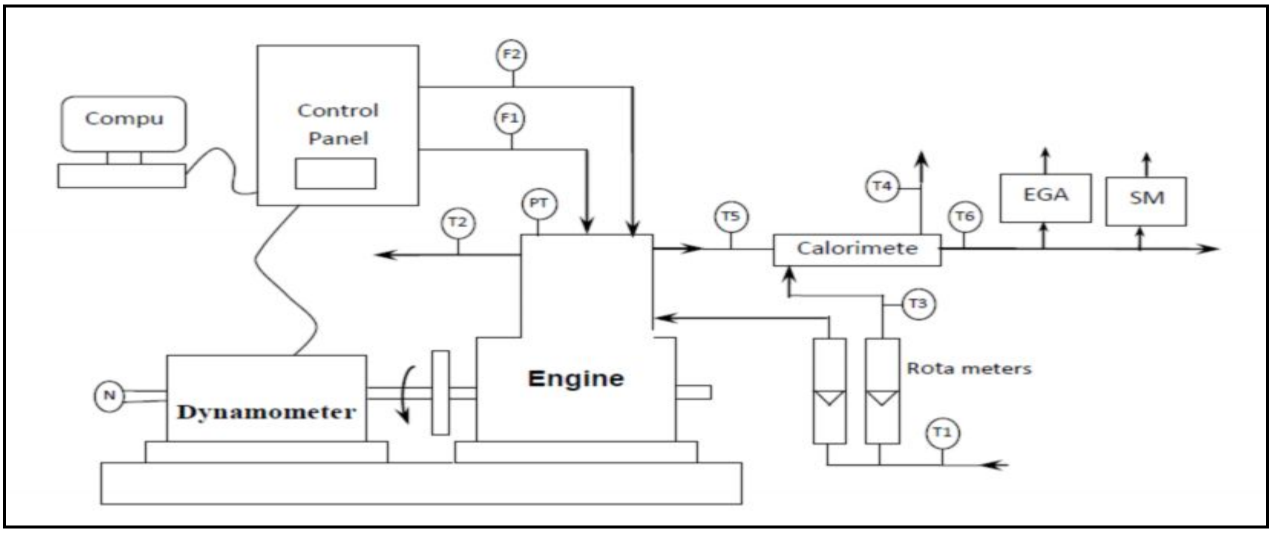

Fig.1 Schematic of experimental set up

Table.2 Specifications of the test engine.

Make	**Kirloskar, TAF 1**
Engine, Type	Vertical, Water cooled
Bore Diameter	87.5 mm
Stroke Length	110mm
Brake Power	4.44 kW
Compression Ratio	17.5:1
Speed	1500 rpm
Fuel injection	23^o before TDC
No of Cylinder	1

Table 3. The uncertainities of measured parameters

Prameters	Max.errors
BTE	1.01
BSFC	1.01
EGT	1.28
CO	0.2
HC	0.15
NO	1.01
Smoke	0.2

3. Results and Discussion

3.1 Cylinder peak pressure

Figure 2 Ceramic (PSZ) coated piston

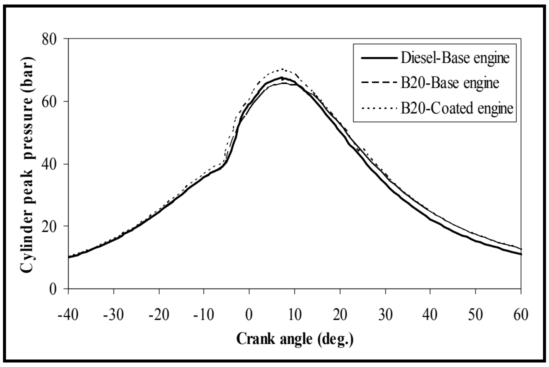

Figure 3 Variation of peak cylinder peak pressure with CA at full load

The variation of cylinder peak pressure with crank angle at full load for diesel and bio diesel blend for both the engine operations is shown in Figure 3. The peak pressure depends on the amount of fuel taking part in the uncontrolled combustion phase, which is governed by the delay period and the spray envelope of the injected fuel [14]. The cylinder peak pressure for diesel and B20 with base engine is 67.2 bar and 65.6 bar respectively, whereas for coated engine with B20 is 70 bar at full load. It can be seen that the cylinder peak pressure for B20 increased by about 3 bar and 4.5bar for the coated piston engine compared with diesel and B20 with base engine. This may be due to the shorter ignition delay period for biodiesel blend by the higher temperature prevalent in the coated engine combustion chamber resulting in, increased peak pressure.

