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An Experimental Investigation on neat Ceiba Pentandra Oil Methyl Ester as a Renewable Bio-Fuel for Diesel Engine

S.Kathirvelu*[1], Dr.N.Shenbaga Vinayaga Moorthi [2], Dr.S.Neela Krishnan[3] Dr. P Koshy Mathews[4]

[1]Faculty of Mechanical Engineering, Anna University: Chennai,Tamil Nadu, INDIA
[2]Regional Centre-Tirunelveli , Anna University, Chennai, Tamil Nadu, INDIA
[3]PSG College of Technology, Coimbatore, Tamil Nadu, INDIA.
[4]Kalaivani College of Technology, Coimbatore, Tamil Nadu , INDIA

Abstract: In recent times, the biomass resources are being considered as alternative to fossil fuels to solve the problem of global warming and the energy calamity. Among the various biomass resources, vegetable oils are observed to be an excellent substitute fuel for use in diesel engine and also attractive for its renewability. The present work aims at, production of biodiesel, performance, exhaust and combustion analysis of a diesel engine fuelled with diesel fuel and a neat biodiesel of Ceiba Pentandra Oil Methyl Ester (CPOME). The transesterification process converts the high FFA crude ceiba pentandra oil to its methyl esters in two step process. The viscosity of CPOME is nearer and the calorific value is less than that of diesel because of their oxygen content. The important fuel properties are compared with that of conventional diesel fuel. Engine tests have been conducted at various load conditions for a compression ratio of 18, to get the comparative measures of SFC ,brake thermal efficiency, EGT and exhaust emissions such as CO, CO_2, HC, NO_x, smoke density and combustion analysis to evaluate the behavior of CPOME(B100) and diesel. Brake thermal efficiency at maximum load for CPOME is 6.26% less than diesel for the same load. Emissions of CO, CO_2, hydrocarbons, oxides of nitrogen were reduced. It has been observed that the CPOME produce similar in-cylinder pressure and heat release rate patterns as conventional diesel fuel. The experimental analysis revealed that neat CPOME (B100) can be used as an alternate bio-fuel for diesel in diesel engine.
Keywords: Transesterification, biodiesel, CPOME, engine performance and emissions, combustion.

Introduction

Diesel engines are more trusted influence sources in the transportation industry. The fast depletion of fossil fuel and environmental degradation has revived the interest in exploring alternative fuels for diesel engines. Emerging countries like India rely a lot on crude oil import. Diesel being the major transportation fuel in India, finding an appropriate substitute to diesel is a vital need[1].Biodiesel made from trans-esterification of vegetable oils are said to be the suitable substitute for fossil diesel. Many researchers[2-4] have investigated the use of different vegetable oils some of them are, soyabean, rapeseed, pongamia, sunflower, rice bran, rubber seed and jatropha. While the petroleum and other fossil fuels contain sulfur, ring molecules and aromatic components the biodiesel molecules are very simple hydrocarbon chains, containing no sulphur, ring molecules or aromatics. The major problem associated with direct use of raw vegetable oils is their viscosity. One possible method to overcome the problem of high viscosity is transesterification of oils to produce esters (commonly known as biodiesel)[5]. In diesel engine, biodiesel can be used either as a blend (Diesel+Biodiesel) or as neat fuel (B100). The advantages of biodiesel are that it replaces petroleum fuels there by dipping global warming gas emission, PM, HC, CO and other toxics. It is biodegradable and renewable in nature. Biodiesel has good potential for rural employment generation, aid rural industrialization and greatly reduce environmental pollution. The objective of this study is to investigate the performance, emission and combustion characteristics of the CI engine fuelled with neat biodiesel and compare it with conventional diesel fuel.

