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Combustion and performance analysis of variable compression ratio engine fueled with preheated palm oil - diesel blends

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The effect of compression ratio on combustion and performance of single cylinder four-stroke variable compression ratio engine, when fueled by pre- heated palm oil and its 5, 10, 15 and 20% blends with diesel, has been investigated and compared with petroleum based diesel fuel (PBDF) . The suitability of palm oil (pre-heated at 90ºC) as fuel has been studied in this work. The brake thermal efficiency at full load in pre-heated palm oil blends and PBDF has been analyzed and the blend O20 (20% preheated palm oil + 80% diesel) is found to give maximum thermal efficiency at the highest compression ratio. Also, the specific fuel consumption of O20 blend is found to be lower than that of PBDF at a higher compression ratio. Exhaust gas temperature is low for all the blends as compared to PBDF. The emission of carbon monoxide and hydrocarbon decreases with an increase in blending ratio and compression ratio. Also CO_2 emission is found to be higher than in PBDF. The combustion parameters of testing fuel blends are also investigated and the results are found to be closer to that of PBDF at a higher compression ratio and full load. The engine performance is found to be optimum using O20 as fuel at 20:1 compression ratio during full load condition.

Keywords: Combustion, Compression ratio, Emission, Pre-heated palm oil, Palm oil-diesel blend, Variable compression ratio engine

Now-a-days the reserves of traditional petroleum based fuels are very limited, whereas there is an increase in usage of motorization and growing of industrial sector. To overcome such type of problems in the future we need to go for some other alternate solutions like alcohol, biodiesel, vegetable oils, etc. Hence in this research, small amount of raw palm oil is thought to be blended with diesel on volume basis and preheating of vegetable oil is chosen as it is low cost and the processing is easy.

In order to reduce the viscosity of straight vegetable oil, the following four techniques are adopted, namely heating/pyrolysis, dilution/blending, micro-emulsion, and transesterification. Among all these techniques, the transesterification is an extensive, convenient and most promising method for reduction of viscosity and density of the straight vegetable oils. However, this adds extra cost of processing because transesterification reaction involves chemical and process heat inputs[1–5].

Most of the researchers have reported that the preheating of inlet fuel reduces viscosity and can be implemented as indicated by the following results. Agarwal ***et al***.[6] reported that preheating of Jatropha oil reduces the viscosity and also found optimum fuel injection pressure. Bari ***et al***.[7] observed that preheating of crude palm oil up to 90ºC reduces the viscosity, gives smooth flow and avoids fuel filter clogging. Preheating oil with diesel substitute is used for short-term engine operation as also indicated by performance and emissions results[8-9]. Ingle ***et al***.[10] compared the performance of neat and preheated transesterified cotton seed oil with diesel at various temperatures, such as 50, 70 and 90°C and the properties such as viscosity, flash point, pour point were experimentally measured. The results revealed that preheating of cotton seed oil methyl ester up to 90°C at higher load leads to increase the brake thermal efficiency as compared to that diesel. The brake specific fuel consumption increases at higher load as compared to diesel. Senthil Kumar ***et al***.[11] studied the combustion characteristics of animal fat and found that these are closer to diesel, while emissions are found to be lower than diesel. Venkatraman and Devaradjane[12] observed that the increase in compression ratio, injection timing and injection pressure increase the performance with

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lower emissions for pungam methyl ester as compared to diesel. The optimum parameters are also evaluated. They improved the performance of the engine with higher compression ratio, injection timing and injection pressure with lower emissions, which are still lower than with the diesel fuel of different loads and biodiesels[13-14].

From the literature review it can be inferred that a lot of research works have been carried out on evaluating the performance and emission characteristics of different grades of vegetable oils and biodiesels at a standard compression ratio but very little work has been done for evaluating the performance of preheated palm oil. The effect of compression ratio has not been analyzed for the preheated palm oil - diesel blends. This oil has the potential to become an alternate for conventional diesel oil. Hence, the study of the characteristics of preheated palm oil on diesel engine for variable compression ratio is very essential. In the present work, effect of compression ratio and combustion characteristics of preheated palm oil – diesel blended fuel on performance and emission characteristic of fuel has been studied. The results are also compared with petroleum based diesel fuel (PBDF).

