Performance of a Compression Ignition Engine with Blends of Biodiesel (from a mixture of Spirulina Microalgae Oil and Sunflower Oil) and Diesel

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Abstract: In this paper, a high viscous micro algae oil, approximately 8 times more than that of diesel, obtained from spirulina micro algae using soxhlet apparatus was mixed with sunflower oil in three different volume percentage say 5:95 ml, 10:90ml and 15:85ml in order to decrease the viscosity by 40%. In addition, the above mixture was converted to biodiesel through two step trans-esterification process with methanol. Also, the produced 3 types of bio-diesel were mixed with pure diesel in 10:90 ml by volume percentage. Furthermore, a 5 HP single cylinder, 4 stroke, water cooled diesel engine was evaluated at constant speed with varying load by rope brake dynamometer using blends of biodiesel B10A,B10B and B10C with conventional diesel in terms of brake power, total fuel consumption, brake specific fuel consumption, brake thermal efficiency, brake specific energy consumption and volumetric efficiency. The study also includes, physical and chemical property inspection, measurements of calorific value, PH value, flash and fire point and testing of calculated cetane index for biodiesel, blended biodiesel and pure diesel. It is inferred from the above study that the properties and performance of blended biodiesel are very close to the conventional diesel. The innovation in this paper as compared to the literature and our previously published paper is the usage of an alternative fuel to the diesel using biomass feedstock blended with Sunflower oil. Apart from, increasing the performance of a CI engine, it reduces our carbon footprint and pave a way to become a greener planet.
Keywords: Micro Algae Oil, Sunflower Oil, Methanol, Biodiesel, CI Engine Performance

test

1 Introduction

Algae are a diverse group of macro or micro photosynthetic organism that inhabit freshwater and marine environments. Algae biomass has the potential to contribute to outstanding progresses towards a sustainable environment with low impact on economy. Recent research had brought to light multiple uses of algae for tackling global environmental issues. Algae which has been studied to be an efficient feedstock for biodiesel production, has vast uses in pharmaceutical industry, health care products, as a source of food, as a product capable of electricity generation and waste water treatment, etc. The search for an alternative fuel to encounter the world current crisis of fossil fuel depletion and environmental degradation, which not only offers energy conservation, but also environmental preservation, has become highly pronounced within context. The fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis. Gasoline and diesel-driven automobiles are the major sources of Green House Gases (GHG) emission. Scientists around the world have explored several alternative energy resources like biomass, biogas, primary alcohols, vegetable oils and biodiesel. The merits and de-merits of using alternative biofuels have their own limitation in case to case basis with respect to their specific application too by using them directly. Hence, blending these with suitable substitute will offer the similar properties closer to the conventional fuel. Hariram and Mohan Kumar have studied the single cylinder pressure characteristics, the rate of pressure rise, heat release analysis, performance and emission analysis in a single cylinder direct injection compression ignition engine using straight diesel and the blends of Algal Oil Methyl Ester (AOME) with diesel in 5%, 10% and 15% blend ratio. Suresh Kumar and Velraj have carried out a performance and emission analysis in an unmodified diesel engine fuelled with Pongamia Pinnata Methyl Ester (PPME) and its blends with diesel. Hifjur Raheman evaluated a 10 kW single cylinder, water cooled, direct injection diesel engine using blends of biodiesel obtained from a mixture of Mahua and Simarouba oils with high speed diesel. An investigation has been carried out in diesel engine by Raheman and Phadatre to study the fuel properties of Karanja Methyl Ester and its blends with diesel. A performance and emission characteristic of the compression ignition engine was analysed by Ramadhas, Muraleedharan and Jayaraj using pure rubber seed oil, diesel and biodiesel. According to them an optimum blends of biodiesel increased the brake thermal efficiency and reduced the fuel consumption. The performance and exhaust emissions of a single cylinder diesel engine was evaluated by Pugazh Vadivu and Jayachandran using diesel, waste frying oil with and without preheating. During this study, they found that the engine performance was improved while using preheated waste frying oil. Sankar, Mani Varma and Arun Thampi have produced a biodiesel from non-edible oil seed Jatropha curcas though trans-esterification process. An experimental investigation have also been carried out without altering the CI engine fuelled with JOME-JOEE- Diesel blends to examine the performance parameters in terms of brake thermal efficiency, total fuel consumption and brake specific fuel consumption for several engine load from 0 Kg to 8 Kg. Performance, combustion and emission parameters were analysed on a single cylinder direct injection compression ignition water cooled diesel engine having capacity 5.2 kW fuelled with diesel, microalgae oil and microalgae oil methyl ester by Sushant. During this study, a general trend of decrease in the brake thermal efficiency with the use of microalgae oil and micro algae oil methyl ester was observed. The performance of a single cylinder C.I Engine was evaluated by Pramanik using blends of varying proportions of Jatropha curcas oil and diesel. They compared the results with the performance obtained from diesel. Hanbey Hazar and Huseyin Aydin have conducted performance and emission evaluation study of a CI engine fueled with preheated raw
rapeseed oil-diesel blends. They concluded that the preheating of fuel have positive effects on engine performance and emission when compared with non-preheated vegetable oil. Deepak Agarwal, Lokesh Kumar and Avinash Kumar Agarwal performed an engine test using blends of linseed oil, Mahua oil, Rice bran oil and LOME with diesel in different proportions. In addition, baseline data for diesel fuel was collected. The study revealed that straight vegetable oil posed operational and durability problems when subjected to long term usage in CI engine. Deepak Agarwal and Avinash Kumar Agarwal have studied reduction in jatropha oil’s viscosity through an experiment by the heat emitted from waste exhaust gases by increasing the fuel temperature. Further, they have studied the effect of reduced blend viscosity on emissions and performance of diesel engine through an experiment by using various blends of jatropha oil with mineral diesel. Banapurmath, Tewari and Hosmath have presented the results of investigations carried out on a single cylinder four stroke direct injections CI engine operated with methyl esters of Honge oil, Jatropha oil and Sesame oil. Comparative measures of brake thermal efficiency, emission, ignition delay, combustion duration and heat release rates have also been discussed. Avinash Kumar Agarwal and R Rajamanoharan have analysed the effect on emission and performance of a compression ignition engine by using Karanja oil and its blends with mineral diesel. The study revealed that the Karanja oil blended with diesel (upto 50% by v/v) without preheating as well as with preheating can replace the diesel for operating a CI engine with lower emission and improved engine performance. It is observed from the above literature reviews that many research papers are available for the blends of, Algaloil Methyl Esters with Diesel [1], Pongamia Pinnata Methyl Ester (PPME) and its blends with diesel [2], a mixture of Mahua and Simarouba oils with high speed diesel [3], Karanja Methyl Ester and its blends with diesel [4], Pure rubber seed oil, diesel and biodiesel [5], diesel, waste frying oil with and without preheating [6], Jatropha oil with diesel [7]; but an attempt has not been made with a mixture of Microalgae oil and Sunflower oil with diesel blends to the best knowledge of the investigator. So, it was taught worthwhile to take this study to evaluate the performance of a CI engine fuelled with a mixture of Microalgae oil and Sunflower oil with the diesel blends.