3.2 Heat release rate

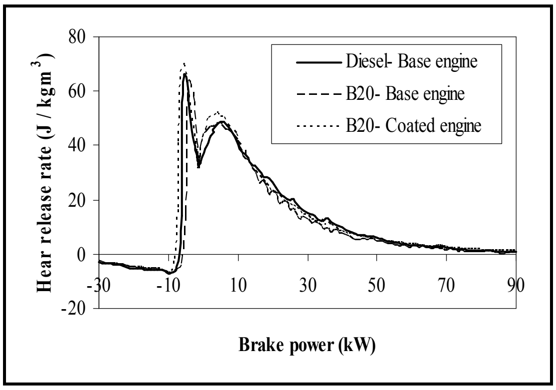

Figure 4 Variation of heat release rate with CA at full load

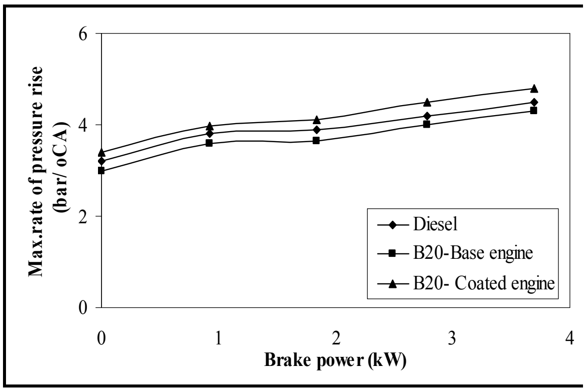

Figure 5 Variation of maximum rate of pressure rise with BP

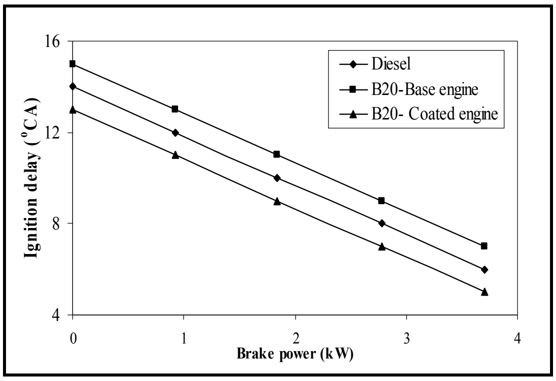

Figure 6 Variation of Ignition delay with BP

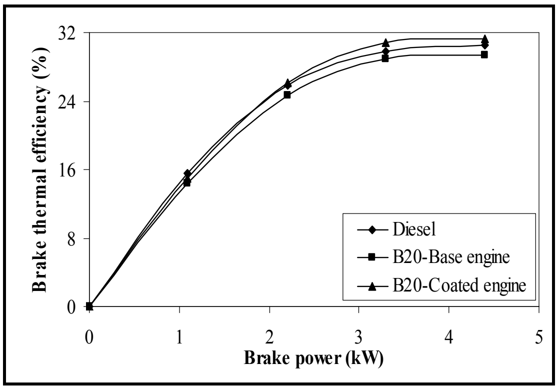

Figure 7. Variation of brake thermal efficiency with BP

The variation of peak cylinder pressure with crank angle at maximum power output is shown in Figure 4. It is observed that B20 with base engine have lower heat release and it is higher for coated engine compared with diesel fuel. It can be seen that the combustion is more pronounced at the diffusion phase rather than premixed phase with biodiesel blend. The premixed burning phase is more with diesel for base engine. The higher viscosity of biodiesel blend resulted in poor atomization and vaporization and lead to reduction of air entrainment and fuel air mixing rates compared with diesel. Hence more burning occurred in the diffusion phase. However, biodiesel blend with coated engine indicated improvement in heat release rate at the premixed combustion period as a result of improvement in combustion. The maximum heat release for diesel and biodiesel blend is 66.3 kJ/kgm3 and 63.4 kJ/kgm3 and for the coated engine with biodiesel blend is 70 kJ/kgm3 at maximum power out put.