Different compression ratios like 16:1, 17:1, 18:1, 19:1 and 20:1 for a full load are used in the study and the results are compared with the finding of standard diesel fuel. The emission parameters such as carbon dioxide (CO_2) and hydrocarbon (HC) are discussed with different compression ratios for different blends at full load conditions.

Experimental Procedure

The experimental setup is shown in Fig. 1. It consists of a single cylinder, four-stroke diesel engine with data acquisition system. It has eddy current dynamometer for loading. The setup is provided with necessary instruments for combustion pressure and crank-angle measurements. The Kistler piezoelectric air cooled pressure transducer and 360 pulse count (ppr) crank angle encoder which measures the combustion pressure and the corresponding crank angle respectively are mounted into the engine cylinder head. The pressure transmitter type 6613CA contains a piezoelectric sensor and an integrated charge amplifier. These signals interface to a computer through engine indicator for pressure - volume diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has a stand-alone panel box consisting of two fuel tanks for multi-fuel test, manometer reading, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for measurement of engine cooling water and calorimeter

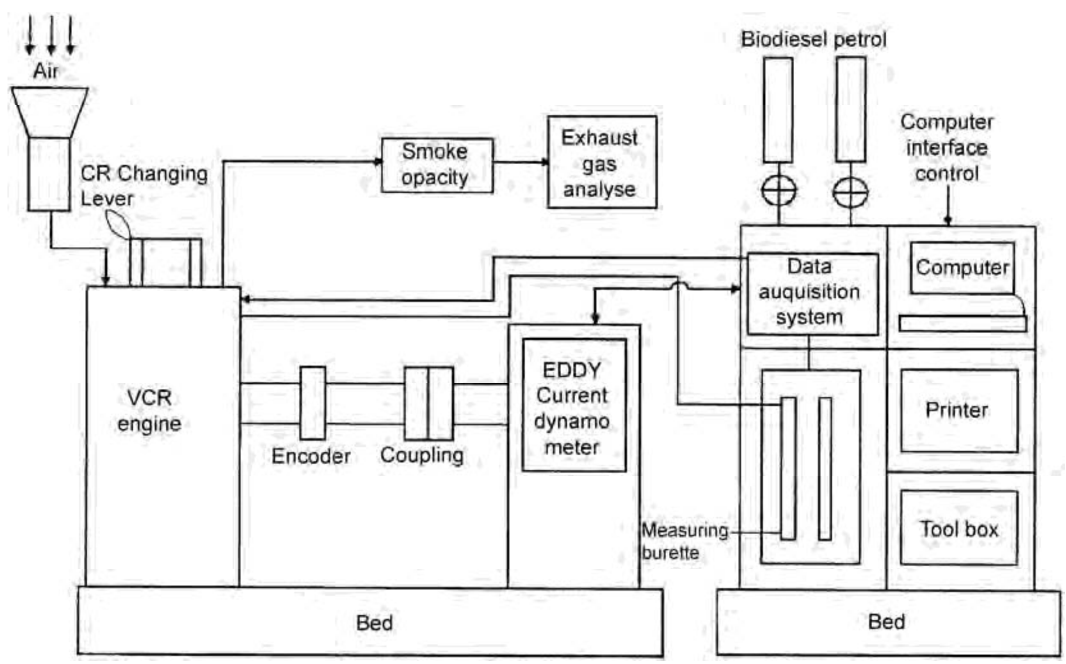

Fig. 1—Schematic diagram of experimental setup

water. The setup enables study of diesel engine performances and combustion parameters. Lab view based engine performance analysis software package "Engine test express V5.75" is used for online performance evaluation. A computerized cylinder in line pressure measurement is optionally provided. The specifications of the variable compression ratio engine[15, 16] are given below:

