Investigation on Performance and Emission Characteristics of CI Engine Fuelled with Cucurbita Pepo L. and Prosopis Juliflora Seed Oil Biodiesel Blends

Vinoth Kannan Viswanathan¹* and Pushparaj Thomai ²

¹ Department of Mechanical Engineering, Parisutham Institute of Technology and Science, Thanjavur, Tamilnadu, India
² Department of Mechanical Engineering, Kings College of Engineering, Punalkulam, Pudukkottai, Tamilnadu, India

¹E-mail: vinkan18mech@gmail.com

Abstract

Recent researches of different countries have used traditional seed oils such as sunflower oil, soybean oil for the synthesis of biodiesel. In the present investigation, (pumpkin) Cucurbita pepo.L and prosopis juliflora seed oil was used for the synthesis of biodiesel. Since these are produced in large quantities in India, oil cost is low. Diethyl ether as additive was added to the above blend and performance and emission parameters were compared. Performance tests were conducted using biodiesel blend in water cooled, constant speed, CI engine and the emission characteristics were analyzed using a five-gas analyser. It was observed that there was 9.89 % increase in Brake Thermal efficiency and 14.35 % reduction in Brake Specific Fuel consumption at the maximum load for B20 blend with 5ml additive. It was also noted that emission of CO reduced by 0.65 % than that of diesel. CO2 by 10.3 % and NO by 21.1 % for B20 blend and further, emission of CO reduced by 14.3 %; CO2 by 13.8 % and NO by 25.83 % was noticed when additive was added to B20 blend. HC emission and smoke opacity increased by 33.8 % and 16.56 % respectively for B20 blend and increased by 26.47 % and 5.15 % for B20 blend with additive which indicates reduction of HC emission and smoke opacity by adding additive to biodiesel. The combustion characteristics of blended biodiesel (50:50 for Cucurbita pepo L and prosopis juliflora) with additive closely follow that of diesel. Hence this blend is used as fuel in CI engine without any engine modification.

Keywords: Cucurbita pepo L, Prosopis Juliflora, B20 biodiesese blend, Diethyl ether, Emission characteristics, 5-gas analyser.

1. Introduction

Bio-diesels are extracted from the organic vegetables, waste oil and animal fat that have increased the higher potency as compared to fossil fuels in current engineering researches [1]. The biodiesel plays a major role in India for the usage in commercial applications and also decreases the usage of non-renewable sources. Industrial
applications have aimed to decrease the fossil fuel uses in power production, transportation and other different power utilization industries because of the expansion of civilization and to reduce environmental impact [2]. Fossil fuels resources decrease due to their increasing usage. Biodiesel consists of nontoxic, biodegradable and lower carbon level compared with the other fuels. Instead of the fossil fuel, a recent research has focused on development of the biodiesel with blends of different fatty acid methyl esters [20]. The biodiesel is extracted from digestible or non-digestible vegetables by using transesterification production method. The recently researched biofuels are Schleichera Oleosa (kusum oil), Nicotiana tabacum (Tobacco oil), and Amoora Wallichii King and Meyna spinosa Roxb Ex (Kutkura oil) extracted from the non-edible food sources. The biodiesel have most widely used five types of methyl esters like methyl linolenate, methyl stearate, and methyl oleate and methyl palmitate [3, 21]. During the combustion phase of the biodiesel, engine emitted 9% carbon composition which is less than high speed diesel.

The blended biodiesel indicate substantial reduction of NO, CO and polycyclic aromatic hydrocarbons (PAHs) emissions [13]. The percentage increase of biodiesel in the blends increases emissions due to improper combustion process [3]. However, the selecting of oil or fat is a very important criterion for biodiesel performance. In biodiesel production, it is needed to produce the low cost oil crops. Pumpkin oil and juliflora oil are few of the good oil crops for biodiesel production. The pumpkin seed oil contains an oil level of 42-54% depending on several factors such as plant area, climate and state of ripeness [3]. In any type of biodiesel preparations FFA oil content of less than 3% has been easily converted by using a catalyst [6, 7]. Similarly, the transesterification process of base catalyst cannot access the high amount of FFA content in vegetable oils [8]. In this regard, the two-step transesterification methodology is sought after to convert pumpkin oil into methyl esters [22, 23]. For each oil sample, transesterification processes (each with two steps) were carried out, using the exact amount of methanol and KOH and washed with water and heated for removing traces of water [9, 26].

