Comparison of performance and emission characteristics of diesel engine fuelled with different blends of bio-diesel

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Abstract: In these times of potential energy crisis and climate change, search for alternative sources for conventional fuel has led us to bio-diesel. Vegetable oils are typically highly dense and viscous and to overcome it we prefer the methyl ester of the oil. In our study we have used methyl ester of Palm stearin oil, which can be found in our country (India) abundantly, and conducted emission and performance tests on a non-modified diesel engine. Diesel along with four different blends of 5%, 10%, 20% and 30% by mass were used to carry the tests in different loading conditions. The results have shown promising possibility of the use of palm-stearin oil blended bio-diesel as CO, NOX and HC emissions reduced and B-30 provided the best mechanical efficiency.

Keywords: Bio-diesel, Palm-Stearin, Methyl Ester, Climate change, Efficiency

1. Introduction

We are at an important point in history where on one hand we have to maintain and accelerate the present rate of technological advancement and on the other hand- deal with climate change. And hence, at such a time, immediate focus must be shifted on our means of energy production. Most of our energy requirements, almost 80%, are satisfied by non-renewable fossil fuels like diesel, petrol, coal and natural gas. These take millions of years to form [1]. Apart from the climate-change issue, the rampant increase in population is exponentially increasing the demands of fossil fuels. The limited nature of its supply is shooting up the oil prices [1]. In the recent days, there has been a huge concern in shifting towards the usage of bio-diesel [2]. Many studies and experiments have suggested that bio-diesel extracted out of vegetable oils is suitable for use in unmodified diesel engines [3-6]. The comparable results of emissions and performance between bio-diesel and regular diesel validate bio-diesels potential to become a significant alternative [7]. Bio-fuel using vegetable oil however has its own demerits too. The low volatility, higher density and viscosity create problems during atomization of the fuel. These obstacles are overcome by trans esterification of the vegetable oils [8]. The trans esterification is carried out using enzymatic catalysts [9]. Palm stearin contains significantly more saturated fatty acids when compared to palm oil, also more TAGs with higher melting point [10]. Palm stearin seems to be very economical compared to conventional fuels. Methyl Esters of Palm oil has claimed to have similar characteristics of performance to that of diesel [8]. In this test conducted, the performance of methyl ester of palm stearin oil that was blended with diesel fuel in the following ratios: 5% (B5), 10% (B10), 20% (B20) and 30% (B30). And an investigation was made to compare
the results of emission and performance with regular diesel. Four different loading conditions were applied on the engine at a speed of 1500 rev/min.

2. Material and Methodology

A four-stroke single cylinder, direct injection diesel engine was used to conduct the tests. An electric dynamometer (rated power output of 4.41(6) kW (hp)) was used alongside the engine. Different blends of the bio-fuel and conventional diesel were then used to run the engine at different torques. A strain gauge was used to measure the load on the dynamometer. The engine speed was measured using an inductive pickup sensor; an optical tachometer was used for its calibration. The emission measured was CO, HC and NOx, and for the purpose we used an AVL DICOM4000 gas analyzer. At 1500 rpm, as mentioned above, tests of all fuel were done at different loads. We can summarize the test as follows: First, the pure diesel was used to run the engine, after completion of the standard warm-up cycle. The tests were performed and data collected. Bio diesel used for the experiment was extracted from palm stearin oil through transesterification. The properties of Bio diesel extracted from palm stearin are tabulated against the properties of mineral diesel in Table 1.

### Table 1. Comparison of Properties of diesel fuel and Palm Stearin

| PROPERTY                     | MINERAL DIESEL | PALM STEARIN |
|------------------------------|----------------|--------------|
| Specific Gravity             | 0.85           | 0.88         |
| Kinematic Viscosity at 40°C (m²/sec) | 3.29           | 4.98         |
| Flash Point (°C)             | 70             | 110          |
| Calorific Value (kJ/kg)      | 44.8           | 32.2         |
| Density (g/cc)               | 0.832          | 0.86         |
| Carbon content (%)           | 87             | 77           |
| Moisture content (%)         | 0.161          | 0.12         |

2.1 Experimental Setup

The following figures show the experimental setup. Figure 1 shows the Kirloskar single cylinder diesel engine. Figure 2 shows the setup of the gas analyzer that measures the quantity of the gas.
2.2 Engine Specifications

The following table 2 mentions the engine specifications.

