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BIODIESEL DEVELOPMENT FROM CEBIA PENTANDRA SEED OIL AND PERFORMANCE EVALUATION IN A CI ENGINE

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ABSTRACT

Fossil fuels are widely known as non-renewable due to the depletion of naturally occurring reserves and also result in environmental degradation. Renewable fuel are necessary for sustainable economic and environmental development. An alternative to petroleum sourced fuels is bio-diesel derived from edible and non-edible oils. Bio-diesel is also known as Fatty acid methyl ester (FAME) since chemically, bio-diesel is mono alkyl esters of long chain fatty acids obtained from renewable sources like vegetable oils or animal fats. It is produced by the process of transesterification in which the oil or fat is reacted with an alcohol such as methanol in the presence of a catalyst. Process parameters such as the type and molar ratio of alcohol to oil, type of alcohol, type and amount of catalyst, reaction time and temperature. In this study bio-diesel was produced from Ceiba Pentandra(Kapok) oil. Methanol and KOH were used in the transesterification process. Performance characteristics of a CI engine were found out using different blends of bio-diesel, emission characteristics were also studied. From the study it can be observed that due to the difference in properties of bio-diesel and diesel there is a difference in parameters such as Brake specific fuel consumption (BSFC) and Brake thermal efficiency(BTE). Moreover the emission characteristics of bio-diesel blends also differ from that of diesel. Ceiba Pentandra bio-diesel blends can be used at most operating conditions in terms of performance and emission characteristics in the existing CI engines without any modifications.

Keywords: Biodiesel, Diesel Engine, Emissions, Performance, Transesterification.

1. INTRODUCTION

In today's world fossil fuels continue to be the major source of energy. Since 1900 there has been a rapid growth in industrialization that has led to an increasing demand for energy throughout the globe. A number of developing countries continue to import a lot of crude oil to meet their ever increasing demand. A majority of their earnings is spent on such imports. Besides depleting fossil fuels, the other major concern is the impact of these fuels on the environment. Thus it is quintessential that an alternate source of fuel with low emissions be developed that can be used in diesel engines. One of the main sources of alternate fuels is vegetable oil and animal fat. This is not a completely new concept as the inventor of diesel engine "Rudolf Diesel" demonstrated his first diesel engine at the World Exhibition at Paris in 1900 by using peanut oil as fuel [1]. It received attention only recently when it was conclusively realized that petroleum fuels are dwindling fast and environment-friendly renewable substitutes must be identified [1]. Sunflower, saffola, soybean, rapeseed, peanut and a host of other oils have been researched in other countries. Most of these oils are edible in Indian context. The idea behind this study is to evaluate the possibility of developing and using biodiesel from a non-edible source

2. BIODIESEL PRODUCTION PROCEDURE

To perform the transesterification procedure, the amount of catalyst i.e KOH required was found out by standard titration procedure. It was found to be 17 grams per liter of raw oil. The raw oil was reacted with a mixture of 0.2(v/v) Methanol and KOH at 60^{o}C. The mixture was stirred at a constant speed of 450 rpm for one hour at 60^{o}C. This mixture was allowed to settle down in a separating funnel for 4 hours after which it separated into two distinct layers. The lower layer contained impurities and glycerol and the upper layer consisted of methyl esters. The top layer was separated and washed with 0.4(v/v) distilled water at 50^{o}C. An aqua air pump was used to mix the water with ester and this mixture was allowed to settle down, upon which the excess water was drained out along with any impurities. The remaining mixture was heated to a temperature of 110^{0}C so that the remaining water evaporated and pure biodiesel was left behind. This resulted in a clear amber-light yellow liquid with a viscosity similar to petro-diesel.

2.1 Biodiesel Characterization

The physio-chemical properties of the Cebia Pentandra biodiesel, neat petro-diesel, neat biodiesel (B100) and its blend of 20% were evaluated as per the ASTM standard methods and the results are in accordance with ASTM. The fuel properties of Cebia Pentandra oil methyl ester and its different blends with diesel are shown in Table 1. It is observed that the chemical characteristics of the Cebia Pentandra oil methyl ester were found to be in the close range of engine requirement.