Preparation of Bio-Fuel

In the transesterification of vegetable oils, a triglyceride reacts with an alcohol in the existence of a strong acid or base, producing a blend of fatty acid alkyl esters and glycerol[6].The process consists of two steps namely, acid esterification and alkali esterification. The high FFA (14.71%) crude ceiba pentandra seed oil can be reduced to less than 1% in acid esterification, using acid catalyst (1% v/v H_2SO_4) reacting with methanol oil ratio of 9:1 at 60°C and 45min reaction time. The initial stage product having acid value less than 2mg KOH/g is used for the following step alkali catalyzed (1% w/w KOH) transesterification reaction. Molar ratio of 6:1 favors the achievement of alkaline catalyzed esterification process in 45min. The resulting mixture was then taken out and poured into the separating funnel and the glycerol was separated from the mixture to get methyl ester. The maximum ester conversion is achieved at the reaction temperature of 60°C. The process gives a yield of about 93% ceiba pentandra seed oil methyl ester (CPOME), which has comparable fuel properties with that of diesel as listed in Table 1. The viscosity of biodiesel is nearer to that diesel. The flash point of biodiesel is greater than that of diesel and the calorific value is slightly lower than that of diesel. It is observed that biodiesel from ceiba pentandra seed oil is reasonably suitable as a substitute to conventional diesel fuel[10].

Table 1. Properties of CPOME and Diesel

Manufacturer	Kirloskar AV-1
Engine type	Vertical, Four-stroke, single cylinder, constant speed, direct injection
Compression ratio (CR)	12-18
Rated Power	3.7 KW at 1500 rpm
Bore and stroke	80 mm and 110 mm
Dynamometer	Eddy current

Experimental Procedure

The experiment was carried out on a Single cylinder Kirloskar AV1, four stroke, constant speed, DI, diesel engine and is generally used in a agricultural pumps in India and its specifications are given in Table 2.

Table 2. Technical Specification of the Engine

Property	CPOME	Diesel
Density (kg/m^3)	885.2	854
Kinematic Viscosity@40°C(cSt)	4.36	2.60
Flash Point(°C)	158	52
Fire Point (°C)	169	64
Cetane Number	49	52
Calorific Value(MJ/kg)	41.79	44.72

The experimental setup is shown in Fig.1. Initially the engine was started with diesel fuel and warmed up. The warm up phase ends when the cooling water temperature is get stabilized. Then the SFC, EGT and different exhaust emissions like oxides of nitrogen, hydrocarbon, carbon monoxide, carbon dioxide and smoke were measured. The similar process was repeated for CPOME. Smoke density was measured using AVL437 smoke meter in terms of HSU. The exhaust gas composition was measured using AVL digas444 gas analyzer; it measures CO_2, CO, O_2, NOx and Hydrocarbon emissions. A lab view based engine performance analysis software package is provided for online performance evaluation. The experiments were performed for diesel and neat CPOME for a compression ratio of 18:1 at different load conditions at a constant speed of 1500 rpm. Three test runs were performed under identical conditions for each fuel operation at a particular load, to check for the repeatability of all the results and it was found to be within an acceptable limit.

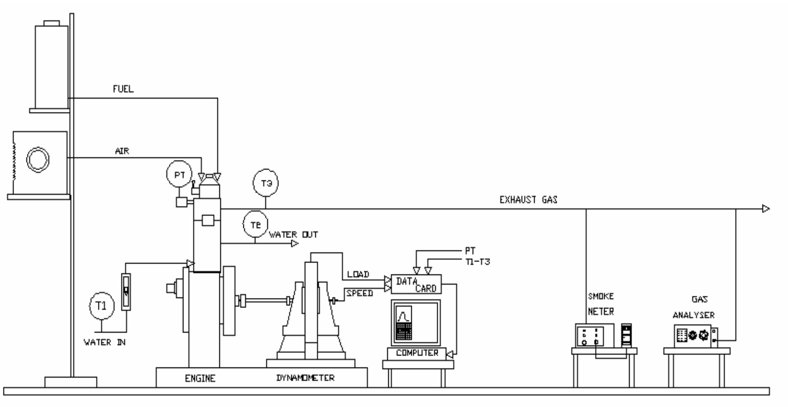

Fig. 1.Variable Compression Ratio (VCR) Engine Set Up T1-Inlet water temperature, T2-Outlet engine jacket water temperature, T3-Exhaust gas temperature PT- Pressure transducer