Type	:	Kirloskar, single cylinder, inline, vertical, Water cooling
No. of strokes	:	Four
Rated power	:	3.7 kW
Bore/stroke	:	80mm/110mm
Rated RPM	:	1500
Compression ratio	:	7:1 ─ 20:1
Injection timing	:	23 º before top dead center
Type of ignition	:	Compression ignition
Method of loading	:	Eddy current dynamometer
Method of starting	:	Manual crank start
Injection opening pressure	:	200 bar

The variable compression ratio engine is started by using diesel and when the engine reaches the stable operating conditions applied with full load. To cool the engine socket, water is used maintaining the flow rate at 60 mL and the cooling water temperature at 40ºC. The tests are conducted at a constant speed of 1500 rpm. In every test, all the performance and combustion parameters are measured. From the initial measurement specific fuel consumption and brake thermal efficiency with respect to compression ratios 16:1, 17:1, 18:1, 19:1 and 20:1 for different blends are calculated and recorded. The combustion and emission levels are also processed and stored in computer for further processing of the results. The same procedure is repeated for different blends of preheated palm oil.

Measurement of fuel properties

Palm oil, derived from the fruits of palm trees, is naturally reddish in color because it contains a high amount of beta-carotene. This oil can be used in diesel engine in two ways, namely (i) transesterification and (ii) preheating and blending with diesel. Among this method (ii), preheating and blending is low cost and convenient. The palm oil was preheated up to 90ºC and the following properties of the preheated oil were measured as per the ASTM standard methods. The smallest amount of preheated palm oil was blended with diesel on volume basis[17-19]. Table 1 shows the properties of diesel and preheated palm oil and Table 2 shows the free fatty acid profile of palm oil.

Results and Discussion

Performance and emission characteristics

The variable compression ratio multi fuel engine performances and emissions are discussed with respect to different compression ratios and full load conditions of the four blends of preheated oils and PBDF. Here, the focus of research is to optimize the engine performance.

Effect on specific fuel consumption

Figure 2a shows the variation of specific fuel consumption (SFC) with different compression ratio for various blends. The specific fuel consumption for O20 blend is lower than that of all other blends at compression ratio 17.7 **-** 20 and for compression ratio 16 **-** 17.6, the blend O15 (15% preheated palm oil+ 85% diesel) shows lower SFC. So, the higher percentages of blends attain lower SFC at higher

Table 1—Fuel properties of PBDF and preheated palm oil

Property	Test method	PBDF	Preheated palm oil at 90ºC
Density, kg/m^3	ASTM-D1298	835	856.1
Viscosity at 40ºC, mPas	ASTM-D445	3.66	8.087
Flash point, ºC	ASTM-D93	65	195
Cetane number	ASTM-D 976	52	49
High calorific value, kJ/kg	ASTM-D2382	44000	39500
Carbon residue, %wt	ASTM-D5291	0.13	0.09
Sulfur content, %wt	ASTM-D5453	0.10	0.04
Acid value (Mg KOH/g)	ASTM-D664	0.18	0.6
Pour point, ºC	ASTM-D 97	15	16

Table 2—Fatty acid profile of palm oil

Analysis	
% of oil in seed or kernel	30-60
Specific gravity	0.921 - 0.925/15°C
Saponification value	196-205
Iodine value	48-58
Melting point	42-45°C
% USM maximum	1.0
Fatty acid composition	
Myristic (Tetradecanoic) C14	0.5-2.0 %
Palmitic (Hexadecanoic) C16	32.0-45.0 %
Stearic (***n***-Octadecanoic) C18	2.0-7.0 %
Oleic (C18:1)	38.0-52.0 %
Linoleic (C18:2)	5.0-11.0 %

compression ratios. The SFC of the blend O20 at the compression ratio 20 is 0.213 kg/kWh, whereas for PBDF it is 0.237 kg/kWh. So, the O20 blend shows 10.27% lower consumption than PBDF. Also the other blends like O5 (5% preheated palm oil +95% diesel), O10 (10% preheated palm oil +90% diesel) and O15 show 6.8%, 9.75% and 2.28% lower consumption than that of PBDF. At compression ratio 17, SFC of PBDF suddenly increases and then decreases gradually, because poor spray formation leads to more fuel getting accumulated in the combustion chamber.

