PERFORMANCE ANALYSIS OF COMPRESSION IGNITION ENGINE USING RUBBER SEED OIL METHYL ESTER BLEND WITH THE EFFECT OF VARIOUS INJECTION PRESSURES

by

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Original scientific paper
DOI: 10.2298/TSCI16S4083S

Biodiesel is an alternate fuel for Diesel engine due to its properties is close to diesel fuel. Also it is biodegradable, non-toxic, and renewable in nature. In the present work, the performance, emission, and combustion characteristics of a Diesel engine using diesel and 25% rubber seed oil methyl ester diesel blend have been investigated with the effect of different injection pressures like 200 bar, 225 bar, and 250 bar with different load conditions. The biodiesel was prepared from raw rubber seed oil using transesterification process. The performance and emissions parameters were measured and compared with diesel and B25 blend with standard injection pressure of 200 bar. The results showed that the brake thermal efficiency for 25% rubber seed oil methyl ester is increased with 250 bar injection pressure compared to other injection pressures. It is closer to diesel fuel operation with standard injection pressure of 200 bar injection pressure at full load. The carbon monoxide, hydrocarbon, and smoke were decreased for the injection pressure 250 bar, whereas the NO emission is increased at full load compared to other injection pressures. The cylinder peak pressure, heat release rate are increased for 25% rubber seed oil methyl ester and the ignition delay is decreases with increase in injection pressures.

Key words: *Diesel engine, rubber seed oil methyl ester, emissions, injection pressure, performance*

Introduction

Compression ignition engines are mainly used for automotive passenger cars and trucks, power generation, and agricultural sectors. This is due to its better fuel economy and high part load efficiency. Diesel engine emits lower HC and CO emissions. The particulate matter and NO_x emissions are high for Diesel engines. Increasing cost petroleum fuels, fast depletion of petroleum reserves, and environmental degradation by the automotive pollution and stringent emission norms have forced us to search for alternative fuel for Diesel engines. Many researches have been carried out on the performance of engines fueled with vegetable oil and its methyl esters. The disadvantage of using vegetable oil is carbon deposits on piston crown and

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nozzles, sticking of piston rings and cylinder liner and, *etc*. [1-4]. Dorado *et al*. [4] studied the use of olive oil biodiesel in Diesel engine. Their results showed that the CO and HC emissions are lower for biodiesel and its blends. The performance and emission characteristics of Diesel engine with biodiesel were improved by using internal jet piston by Rajan and Senthil Kumar [5]. They reported that the brake thermal efficiency (BTE) increased, the CO and smoke emissions decreased at full load. The NO emission increased with internal jet piston using neat bio diesel at full load.

Park *et al.* [6] have investigated the combustion and exhaust emissions characteristics of biodiesel fuel in a Diesel engine and found that the soot, HC, and CO emissions decreased, while NO_x emissions increased and the power output was increased with single-injection mode. Tan *et al*. [7] have tested the regulated and unregulated emissions with diesel fuel and Jatropha based biodiesel blends. The biodiesel blends showed slight increase in NO_x emissions at medium and high engine loads. The CO emission increases for neat biodiesel at low engine loads and reduction in HC emissions at higher biodiesel blends. Selvam and Vadivel [8] have investigated the use of methyl esters and reported that BTE decreased and increase in specific fuel consumption for all the blended fuels. The CO, HC, and smoke density were decreased for neat biodiesel and the oxides of nitrogen emission increased slightly for all the blends compared to diesel fuel. The fuel droplets are broken into fine particles which help in better mixture formation of fuel and air during ignition period with increases in injection pressures. This will results in increase in performance and decrease in exhaust emissions. High-pressure injection with small orifice can achieve lean combustion which creates better fuel atomization, evaporation, resulting in reduction in soot emissions [9, 10].

Many researchers [11-13] investigated the effect of injection pressure in the range of 160-220 bar on the emission characteristics of a Diesel engine using diesel-biodiesel blends. The BTE and NO emissions were increased and the brake specific fuel consumption (BSFC), CO, HC, and smoke emissions decreased with the increase in injection pressure from 160-220 bar. They optimized that the injection pressure 220 bar produce better performance and reduction in emissions. Many researchers found that effect of injection pressure on the emission characteristics of a Diesel engine using *pongamia pinnata* blends with diesel and reported that CO, HC, and smoke emissions reduced but the NO emissions increased with increase in injection pressure at full load [14-16]. The objective of this present research work is to investigate the performance, emission, and combustion characteristics of a single cylinder Diesel engine with diesel and 25% of rubber seed oil methyl ester (RSOM) diesel blends (B25) with different fuel injection pressures like 200 bar, 225 bar, and 250 bar. The measured values are analyzed and compared with diesel fuel and B25 of rubber seed oil diesel blends.

