An Interpretation of Performance and Emission Outcomes of the Compression Ignition Engine using Palm Oil Biodiesel-Diesel Blends

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Abstract. Research on alternative sources to replace fossil fuels has been started decades ago and still an uninterrupted process. Partial replacement rather than complete is justified with real-time applications. In this research, engine outcomes based on palm oil biodiesel blends are elaborated. The transesterification processed biodiesel from raw palm oil is used to run the engine with a blend proportion of P10D90 and P20D80. From the results obtained, the performance of an engine was degraded with an increase in biodiesel proportion and consumes higher fuel. At lower load diesel and P10D90 have almost equal thermal efficiency whereas at peak load it is found that 39.1% and 37.6% respectively. Apart from CO emissions, there is an increment in CO₂, HC, and NOₓ with the load. NOₓ emissions are in the margin with diesel for P10D90 at part load. P10D90 shown slightly lower in-cylinder pressure at full load compared to diesel. However, it is seen that P20D80 has given depreciated performance readings, lowered cylinder pressure 55.8 bar, and higher emissions at rated torque. From the experiment, it is noticed that above 10% of the biodiesel blend engine required suitable modifications and accessories to overcome demerits associated with blend characteristics.

Keywords: Biodiesel, Performance, Emission, P10D90, P20D80.

1. Introduction

Immense renewable sources can be supportive to eliminate full or partial conventional sources, biodiesel is an important kind among the same. Blends of 10% biodiesel with diesel when used in the engine it is observed that there is a reduction in brake power and an increase in fuel consumption with inferior combustion characteristics compares to diesel [1]. Neat biodiesel with methane gas as dual fuel mode increased thermal efficiency [2]. Blends of different biodiesel have no impact on engine performance and given improved combustion plots [3]. Increasing biodiesel and ethanol with diesel has given improved performance than biodiesel alone [4]. Castor seed biodiesel up to 20% blends can...
be used directly in a diesel engine without any modification in the injection system [5]. Exhaust gas circular with biodiesel up to certain limits can be an advantage to control the emissions but it affects engine brake thermal efficiency[6,7]. Carbon monoxide and hydrocarbons were reduced when 10-20% of pentanol is blended with biodiesel [8]. Higher thermal efficiency and NOx, lower CO, CO2, and HC emissions were recorded with clustered apple seed biodiesel [9]. The addition of Nan particles with biodiesel has reduced NOx and hydrocarbon emissions with improved engine performance [10]. Corn seeds biodiesel of 20% blend with the diesel shown improved performance and combustion process at full load [11]. 

As Lord increases irreversibility process decreases and increases the unavailability of energy. At full load, there is a loss of 3. 68% of exergy with biodiesel compared to diesel [12].

Emission of NOx depends on blends ration, B2O of soybean methyl ester emitted lower NOx when tested on conventional engine [13]. Blend of 10% cashew nutshell and waste cooling oil with diesel at peak load has almost equal thermal efficiency as diesel and decreases NOx emission whereas HC and CO are slightly increased [14]. Biodiesel from fish waste has similar performance and combustion characteristics as diesel. Apart from carbon monoxide, all other emissions are recorded with lower reading [15]. Jatropha biodiesel emission is decreased compared to diesel whereas NOx quantity increased [16]. Cooked exhaust gas recirculation at a flow rate of 15% ensured a drastic reduction in NOx, but influenced the oxidation process that increases CO2 [17]. Fuel consumption is increased by 4% when castor seed biodiesel is used, and a reduction of 2.2% thermal efficiency than diesel is observed [18]. Test conducted on the engine with neem biodiesel has given improved performance and reduced emission than that of diesel [19]. Higher density and viscosity of biodiesel influence the narrowing of the aerodynamic spray cone angle [20]. Blends of palm and animal fat biodiesel of 20% blend have almost equal performance attributes as of diesel but an increase in blends ration increase CO2 and NOx [21]. The combined effect of EGR and increased compression ratio have given improved performance characteristics and reduced NOx compared to diesel [22].

