Study on the performance and emission characteristics of a CI engine using diesel-calophyllum inophyllum blends

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Abstract. The limited supply of fossil fuels and modern emission norms necessitates the use of mixture of alternate fuels with fossil fuels. Bio-diesel is a renewable source of energy obtained from agro-wastes or agro-based products. Oils obtained from these products maybe edible or non-edible. In this study, the suitability of Calophyllum inophyllum oil (CIO), a non-edible oil, as a bio-diesel source is studied. The bio-diesel fuel is first synthesized from the oil obtained through various stages, including transesterification. The performance characteristics such as brake thermal efficiency (BTE), specific fuel consumption (SFC) and emission variables such as CO2, NOx, HC, CO and smoke are studied. The blend percentage by volume used in the investigation are 10%, 20%, 30%, 40% and 100%. It is observed that HC and CO emissions are less for B10 blend. B10 blend has 20.3% less NOx emissions when compared to that of diesel fuel. BSFC is decreased by 8% and BTE is increased by 9.5% in B10 blend. Among all blends used, the lowest soot concentration is obtained with B10 blend. B10 blend provides the most suitable combination of characteristics to be used as an alternate fuel blend.

1. Introduction
Energy has been the key input for socio-economical, industrial and technological advancements for a long period. Fossil fuels have been the main sources of energy for ages. Their exhaustion has now resulted in the quest for alternate energy resources. Depleting reserves of conventional sources and the growing concerns on environment have made renewable energy an attractive proposition for future energy generation.

Biodiesel emerged as one of the most sustainable alternative for diesel needs and its usage have been promoted by most of the countries [1]. Various vegetable-based oils can be used as substitute for fossil fuels. Currently, transportation sector depends predominantly on internal combustion engines. Biodiesel have direct applications in Compression Ignition Engines (CI engines), but when mixed with petroleum (Biodiesel blend) it can be utilized in Spark Ignition engine vehicles as well [2]. Emission is a matter of concern, as SI engines and CI engines run on petrol and diesel respectively. [3]. Strict emission norms have made manufacturers redesign their engine setup. Biodiesel is a blend of monoalkyl ester of long chain fatty acid, gathered from inexhaustible, agro-based products vegetable oils and/or animal fats [4]. By carrying out transesterification process and blending with conventional fuels, biodiesels can be used as alternatives for diesel. Biodiesel is a clean burning oil and does not have emissions which are toxic. It is comprised mainly of esters of glycerol i.e., triglycerides [5]. Oils obtained from vegetable based sources have good quality of ignition due to unbranched, long chain molecules [6]. A well-known plant
commonly used in the synthesis of biodiesel is Calophyllum Inophyllum, which is an evergreen, oil rich plant that has high cetane value and mostly found in coastal area [7]. In flash point, the purpose of these Oils is significantly greater than that of diesel, allowing easier and safer storage of the oil [8]. The percentage of NO\textsubscript{x} emissions can be minimised by using the blend of diesel and ground nut oil biodiesel and when the percentage of ground nut oil based biodiesel is increased, the NO\textsubscript{x} emission is gradually reduced [9]. The emission characteristics such as CO, HC and NO\textsubscript{x} in PCCI-DI engine can be optimized by using diethyl ether biodiesel-diesel blends [10]. Due to the shortage of enough feedstock, the production of biodiesel from microalgae has played a major role in the field of alternative fuels and it satisfies all the fuel properties of standard diesel [11]. Also, the mixture of cotton seed oil and sun flower oil blended with diesel can be used as substitute for diesel since this mixture reduces the smoke emissions [12]. Chavan S.B et al. [13] utilized Calophyllum Inophyllum oil for biodiesel creation with molar proportion 8:1 KOH was utilized as impetus in the planning this bio diesel and its temperature were tried in like manner according to ASTM 6751 Standards.

This paper aims to study the effect of CIO biodiesel-diesel blends on the performance and emission characteristics of the CI engine and substitute diesel fuel partially with bio-diesel. An appropriate CIO biodiesel-diesel blend is found.

