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Performance, emission and combustion characteristics of fish-oil biodiesel engine

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ABSTRACT

Biodiesel has become one of the most versatile alternative fuel options for diesel engine applications. The recent biodiesel research in India receives its attention towards fish-oil based biodiesel. In the present work, biodiesel derived from the fish-oil extracted from fish species was used as fuel in diesel engine to investigate its performance, combustion and emission characteristics. The various blends of fish-oil biodiesel with diesel, B25, B50, B75, B100 were used in the experiments and the results indicate that brake specific fuel consumption and brake thermal efficiency were higher with B100 fuel than that of diesel. The combustion analysis shows that the peak cylinder pressures of B25, B50, B75 and B100 are lower than that of the diesel and the starts of combustion timing was taken place at earlier crank angle degrees for fish-oil biodiesels. The exhaust gas temperatures of B100 were lower than that of diesel at the different loads. At full load, B100 fuel produced higher smoke, NO_x, CO and HC emissions of 34.95%, 1.65%, 14.6%, and 1.8% respectively with reference to diesel fuel.

INTRODUCTION

It is quite common nowadays to learn that every country is in the race to find suitable and affordable alternative fuel options for diesel engine as the present-day diesel fuel reserve is depleting fast. In addition, the price of conventional diesel fuel is sky rocketing due to great demand, exponential increase of vehicles number on road and political turmoil.

Therefore, it is an urgent need for India as well to search for an option to run diesel engine using a fuel other than conventional and petroleum based diesel. Biodiesel, as diesel engine fuel alternative, receives more attention among many feasible options. Biodiesel has been considered as one of the most versatile alternative fuel options for petroleum diesel in direct injection diesel engine applications because it has substantial prospect as a long-term replacement for diesel fuel [1].

Research work on biodiesel reveals that large number of experimental studies of biodiesel, derived from various feed stocks, as fuel for engines used for transportation and or other applications have been carried out all over the world. Application of biodiesel, as a fuel in transportation vehicles, has nowadays become common in almost all oil importing nations, due to the high oil import bills and uncertainties associated with the imports due to political chaos. Depending upon the availability of domestic products of feed stock material these countries started using biodiesel from domestically available or producible vegetable oil. In this context, many raw materials have been used by different countries, depending upon the availability and economical affordability. It is reported that biodiesels derived from soybean [2], rapeseed [3], sunflower [4], palm [5], coconut oil [6], rubber seed, waste cooking-oil, waste plastic oil etc. have been found suitable and feasible for use in diesel engines. Several researches carried out in India reveal that biodiesels derived from jatropha, karanja, mahua, polanga, [7-11] etc, are suitable fuel for use in diesel engine applications. The recent biodiesel research in India includes its attention towards the use of algae biodiesel, waste cooking-oil biodiesel, fish-oil biodiesel, etc. The use of fish-oil biodiesel as a fuel in diesel engines and the performance, combustion and emission studies carried out on single cylinder direct injection diesel engine is presented in this paper.

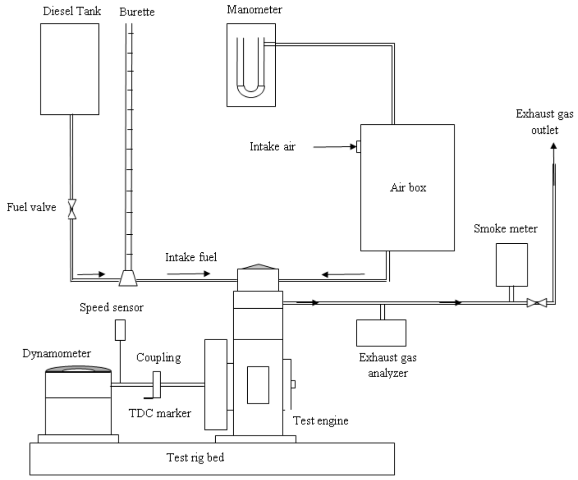

Figure 1. Schematic diagram of experimental setup

2. Experimental setup and procedure

In order to study the performance, combustion and emission characteristics of the fish-oil biodiesel engine, experiments were conducted on a single cylinder, four-stroke, direct injection, water cooled, Kirloskar TV-1, diesel engine. The detailed specifications of the test engine are given in Table 1. The schematic diagram of experimental setup is shown in Fig.1. The engine load was applied using an eddy current dynamometer. An orifice meter connected to a large surge tank was attached to the engine to make air flow measurements. The fuel consumption rate was measured using the glass burette and stopwatch. A digital tachometer was employed for measuring the engine speed. An AVL shaft position encoder was used to give signals at TDC and AVL GM12D miniature pressure transducer was used for measuring the cylinder pressure. An AVL 444 Di gas analyser was employed for measuring the exhaust gas components such as CO, HC and NO_x. The smoke density was measured using AVL 413 smoke meter. The exhaust gas temperature (EGT) was measured with k-type thermocouple.