Direct addition of waste fried oil without converting to biodiesel given lowered engine performance and increased emission[23]. Increasing injection pressure and the addition of nanoparticles in biodiesel-diesel blends have shown improved efficiency with reduced fuel consumption [24]. Engine tested with biodiesel at a higher compression ratio shown a reduction in HC and a slight increment in NOx with improved thermal efficiency [25] Jamun seed powder and jackfruit seed powder mixed diesel has improved performance over plain diesel and there is a slight reduction in NOx is recorded [26]. Higher injection pressure on the CRDI engine revealed that biodiesel-diesel blends can achieve higher thermal efficiency and lower CO, HC emissions as injection pressure increases [27].

From the research history, it is justified that increased blend ratio harm engine performance as well as on emissions. Hence the trial has made with a limited proportion up to 20% of palm oil biodiesel. In-cylinder pressure variation which directly proportional to power output is discussed.

2. Test fuels, Engine setup, and experimental methodology

2.1 Preparation of test fuels and Characterization

Biodiesel from raw palm oil is prepared by the transesterification process;a line diagram of the process is shown in figure 1. Prepared biodiesel is characterized according to ASTM standards to ensure the suitability of usage to run an engine without modification. Two proportions of blends are prepared namely P10D90 which is 10% of palm biodiesel and 90% of diesel similarly, P20D80 which is 20% of palm biodiesel, and 80% diesel.
Properties of diesel and test fuels are tabulated in table 1, characterized outcomes indicated that the addition of biodiesel to the diesel will reduce the calorific value, increases the flash and fire point of the fuel. Hence the addition of biodiesel is limited to 20% of total volume.

Table.1: Properties of fuels

| Properties                  | DIESEL | P100 | P10D90 | P20D80 |
|-----------------------------|--------|------|--------|--------|
| DENSITY (kg/m³)             | 831    | 853  | 835    | 837    |
| Kinematic Viscosity(cSt)    | 3.1    | 8.1  | 3.3    | 3.6    |
| Flash Point (°C)            | 61     | 209  | 67     | 71     |
| Calorific value(kJ/kg)      | 42000  | 39648| 41778  | 41200  |

2.2 Test setup

The test engine shown in figure 2 is an integrated computerized setup which is connected to an eddy current dynamometer for loading purpose. Four-stroke natural air intake system with a water-cooled single-cylinder of capacity 35 kW, Kirloskar made prime mover is considered. The line diagram of the setup is shown in figure 3 with notations in table 2, and engine instruments with specifications are tabulated in table 3.
Fig. 2 Test engine setup

Fig. 3 Line diagram of engine setup

Table 2: Engine notations

| PT       | Description                                           |
|----------|-------------------------------------------------------|
| N        | Rotary encoder                                       |
| F1, F2, F3, F4 | Fuel flow, Airflow, Jacket water flow, Calorimeter water flow |
| T1&T2    | Jacket water inlet and jacket water outlet temperature |
| T3&T4    | Calorimeter water inlet and calorimeter water outlet temperature |
| T5&T6    | Exhaust gas in & Exhaust gas out calorimeter temperature |
Table 3: Test engine specifications

| Manufacturer                  | Kirloskar oil engines Ltd. India |
|-------------------------------|----------------------------------|
| Model                         | TV-SR, naturally aspirated       |
| Engine                        | Single cylinder, DI              |
| Bore/stroke                   | 87.5mm/110mm                     |
| C.R.                          | 16.5:1                           |
| speed                         | 1500 RPM, constant               |
| Rated power                   | 3.5 kW                           |
| Working cycle                 | Four-stroke                      |
| Injection pressure            | 200bar/23 degree before TDC      |
| Type of sensor                | Piezoelectric                    |
| Response time                 | 4 micro-seconds                  |

2.3 Test method and uncertainty analysis

The engine is tested with diesel, P10D90, and P20D80 fuels at a constant speed of 1500 rpm and load from zero to full of an incremental order 25%. The lubrication oil level is ensured as per standards and a water flow rate of 42 cc/sec is maintained to avoid engine abnormalities.

Accuracy of an instrument used to measure the readings plays an important role to ensure validation of the experiment. Holman method is used to find uncertainty associated with pressure, speed, flow, and emission measuring instruments together which is about ±1.9.

3. Results and discussion

Natural aspirated without modification of an engine is tested with three fuels-diesel, P10D90, and P20D80. Results are discussed based on performance and emission categories. The pressure and crank angle plot at full load are summarized to justify the suitability and characteristics of test fuels.