3.3 Maximum rate of pressure rise

Figure 5 depicts the variation of maximum rate of pressure rise with brake power for both the engine at full load. The rate of pressure rise depends on the combustion rate in the initial stages, which, in turn, is influenced by the amount of fuel taking part in the uncontrolled combustion. The uncontrolled or premixed combustion phase is governed by the delay period causing, a higher value of the maximum rate of pressure rise. In diesel fuel engine, the lower ignition delay leads to a high premixed heat release rate and rate of pressure rise. The maximum rate of pressure rise for diesel and B20 is 4.5 bar/^{o}CA and 4.3 bar/^{o}CA respectively with the base engine, whereas for the coated engine with B20 is 4.8 bar/^{o}CA at full load. It is observed that the maximum rate of pressure rise for B20 with coated engine increased by 0.3bar/^{o}CA and 0.5 bar/^{o}CA respectively with diesel and B20 compared with base engine at maximum power output. This may be due to the high temperature of the combustion chamber leading to the less accumulation of fuel which decreases the ignition delay period and increases the rate of pressure rise.

3.4 Ignition delay

Figure 6 illustrates the variation of the ignition delay with brake power for both the engine. The ignition delay decreases with the increase in the load for all the test fuels. Ignition delay is calculated as the period from the start of injection to the start of combustion in terms of the crank angle. The ignition delay for diesel and B20 with the base engine is 6^{o}CA and 7^{o}CA respectively, whereas for coated engine with B20 is 5^{o}CA at full load. It is observed that B20 with coated engine resulted in reduced ignition delay at all power outputs as compared to base engine due to better vaporization of the fuel as a results of high temperature of the combustion chamber.

3.5 Brake Thermal Efficiency (BTE)

Brake thermal efficiency indicates the ability of the combustion system to accept the experimental fuel, and provides the comparable means for assessing how efficiently the energy in the fuel was converted in to mechanical efficiency. Figure 7 shows the variation of the brake thermal efficiency with brake power for the coated and base diesel engine. It is observed that the brake thermal efficiency obtained for diesel and B20 blend are 30.48% and 29.4% respectively for the base engine, whereas for B20 is 31.24% with coated engine at maximum power output. The brake thermal efficiency of B20 with coated engine is increased by 2.4% and 6.2% than diesel and B20 respectively with base engine at maximum power out put. The increase in BTE for the coated engine with biodiesel blend may be due the higher combustion peak temperature by the coated piston and reduction in heat loss from the combustion chamber by the insulated piston, resulting in complete combustion of biodiesel blend and thus increased brake thermal efficiency.

3.6 Brake specific fuel consumption (BSFC)

The variation of brake specific fuel consumption with brake power for the all the tests fuels is shown in Figure 8. The brake specific fuel consumption for diesel and B20 blend are 0.293kg/kW-h and 0.305kg/kW-h with base engine and for the coated engine with B20 is 0.28kg/kW-h at maximum power output. It is observed that for the coated engine, the BSFC is decreased by 4.4 % and 8.5% for the B20 blend compared with base engine at maximum power output. This may be due to the reduction of heat loss from the combustion chamber by the insulated piston, resulting in increases the combustion chamber peak temperature and thus reduction in BSFC at maximum power output.