At full load condition the SFC of blend O15 is increased from compression ratio 17:1 to 20:1. This is due to improper mixing of air-fuel (air/fuel ratio is decreased), which leads to incomplete combustion and also results in reduced brake thermal efficiency for CR 17:1 to 20:1 of blend O15 (Fig. 2a). The above observation shows that the specific fuel consumption is inversely proportional to brake thermal efficiency[20].

Effect on brake thermal efficiency

Figure 2b shows the effect of different compression ratio along with different fuel blends on brake thermal efficiency. The results indicate that the brake thermal efficiency of O20 blend is slightly higher than that of the other blends and PBDF. Here the maximum brake thermal efficiency of O20 is 39.33% and for PBDF it is 34.62% at higher compression ratio 20:1. The brake thermal efficiency of other blends (O5, O10 and O15) are also found to be slightly higher than that of PBDF and these are about 38.88%, 37.45% and 36.11% under higher compression ratio and full load conditions. It is observed that on increasing the compression ratio of the engine, the brake thermal efficiency is also increased for all the tested fuels. It has been concluded that the highest brake thermal efficiency is obtained for the blend O20 and compression ratio 20:1.

Effect on emission characteristics

Multi gas analyzer (NETEL make, NPM-MGA-2 model) was used for measuring the exhaust gas emissions. The probe of the analyzer is inserted into the exhaust pipe of the engine before taking the measurements. After the engine is stabilized in working condition, the exhaust emissions are measured. By using this analyzer, carbon monoxide