Before conducting all the experiments, preliminary analysis was done with fish-oil biodiesel and its blends with diesel to obtain the important fuel characteristics like, kinematic viscosity, specific gravity, calorific value, flash point, pour point, etc. to find its suitability as diesel engine fuel. The obtained properties of fish-oil biodiesel and its blends were compared with diesel in Table 2.

Table.1 Test engine specifications

Parameter	Specification
Engine model	Kirloskar TV-1
Engine type	DI, naturally aspirated, water cooled
Number of cylinders	1
Bore (mm)	87.5
Stroke (mm)	110
Displacement (cm^3)	661
Compression ratio	17.5
Maximum power (kW) at rated rpm	5.2
Rated rpm	1500
Injection pressure (bar)	220
Injection timing (°btdc)	23

The engine was operated initially with base reference fuel, i.e. diesel for about 30 min to attain a normal working temperature condition. The base line data were generated by noting down the corresponding readings for diesel fuel. The test engine was then subsequently operated with blends of fish-oil biodiesel and diesel. The blend containing 25% of fish-oil biodiesel and 75% of diesel by v-v basis is denoted as B25. Similarly the different blends namely, B50, B75 and B100 are made and used for running the diesel engine. At every experimental setting, the engine speed was checked and maintained constant. All the observations were repeated twice and the arithmetic mean of these readings was employed for calculation and analysis. The performance, combustion and emission characteristics presently investigated include brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), exhaust gas temperatures (EGT), cylinder pressure, heat release rate, smoke, oxides of nitrogen (NO_x), carbon monoxide (CO) and unburned hydro carbon (HC).

Table 2 Properties of fish-oil biodiesel blends and diesel

Fuel property	Unit	Diesel	Fish-oil biodiesel			
			B25	B50	B75	B100
Kinematic viscosity @ 37 °C	cSt.	5.8	6.0	6.1	6.2	6.2
Specific gravity @ 15°C		0.867	0.872	0.882	0.899	0.920
Flash point	°C	72	111	130	141	147
Pour point	°C	-3.0	-1.7	-0.2	0.7	1.0
Calorific value	MJ/kg	42.0	41.1	40.7	39.9	39.5

RESULTS AND DISCUSSION

The several performance, combustion and emission characteristics were analysed as detailed in the following sections in order to investigate the effect of use of fish-oil biodiesel and diesel blends in the test engine. The performance parameters studied in the present analysis are BSFC, BTE and EGT and emission parameters are CO, unburned HC atoms, NOx and smoke. In addition, the combustion parameters analysed are cylinder pressure and heat release rate.

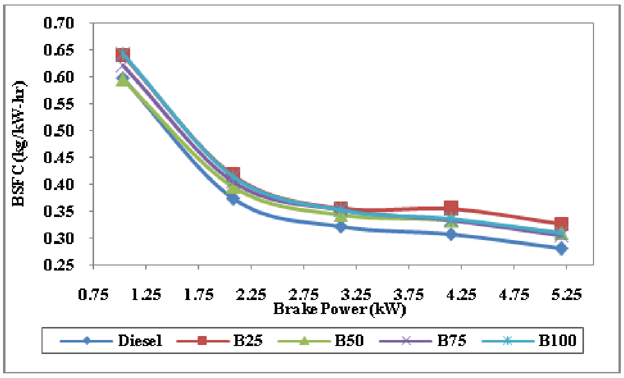

Figure 2. Comparison of brake specific fuel consumption

3.1 Performance characteristics

The comparison of the performance parameters in terms of BSFC, BTE and EGT versus brake power for fish-oil biodiesel and its blends (B25, B50, B75 and B100) with diesel fuel is shown in figures 2 to 4. It can be noted from figure 2 that BSFC of fish-oil biodiesel and its blends was higher than that of diesel at all loads. This is because of lower calorific values of fish-oil biodiesel and its blends as compared to diesel. BSFC decreased sharply with increase in brake power for all fuels, diesel, B25, B50, B75 and B100. The reason for this could be that percentage increase in fuel required to operate the engine is less than the percentage increase in brake power output due to relatively less portion of the heat energy losses at higher loads due to lower temperature gradient at warmed-up condition.