2. Materials and Methods

2.1 Biodiesel preparation and properties

Pyrolysis and transesterification techniques are normally used to produce biodiesel. The commercial strategy utilized for the biodiesel production is the transesterification (alcoholysis) process. The condition or physical appearance of the seeds are important. The seeds are carefully chosen, seeds that are damaged are disposed. The good seeds are selected and then cleaned. Drying is carried out at 100-105°C for 30 min in an oven after de-shelling. It is then followed by oil extraction at room temperature. Moisture is eliminated from the sifted CIO, to maintain moisture content beneath 0.06% for better transesterification process. The oil is heated in a boiler at 105°C for 2-3 hrs for the eliminated of water content. After this process, detoxification with 1% (HCl) is done. Trace amounts of the compounds found are removed. Standard titrimetric systems (ASTM-664) was used to determine the free unsaturated fat substance present in the raw oil and its products.

CIO contains 19.58% free unsaturated fats. Transesterification of CIO is completed using a two stage process. The primary stage (corrosive catalysis) of the method is to reduce the free unsaturated fats (FFA) content in CIO by the procedure of transesterification with methanol and sulfuric acid (corrosive catalyst) at 55°C in a closed reactor vessel, for a duration of one hour. Raw oil is warmed to 48°C following which 0.68% sulfuric corrosive and 1:6 molar extent of methanol is incorporated. Methanol is incorporated to accelerate the reaction. This is followed by blending at 700 rpm at 53-57°C for 75 minutes with normal analysis of FFA after every 20-25 min. The reaction is paused at the point when the FFA is decreased up to 1%. Water arrangement is the real deterrent to corrosive catalyzed esterification for FFA. In order to accomplish satisfactory level of FFA, it is played out this stage two times.
The reactor used for the process is a three necked round base flask. A measured amount (1000 ml) of esterified CIO was taken in the flask. This oil was heated to 650°C. Potassium methoxide was prepared using 0.5 wt. % sodium hydroxide (NaOH) pellet added to 1:6 oil-methanol solution. Solution is stirred until NaOH pellet was totally disintegrated. The solution is mixed with preheated oil after raising the temperature to 65°C. The blend was vigorously stirred by continuously stirring for one and half hour. The blend was allowed to settle in an isolating pipe after analyzing the FFA. The upper layer biodiesel was purged into an alternate measuring glass and using an isolating channel in the base, the glycerol and soap were collected from the lower layer. The process is executed till pure water is seen beneath the biodiesel in detaching funnel. The properties of the fuel blends are shown in table 1.

Table 1. Physical Properties of Calophyllum Inophyllum and diesel Blend

| Properties                          | Diesel | B100 | B10 | B20  | B30  | B40  |
|------------------------------------|--------|------|-----|------|------|------|
| Flash Point [°C]                   | 54     | 198  | 65  | 62   | 58   | 59   |
| Fire Point [°C]                    | 64     | 224  | 72  | 68   | 63   | 63   |
| Kinematic Viscosity at 40°C [cSt]  | 2.1    | 53.708 | 5.472 | 7.899 | 6.724 | 7.479 |
| Density [kg/m³]                    | 0.86   | 0.827 | 0.832 | 0.838 | 0.840 | 0.859 |
| Lower Calorific Value [kJ/kg]      | 43500  | 41500 | 43318 | 42636 | 41954 | 41272 |

Figure 1. Test Engine
3. Experimental Method

The experiment is performed in a single cylinder, air cooled, four stroke and direct injection diesel engine and the speed was maintained to be constant. The test engine is appeared in figure 1. A eddy current dynamometer has been combined with the engine. The engine is kept running at no load condition and a constant speed of 2200 rpm is maintained at all load conditions. The load conditions are subsequently increased from no load to maximum load (25%, 50%, 75% and full load). Engine specification are shown in table 2. The test engine was operated with different blends of CIO in diesel. The exhaust gas was observed using HORIBA MEXA 584L for measuring the emissions such as CO, HC, CO₂, NOₓ and smoke concentration is observed using AVL 415S are shown in the figure 2.