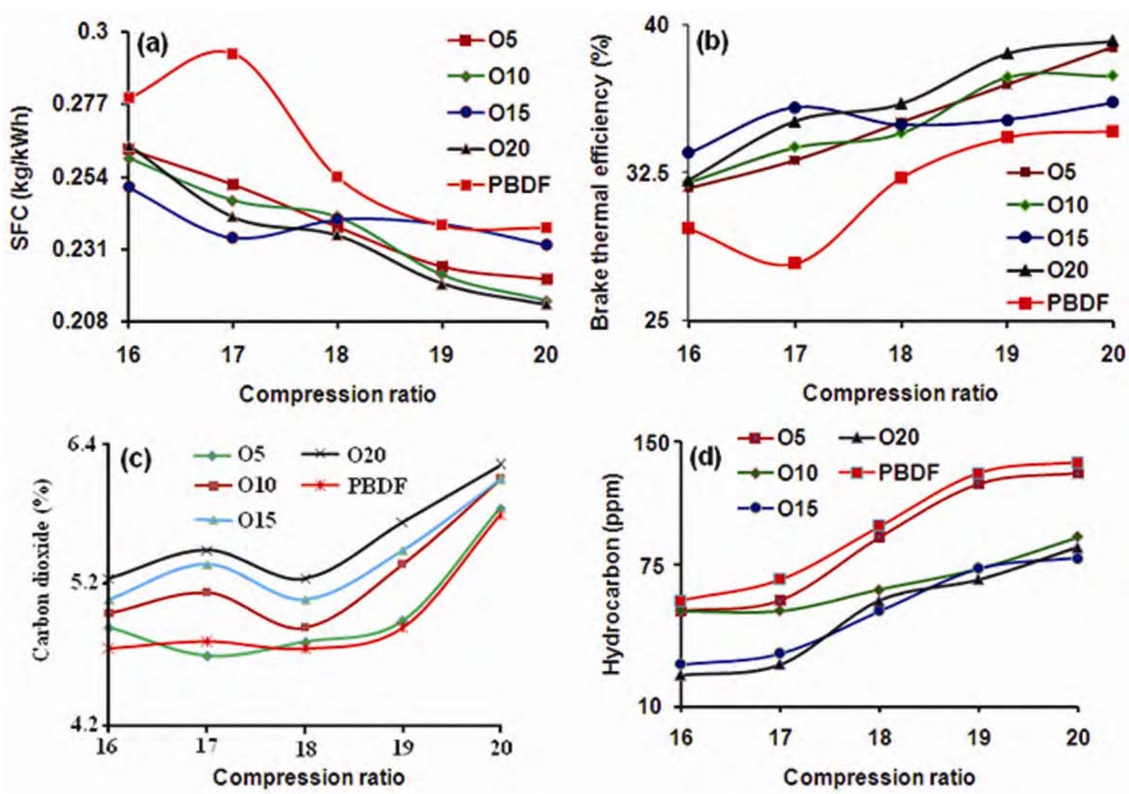

Fig. 2—Variation in (a) specific fuel consumption, (b) brake thermal efficiency, (c) carbon dioxide, and (d) hydrocarbon with compression ratio for different blends

(CO), hydrocarbon (HC), carbon dioxide (CO_2), nitrogen oxide (NOx) and oxygen (O_2) have been measured for different types of preheated palm oil and standard diesel blends for different compression ratios. The emission results of preheated palm oil and diesel blends are within the acceptable limits[21].

The variation in carbon dioxide emission with different compression ratios are shown in Fig. 2c. The tested fuels emit higher amount of CO_2 than by diesel at higher compression ratio 20:1. The other blends O5, O10 and O15 also show higher CO_2 emission than diesel. The more amount of CO_2 is an indication of complete combustion of fuel in the combustion chamber. However, more amount of CO_2 is not much harmful to humans but is leading to higher ozone depletion potential and global warming.

Figure 2d shows the variation in hydrocarbon emission with different compression ratios of the different blends and diesel. The hydrocarbon emission of different blends is higher at a higher compression ratio. Increasing compression ratio increases HC emission for PBDF and O5 blend. For the blend O10, it shows 21.21%, for O15 blend 27.27% and for O20 blend 24.24% lower hydrocarbon emissions than that of PBDF. This is due to longer ignition delay, and more fuels accumulate in combustion chamber which may lead higher hydrocarbon emission[22].

The various Indian standards emission norms are: for CO IS 13270 1992 (reaffirmes 1999), for CO_2 IS 11293 1992 and for NOx IS11255 – (PART 7) – 2005.

Combustion characteristics

Effect on heat release rate

Figure 3a shows the variation in heat release rate with respect to crank angle for compression ratio 19:1 and different preheated palm oil blends. It is observed that the heat release rate is increased at lower compression ratio and then it is slightly decreased at higher compression ratios. The heat release rate of PBDF is higher than that of other oil blends for compression ratios 16:1, 17:1, and 18:1. However, for compression ratio 19:1, the blend O5 shows higher rate than for PBDF and all other blends. Moreover, the heat release rate of preheated raw palm oil blends decreases compared to diesel with the increase in compression ratios. Especially the blend O20 has lower heat release rates for all compression ratios. This may due to the better spray formation and effects of viscosity for higher compression ratios[23].

The more heat release rate is due to the reason that more amount of fuel is accumulated during the combustion phase. The heat release rate is used to identify the start of combustion, fraction of fuel burned in the premixed combustion, and differences in combustion rates of fuels. Due to the above reasons specified, the higher heat release rate affects the combustion parameters like ignition delay period, combustion duration and start of combustion.