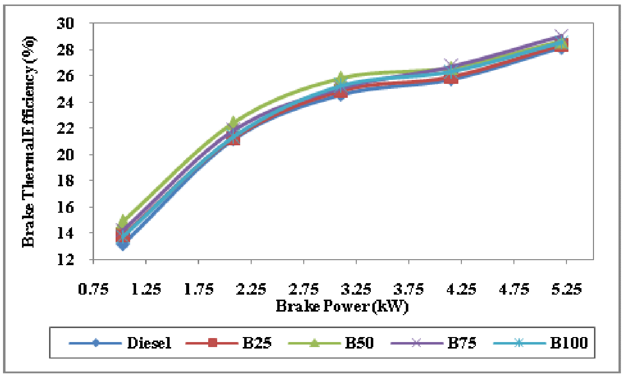

Figure 3. Comparison of brake thermal efficiency

Figure 3 shows the comparison of brake thermal efficiency, BTE between diesel and fish-oil biodiesel blends for different brake power points. In general, BTE of blends is slightly higher than that of diesel at any given load. This is due to the improved combustion which is caused by greater oxygen content of biodiesel molecule and better ignition quality of fish-oil biodiesel blends. BTE increases when the load is increased for a given fuel, because of, more power output due to efficient combustion caused by proper atomisation and good combustible mixture formation at increased loads. However it can be noted that the rate of increase in BTE is high at lower loads and it is low at higher loads as shown in Figure 3 by the higher and lower sloped curves, respectively.

Figure 4 shows the characteristic curves of exhaust gas temperatures, EGTs versus engine loads for diesel and fish-oil biodiesel blends. The exhaust temperatures rise with the increase of engine load for all of the fuels, B25, B50, B75, B100 and diesel. It can be seen from the figure that the EGTs at different engine loads for B50, B75 and B100 blends, are lower than that of diesel. This is because of the higher oxygen content of fish-oil biodiesel and its blends as compared to diesel. However, the exhaust gas temperatures of fish-oil biodiesel blend B25 fuel are 4.4% higher than that of diesel, which might be attributed to better combustion caused improved fuel-air mixing rate.

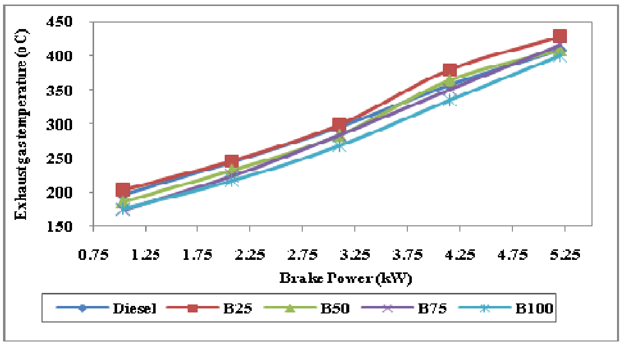

Figure 4. Comparison of Exhaust Gas Temperatures

3.2 Combustion characteristics

The combustion characteristics of the fish-oil biodiesel and its blends can be analysed and compared by referring to cylinder pressure-crank angle diagram and heat release rate-crank angle diagram. To analyze the cylinder pressure, the pressure data of 100 cycles with a resolution of 1°CA was averaged and then used. The cylinder pressure variations for the different fuels, diesel, fish-oil biodiesel and their blends, B25, B50, B75 and B100 are shown in Fig. 5. As seen in the figure, the peak cylinder pressures of the fish-oil biodiesel and its blends are lower than that of the diesel due to higher brake specific fuel consumption of fish-oil biodiesels. The occurrence of peak cylinder pressures of the fish-oil biodiesels is little earlier than that of diesel. For B25 blend, peak pressure occurs at TDC and for other blends B50, B75 and B100 it occurs at 1° before TDC, while for diesel fuel it occurs at TDC. The oxygen content of the fish-oil biodiesels increases fuel–air mixing rate in the cylinder compared to diesel, and this situation may cause to extend the combustion duration and enhance the combustion efficiency resulting in higher thermal efficiency.