Table 2. Test Engine Specifications

| MAKE          | KIRLOSKAR                   |
|---------------|----------------------------|
| MODEL         | TAF1 (6hp Air cooled engine)|
| TYPE          | Vertical, Single cylinder, Air cooled, 4 Stroke cycle, Compression Ignition Diesel Engine |
| NO. OF CYLINDER | 1                           |
| BORE X STROKE | 87.5 x 110 mm              |
| CUBIC CAPACITY | 0.662 Litre                |
| COMPRESSION RATIO | 17.5 : 1                  |
| RATED OUTPUT  | 4.41 (6) kW(hp)            |
| RATED SPEED   | 1500 rpm                   |
| TORQUE AT FULL LOAD (crank shaft drive) | 0.029 (2.865) kN-m (kg-m) |
| LUBE OIL CONSUMPTION | 0.8% of SFC max         |
| LUBE OIL SUMP CAPACITY | 3.7 Litre at higher level mark on dipstick |

3. Results and Discussion

3.1 Emission Characteristics

The tests on the engine were conducted at a rated torque of 1500 rev/min at different engine loads (0%, 25%, 50%, 75% and 100%). Table 3, gives us the CO released at all loading conditions of the blends and pure diesel.

Table 3. CO Emission’s of diesel fuel and of different blends of Palm Stearin

| Load (kW) | % CO Diesel | % CO B5 | % CO B10 | % CO B20 | % CO B30 |
|-----------|-------------|---------|----------|----------|----------|
| 0         | 0.05        | 0.03    | 0.04     | 0.02     | 0.03     |
| 1.1       | 0.05        | 0.04    | 0.04     | 0.02     | 0.03     |
| 2.2       | 0.04        | 0.04    | 0.03     | 0.02     | 0.02     |
| 3.3       | 0.03        | 0.03    | 0.02     | 0.01     | 0.02     |
| 4.4       | 0.02        | 0.04    | 0.04     | 0.03     | 0.03     |
Table 3. and figure 4. shows that the emissions, with an exception during the full loading condition, are lesser of bio-diesel blends than pure diesel. The result shows that there is 0.012% less CO emission between Diesel than B30; when taken the mean of their emissions from all loading conditions. The increased Oxygen levels in the palm stearin blends that facilitates better combustion- greater the content of bio-diesel, greater is the Oxygen content and hence lesser the CO emission. But, at the highest loading condition we can see all other blends have higher emission compared to diesel. The possible cause behind it could be the comparatively greater values of viscosity of the bio-diesel. When viscosity of a fuel is high, it results in poor atomization and hence poorer combustion. At higher loading conditions, more fuel is drawn, hence higher amounts of poor combustion and higher amount of carbon monoxide.

We can see a general decreasing trend for all blends as we go from lower to higher loading conditions. At greater loads, the temperature of the engine is higher which results in between combustion. Also, addition of bio-fuel increases Oxygen content of the mixture, resulting in even better combustion and hence lower CO emission. Figure 3. shows emission levels of CO of different blends against all loading conditions.

![LOAD Vs CO Emission](image)

**Figure 3.** CO Emissions of diesel fuel and different blends of Palm Stearin

Table 4 lists down the NO emissions at different loads for all blends.

### Table 4. NO\textsubscript{x} Emissions of diesel fuel and different blends of Palm Stearin

| Load (kW) | NO (ppm) Diesel | NO (ppm) B5 | NO (ppm) B10 | NO (ppm) B20 | NO (ppm) B30 |
|-----------|-----------------|-------------|-------------|-------------|-------------|
| 0         | 242             | 265         | 295         | 279         | 266         |
| 1.1       | 468             | 480         | 537         | 462         | 434         |
| 2.2       | 970             | 888         | 991         | 907         | 913         |
| 3.3       | 1482            | 1412        | 1430        | 1359        | 1289        |
| 4.4       | 2001            | 1825        | 1563        | 1654        | 1543        |
The experimental values of NO emission for diesel and bio-diesel blends (B5, B10, B20 and B30) are tabulated in table 4. It shows that at higher load the NO emission rate is getting increase respect to lower load. Given below, figure 4. shows graphically the emissions of NO(ppm) Vs loads.

![LOAD Vs NO EMISSION](image)

**Figure 4.** NO, Emissions of diesel fuel and different blends of Palm Stearin

For all blends and neat diesel, an increase in engine load increases the NOx emissions. In pure diesel, the nitrogen content is more as compared to biodiesel blends, so in pure diesel the NOx emission is higher. In contrast, taking the biodiesel into account, the volume of diesel is lesser which results in lesser nitrogen content, therefore lesser NOx emissions. The highest emission concentration at the 75% load are- 1482 ppm, 1412 ppm, 1430 ppm, 1359 ppm and 1289 ppm respectively, for diesel, B5, B10, B20, B30.