Table 1. Properties of diesel, biodiesel, and Biodiesel blend

Characteristics	Diesel	B100	B20
Flash point(^oC)	78	140	128
Fire Point(^oC)	86	150	135
Pour Point(^oC)	-6	-5	Less than -10
Specific Gravity	0.82	0.87	0.84
Viscosity(mm^2/s)	2.6	5.1	2.9
CalorificValue(KJ/Kg)	45000	40120	43801

3. ENGINE PERFORMANCE STUDY

Performance tests were conducted on a single cylinder four-stroke water-cooled diesel engine and the details are given in Table. 2 with neat diesel and its blends in the ratio of 10%, 20% and 30%. The objective here was to evaluate the suitability of these fuels for engine application. The engine was coupled with an electric dynamometer to apply different engine loads. The engine was started on neat diesel fuel and warmed up. Then parameters like the speed of operation, fuel consumption and load were measured. After the engine reached the stabilized working condition, emissions and smoke density were measured using an exhaust gas analyzer and a smoke meter. Each reading was replicated thrice to obtain a mean value. The engine performance and exhaust emissions were studied at different engine loads and constant engine speed. The specifications of the exhaust gas analyzer and the AVL smoke meter are given below

AVL Smoke meter
Make: AVL India
Model: AVL437C
Opacity: 0 to 99.9%

Exhaust gas Analyzer
Make: Horiba
Model: MEXA-5545J
Measure: CO, CO_2, HC, O_2, NO_x

Table 2. Specifications of the Diesel Engine

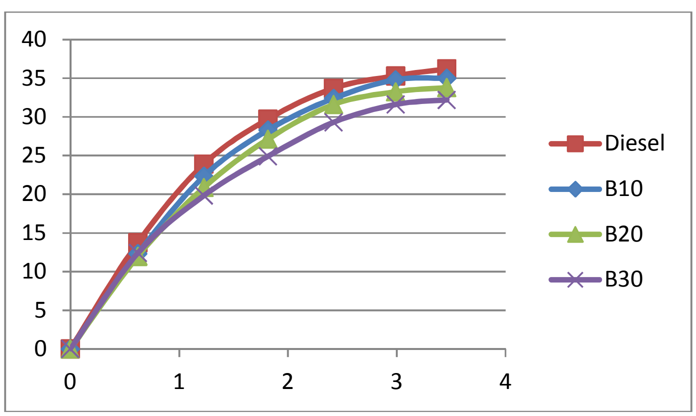
Engine	4 Stroke Single Cylinder
Make	Kirloskar
Maximum Engine Power	5HP
Engine Speed	1500 RPM
Fuel	Diesel
Bore	80mm
Stroke	110mm
Starting	Cranking
Cooling	Water
Lubricating Oil	SAE 30
Compression Ratio	17.5:1
Cubic Capacity	0.661 liters

To evaluate the performance parameters, important operating parameters such as engine shaft speed in rpm, generator output, fuel consumption rate, airflow rate, temperature of engine cooling water and engine exhaust gases were measured and the performance characteristics were determined from their fundamental relations while varying the load on the engine from 0% to 100%. Significant engine performance parameters such as brake specific fuel consumption (BSFC), brake thermal efficiency for petroleum based diesel and its blend with Ceiba Pentandra biodiesel were calculated. The results are plotted below.