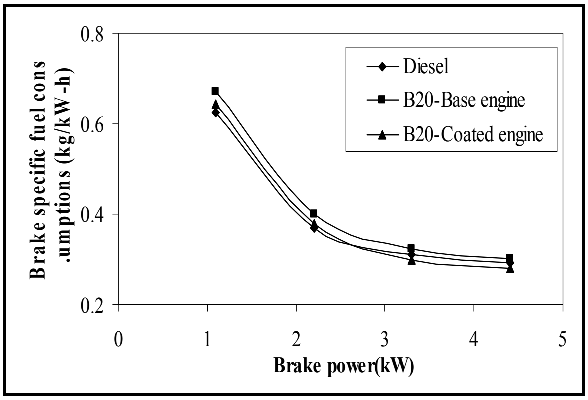

Figure 8. Variation of brake specific fuel consumption with BP

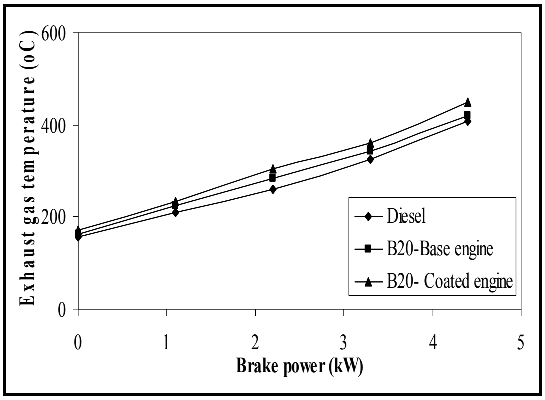

Figure 9. Variation of exhaust gas temperature with BP

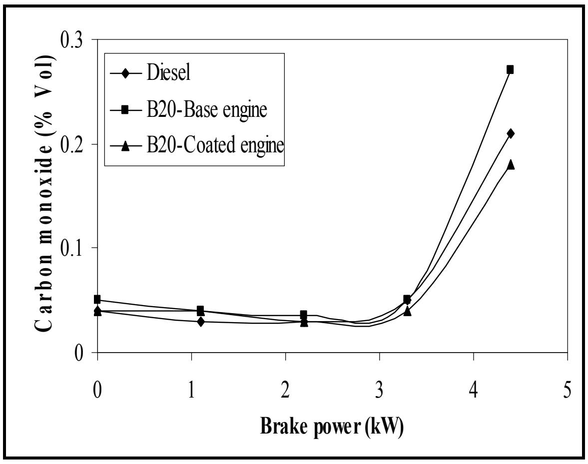

Figure 10. Variation of carbon monoxide emissions with BP

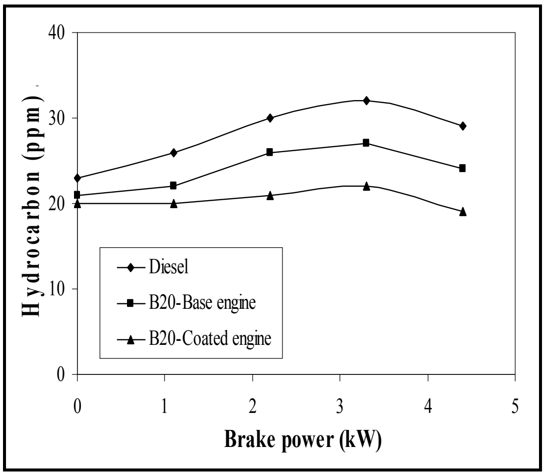

Figure 11. Variation of hydrocarbon emissions with BP

3.7 Exhaust gas temperature

Exhaust gas temperature is an important parameter because it allows estimating the temperature within the combustion chamber. These values are approximate because variations occur in the exhaust gases between the combustion chamber and the point at which measurements were done. Figure 9 depicts the variation of the exhaust gas temperature with brake power. The exhaust gas temperature for base engine with diesel and B20 are 408^{o}C and 420^{o}C respectively and for the B20 with coated engine is 448^{o}C at maximum power. The exhaust gas temperature for the coated engine for B20 is increased by 5.4% and 8.4% compared with diesel and biodiesel blend with base engine respectively at full load conditions. The increase in exhaust gas temperature may be due to the fuel is released more heat energy when the load is increases. The increase in exhaust gas temperature for the biodiesel blend may be due to the higher combustion temperature for the coated piston at maximum power conditions.

3.8 Carbon monoxide emissions (CO)

Figure 10 illustrates the variation of the carbon monoxide emission with brake power. The CO emission obtained for the base engine uncoated engine with diesel and biodiesel are 0.17% and 0.11% respectively and for the coated piston engine operation with B20 is 0.09 at maximum power output. It is observed that the CO emissions are lower at low loads and are higher at full load conditions for the both the piston engine operations. The decrease in CO emission for the coated engine with B20 may be due to complete combustion of bio diesel blend in insulated environment in the combustion chamber by the PSZ coated piston and cylinder head and more oxygen molecules present in the biodiesel. The CO emission decreased by 47% and 28% respectively for B20 fuel with coated engine compared to base engine with diesel and B20 respectively at full load.