In this experiment, pumpkin seed oil, juliflora seed oil are converted to fatty acid, by adding 15 grams potassium hydroxide (KOH) as catalyst for transesterification [10, 18]. Diethyl ether as the additive was added to the above blend and the engine was operated with no load to full load and in over load condition. From the test results, it was found that there was an improvement in Brake Thermal efficiency (BTE) and decrease in Specific Fuel utilization. The benefit of Cucurbita pepo oil as well as prosopis juliflora oil over sunflower oil, soy bean oil and other edible oil lie in the oil cost. From the literature review, it was observed that not much of experimental research have been carried out using mixed biodiesel blends. Little information is available on the combustion and emission behaviour of diethyl ether as additive with juliflora biodiesel and pumpkin biodiesel combination. In this regard the proposed research work is aimed to focus on the combustion performance of the pumpkin and juliflora biodiesel blend.

2. Materials and Methods

2.1 Cucurbita pepo (pumpkin) seed oil and Prosopis Juliflora seed oil

The pumpkin as well as juliflora oil are not readily available in the market as there is no more commercial production. The pumpkin and juliflora seeds were purchased and the oil extraction was done in a laboratory. The preparation of biodiesel from the pumpkin oil and juliflora oil were done separately using catalytic transesterification process. 15grams of KOH (6:1 ratio) was added to pumpkin/juliflora oil followed by 200 ml of methanol [14]. The mixture was maintained at 65-70 °C for 1 hour and then residues were allowed
to settle down for 2 hours in a titration setup [11, 24]. After few hours the residues were separated from the biodiesel by titration. The two different biodiesel namely pumpkin biodiesel and juliflora biodiesel, 0.5 litres each were mixed to form the blended biodiesel. It is then stirred well using magnetic stirrer at a temperature range of 60-100°C. The two biodiesel are mixed in equal ratio of 50% in volume each for the purpose of matching the calorific value of blended biodiesel with diesel and also to meet the standard flash point of the diesel. Pumpkin biodiesel has higher flash point which leads to delayed firing of fuel during ignition, whereas juliflora biodiesel has lower flash point closer to diesel and increase the possibility of easy and fast ignition of air fuel mixture. 50:50 mixture of pumpkin and juliflora biodiesel blend is called PJ biodiesel. The, following blends were made with the diesel and blended biodiesel. 100 ml PJ biodiesel and 900 ml diesel called B10, 200 ml PJ biodiesel and 800 ml diesel called B20, 300 ml PJ biodiesel and 700 ml diesel called B30, 400 ml PJ biodiesel and 600 ml diesel called B40 and 500 ml PJ biodiesel and 500 ml diesel called B50. 5ml Diethyl ether was used as additive with all blends. Table 2.1 represents the physical properties of diesel, biodiesel, PJ biodiesel and B20 blend with DEE.

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Density (kg m⁻³)</th>
<th>Kinematic viscosity (poise)</th>
<th>Calorific value (kJ/kg)</th>
<th>Flash point (°C)</th>
<th>Fire point (°C)</th>
<th>Cetane number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>825</td>
<td>2.870</td>
<td>42000</td>
<td>065</td>
<td>078</td>
<td>49.0</td>
</tr>
<tr>
<td>Pumpkin biodiesel</td>
<td>787</td>
<td>4.410</td>
<td>39128</td>
<td>138</td>
<td>142</td>
<td>51.0</td>
</tr>
<tr>
<td>Juliflora biodiesel</td>
<td>758</td>
<td>5.120</td>
<td>40360</td>
<td>074</td>
<td>088</td>
<td>52.0</td>
</tr>
<tr>
<td>PJ Biodiesel</td>
<td>766</td>
<td>4.960</td>
<td>39846</td>
<td>098</td>
<td>106</td>
<td>51.5</td>
</tr>
<tr>
<td>B20 blend with DEE</td>
<td>830</td>
<td>3.388</td>
<td>41665</td>
<td>072</td>
<td>087</td>
<td>50.0</td>
</tr>
</tbody>
</table>

The properties of pumpkin biodiesel, juliflora biodiesel and the blends such as viscosity, density, calorific value, flash point and fire point were measured. The low acid number indicates that residual free fatty acids remaining after esterification were efficiently removed by the wash protocol applied to the crude ester product [17, 25].