2 Microalgae

Microalgae are prokaryotic or eukaryotic photosynthetic micro-organisms that can grow rapidly and live in harsh conditions due to their unicellular or simple multi-cellular structure. Microalgae are present in all existing earth bio-networks, not just water but also land-dwelling, representing a big range of species living in a wide range of eco-friendly conditions. Microalgae have been considered recently as a promising biomass feedstock with great potential for biodiesel production because they reproduce themselves once in every few days. It reduces emissions of a major greenhouse gas. In addition, microalgae as a fuel source do not conflict with the food crisis, since it is not the main food source. Micro algae are an alternative to popular feed stocks like soyabean, canola and palm. Micro algae are multi-cellular organisms which, like plants, use photosynthesis to convert the sun’s energy into chemical energy. Cyanobacterium Arthrospira (Spirulina) platensis is a commercial product with high nutritional value, serving as a source of nutrients for food, biodiesel production, chemical and pharmaceutical industry. It is also used in aquaculture as feed for fish, crustacean, shellfish and bivalve cultures. It is also applied in wastewater treatment, and agriculture. Spirulinais naturally found in tropical regions inhabiting alkaline lakes with high concentration of NaCl and bicarbonates. These limiting conditions for other micro-organisms allow cultivation of this micro algae in opened reactors.
3 MicroAlgae Oil (MAO)

The spirulina as obtained from the Central Marine Fisheries and Research Institute (CMFRI), Ernakulam, India, was converted into microalgae oil after cultivation of microalgae in culture medium under laboratory condition as well as in open tanks (mass culture). Harvesting, Filtration process, Drying process and finally by oil extraction using Soxhlet apparatus (Chemical method). During this extraction process, only 65ml of microalgae oil could be able to extract from 890 grams of microalgae powder (yield is 7.3%). The Acid Value and the content of Free Fatty Acid in percentage (FFA%) in microalgae oil was determined by titration method using conical flask and burette. The formula used to calculate the Acid Value and FFA% are given in Equation 1 and 2.