Preparation of rubber seed oil methyl ester

The raw rubber seed oil (RSO) was considered for biodiesel preparation. In this process, RSO oil was heated in an open beaker to a temperature of 100-110 °C to remove water particles present in oil followed by filtration. The oil was mixed with 200 ml of methanol and 8.0 grams of sodium hydroxide crystals in a round bottom flask to make sodium methoxide solution. Then this solution is heated on a hot plate magnetic stirring arrangement for 1-1.5 hours up to 60 °C with constant speed. It is allowed to settle down for eight hours to obtain biodiesel and glycerol. After that this mixture is taken out and poured into the separating funnel, soon the glycerol component of the mixture starts settling at the bottom. The bottom layer is separated out, which is glycerol without disturbing the funnel, the layer which is retained in the separating funnel is methyl ester of RSO. Then the methyl ester was washed with distilled water to remove excess methanol from the biodiesel. This process improved the important fuel properties like viscosity, flash point and cetane number of the biodiesel. The properties of diesel, RSO, and its methyl ester are listed in tab. 1.

Table 1. Properties of diesel, RSO, and its methyl ester

Properties	Diesel	RSO	RSOME
Specific gravity	0.830	0.920	0.882
Kinetic viscosity at 40 °C, [cSt]	3.720	52	5.19
Flash point, [°C]	52	175	157
Fire point, [°C]	60	184	163
Calorific value [kJkg^{-1}]	43000	36550	38830
Cetane number	48	38	52

Experimental set-up and procedure

The experimental tests were conducted in a four stroke single cylinder direct injection Diesel engine running at a constant speed of 1500 rpm. The specifications of the test engine are shown in tab. 2. The engine was coupled with swinging field electrical dynamometer with load bank. The exhaust emissions of CO, HC, and NO were measured with the use of AVL-444 gas analyser. The smoke opacity was measured with the help of AVL-437 smoke meter. The K-type thermocouples were used to measure the exhaust gas temperature. The in-cylinder pressure was recorded at every crank angle (CA) with by a piezo electric pressure, which was coupled with the charge amplifier transducer in the range of 0-100 bar. An encoder was mounted on the crankshaft. The in-cylinder pressures were averaged for 100 cycles to calculate the heat release rate. The fig. 1 shows the schematic view of the experimental set-up used for this study. The errors in the measured and calculated parameters are given in tab. 3. The smoke level was measured using AVL-437 Hatridge smoke meter.

Table 2. Test engine specifications

Particulars	Description
Engine	Kirloskar, AV 1
No. of cylinder	Single
Bore diameter, [mm]	80
Stroke length, [mm]	110
Compression ratio	17.5:1
Rated power, [kW]	4.44
Speed, [rpm]	1500
Dynamometer	Electrical
Injection pressure, [bar]	200

Results and discussion

The experiment was conducted on a 4-stroke single cylinder direct injection water-cooled Diesel engine using diesel and 25% of RSOME with with different injection pressures like 200 bar, 225 bar, and 250 bar from no load to full load conditions in the steps of 25%. The performance, emissions, and combustion parameters are analysed and compared with diesel and B25 fuels with standard injection pressure.

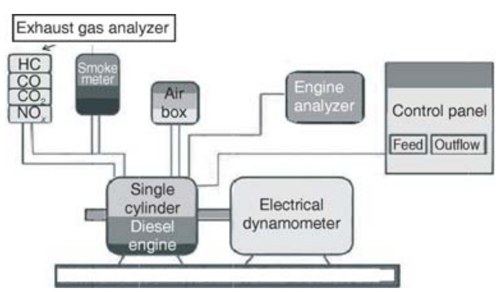

Figure 1. Schematic of experimental set-up

Combustion analysis

The cylinder pressure variations with CA at full load for the diesel and B25 with different injection preesures is shown in fig. 2. It is obsreved that the peak pressure for 25% RSOME with 225 bar is 71.2 bar, whereas for the diesel and B25 with standard injection pressure is 68 bar and 66.2 bar, respectively, at full load. The increased peak pressure for B25 with 250 bar may be due to better atomization of fuel particles at higher injection pressure, resulting in increased peak pressure in the premixed combustion phase. Also the physical delay decreases for

Table 3. Errors in the measurements

Parameters	Maximum errors
BTE	1.01
BSFC	1.01
EGT	1.28
CO	0.2
HC	0.15
NO	1.01
BTE	1.01
BSFC	1.01
EGT	1.28

the blend due to this higher injection pressures. The maximum rate pressure rise variations are shown in fig. 3 for diesel and RSOME blends. The maximum rate of pressure rise obtained for B25 with 250 bar injection prssure is 4.6 bar/°CA, whereas for diesel and B25 with standard injection pressure are 4.8 bar/°CA and 4.4 bar/°CA, respectively, at full load.