4. BRAKE THERMAL EFFICIENCY

The graph in Fig.1 shows the effect of BP (load) on Brake thermal efficiency(BTE) for diesel and the blends. It can be observed that there is a steady increase in efficiency with brake power (BP). This can be attributed to the fact that with increase in load both brake power and fuel consumption increase and there is a decrease in heat loss, but the rate at which fuel flow rate increases is less than the rate at which brake power increases with load. It can be inferred from the graph that the thermal efficiencies are close to each other, however there is a slight decrease in the efficiencies of the blends compared to diesel at all the BPs and as the biodiesel content in the blend increases thermal efficiency decreases. The thermal efficiencies at full load for diesel B10, B20, B30 are 36.2%, 34.9%, 33.8%, 32.2% respectively. A 11% decrease in BTE was observed for B30 blend. Moreover the fuel consumption of diesel, B10, B20, B30 at peak load was observed to be 0.0134 kg/min, 0.0138 kg/min, 0.0144 kg/min and 0.0153 kg/min respectively which meant a 15% increase in fuel consumption for b30 blend. We already know that BTE is defined as the ratio of BP to energy input of the fuel which is the product of fuel consumption and calorific value and since BP remains constant for all the fuels at a particular load. The calorific value of the blends decreases with increase in bio-diesel content, however the increase in fuel consumption is more pronounced, hence overall the BTE of the engine was less for biodiesel blends

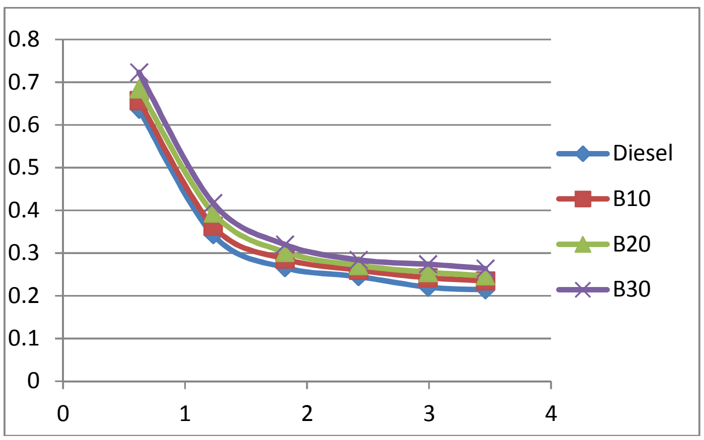
Fig 1.Variation of BTE(%) with BP(kW) for different fuels



5. BRAKE SPECIFIC FUEL CONSUMPTION

As can be observed in Fig. 2 below, the brake specific fuel consumption (BSFC) of various biodiesel blends is compared with diesel at various loads. A similar trend was observed in all the blends with diesel for the entire range of loads. The BSFC decreased with increasing load for the blends as it did for diesel. This can be attributed to the fact that rate of increase in BP was more compared to the rate of increase in total fuel consumption as explained in the previous section, but the BSFC for biodiesel blends was observed to be higher than for diesel at all loads. This is because of the higher fuel consumption for biodiesel blends. The BSFC values for diesel, B10, B20 and B30 at maximum load were found to be 0.228 kg/kWh, 0.235 kg/kWh 0.247 kg/kWh, 0.264 kg/kWh respectively. We know that BSFC is the ratio of fuel flow rate to BP; however the BP at a particular load is constant for all fuels but the fuel flow rate increases with increase in biodiesel content in the blend, hence the BSFC is more for biodiesel blends and this applies for the entire range of loads. Similar trends of BSFC with increasing load in different biodiesel blends were also reported by other researchers [3,4] while testing biodiesels obtained from karanja and rubber seed oils.