Acid value (mg KOH/g) = \( \frac{\text{Mol. Wt of KOH} \times \text{Normality of KOH} \times \text{Titration value}}{\text{Wt of oil}} \) .... (1)

When

- Molecular weight of KOH = 56.1 g/mol.
- Normality of KOH = 0.5
- Titration value from burette = 0.6 ml
- Weight of oil = 1 g

Acid value (mg KOH/g) of Micro Algae Oil = \( \frac{56.1 \times 0.5 \times 0.6}{1} \) = 16.83 mg KOH/g

FFA Content (%) = \( \frac{\text{Mol. Wt of Oleic acid} \times \text{Normality of KOH} \times \text{Titration value}}{\text{Wt of oil}} \) .... (2)

When,

- Molecular weight of oleic acid = 28.2
- Normality of KOH = 0.5
- Titration value from burette = 0.6 ml
- Weight of oil = 1 g

FFA Content (%) = \( \frac{28.2 \times 0.5 \times 0.6}{1} \) = 8.46% .... (3)

The kinematic viscosity of the microalgae oil at 40°C was measured using Redwood Viscometer I (for fluid having viscosity corresponds to rewood seconds from 30s to 2000s) and found to be 12.93 cSt. Similarly, the calculated density of the microalgae oil was found to be 0.942 Kg/L. According to biodiesel standard from American Society for Testing of Materials (ASTM) the recommended kinematic viscosity at 40°C is 4.1 cSt and the acid number (value) for diesel is Max 0.5. So, in order to reduce the acid number of microalgae oil from 16.83 mgKOH/g to less than 1 mgKOH/g, kinematic viscosity from 12.93 cSt to less than 4 cSt and also to reduce the Free Fatty Acid percentage, the produced microalgae oil was mixed with sunflower oil and then the mixture was converted to biodiesel through two step trans-esterification (Re-esterification and Trans-esterification) process.

4 Biodiesel

Biodiesel is a mixture of fatty acid alkyl esters produced by a trans-esterification reaction of vegetable or waste oil with alcohol, such as ethanol and methanol. These lipid feedstocks are composed by 90–98% (by weight) of triglycerides and small amounts of mono and diglycerides, free fatty acids (1–5%), and residual amounts of phospholipids, phosphatides,
carotenes, tocopherols, sulphur compounds, and traces of water. Trans-esterification is a multiple step reaction, including three reversible steps in series, where triglycerides are converted to diglycerides, then diglycerides are converted to monoglycerides, and monoglycerides are then converted to esters (biodiesel) and glycerol (by-product). It is harmless, biodegradable and yields less air toxins than petroleum-based diesel.

4.1 Biodiesel from Microalgae Oil
It is understood from the literature review that the excessive free fatty acid in the microalgae oil will lead to corrosion of the engine components due to presence of water in it and also affects the trans-esterification process by means of soap formation, the microalgae oil was undergone initially the re-esterification process. The above said process is carried out by using 3:1 molar ratio of methanol to triglyceride with acid catalyst (H₂SO₄) by 0.92% of the oil weight at 60°C reaction temperature and 120 minutes of reaction time. The obtained acid number and FFA% after re-esterification process were found to be 5.61 mgKOH/g and 2.82% respectively. With higher value of acid number and FFA% the microalgae oil was converted to biodiesel through trans-esterification process using 3:1 molar ratio of methanol to triglyceride with Potassium Hydroxide (KOH) by 1% of the oil weight as alkaline catalyst at 60°C reaction temperature and 120 minutes reaction time. The type of methanol being used during the entire trans-esterification process is Leishman solution. Due to high viscosity of the microalgae oil, more acid number and FFA% level maintained prior to the trans-esterification process, the biodiesel was not able to produce as expected and obtained biodiesel was in the form of semi-solid state (Figure.1).

![Fig. 1Semi solid biodiesel](image)

4.2 Mixing up of Microalgae Oil with Sunflower Oil
In order to reduce the kinematic viscosity, acid number and the free fatty acid percentage of the microalgae oil it was mixed with sunflower oil in three different volume percentage say 5ml of micro algae oil +95ml of sunflower oil (5:95), 10ml of micro algae oil +90ml of sunflower oil (10:90) and 15ml of micro algae oil +85ml of sunflower oil (15:85) respectively. The physical properties of microalgae oil extracted from the spirulina algae, sunflower oil, the mixture of microalgae oil and sunflower oil and diesel fuel according to biodiesel standard from American Society for Testing of Materials (ASTM) are illustrated in Table.1.