**Table 5.** HC Emissions of diesel fuel and different blends of Palm Stearin

| Load (kW) | HC (ppm) Diesel | HC (ppm) B5 | HC (ppm) B10 | HC (ppm) B20 | HC (ppm) B30 |
|-----------|-----------------|------------|-------------|-------------|-------------|
| 0         | 20              | 19         | 22          | 17          | 10          |
| 1.1       | 23              | 20         | 25          | 17          | 17          |
| 2.2       | 24              | 17         | 24          | 17          | 18          |
| 3.3       | 24              | 20         | 15          | 13          | 13          |
| 4.4       | 25              | 20         | 16          | 22          | 14          |

Figure 5. is the graphical representation of load Vs HC emission of all blends.
From figure 5, we can observe that the HC emission in pure diesel increases with increase in load, whereas in biodiesel the HC emission decreases when compared to diesel because of more oxygen content which leads to better combustion. The decreasing levels of HC emissions for bio-diesel blends can be explained by various factors stated by C.D. Rakopoulos et Al. (2006) [11]. The peak concentrations of HC are 24 ppm, 17 ppm, 24 ppm, 17 ppm and 18 ppm, respectively for diesel, B5, B10, B20, B30 indicating that levels of HC emissions shows a declining trend with increasing levels of palm stearin oil in the mixture. In the next section table 6. gives pressure at different blends according to the crank angle.

3.2 Combustion Characteristics

Table 6. Combustion characteristics of diesel fuel and various blends of Palm Stearin

| Crank angle (degree) | Pressure(bar) Diesel | Pressure(bar) B5 | Pressure(bar) B10 | Pressure(bar) B20 | Pressure(bar) B30 |
|---------------------|----------------------|------------------|-------------------|-------------------|-------------------|
| -90                 | 1.875                | 2.061            | 2.371             | 2.209             | 2.372             |
| -30                 | 14.001               | 14.135           | 15.942            | 15.942            | 15.942            |
| -10                 | 32.956               | 32.975           | 35.933            | 35.933            | 35.933            |
| 0                   | 59.650               | 61.242           | 64.418            | 64.418            | 64.418            |
| 10                  | 69.614               | 68.597           | 73.026            | 73.026            | 73.026            |
| 30                  | 36.167               | 33.909           | 38.056            | 38.056            | 38.056            |
| 90                  | 5.917                | 5.655            | 6.783             | 6.558             | 6.529             |
Figure 6. Combustion characteristics of diesel fuel and different blends of Palm Stearin

Figure 6 gives a graph of crank angles of the piston Vs engine pressure. Cylinder pressure is an indication of the heat release and so, the above given graph will also help understand the next graph. It is evident from figure. 6 that the cylinder pressure of palm stearin is lower by a value of 2.98% when compared with pure diesel, the reason behind this could be the lower calorific value and volatility. Which leads to lower heat release and hence affects the cylinder pressure. Figure 8. Below compares graphically the heat released at different crank angle.

Figure 7. Heat release characteristics of diesel fuel and different blends of Palm Stearin
Figure 7 can be interpreted using different factors. It is clear that the bio-diesel blends have had an earlier start of combustion, which was followed by a slower rate of combustion. It is clear that as the blend increases- i.e, as the percentage of palm-stearin increases, the combustion rate decreases. The smaller value of ignition delay time could be the possible reason behind earlier start of the combustion. But, also, at the premixed stage there was lesser energy released owing to lower calorific value and lower volatility, which explains the slower rate of combustion. Also, with decrease in content of diesel as the blend gets higher, the volatility and calorific value of the mixture keeps getting lower. In the next section, table. 7 sums up the calculated Brake thermal efficiencies of all blends against different loads.

3.3 Performance Characteristics

3.3.1 Load Vs Brake Thermal Efficiency

Table 7. Performance characteristics of diesel fuel and various blends of Palm Stearin

| Load(kW) | % Bth Diesel | % Bth B5 | % Bth B10 | % Bth B20 | % Bth B30 |
|----------|--------------|----------|-----------|-----------|-----------|
| 0        | 0            | 0        | 0         | 0         | 0         |
| 1.1      | 11.10375     | 12.72031 | 12.72031  | 14.21399  | 15.29202  |
| 2.2      | 19.77348     | 20.13797 | 20.13797  | 20.45694  | 22.53841  |
| 3.3      | 22.09269     | 23.38411 | 23.38411  | 22.07127  | 27.4574   |
| 4.4      | 24.32813     | 24.43179 | 24.43179  | 24.91868  | 28.88607  |

Figure. 8 is a plotted graph between values of Brake Thermal Efficiency of different blends and pure diesel at different loading conditions.

Figure 8. Performance characteristics of diesel fuel and different blends of Palm Stearin

It is important to keep in mind that Brake Thermal efficiency is product of the lower calorific value and the value of the inverse of specific fuel consumption. So, in order to maintain a simplicity of the analysis because of the uncertainty over lower calorific values we fix a 32,000 kJ/kg value for bio-diesels throughout while fixing the value for neat diesel at 44,800 kJ/kg. As mentioned above, because
of the relationship between brake thermal efficiency and specific fuel consumption, both figure 8 and figure 9 and be explained and understood.