3.9 Hydro carbon emissions (HC)

The variation of the hydrocarbon emissions with load for the coated and uncoated engine is shown in Figure 11. The HC emission for the base engine with diesel and B20 are 29 ppm and 24 ppm respectively, whereas for the B20 with coated engine it is 19 ppm at maximum power output. The HC emissions are decreased for B20 biodiesel blend with coated engine compared to base engine. It is observed that HC emissions are decreased by 35% and 21 % for B20 biodiesel blend with coated engine compared to base engine with diesel and biodiesel respectively at maximum power output. This decrease in hydrocarbon emissions may be due to higher cetane number of biodiesel blend and the high temperature in the combustion chamber by the PSZ coated piston engine, resulting in complete combustion of biodiesel.

3.10 Nitrogen oxide emissions (NO)

The high combustion temperature and inherent availability of nitrogen and oxygen from fuel and intake charge create favourable condition in accelerating the reaction to result into for more nitrogen oxide emission to release. This is the reason for increased NO concentrations in thermal barrier coated engine. Figure 12 shows the variation of oxides of nitrogen with load for the coated and base engine with biodiesel blends. The NO emission for the base engine with diesel and B20 are 1031 ppm and 1118ppm respectively and for the coated piston with B20 is 1210 ppm at maximum power out put conditions. It is seen that the NO emission is increased by 18 % for B20 blend with coated piston compared to base engine with diesel at full load. The increase in NO emissions may be due to higher combustion temperature by PSZ coated piston engine and inherent availability of oxygen in the biodiesel in the combustion chamber, resulting in complete combustion of biodiesel.

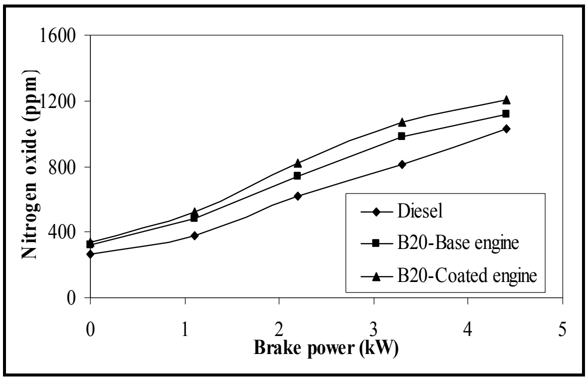

Figure 12. Variation of nitrogen oxide emissions with BP

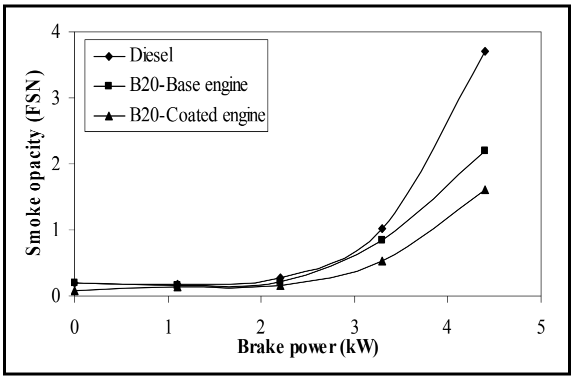

Figure 13. Variation of smoke opacity with BP

3.11 Smoke emission

Figure 13 shows the variation of smoke opacity with load for diesel and bio diesel blend. The smoke opacity increases with increase in load. The smoke opacity for B20 blend decreases with coated and standard engine at maximum power output. The maximum smoke opacity obtained for diesel and B20 are 3.7FSN and 2.2 FSN with standard engine and for the coated engine with B20 is 1.6 FSN at maximum power output. It is seen that the smoke opacity decreased by 58% for B20% blend with coated engine compared to base engine with diesel at maximum power output. The reduction in smoke opacity may be due to more oxygen molecules present in the biodiesel and higher combustion temperature by the PSZ coated piston, resulting in more complete combustion oxidation of the biodiesel blend.

4. Conclusions

The experimental test have been conducted on a single cylinder direct injection diesel engine with diesel and B20 blend with base engine and partially stabilized coated piston diesel engine at different load conditions. The following conclusions were drawn from the experimental results.