Table 1: Comparison of different properties of MAO, sunflower oil and diesel
<table>
<thead>
<tr>
<th>S.No</th>
<th>Description</th>
<th>Kinematic Viscosity, 40°C (cSt)</th>
<th>Density (Kg/L)</th>
<th>FFA %</th>
<th>Acid Number (mg KOH/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Micro algae oil</td>
<td>12.93</td>
<td>0.942</td>
<td>8.46</td>
<td>16.83</td>
</tr>
<tr>
<td>2</td>
<td>Sunflower oil</td>
<td>7.77</td>
<td>0.964</td>
<td>0.26</td>
<td>0.435</td>
</tr>
<tr>
<td>3</td>
<td>5ml micro algae oil +95ml sunflower oil</td>
<td>8.26</td>
<td>1.01</td>
<td>1.05</td>
<td>2.11</td>
</tr>
<tr>
<td>4</td>
<td>10 ml micro algae oil +90ml sunflower oil</td>
<td>8.54</td>
<td>0.998</td>
<td>1.41</td>
<td>2.136</td>
</tr>
<tr>
<td>5</td>
<td>15ml micro algae oil +85ml sunflower oil</td>
<td>9.05</td>
<td>0.975</td>
<td>1.49</td>
<td>2.16</td>
</tr>
<tr>
<td>6</td>
<td>Diesel</td>
<td>1.3-4.5</td>
<td>0.81</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### 4.3 Re-Esterification Process

It is obvious from Table 1 that the kinematic viscosity of the microalgae oil (12.93 cSt) is reduced to less than 9 cSt after mixing up of it with the sunflower oil. Similarly, we can see drastic reduction in acid number as well as free fatty acid percentage too. In addition, the mixture of microalgae oil and sunflower oil was re-esterified (acid esterification) using methanol and acid catalyst at 60°C to reduce the acid number to less than 0.5%. The obtained Free Fatty Acid percentage (FFA %) and acid value of all the oil mixture after re-esterification process is given in Table 2.

**Table 2** Comparison of FFA% and acid value of oil after re-esterification process

<table>
<thead>
<tr>
<th>Oil</th>
<th>FFA%</th>
<th>Acid Value (mgKOH/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5ml micro algae oil +95ml sunflower oil</td>
<td>0.22</td>
<td>0.46</td>
</tr>
<tr>
<td>10ml micro algae oil +90ml sunflower oil</td>
<td>0.25</td>
<td>0.48</td>
</tr>
<tr>
<td>15ml micro algae oil +85ml sunflower oil</td>
<td>0.25</td>
<td>0.48</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Max 0.5</td>
<td>Max 0.5</td>
</tr>
</tbody>
</table>

### 4.4 Biodiesel from a Mixture of Microalgae Oil and Sunflower Oil

After re-esterification process, the three different mixtures of microalgae oil and sunflower oil were converted to biodiesel through trans-esterification process. Thereafter, the produced biodiesel was separated from Glycerol using separating funnel. Then, it was washed with warm water to remove residual catalyst and soaps. Finally, the biodiesel was filtered using normal filter paper to remove impurities and others. Figure 2 shows the set up used during trans-esterification process and Figure 3 shows the produced biodiesel with glycerol after trans-esterification process. Similarly, Figure 4 illustrates the final product of biodiesel produced from different mixture of micro algae oil and sunflower oil after the filtering process.
Fig. 2 Experimental setup used to perform trans-esterification process

Fig. 3 Biodiesel and glycerol after trans-esterification process
4.5 Physical properties of Test Fuel