Fig 2. Variation of BSFC(kg/kWh) with BP(kW) for different fuels

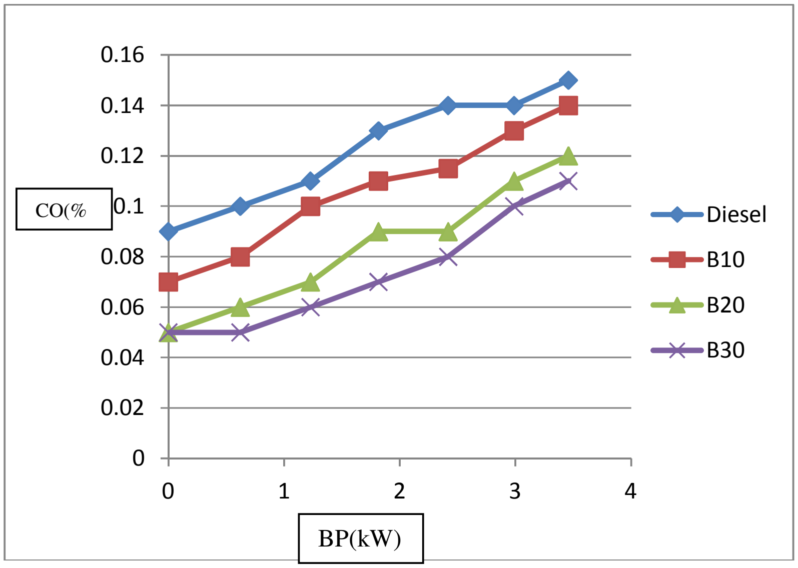


BP(kW)

6. CARBON MONOXIDE

In Fig.3 CO emissions for various blends and diesel is plotted against BP. The variations of CO can be observed from the graph. It is interesting to note that the CO emissions for biodiesel blends were lower compared to diesel at all loads. This is probably due to more complete oxidation of the blends compared to diesel. There is a very good chance that the CO formed during combustion of the blends might have been converted into CO_2 by taking up the extra oxygen molecule present in the biodiesel chain. It can also be inferred from Fig.3 that the CO emissions decreased initially and then sharply increased up to maximum load for all fuels tested. This phenomenon most likely occurred because, as the load was gradually increased performance of the engine improved at elevated temperature and led to better combustion of the fuel which resulted in less CO emissions, However as the load increased to maximum the excess fuel required led to formation of smoke, which in turn might have prevented the oxidation of CO to CO_2, hence CO emissions increased sharply towards the end.

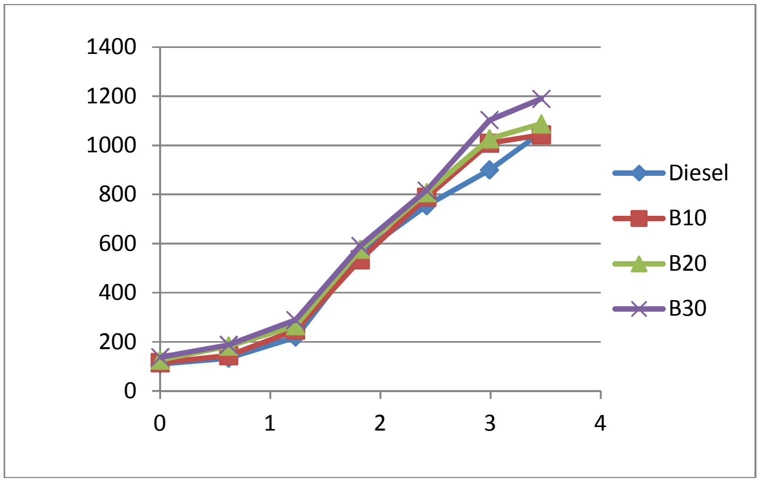
Fig 3. Variation of CO(%) with BP(kW) for various fuels



7. NITROUS OXIDES

The variation of NO_x emissions with engine loading for different fuels is compared in Fig. 4. It can be observed that the NO_x emissions increased with increasing loads and were higher than diesel for all the biodiesel blends. It varied 200 and 1200 for all biodiesel blends. The NO_x emissions for diesel, B10, B20, B30 at maximum load were 1052 ppm, 1043 ppm, 1088 ppm, 1189 ppm respectively. It can be inferred that the increasing proportion of biodiesel in the blends led to an increase in NO_x emissions. This proves that the most important factor for the emissions of NOx is the combustion temperature in the engine cylinder and the local stoichiometry of the mixture and since biodiesel has some oxygen content in it, it could have facilitated NO_x formation at such high temperatures. Overall the NO_x emissions increased linearly with load. The air-fuel ratio increased with load resulting in an increase in the average gas temperature in the combustion chamber and hence NO_x formation which is temperature sensitive increased. It can be observed from these values that the peak occurred just before reaching the full load conditions. Similar trend was observed in case of all the fuel blends tested. This might be due to a very high fuel–air ratio at full load conditions where the additional fuel might have cooled the charge, thus lowering the localized peak temperatures and resulting drop in NOx concentration. This is what is generally observed in case of indirect injection engines.