The variation of heat release rate with CA at full load is presented in fig. 4. For the diesel and and B25 with standard injcetion pressure, the heat release rate is 67 kJ/m^3 and 62.3 kJ/m^3, respectively, at full load, whereas for B25 with 250 bar and 225 bar it is 71 kJ/m^3 and 68 kJ/m^3, respectively, at full load. It is clear that the premixed combustion phase for B25 with higher injection pressure is higher than other injection pressures. This is due to better atomization of fuel particles, which easily penetrates in the air resulting in increase in premixed combustion pahse.

Ignition delay is calculated between the duration of start of injection of fuel to the start of combustion of the fuel. The ignition delay variations with brake power (BP) is shown in fig. 5. The maximum ignition delay period is achived for diesel and B25 with standard injection pressure is 6 °CA and 7 °CA, respectively, at full load, whereas for B25 with 225 bar and 250 bar is 5.8 °CA and 5.3 °CA, respectively, at full lad. It is noticed that the ignition delay is decreased with increase in injection pressure and at all loads. The ignition delay includes both the physical and chemical delay periods. The physical delay is reduces considerably with the increase in injection pressures and it may be due to the reduction in viscosity at high temperatures.

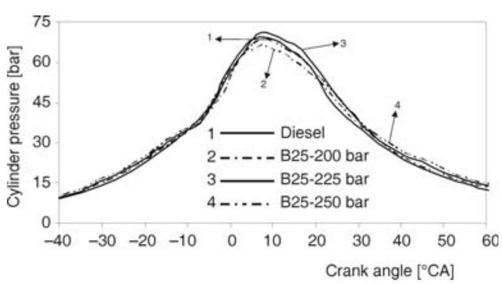

Figure 2. Variation of cylinder pressure with CA

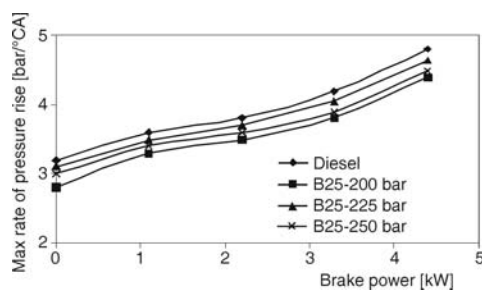

Figure 3. Variation of maximum rate of pressure rise with BP

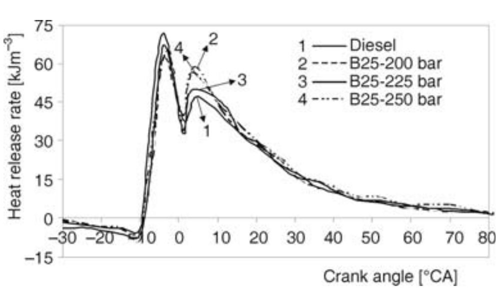

Figure 4. Variation of heat release rate with CA

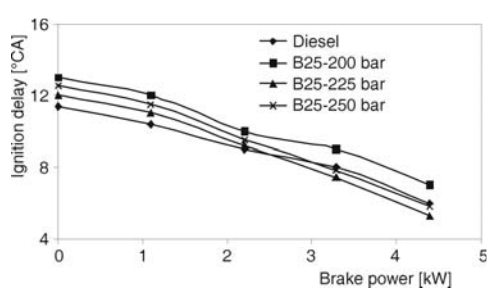

Figure 5. Variation of ignition delay with BP

Performance analysis

Figures 6 and 7 illustrates the variations of BTE and BSFC with BP for diesel and biodiesel blend, respectively. For the increase in injection pressures the BTE is increased for B25 blend. It is noticed that the maximum BTE is obtained for 250 bar with 20% biodiesel blend is 29.62% compared with the other two injection pressures. The BTE for biodiesel with 200 bar and 225 bar is 28.84% and 29.28%, respectively, at maximum power output, whereas for diesel it is 30.28%. The BTE for B25 biodiesel with 250 bar injection pressure is increased by 2.7% and 1.5% compared with B25 with standard injetion pressure of 200 bar and 225 bar injection pressures, respectively, at maximum load and the it is lowered with diesel fuel. The reason for increase in BTE may due to increase in injection pressure. The higher injection pressur results the fuel droplets are properly atomized and mixed with air, resulting in increased BTE with higher injection pressures than that of standard injection pressure.