The physical properties of biodiesel produced from different mixture of microalgae oil and sunflower oil after trans-esterification process and the diesel fuel is illustrated in Table 3. The flash and fire point of the biodiesel and the diesel were checked using Cleve Land flash and fire point apparatus. It is observed from Table 3 that the flash point of the biodiesel was higher than that of the sole fuel. In addition, the pH value of the produced biodiesel and the diesel were tested using Elico L1617pH meter at Integrated Rural Technology Centre-Mundur, Kerala, India. Before this testing an electrodos of the pH meter were washed with distilled water and then wiped off using tissue paper. It is evident from Table 3 that the pH value of all the three biodiesel is same as sole fuel. Similarly, the calorific value of the biodiesel and the diesel were checked using Bomb Calorimeter at Jawaharlal Nehru College of Engineering and Technology- Lakkidi, Kerala, India. Among three samples produced, the calorific value is maximum for sample 3 (32270 KJ/Kg) but all are less when compared with sole fuel (45,000 KJ/Kg). Besides, the calorific value is increasing with increase in content of the micro algae oil. Also, the Calculated CetaneIndex of the fuel is one such important parameter which is responsible for the delay period and it defines the quality of fuel. A fuel of higher cetane number gives reduced delay time and gives quiet engine running. In short, the higher the cetanenumbers the more easily the fuel will combust in a combustion chamber (such as a diesel fuel). The typical diesel “Knock” ascends when fuel that has been introduced into the cylinder clasp fire after a postponement creating a late shock wave. Minimizing this delay results in fewer unburned fuel in the cylinder and less intense knock. Therefore, higher cetane fuel usually causes an engine to run more smoothly and quietly. This does not essential transform into improved efficiency, while it may in certain engines.

Table 3 Comparison of different properties of biodiesel and diesel after trans-esterification

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Biodiesel (5ml micro algae oil+95 ml sunflower oil) Sample 1</th>
<th>Biodiesel (10ml micro algae oil + 90ml sunflower oil) Sample 2</th>
<th>Biodiesel (15ml algae oil+85 ml sunflower oil) Sample 3</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (Kg/L)</td>
<td>1.036</td>
<td>1.018</td>
<td>0.999</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Fig. 4 Produced biodiesel after final washing
The cetane number of the biodiesel produced and the diesel were tested using Fuel Ignition Tester (FIT) at ITALAB private limited Chennai, India. It is obvious from Table 3 that the calculated cetane index of the biodiesel is increasing with increase in content of the microalgae oil.

4.6 Chemical Properties

The composition of Fatty Acid Methyl Ester (FAME) obtained from the mixture of spirulina microalgae oil and sunflower oil after trans-esterification process was analysed by Gas Chromatograph (Trace GC 700) at SreeNeelakanta Govt. Sanskrit College, Pattambi- Kerala- India. Most of the FAMEs were determined by comparison with retention time of the peaks with those of the standards ASTM D 6584, which is the prescribed method for measuring the methyl ester and glycerides (mono, di and tri glycerides) in the biodiesel. Basically, Gas Chromatograph study is performed on the sample to determine the amount of biodiesel obtained after the trans-esterification process. Methyl Ester content is meant to be a guide as to the purity of biodiesel by way of measuring conversion of triglycerides to methyl esters. The results obtained from the gas chromatography study for the content of methyl ester and the content of triglycerides for the three samples is given in Table 4. It is evident from Table 4 that the maximum amount of 75.06 % of the triglyceride (oil) is converted into methyl ester (fuel) in sample 1 and remaining 24.936% is still not converted into methyl ester. The setup of the Trace GC 700 gas chromatography is shown in Figure 5 and the above said analysis was conducted on all the three sample of biodiesel (i.e. Sample 1 means biodiesel from 5% of micro algae oil and 95% of sunflower oil, sample 2 means biodiesel from 10% of micro algae oil and 90% of sunflower oil and sample 3 means biodiesel from 15% of micro algae oil and 85% of sunflower oil). The gas chromatogram of three samples is illustrated in Figure 6.

<table>
<thead>
<tr>
<th>Kinematic Viscosity 40°C (cSt)</th>
<th>4.62</th>
<th>4.98</th>
<th>5.94</th>
<th>1.3-4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash point (K)</td>
<td>393</td>
<td>397</td>
<td>399</td>
<td>333-353</td>
</tr>
<tr>
<td>Fire point (K)</td>
<td>423</td>
<td>413</td>
<td>403</td>
<td>353-433</td>
</tr>
<tr>
<td>pH Value</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Calorific value (kJ/kg)</td>
<td>31587.5</td>
<td>31782</td>
<td>32270</td>
<td>45000</td>
</tr>
<tr>
<td>Calculated Cetane Index</td>
<td>44</td>
<td>45</td>
<td>46</td>
<td>40-55</td>
</tr>
<tr>
<td>Methyl ester content (%)</td>
<td>75.06</td>
<td>72.4</td>
<td>71.8</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4 Comparison of methyl ester content in various biodiesel