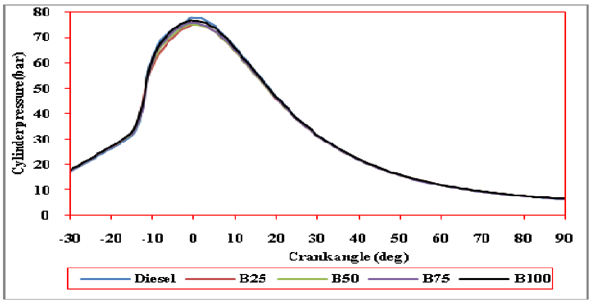

Figure 5. Comparison of Cylinder Pressure-Crank Angle Diagram

Heat release calculations provide important information about the combustion process in a diesel engine. The comparison of heat release rate versus crank angle diagrams between different fish-oil biodiesel blends and diesel are shown in Fig. 6. As seen in the figure, the starts of combustion (SOC) timing for fish-oil biodiesels and blends are little earlier than diesel due to their earlier start of injection timings. The SOC timing of the B25, B50, B75 and B100 was taken place at 16°CA before TDC, while the SOC timing in the case of diesel was occurring at 15°CA before TDC. This value shows that the SOC timing with the use of the biodiesels advanced more than 1°CA compared to diesel. The premixed combustion phase for all blends of fish-oil biodiesels was found longer than that of diesel. This situation can be explained with the vaporization of fish-oil biodiesel which is more slowly than diesel and contributes less premixed combustion. However, its oxygen content affects SOC timing.

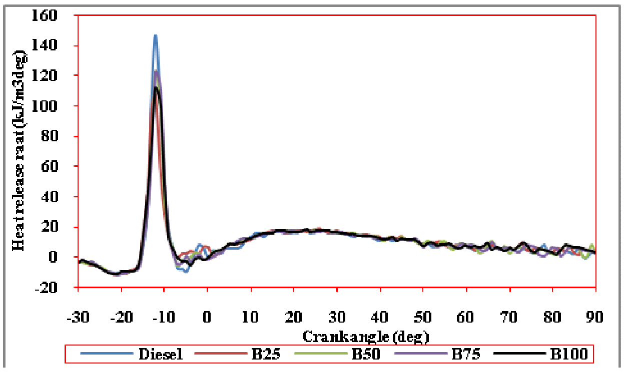

Figure 6. Comparison of Heat Release Rate-Crank Angle Diagram

3.3 Emission characteristics

The important emission characteristics of diesel engine include smoke, oxides of nitrogen, carbon monoxide and unburned hydro carbon emissions. These emissions emitted by the engine when fuelled with fish-oil biodiesel and its blends, B25, B50, B75 and B100 have been compared with diesel and reported in the following paragraphs.

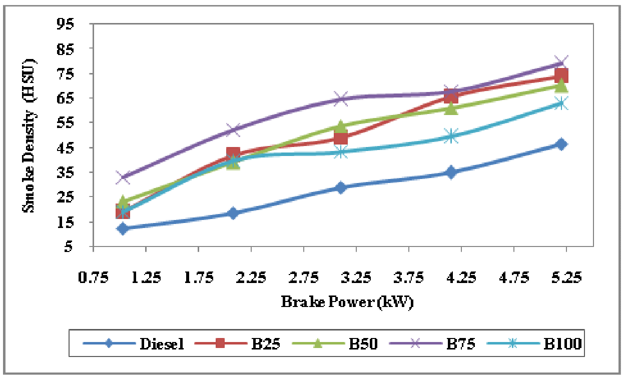

Figure 7. Comparison of Smoke density

The comparison of smoke density between fish-oil biodiesel blends and diesel is given in Fig. 7. As seen in the figure 7, the fish-oil biodiesel blends B25, B50, B75 and B100 produced higher smoke density, compared with diesel operations. The higher smoke density is due to incomplete combustion of fish-oil biodiesel fuel caused by poor vaporization and fuel-air mixing because of its higher viscosity. As the brake power is increased the smoke density is also increased for all fuels, which is obvious. Figure 8 shows the variation of oxides of nitrogen (NO_x) versus brake power for different fuels, B25, B50, B75 B100 and diesel. It can be seen that in general, fish-oil biodiesel blends produced higher oxides of nitrogen emissions compared to diesel. However, the higher blends of fish-oil biodiesel with diesel (B75) and B100 produced lower NO_x emissions compared with lower blends of fish-oil biodiesel with diesel (B25, B50). The higher NO_x emissions of fish-oil biodiesels are due to its earlier or advanced combustion starting compared with diesel.