2.2 Experimental setup

The performance and emission characteristics of biodiesels were analyzed using a single cylinder, 4 strokes, water cooled and constant speed CI engine running at 1500rpm. The compression ratio of the engine is 17.5:1 with a maximum power output of 5.2kW. The motor receives the load from a load cell connected with an eddy current dynamometer. The engine performance is monitored by using a data acquisition system. The solenoid controller is used to measure specific fuel consumption. The pulsation impact is measured from the engine by employing a surge tank to confirm that the steady air flow through the intake manifold system. A non contact type of sensor mounted on the engine measures the flywheel speed. The eddy current produced is dissipated in the form of heat; the cooling water carries this heat away. The other combustion characteristics such as pressure, heat transfer rate and ignition delay are monitored by using data prediction software. The engine load were applied at different percentage such as 20%,
40 %, 60 %, 80 %, 100 % (maximum load) and 120 % (over load) by eddy current
dynamometer. Table 2.2 shows the specification of exhaust gas analyser and smoke
meter. Figure 1 shows the schematic arrangement of KIRLOSKAR TV-1 test engine.

Table 2.2: Specification of Exhaust Emission Measuring Equipment

<table>
<thead>
<tr>
<th>Equipment Name</th>
<th>Model</th>
<th>Measurement Range</th>
</tr>
</thead>
</table>
| Exhaust gas analyzer  | Make Model and AVL 444 di-gas analyzer | CO,HC, NO, CO₂  
CO : 0-10 (% Volume), HC : 0-20000 ppm,  
CO₂ : 0-10 (% Volume), NO: (0-5000 ppm) |
| Smoke meter           | AVL 437C smoke meter      | smoke density                            
0-100 (Opacity in %) |

3. Result and discussions

The test engine was analyzed for the performance and emission characteristics using PJ
biodiesel blend and compared with the diesel. Further, 5ml diethyl ether was added to the
PJ biodiesel blend (10 %, 20 %, 30 %, 40 % and 50 %) for improving the performance
characteristics of biodiesel. The exhaust emissions of blended biodiesel such as CO, CO₂,
HC, and NO was observed using 5-gas analyser. The percentage of smoke opacity was
examined with AVL 437C Free accelerometer Smoke meter. The performance of the
engine was also analyzed for brake specific fuel consumption (BSFC) and brake thermal
efficiency (BTE).
3.1 Performance characteristics

Figure 2 and Figure 3 shows the comparison of BTE and BSFC for both type of biodiesel used in the test engine. Higher engine temperature was observed when PJ biodiesel is used with DEE and this improves the combustion process due to excess amount of oxygen present in DEE. Figure 2(a) and 2(b) shows the BTE for PJ biodiesel and PJ biodiesel with additive. At maximum load (100 %) the BTE was observed to be 31.42 % for diesel, 33.4 % for B20 blend and 34.57 % for B20 blend with additive. This shows that PJ biodiesel with DEE results in higher BTE and good thermal performance with B20 blend compared to other blends. The BTE improvement of about 6.30 % for B20 blend and 10.03 % for B20 blend with additive compared to diesel was noted. When the load exceeds the maximum limit, the efficiency tends to decrease for both diesel as well as biodiesel blends.