<table>
<thead>
<tr>
<th>Biodiesel Sample</th>
<th>Content of Methyl Ester (%)</th>
<th>Content of Mono Glyceride (%)</th>
<th>Content of Di Glyceride (%)</th>
<th>Content of Tri Glyceride (%)</th>
<th>Content of Free Glycerin (%)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>75.06</td>
<td>Nil</td>
<td>Nil</td>
<td>24.93</td>
<td>Nil</td>
<td>EN14214</td>
</tr>
<tr>
<td>Sample 2</td>
<td>72.4</td>
<td>Nil</td>
<td>Nil</td>
<td>27.5</td>
<td>Nil</td>
<td>EN14214</td>
</tr>
<tr>
<td>Sample 3</td>
<td>71.87</td>
<td>Nil</td>
<td>Nil</td>
<td>28.12</td>
<td>Nil</td>
<td>EN14214</td>
</tr>
</tbody>
</table>

The cetane number of the biodiesel produced and the diesel were tested using Fuel Ignition Tester (FIT) at ITALAB private limited Chennai, India. It is obvious from Table 3 that the calculated cetane index of the biodiesel is increasing with increase in content of the microalgae oil.

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5. Blending of Biodiesel with Diesel

The relatively high kinematic viscosity of vegetable oils must be reduced to make them compatible with the conventional combustion ignition engine and fuel properties. Table 3 elicits the fact that the kinematic viscosity of all the produced biodiesel are higher but the calorific value of all seen very low to that of diesel. In order to allow proper atomization of the fuel and also to prevent incomplete combustion, which would damage the engine by causing a build-up carbon, the biodiesel was blended with diesel. From the literature review, it was observed that the most recommended ratio for blending the biodiesel with the conventional diesel are 5%, 10%, 15% and 20%. So, in this study, 10% by volume of the biodiesel produced by trans-esterifying of microalgae oil and sunflower oil (each sample) is blended with 90% by volume of the diesel to reduce the viscosity further and to increase the calorific value. The following three types of blends were prepared to perform engine performance test and Figure 7 shows the final form of blended biodiesel before going for an engine test.
(i) **B10A** - 10% biodiesel (5ml micro algae oil and 95 ml sunflower oil) and 90% diesel.

(ii) **B10B** - 10% biodiesel (10 ml micro algae oil and 90 ml sunflower oil) and 90% diesel.

(iii) **B10C** - 10% biodiesel (15ml micro algae oil and 85 ml sunflower oil) and 90% diesel

As a routine practice, the physical properties of the blended biodiesel were inspected and compared with the conventional diesel fuel for any deviation before going for an engine performance test and are presented in Table 5. It is seen from Table 3 and Table 5 that there is drastic reduction in kinematic viscosity after blending the biodiesel with diesel in the entire sample. Also, it is seen that the kinematic viscosity of the entire sample is well within the limit of the conventional diesel. Similarly, there is an appreciable and significant increase in calorific value and calculated cetane index in all the three samples. Since, the viscosity of the blended biodiesel is well within the recommended limit (1.3-4.5); no preheating on the tested fuel (blended biodiesel) was made before going for an engine performance test.

**Table 5** Comparison of different properties of blended biodiesel and diesel

<table>
<thead>
<tr>
<th>Parameters</th>
<th>B10A</th>
<th>B10B</th>
<th>B10C</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic Viscosity 40°C (cSt)</td>
<td>2.12</td>
<td>2.11</td>
<td>2.14</td>
<td>1.3-4.5</td>
</tr>
<tr>
<td>Density (Kg/L)</td>
<td>0.986</td>
<td>0.971</td>
<td>0.959</td>
<td>0.83-0.85</td>
</tr>
<tr>
<td>Calorific Value (KJ/Kg)</td>
<td>39103.70</td>
<td>39786.99</td>
<td>40079.8</td>
<td>45000</td>
</tr>
<tr>
<td>Flash Point (K)</td>
<td>328</td>
<td>313</td>
<td>311</td>
<td>333-353</td>
</tr>
<tr>
<td>Fire Point (K)</td>
<td>335</td>
<td>320</td>
<td>318</td>
<td>353-433</td>
</tr>
<tr>
<td>Calculated Cetane Index</td>
<td>54</td>
<td>55</td>
<td>56</td>
<td>40-55</td>
</tr>
</tbody>
</table>

**6 Engine Set-up Details**

Single cylinder four stroke water cooled Kirloskar make diesel engine with a bore of 80mm and a stroke of 110mm is used in this study. The brake horse power and speed of the engine is 5hp and 1500 rpm respectively. Cubic capacity is 552.64 cc with a 16.5:1 compression ratio. Fuel consumption was determined by measuring the fuel used (5 cc) for a period of...
time and the test was carried at constant engine speed 1500 rpm. The engine is coupled to a water cooled Triplee make rope brake dynamometer (Figure.8) made up of cast iron. The diameter of the rope and the brake drum is 16 mm and 300 mm respectively. The loading radius is 158 mm and the hanger weight is 1 Kg.