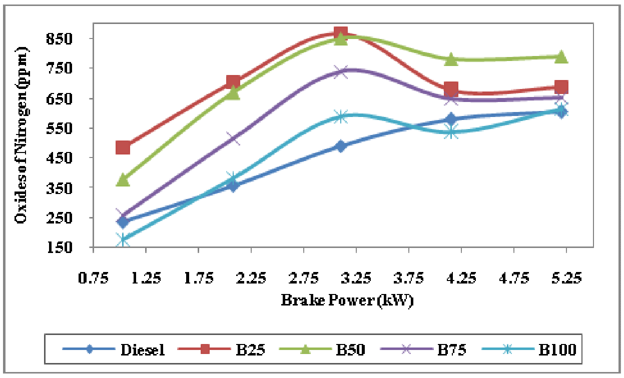

Figure 8. Comparison of Oxides of Nitrogen

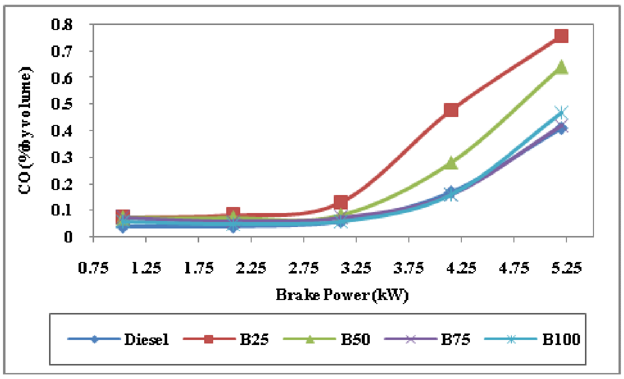

Figure 9. Comparison of Co Emissions

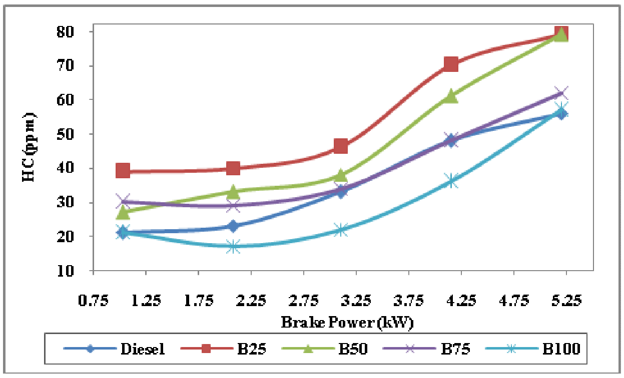

Figure 10. Comparison of HC Emissions

Figure 9 and 10 indicate the CO and unburned HC emissions of fish-oil biodiesel blends compared with diesel for different engine loads. It is seen that CO emissions of fish-oil biodiesels are higher than that of diesel and HC emissions of fish-oil biodiesel blends, except B100, are higher than that of diesel, however B100 fuel produced lower HC emissions than the diesel. The presence of higher CO and HC emissions indicate the chemical energy of the fuel which is not utilized during combustion process. In this study the unburned HC, CO, NO_x, emissions and smoke density, increased by 1.8%, 14.6%, 1.65% and 34.2% with use of fish-oil biodiesel B100 at full load condition respectively when compared with diesel.

CONCLUSION

The engine performance, combustion and emission characteristics of hundred percent fish-oil biodiesel B100 and its blends with diesel B25, B50, B75 were investigated and the results were compared with diesel and reported in this paper. It was evidently seen that brake specific fuel consumption and brake thermal efficiency were respectively 10.54% and 1.5% higher for (B100) fish-oil biodiesel fuel than that of diesel at full load condition. The combustion analysis shows that the peak cylinder pressures of B25, B50, B75 and B100 are lower than that of the diesel and the starts of combustion (SOC) timing of the B25, B50, B75 and B100 was taken place at 16° before TDC, while the SOC timing in the case of diesel was occurring at 15° before TDC. The exhaust gas temperatures of B100 were 2.2% to 9.7% lower than that of diesel at the different loads. The use of hundred percent fish-oil biodiesel fuel, B100 in the test engine at full load produced 34.95%, 1.65%, 14.6%, and 1.8% higher smoke, NO_x, CO and HC emissions respectively when compared with diesel fuel.

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