Effect on combustion pressure

The variation in combustion pressure with respect to crank angle is shown Fig. 3b at compression ratio 19:1 and different fuel blends. It is observed that the combustion pressure of PBDF is higher than that of other tested fuels for lower compression ratio and the combustion pressure for blended fuels are higher than that of PBDF for a higher compression ratio. The rate

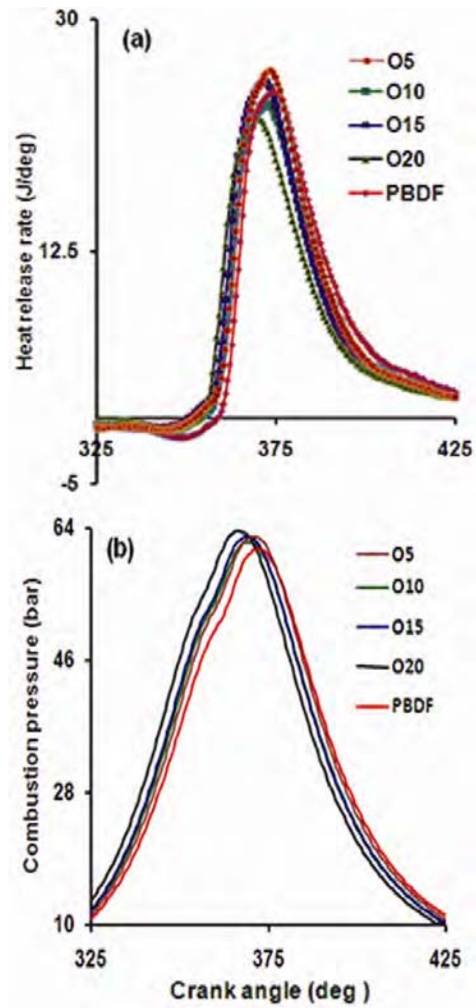

Fig. 3—Variation in (a) heat release rate, and (b) combustion pressure with crank angle for different blends at CR 19:1

of combustion pressure increases with increase in compression ratio of PBDF and all other tested fuels. Also it can be observed that blend O20 has maximum combustion pressure and it decreases with decrease in blended percentages. For a compression ratio of 16:1, blend O15 and O20 have highest combustion pressure at full load. At 17: 1 compression ratio, the maximum combustion pressure for O15 is about 57.55 bar. Similarly for compression ratio 18:1, 19:1, 20:1 the highest combustion pressure is 60.66 bar for blend O20, 63.57 bar for blend O20 and 67.11 bar for blend O20.

Conclusion

The following results are obtained in variable compression ratio engine fuelled with preheated palm oil-diesel blends.

- The specific fuel consumption of the blend O20 is lower than that of PBDF and other tested fuels for the higher compression ratio at full load condition. The blend O20 consumes 10.27% lower than PBDF.
- The brake thermal efficiency of blended fuel is higher as compared to PBDF for the higher compression ratio at full load, especially for blends O20 and O5. The maximum brake thermal efficiency, obtained for the blend O20, is 11.72% higher than PBDF.
- There is a significant reduction in unburned hydrocarbon for all blends of preheated palm oil at a higher compression ratio and full load. But the CO_2 level is found to be higher than that of PBDF for all other tested fuels from lower compression ratio to higher compression ratio.
- From combustion analysis, it is observed that for lower compression ratio, the heat release rate is increased and for a higher compression ratio it is slightly decreased. Compared to PBDF the heat release rate of preheated palm oil blends is decreased with increasing the compression ratios at full load.
- The blend O20 attain maximum combustion pressure for compression ratio 18:1, 19:1 and 20:1 and then it decreases with decrease in blended percentages.

From the above observation, it has been inferred that the blend O20 shows better performance, emission and combustion characteristics than other blends and PBDF at compression ratio 20:1 and full load condition. So, we strongly recommend that preheated palm oil blend O20, compression ratio 20:1 with full load can be used as best alternate fuel for diesel without any modification in the present setup. The experimental results also prove that lower percentages of preheated palm oil can be substituted as diesel fuel.

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