1. The brake thermal efficiency of B20 is increased by 2.4% and 6.2% compared to diesel and B20 respectively with the base engine at maximum power out.
2. The BSFC is decreased by decreased by 8.5% for the B20 blend compared to diesel with base engine at maximum power output. The exhaust gas temperature for the coated engine for B20 is increased by 8.4% compared with diesel and blend respectively with base engine.
3. The CO and HC emissions decreased by 47% for 35% for B20 blend respectively with coated engine as compared base engine with diesel at maximum power output.
4. The NO and smoke emissions decreased by 18 % and 58% for B20 blend respectively with coated engine as compared to diesel with base engine at maximum power output.
5. The peak pressure, maximum rate of pressure rise and heat release rate were increased and ignition delay was decreased for B20 with coated engine and compared with base engine with diesel at full load.
6. On the whole, in concluded that the coated engine (semi adiabatic mode) operations with biodiesel blend improved the combustion and performance characteristics and drastically reduced the exhaust emissions with slightly increased in NO emissions.

References

1. Ramadhas A.S., Jayaraj S and Muraleedharan C., Characterization and effect of using rubber seed oil as fuel in compression ignition engines, Renewable Energy., 2005, 30,795-803.
2. Narayana Reddy J and Ramesh A., Parametric studies for improving the performance of a Jatropha oil-fuelled compression ignition engine, Renewable Energy., 2006, 31, 1994-2016.
3. Raheman H and Ghadge S.V., Performance of compression ignition engine with mahua (Madhuca indica) biodiesel, *Fuel.,2007,* 86, 2568–2573.
4. SahooP.K., Das L.M., Babu M.K.G and Naik S.N., Biodiesel development from high acid polanga seed oil and performance evaluation in a CI engine, Fuel., 2007, 86, 448-454.
5. Lakshmi Narayana Rao G., Saravanan S., Sampat S and Rajagopal K., Combustion and emission characteristics of diesel engines fueled with rice bran oil methyl ester and its diesel blends. Thermal Science., 2008, 12, 139-150.
6. Suresh Kumar K.R., Velraj R., Ganesan R., Performance and Exhaust emission characteristics of a CI engine fueled with Pongamia pinnata methyl ester and its blends with diesel, Renewable energy., 2008, 33, 2294-2302.
7. Rajan K., Senthil Kumar K.R., Performance and Emission Characteristics of Diesel Engine with Internal Jet Piston using Biodiesel, International Journal of Environmental Studies., 2010, 67 (4), 556-567.
8. Usta N., Ozturk E., Can O., Conkur E.S., Nas S., Con A.H., Con A.C and Topcu M., Combustion of biodiesel fuel produced from hazelnut soapstock/waste sunflower oil mixture in a diesel engine,Energy Conversion Managemetnt., 2005, 46, 741-755.

9. Satyanarayana Y.V.V., Murthy G.R. K., Sastry M. R. S., Satyanaryana., 'Experimental Investigation of Performance and Emissions on Low Speed Diesel Engine with Dual Injection of Solar Generated Steam and Pongamia Methyl Ester', Indian Journal of Science and Technology., 2011, 4(1), 29-33.
10. Hemanandh J and Narayanan K.V., Experimental Studies of Emissions in a CI Engine Blended with Refined Sunflower Oil, Indian Journal of Science and Technology., 2013, 6 (7), 4954-4959.
11. Pugazhvadivu M., Studies on the effect of ethanol addition to biodiesel: Performance and emissions of a diesel engine, Indian Journal of Science and Technology., 2009, 2 (11), 23-26.
12. Hanumantha Rao Y.V., Ram Sudheer Voleti A.V., Sitarama Raju and Nageswara Reddy P., Experimental investigations on Jatropha biodiesel and additive in diesel engine. Indian Journal of Science and Technology., 2009, 2(4), 25-31.
13. Kamo R., Bryzik W and Reid M., Coatings for improving engine performance. SAE Transactions., 1997, 970204.
14. Boehm G and Harrer J., Nickel Coated Pistons for Improved Durability in Knock Control Engines"- SAE Transtactions., 1990, 900453, 1031-103.
15. Rajan K and Prabhahar M., Performance and combustion characteristics of a diesel engine with titanium oxide coated Piston using Pongamia methyl ester, Journal of Mechanical Science and Technology., 2013, 27 (5), 1519-1526.
16. Banapurmath N.R and Tewari P.G., Performance of a Low Heat Rejection Engine Fuelled with low volatile honge oil and its methyl ester (HOME), Proceedings Inst. of Mech. Eng., Part A: Journal of Power and Energy.,2008, 222 (3), 323-330.
17. John B Heywood., Internal combustion engine fundamentals Mc Graw Hill Publishers. New York, USA.1998.

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