![Figure 2, BTE vs. Load Variations without Additive (a) and with Additive (b) to the Biodiesel Blend](image1)

![Figure 3, SFC vs. Load Variations without Additive (a) and with Additive (b) to the Biodiesel Blend](image2)
Figure 3(a) and 3(b) shows the BSFC for PJ biodiesel and PJ biodiesel with additive. BSFC influences the combustion characteristics of the diesel engine and therefore, increasing the load of engine with reduced fuel consumption demonstrates the better fuel usage. At maximum load the BSFC was observed to be 0.273 kg/kW·hr for diesel, 0.259 kg/kW·hr for B20 blend and 0.249 kg/kW·hr for B20 blend with additive. The BSFC decrease of about 5.13% for B20 blend and 8.79% for B20 blend with additive compared to diesel was noted. The BSFC is least while using biodiesel with additive and this is because of the higher calorific value and lower kinematic viscosity of the blend. When the load exceeds the maximum limit the BSFC tends to increase for both diesels as well as for biodiesel blends.

3.3 Emission Characteristics

Figure 4(a) and 5(a) shows the emission of carbon monoxide (CO) at different loads from the test engine by using diesel, PJ biodiesel blend and PJ biodiesel blend with additive. The features affecting CO emission were air-fuel mix and oxygen. CO emission was because of the inadequate burning of fuel, where the oxidation has not occurred properly [16, 28]. This is due to inadequate air quantity and inability of carbon conversion to CO₂ at exhaust manifold. At maximum load the CO emission was observed to be 0.154% by volume for diesel, 0.153% by volume for B20 blend, and 0.132% by volume for B20 blend with additive. The CO emission was observed to be reduced by 0.65% for B20 blend and 14.3% for B20 blend with additive. It was observed that the blended biodiesel with additive has comparatively lower emission. This decrease in CO output was because of increase in burning chamber temperature and nearness of more oxygen in additive based biodiesel.

Figure 4 (a) and Figure 5 (a), Load vs. Emission Characteristics of CO for PJ Blended Biodiesel and PJ Blended Biodiesel with DEE Additive.

Figure 4(b) and 5(b) shows the emission of Carbon dioxide (CO₂) at different loads from the test engine by using diesel, PJ biodiesel blend and PJ biodiesel blend with additive. This CO₂ emission shows complete combustion process due to the amount of oxygen present in the biodiesel. As the calorific value of the biodiesel blends is lower, more fuel is utilised to get proportionate power yield. The presence of more carbon content in the biodiesel prompts increase of carbon dioxide emission. At maximum load the CO₂ emission was observed to be 5.8% by volume for diesel, 5.2% by volume for
B20 blend and 5.0 % by volume for B20 blend with additive. CO₂ emission was observed to be reduced by 10.3 % for B20 blend and 13.8 % for B20 blend with additive compared to diesel was noted.

Figure 4 (b) and Figure 5 (b), Load vs. Emission Characteristics of CO₂ for PJ Blended Biodiesel and PJ Blended Biodiesel with DEE Additive.

Figure 4(c) and 5(c) show the emission of hydro carbon (HC) at different loads from the test engine by using diesel, PJ biodiesel blend, PJ biodiesel blend with additive. HC emission was observed with unburned fuels due to insufficient temperature formation at near the cylindrical walls in the engine [15]. The lower HC emission occurs due to lower heat rejection by high in-cylinder temperature. At maximum load the HC emission was observed to be 68 ppm for diesel, 88 ppm for B10 blend, and 82ppm for B10 blend with additive, which is increased by 29.4 % for B10 blend and 20.5 % for B10 blend with additive compared to diesel, was noted. Similarly, at maximum load HC emission was observed to be 91 ppm for B20 blend and 86 ppm for B20 blend with additive. HC emission was increased by 33.8 % for B20 blend and 26.5 % for B20 blend with additive compared to diesel was noted. It was observed that the blended biodiesel with additive has lower emission than that of biodiesel without additive.

Figure 4 (c) and Figure 5 (c), Load vs. Emission Characteristics of HC for PJ Blended Biodiesel and PJ Blended Biodiesel with DEE Additive.
It shows the oxygen content in additive increases the possibility of complete fuel burning [16]. At lower loads, HC emission noted to be lower but when blend ratio increases, HC emission also increase compared to diesel. However, the reduction in HC emission was mostly influenced by increasing wall temperature in the cylinder towards the exhaust manifold [5]. This is because of the accessibility of moderate oxygen when more fuel is infused into the engine chamber at higher engine burden. Still the emission from biodiesel with additive is comparatively more with respect to diesel. The researchers found an analogous reduction in HC emission by using pumpkin seed oil processed with coated and uncoated engines that shows the possibility for further reduction of HC with coated engine [12, 19]. As present results shows, B10 and B20 blend with additive achieved a better reduction in emissions compared with other biodiesel blends.