| Description          | Specification |
|----------------------|---------------|
| Model                | GL-400        |
| Stroke(mm)           | 63            |
| Bore(mm)             | 86            |
| Compression Ratio    | 18:1          |
| Displacement(cc)     | 395           |
| Rated power (kW)     | 5.5           |

![Schematic Diagram of the Experimental Setup](image)
4. Results

4.1 Effect of biodiesel blends in brake thermal efficiency
Figure 3 illustrates the relation between Brake Thermal Efficiency (BTE) with brake power (BP). B10 blend is observed to have the highest BTE and 9.5% higher than standard diesel which could be due to higher energy conversion efficiency.

![Figure 3. BTE vs. BP.](image_url)

4.2 Brake specific fuel consumption
Specific Fuel Consumption (SFC) varies with respect to BP is illustrated in figure 4. It is observed, SFC decreases with increment in BP. At higher loads specific fuel consumption is minimum for B10 blend and maximum for B40 blend because of lower calorific value compared to diesel. At full load condition, B10 blend has 8% lower SFC than that of diesel.

![Figure 4. SFC vs. BP.](image_url)

4.3 Exhaust gas temperature
The exhaust gas temperature (EGT) is maximum for B40 blend at all the load conditions. EGT for B10 blend is found to be minimum at higher brake power, as illustrated in figure 5. It could be because of the decrease of calorific value of the blend which reduced the EGT. It is advantageous, since it increases the life of the engine components.
4.4 Nitrogen oxide emission

Figure 6 shows a graph between NO\textsubscript{x} emissions with BP. It is noted that, there is an increase in NO\textsubscript{x} emissions when brake power is increased. At higher brake power, maximum NO\textsubscript{x} emission is observed for diesel and minimum NO\textsubscript{x} emission is obtained for B10 blend. Hence, NO\textsubscript{x} emission decreases as compared to conventional diesel engine and percentage reduction in NO\textsubscript{x} emission is about 20.3 % in B10 blend. This is due to the decrease in the combustion temperature of the B10 blend.

4.5 Smoke concentration

The variation of smoke concentration with brake power is shown in figure 7. Smoke emission is lesser for B10 blend when compared to diesel at maximum load conditions. The fuel bond oxygen supports the combustion process and reduces the smoke concentration in the exhaust. At maximum load condition, the smoke concentration is reduced by 14 % when compared to diesel.
4.6 Hydro carbon emission

HC emission varies with BP is shown in figure 8. Lowest HC emission is observed for B10 blend. This could be due to the better oxidation of the fuel particle at maximum load condition. HC emission is higher as the load increases. The maximum HC emission is observed for B30 blend. This is due to flame quenching and crevices volume.

4.7 Carbon monoxide emission

It is noticed that, an increase in brake power, leads to increase in CO emissions as shown in figure 9. CO emission with B10 is at par with diesel when compared to all other blends. Higher CO emission is observed for B40 blend. This could be due to the partial oxidation of fuel particles which reduced CO to CO\textsubscript{2} conversion process. The lowest CO emission is observed for diesel.
4.8 Carbon dioxide Emission

Figure 10. Indicates the comparison of CO₂ with brake power. It is observed that, with an increase in brake power, there is a significant increase in carbon dioxide emission for all blends. Further, carbon dioxide emission is maximum for diesel and minimum for B10 blend at higher load conditions. Higher CO₂ emission indicates complete combustion.

5. Conclusion

The following conclusions are drawn based on the experimental results when CIO is blended with diesel.

- 20% reduction in NOₓ emissions is obtained with respect to standard diesel and this phenomenon is mainly because of the decrease in temperature in combustion chamber.
- CO₂ is lower for all the blends. For B10 it is 14.24% lesser.
- HC and CO emissions are increased as the below proportion of the CI increases and also their emissions are increased as the load increases.
- A maximum reduction in Smoke concentration is decreased of about 14% at medium load condition for B10 blend is observed.
- A 7% increase in BTE is observed for B10 blend.
- Among all the blends B10 shows significant reduction in improved performance.

6. References

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