Fig.8 Experimental setup used to perform engine test

At the beginning, the engine was started in diesel mode at no load condition and warmed up before starting the experiment after which the other parameters such as engine speed, time for 5 cc fuel consumption and manometer readings were noted. The diesel, biodiesel of B10A, B10B and B10C were used as test fuel in diesel engine with variable load conditions 0-18 kg (100% load) in step of 2 kg and also overload by 10 percentage (20 kg) at the constant engine speed of 1500 rpm. The engine was initially run on diesel fuel to generate base line data and after that it was run on three types of biodiesel. The performance of the diesel engine was evaluated in terms of Brake power, Total fuel consumption, Brake specific fuel consumption, Brake thermal efficiency, Brake specific energy consumption and Volumetric efficiency. As a precaution measure, the engine was permitted to run for sufficient time to vacant the remaining fuel from the previous test before going for an every test with new fuel blend.

7. Results and Discussion

Experimental results of performance of single cylinder four-stroke water cooled diesel engine testing for diesel and three types of biodiesel for different operating parameter is described below.

7.1 Total Fuel Consumption (Kg/hr)

The Total Fuel Consumption (TFC) is expressed by weight of fuel consumed by the engine during a specified time. The total fuel consumption observed with brake power for diesel and three types of biodiesel is shown in Figure.9. It is observed that the total fuel consumption in case of biodiesel B10A and B10B are more as compared to diesel. It indicates that the engine takes more fuel to give the same power output when using biodiesel B10A and B10B as compared to diesel. This trend is observed owing to the fact that the biodiesel B10A and B10B have more density (0.986 g/cc and 0.971 g/cc) than that of neat diesel fuel (0.85 g/cc) and lower heating value per unit mass of the fuel (39103.70 KJ/Kg and 39786.99 KJ/Kg).
which is distinctly lower than that of the diesel fuel (45000 KJ/Kg). Besides, the total fuel consumption of biodiesel B10C is more or less following the curve of sole fuel (diesel).

Fig.9 Brake power Vs Total fuel consumption

7.2 Brake Specific Fuel Consumption (Kg/kW-hr)

The Brake Specific fuel consumption (BSFC) is a measure of the fuel flow rate per unit power output. It measures how efficiently the engine uses the fuel supplied to produce the shaft power. It is typically used for comparing the efficiency of Internal Combustion (IC) engines with a shaft output. It is the ratio between total fuel consumption and brake power. Figure 10 demonstrate the effect of the blended fuel as well as the sole fuel on brake specific fuel consumption at constant engine speed (1500 rpm) against various brake power. As shown in the Figure 10, the brake specific fuel consumption is decreased gradually for all the model fuel with increase in brake power. This is a normal consequence of the behaviour of the engine brake thermal efficiency. It is observed that the brake specific fuel consumption in case of B10A is more as compared to diesel for all the brake power. This indicates that the engine takes more fuel to give the same power output when using blended biodiesel B10A as compared to diesel. This trend is observed owing to the fact that blended biodiesel B10A have a lower heating value (39103.70 KJ/Kg) than that of sole fuel (45000 KJ/Kg), and thus more blended biodiesel B10A is required for the maintenance of a constant power output.

Also, it is observed from Figure 10 that among the three blended biodiesel, the brake specific fuel consumption is less for the blended biodiesel B10C, and, more or less, it followed the curve of the diesel fuel.

Fig.10 Brake power Vs Brake specific fuel consumption
7.3 Brake Thermal Efficiency(%) 

Brake Thermal Efficiency (BTE) give an idea of the output generated by the engine with respect to heat supplied in the form of fuel. It is the ratio of brake power developed by the engine to the energy supplied by the fuel. In short, it is the measure of the engine efficiency or the fuel conversion efficiency. The results observed for the diesel and various blended biodiesel are shown in Figure. 11. From the Figure, it is very clear that the brake thermal efficiency with blended biodiesel B10C is more than that of neat diesel fuel. But, the trend is opposite in nature for blended biodiesel B10A and B10B and it is attributed to poor spray characteristics, poor air fuel mixing, lower viscosity, more fuel consumption and lower calorific value. Blended biodiesel B10A and B10B showed the maximum reduction of brake thermal efficiency of 4.39% and 6.39% on 0.44 kW brake power respectively. The maximum brake thermal efficiency of 28.6% on 4.12 kW is observed for blended biodiesel B10C. In addition, a marginal increase of brake thermal efficiency is observed, with an increase in brake power for all the test fuels.