3.1 Performance outcomes

3.1.1 Brake Thermal Efficiency

Characterization of fuels revealed that the calorific value of test fuels is lower than diesel which impacts brake thermal efficiency. From figure 4 it is observed that at 25% of load P10D90 and diesel have very close values 17.4% and 17.2% respectively. As load increases, this difference increased, and at full load diesel, P10D90 and P20D80 shown 39.1%, 37.26%, and 36.38% of brake thermal efficiency, respectively.
3.1.2 Specific Fuel Consumption

Another important attribute which measured based on fuel burnt on that specific load influences rating of the fuel. Figure 5 shows the fuel expenditure of diesel, P10D90, and P20D80 at various loads. It is seen from the column chart, at lower load engine requires higher fuel quantity to run with rated speed. This gradually decreases with an increase in load. At peak load diesel and P10D90 have almost equal consumption of 0.220 and 0.226 kg/kW hr. As the calorific value decreases engine needs a higher chemical reaction rate to produce power which depends on the mass fraction of fuel burnt. Dilution of fuel quality by higher blend ratio increase SFC which is witnessed by P20D80 at peak load by consuming 0.236 kg/kW hr of fuel.

3.1.3 In-cylinder Pressure

A graphical representation of in-cylinder pressure versus crank angle at peak load is shown in figure 6. From the plot, it is noticed that. Diesel and P10D10 liberated the same pressure after a 14-degree crank angle in the expansion stroke. P10D90 has a higher flash and fire point with the moderated calorific value which influenced the delay period and proper mixing of charge. P20D80 was given a low-pressure rise due to higher density, flash point, viscosity, and lower heating value.
From the graph, it is noted that pressure rise for diesel, P10D90, and P20D80 at peak load is 62.08, 61.58, and 55.84 bar, respectively.

3.2 Emission Interpretation

3.2.1 Carbon Monoxide and Carbon Dioxide

Figure 7 and 8 show the variation of CO and CO$_2$ with load respectively, from the chart carbon monoxide emitted by test fuels, are less compared to diesel at all load conditions. This is because of the availability of oxygenated biodiesel that enhanced the combustion process. At peak load, P10D90 and P20D80 have the same quantity 0.04% volume of CO emission whereas diesel has a 3.5% higher contribution. At no load, diesel has 4.5% higher CO emissions than test fuels.

Carbon dioxide contribution is more with test fuels. As blends have an environment suitable for oxidization that triggers CO to CO$_2$. From the chart, it is seen that the increased blend ratio has higher CO$_2$. Diesel, P10D90, and P20D80 have contributed 2.35, 5.63, and 5.73% volume of carbon dioxide at full load.
3.2.2 Un-burnt Hydrocarbon and NOx

Figure 9 and 18 show the variation of HC and NOx emission with the load respectively. Improper combustion and constraints of combustion chamber design influence the fuel to produce more hydrocarbon. From the figure, it is observed that at peak load diesel, P10D90 and P20D80 have given 30, 31.2, and 34 ppm of hydrocarbons, respectively.

NOx emission is associated with many factors including fuel property, flame temperature, and time of stay. From the figure, it is revealed that higher NOx is emitted with test fuels in all load conditions. At full load diesel, P10D90 and P20D80 emitted 1043, 1100, and 1160 ppm of NOx which is 5.4% and 11.2% higher than diesel, respectively.
4. Conclusion

From the research, it is summarized that biodiesel can be used to replace fossil fuel partially but not completely without engine modification. A blend ratio increases the performance of an engine degraded with increased pollutants. With a 10% blend, there is not much or negligible deviation in performance, and emission is recorded but with a 20% blend, rapid effect on engine outcome recorded. In this work, brake thermal efficiency at full load for P10D90 is reduced by 4.7 % and fuel consumption is increased by 2.7% than diesel. There is a slight deviation in pressure rise at peak load for P10D90 which affects mean effective pressure that interlinked to power output. Apart from CO all other pollutants CO$_2$, HC and NO$_x$ are higher for blends than diesel.

From the experiment, it is concluded that above 10% of palm biodiesel-diesel blend test fuels cannot be used directly in the conventional engine without suitable modification and by providing necessary accessories.

DECLARATION

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Availability of data and material - Data available on request from the authors.

Code availability- Not applicable.

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