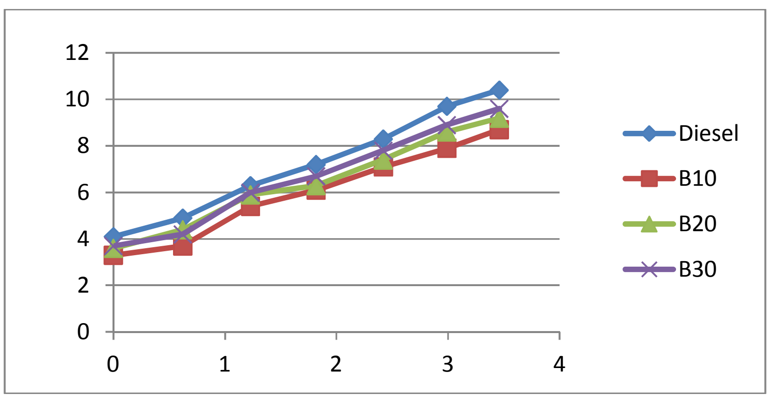
Fig 4. Variation of NO_x(ppm) emissions with BP(kW) for various fuels



8. CARBON DIOXIDE

Fig. 5 shows the CO_2 emissions for all fuels at different loads. It is quite clear that the CO_2 emissions of diesel are higher than biodiesel blends at all loads. This is because vegetable oil contains oxygen element; the carbon content is relatively lower in the same volume of fuel consumed at the same engine load, consequently the CO_2 emissions from the vegetable oil and its blends are lower.

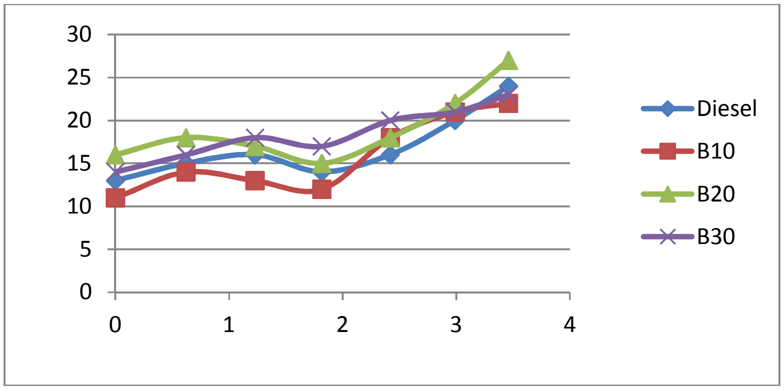
Fig 5. Variation of CO_2(%) with BP(kw) for various fuels



9. HYDROCARBONS

Fig.6 represents the hydrocarbon emissions for all fuels at various loads. Overall HC emissions increased at higher loads due to lesser availability of oxygen for reaction when more fuel is injected. However the HC emissions for biodiesel blends were observed to be lesser than that of diesel fuel.

Fig 6. Variation of HC(ppm) with BP(kW) for various fuels



10. CONCLUSIONS

The fuel properties of Cebia Pentandra biodiesel were found to be within the limits specified by the ASTM D 6751-02 and EN 14214 standards.

The BTE decreased and the BSFC increased with increase in the biodiesel proportion in the blends The smoke level and CO emissions in the exhaust were reduced, whereas NO_x increased with increase in biodiesel content in the blends. However, the level of emissions increased with increase in engine load for all fuels tested.

It can be concluded tha B100 can be safely blended with diesel upto 20% without significantly affecting the engine performance and emissions and thus could be an alternative to diesel.

For further research, additives like ethanol can be added so as to decrease NO_x emissions and improve performance. Moreover coupling it with Exhaust Gas Recirculation of about 5% could prove highly beneficial in terms of increasing the amount of biodiesel that can be blended with diesel without affecting engine performance drastically.

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