![Fig.11 Brake power Vs Brake thermal efficiency](image-url)

7.4 Brake Specific Energy Consumption(MJ/kW-hr)

The comparison based on the specific fuel consumption cannot be made since the fuel has different energy contents. Therefore, a comparison is made based on the brake specific energy consumption (BSEC) of the different blended biodiesel with diesel fuel. The brake specific energy consumption is the product of brake specific fuel consumption and the calorific value of the fuel. The comparison of brake specific energy consumption of diesel and various blended biodiesel is shown in Figure. 12. A trend of decrease in BSEC is observed from lesser load to higher load for all the fuels. Among all the tested fuel, the blended biodiesel B10C shown lesser brake specific energy consumption (12.42 MJ/kW-hr at 4.12 kW) and blended biodiesel B10A shown higher brake specific energy consumption (16.032 MJ/kW-hr at 4.17 kW). The blended biodiesel B10B show an almost similar trend with that of diesel fuel. It is very clear that due to the lower calorific value of the blended biodiesel B10A (39103.70 KJ/Kg), it requires more amount of fuel to give the same power output resulting in higher energy consumption.
7.5 Volumetric Efficiency (%)

Volumetric Efficiency (VE) is a measure of the success with which the air supply, and thus the charge, is inducted into the engine. It is a very important parameter, since it indicates the breathing capacity of the engine and is defined as the ratio of the volume of air actually inducted at ambient condition to swept volume, and it indicates the measure of the degree to which the engine fills its swept volume. It puts a limit on the amount of fuel that can be effectively burned in an engine. The variation of volumetric efficiency with brake power for different blended biodiesel and conventional diesel has been presented in Figure 13. From analysing the plots, it is evident that the volumetric efficiency of all the test fuels is above 83% and observed maximum of 87.37% on 4.12 kW for blended biodiesel B10C. But, it is observed as 85.85% on 4.18 kW for diesel fuel. In addition, it shows that the volumetric efficiency of blended biodiesel B10C and B10B increased as the brake power increased. It is also seen that the volumetric efficiency of test fuel B10A and neat diesel fuel are almost parallel and showed the least variation with brake power.

8. Conclusion

In this study, the trans-esterification process was carried out to produce biodiesel from mixture of spirulina microalgae oil and sunflower oil. In addition, CI engine performance have been investigated experimentally using produced biodiesel and the neat diesel. From the above study, the following conclusions can be deduced.

- The produced biodiesel is meeting the ASTM standards for biodiesel for kinematic viscosity and the Calculated Cetane Index.
This study establishes the feasibility of biodiesel B10A, B10B and B10C as a new alternative fuel for CI engine without any modifications.

Among the three blended biodiesel, sample containing 15ml micro algae oil and 85ml sunflower oil (B10C) gives the best result. Out of three samples, its calorific value (40079.8 KJ/Kg) is closer to the conventional diesel (45000 KJ/Kg). In addition, its total fuel consumption (1.32 Kg/hr) is also equal to the conventional diesel fuel for almost the same brake power (4.12 kW).

It is very clear from the above study that the level of kinematic viscosity, acid number and FFA% of the oil plays an important role in the production of biodiesel. If it is more than that of the limit prior to the tans-esterification process then we may not get semi solid the biodiesel as anticipated.

It is seen from the study that with increasing amount of micro algae oil content there was significant improvement in the fuel properties such as calorific value and calculated cetaneindex.

Biodiesel blended with diesel leads to an improvement in the engine performance. Among the three blended biodiesel, brake thermal efficiency is higher by 2.77% for the blended biodiesel B10C than that of the conventional diesel and it is more by 2.02% for blended biodiesel B10B. Similarly, the volumetric efficiency is more by 1.52% for the blended biodiesel B10C even for less engine load when compared with sole fuel (Diesel).

Further, it is understood from the above study that the brake specific energy consumption is least (12.42 MJ/kW-hr) for the fuel B10C when compared with diesel fuel (13.905 MJ/kW-hr). Similarly, with regard to brake specific fuel consumption it is almost equal with the conventional diesel fuel.

References