Figure 4(d) and 5(d) shows the emissions of nitrogen oxide (NO) from the exhaust system while using different biodiesel blends with and without additive. NO occurs due to combustion process at higher temperature and lower oxygen concentration. While using biodiesel blends, the oxygen levels are higher and this results in lower NO emission. At maximum load, NO emission was observed to be 1212 ppm for diesel, 956 ppm for B20 blend and 899 ppm for B20 blend with additive. The NO emission was observed to be decreased by 21.12% for B20 blend and 25.8% for B20 blend with DEE compared to diesel was noted. In case of biodiesel with DEE an optimized performance was achieved at B50 blend of biodiesel owing to sufficient heat generation and better oxygen concentration.

Figure 4 (d) and Figure 5 (d), Load vs. Emission Characteristics of NO for PJ Blended Biodiesel and PJ Blended Biodiesel with DEE Additive.

It was also observed that even at lower loads, the BJ biodiesel and BJ biodiesel with additive has comparatively lower values than that of diesel. Yilmaz N et.al., found reduction in NO, by using di-tertiary-butyl peroxide (DTBP) in coated engine while using biodiesel [27].

Figure 6 (a) and (b) shows the smoke density values for diesel as well as biodiesel blends. The enhancement of oxygen plays a crucial role in smoke emission from the engine at different loading conditions. At maximum load, the smoke opacity was observed to be 64.0% for diesel, 74.6% for B20 blend and 67.3% for B20 blend with additive. The smoke emission was observed to be increased by 10.6% for B20 blend and increased by 3.3% for B20 blend with additive compared to diesel was noted. Use of biodiesel generates higher smoke levels when compared with the diesel due to the rate of adjourned oxidation process. In this regard use of PJ biodiesel with additive reduces the
The presence of DEE has reduced the smoke density than that of all diesel and biodiesel blends. For B20 blend with additive the smoke density is nearly equal to that of the diesel. It exhibits the presence of sufficient oxygen content and non-defective combustion process. As a result, it was inferred that the exhaust temperature is important for characterizing the smoke behavior. Also, the smoke density was observed to increase with percentage increase of biodiesel in the blends as well as with increasing loads.

Figure 6(a) and 6(b), Smoke Density vs. Load Variations without Additive and with DEE Additive to the Biodiesel Blend

4. Conclusion

The experimental work on PJ biodiesel and PJ biodiesel with DEE was conducted on a single cylinder, four-stroke direct infusion water cooled diesel engine with an eddy current dynamometer. Performance and emission characteristics of PJ biodiesel and PJ biodiesel with DEE were observed as follows:

- The diesel, PJ biodiesel blend and PJ biodiesel blend with DEE demonstrated a reduction pattern for BSFC and increasing pattern of BTE. B20 blend with DEE decreases the Brake Specific Fuel Consumption (BSFC) by 8.79% at maximum load compared with the diesel. B20 blend with DEE prompts 10.03% increased Brake Thermal Efficiency (BTE) at maximum load compared with diesel.

- B20 blends with additive exhibited a reduction in CO₂ emission by 13.8% at maximum load compared to diesel. Similar results were found in the B20 blends with additive for the CO emission that was reduced by 14.3% at maximum load due the combustion process because of the presence of excess oxygen and elevated temperature of the system.

- The HC emission for B10 blend and B20 blend with additive shows an increase of 20% and 25% respectively compared to diesel.

- The NO emission for B20 blend with additive demonstrates a reduction of 25.8% by volume at maximum load compared with diesel. NO output decreases with increasing biodiesel blends with and without DEE.

- From the results, it is evident that B20 blend with DEE exhibits better performance and decreased emission characteristics and therefore could be considered as an alternative fuel to diesel.
References