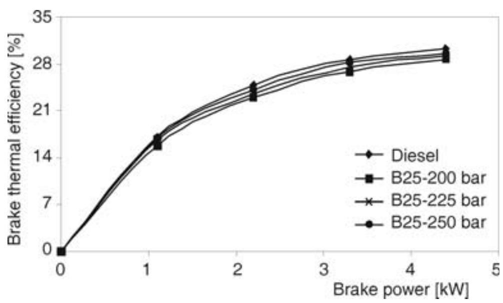

Figure 6. The BTE variation with BP

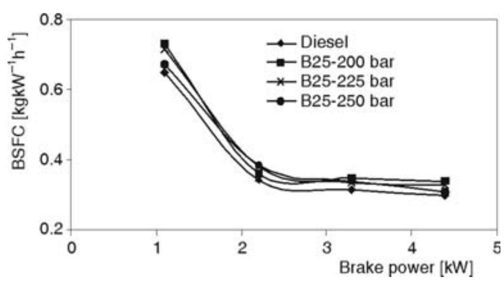

Figure 7. The BSFC variation of with BP

The BSFC of biodiesel blend lowered with increase in injection pressure at maximum load conditiona. The BSFC for B20 with 250 bar injection pressure is decreased by 9% and 5%, respectively, with standard injection pressure of 200 bar and 225 bar, respectively, and it is higher than diesel fuel at full load. The decrease in BSFC may be due to better atomization and vaporization of fuel particles at higher injection pressures. Also the increase in BSFC compared with diesel fuel may be due to lower energy content of the fuel blend. The maximum BSFC obtained for B20 with standard injection pressure of 200 bar, 225 bar, and 250 bar are 0.34, 0.324, and 0.31 kg/kWh, respectively, and it is 0.298 kg/kWgh for diesel at maximum power output.

Emission analysis

The CO emissions with BP for various injection pressures are presented in fig. 8. The CO emission lowered with higher injection pressures for B25 with load and it is obtained higher values at maximum load. The CO emission decreases with increase in injection pressure for 25% biodiesel at maximum load conditions. The maximum CO emissions obtained for B25 with 200 bar, 225 bar, and 250 bar injection pressures are 0.14 vol.%, 0.12 vol.%, and 0.1 vol.%, respectively, and it is 0.17 vol.% for diesel at maximum load. The CO emission for B20 biodiesel with 250 bar is decreased by 42% and 30% compared to biodiesel with 200 bar and 225 bar, respectively, at maximum load conditions. The reason behind for that the biodiesel contains more oxygen molecules and better atomization of fuel particles at higher injection pressures, resulting in better combustion of biodiesel.

Figure 9 illustrates the of HC emission with BP for various injection pressures for both the fuels. The HC emissions obtained for B25 is higher compared with B25 with other injection pres-

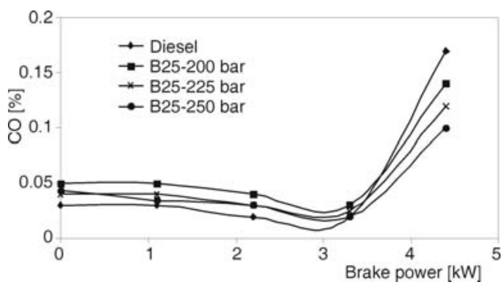

Figure 8. The CO emission variation with BP

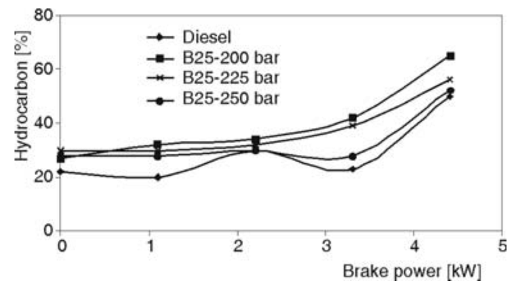

Figure 9. The HC emissions variation with BP

sures. The maximum HC emissions obtained for B25 with 200 bar, 225 bar, and 240 bar injection pressures are 65 ppm, 56 ppm, and 52 ppm, respectively, and for diesel it is 50 ppm at full load. There is 20% and 14% reduction in HC emission for 25% biodiesel with 250 bar injection pressure compared to 200 bar and 225 bar injection pressures, respectively, with B25 at full load. This is because of better atomization of fuel particles at higher injection pressures and also the more oxygen contents present in the biodiesel, which leads to improved combustion of biodiesel blend.