Brake thermal efficiency of the blend B30 has shown the highest values in all loading conditions. For other blends, there are certain anomalies, but, overall performance of bio-diesel blends have been better than neat diesel.

Table 8. gives tabular data at all loading conditions for all blends.

3.3.2 Load Vs Specific Fuel consumption

Table 8. Specific Fuel Consumption of diesel fuel and various blends of Palm Stearin

| Load (kW) | SFC Diesel | SFC B5  | SFC B10 | SFC B20 | SFC B30 |
|-----------|------------|---------|---------|---------|---------|
| 0         | 0          | 0       | 0       | 0       | 0       |
| 1.1       | 0.723694   | 0.694167| 0.694167| 0.633337| 0.605185|
| 2.2       | 0.406388   | 0.438476| 0.438476| 0.440059| 0.41061 |
| 3.3       | 0.363727   | 0.377608| 0.377608| 0.407872| 0.337049|
| 4.4       | 0.330306   | 0.361415| 0.361415| 0.361265| 0.320379|

Figure. 9 represents the specific fuel consumption of different bio-diesel blends and pure diesel against different loading conditions.

**Figure 9.** Specific Fuel Consumption of diesel fuel and different blends of Palm Stearin

Specific Fuel Consumption (SFC) Vs Load gives us a trustable comparison between two fuels of different calorific values and density. The above given figure can help make observations that the SFC of certain blends are higher than Diesel fuel as the loading conditions get higher. One possible reason behind this trend can be the lower calorific value of the palm-stearin blends against the conventional diesel. That could be a reason as to why this is a general trend in almost all vegetable oils. But, an anomaly occurs with B30 blend which seemingly shows lowest SFC at almost every loading condition. The possible cause behind this might be the higher concentration of oxygen content as the blend goes higher.
3.3.3 Exhaust Gas Temperature (EGT)

Of an engine, the temperature of its exhaust gases gives us an idea about the conversion into work from heat. The figure 10 shows the variation of exhaust gas temperatures of pure diesel and other fuels against different loading conditions.

![Graph of Exhaust gas temperature of diesel and various blends against different loading conditions.](image)

**Figure 10.** Graph of Exhaust gas temperature of diesel and various blends against different loading conditions.

The figure indicates optimal performance of the blend B20, followed by B30. In lower loading conditions, pure diesel shows the lowest temperatures, however it rises above a few blends in the higher loading zones. For 20 percent blend, the EGT goes from 140°C at 0 load to 440°C at maximum (full) load. While, B20 ranges from 170°C-410°C from no load to full load.

The bio-diesel blends, especially B20 and B30 show higher EGT, we can attribute it to the lower amounts of time it takes for heat dissipation. The reason behind this could be the fact that palm stearin has lower volatility and hence heat release may primarily occur in the later part of the power stroke.

3.3.4 Mechanical Efficiency

Figure 11 is a plotted graph between the calculated mechanical efficiency of different blends Vs the loading conditions.

It is evident that the comparative mechanical efficiency of diesel fuel is the least. The mechanical efficiency goes higher from 72.3393% 4.4 kW load to 79.68214% at full load compare to Diesel and B30, while for B20 the mechanical efficiency rises 77.609% at full load. From the graph, the conclusion can be drawn that the mechanical efficiency of B30 is higher than all other blends and the pure diesel fuel at all loading conditions.
Figure 11. Mechanical Efficiency of diesel fuel and different blends of Palm Stearin

4. Conclusions

Palm Stearin appears to be a good alternative source if used as a bio-diesel. The preliminary problems of viscosity are tackled by blending it with neat fuel. The conclusions drawn are summed up here:

- B30 (30% Palm-stearin and 70% Neat diesel) showed slightly better performance than all blends and neat diesel in terms of Brake thermal efficiency.

- In terms of Specific fuel consumption parameter too, the different blends showed promising results- B30 being the winner. For B30, the SFC value was 0.334645kg/kWhr that is lower in value than conventional diesel (0.364823kg/kWhr) at all of the tested loading conditions.

- Factors like the coarse nature of the spray formation and slower rate of combustion leads to increase in the EGT with increasing blends, which was found to range from 270.8°C to 286.8°C.

- At all the tested loading conditions, the mechanical efficiency achieved by B30 was seen to be better than other blends and pure diesel.

- The results of emissions are satisfactory, not impressively better than diesel. Also, there are certain anomalies.

- B30 comes out as a promising alternative. Further studies can be done on it to improve certain parameters for its usage in non-modified engines.

From the various tests done, we have reached a practical conclusion that setting aside the slight concern of emitted smoke from vegetable oil based bio diesel blends; palm stearin based Bio-diesel can be advised to be used safely without any major engine modifications, by blending it in smaller ratios along with neat diesel. This provides a viable solution to the ever increasing energy crisis.

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