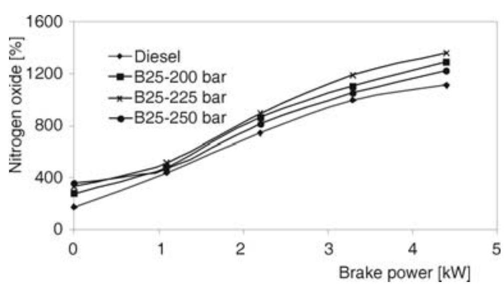

Figure 10. The NO emission variation with BP

The NO emissions with BP for various injection pressures in depicted in fig. 10. The formation of NO_x is strongly dependent upon in-cylinder combustion temperature and the availability of atmospheric oxygen presents during combustion process. It is noticed that the NO emissions for B25 increases with increase increase in injection pressures. The reason behind is due to the higher heat release rate in the premixed combustion. At higher injection pressure of 250 bar, the NO emission decreases slightly, because of lower peak cylinder pressure arises due to lesser heat release rate during combustion process, which leads to lesser spray penetration inside the combustion chamber. The NO for B25 with 250 bar injection bar is decreased by 5% and 10%, respectively, compared with 200 bar and 225 injection pressures, respectively, with B25 at full load. The maximum NO emission obtained for B25 with 200 bar, 225 bar, and 250 bar are 1289 ppm, 1360 ppm, and 1222 ppm, respectively, and for diesel it is 1110 ppm at full load.

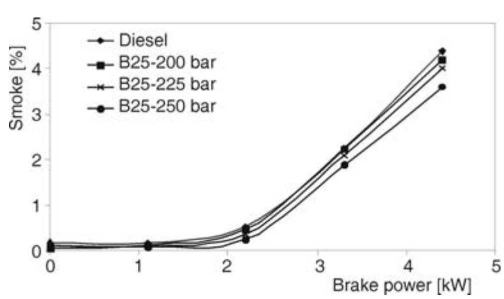

Figure 11. Smoke opacity variaton with BP

Figure 11 shows the smoke opacity with load for different injection pressures for the fuels. The solid carbon particles are generated in the fuel-rich zones within the cylinder during combustion process of Diesel engine. The smoke opacity increases with an increase in the load and decreases with increase in injection pressures for B25 biodiesel blend with all injection pressures. The smoke emission decreased by 18% and 15% for B25 biodiesel with diesel and B25, respectively, with standard injecction pressure of 200 bar at full load. This may be due to better atomization and vaporization of biodiesel at higher injection pressures and also more oxygen atoms present in the biodiesel resulting in better combustion. The smoke opacity of B25 with 200 bar, 225 bar, and 250 bar injection pressure are 4.2%, 4%, and 3.6%, respectively, and for diesel it is 4.38% at full load.

Conclusions

The engine tests were conducted with 25% RSOME blend with different and combustion characteristics of a Diesel engine. The following conclusions were arrived from the experimental results.

- The cylinder peak pressure, heat release rate, and maximum rate of pressure rise is higher for 25% RSOME with 250 bar increased by 2.1% and 1.5% with 200 bar and 225 bar injection pressures and the ignition delay is decreased with increase in injection pressures.
- The BTE of 25% RSOME with 250 bar increased by 2.1% and 1.5% with 200bar and 225 bar injection pressures with B25 at full load. The BSFC are also decreased by 9% and 5% for 25% RSOME for the injection pressure 250 bar compared with other two injection pressures 200 bar and 225 bar, respectively.
- The CO emissions decreased about 42% and 40% for 25% RSOME with 250 injection pressure compared with other two injection pressures 200 bar and 225 bar, respectively.
- The HC emissions decreased about 20% and 14% for 25% RSOME with 250 injection pressure compared with other two injection pressures 200 bar and 225 bar, respectively.
- The NO emissions are decreased about 10% and 5% for 25% RSOME with 250 injection pressure compared with other two injection pressures 200 bar and 225 bar, respectively.
- The smoke opacity was decreased by 18% and 15% 25% RSOME with 250 injection pressure compared with other two injection pressures 200 bar and 225 bar, respectively.
- On the whole, it is concluded that the engine produced better performance and drastic reduction in exhaust emissions at injection pressure 250 bar and also imroved combustion with 25% RSOME fuel compared with other injection pressures without any change in hardwares of the Diesel engine.

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Paper submitted: September 15, 2015
Paper revised: January 12, 2016
Paper accepted: February 4, 2016