Result and Discussion

Specific Fuel Consumption

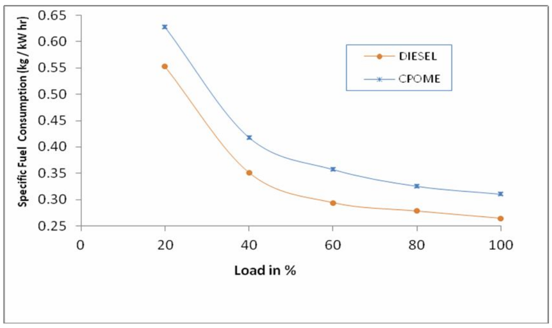

Fig. 2. Variation of Specific fuel consumption with Load

The deviation of specific fuel consumption (SFC) for diesel fuel and CPOME at different loads is shown in Fig..2. It seems that the SFC of the diesel fuel and CPOME get reduced with increasing load conditions. However, the fuel consumption was found to be rising with CPOME compared to diesel fuel for the complete load range. This is primarily due to the fact that combined effects of the viscosity, density, and calorific value of the fuel[7].

Brake Thermal Efficiency

Fig.3. compares the variation of engine brake thermal efficiency fuelled with diesel and CPOME. From the test outcome, it was observed that there was a significant rise in efficiencies with the neat biodiesel with rise in load. This is due to the decline in heat loss and rise in power with increase in load. Also it was observed that the CPOME developed similar trend in efficiency to that of conventional diesel fuel. Maximum brake thermal efficiency of CPOME at maximum load is observed as 27.52%, which is less than 6.26% of diesel fuel for the same load.

Exhaust Gas Temperature (EGT)

The variation of EGT with load for diesel fuel and CPOME is shown in Fig.4. The EGT of the CPOME was found to be high at the entire load in comparison with diesel fuel. This is because of the improved burning characteristics of the CPOME due to its 10% dissolved oxygen content. The combustion process is affected by the changes in ignition delay, which results in a late burning and elevated exhaust temperature[8]. Due to low cetane value, ignition delay increases for CPOME compared to diesel.

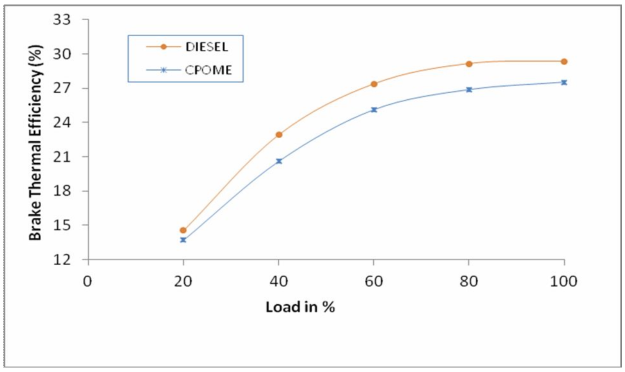

Fig.3. Variation of brake thermal efficiency with Load

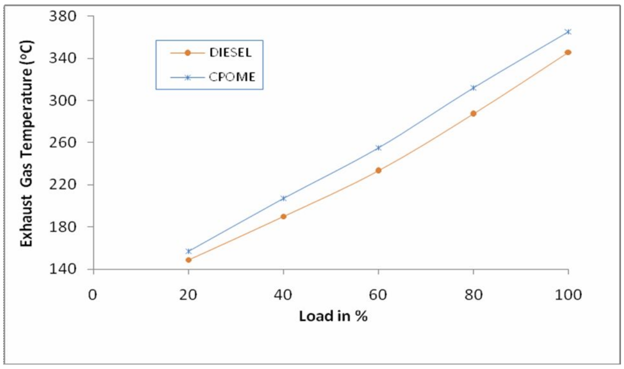

Fig.4. Variation of exhaust gas temperature with Load

Smoke Density

Fig.5. shows the deviation of smoke density for diesel and CPOME over the entire range of load. It was observed that smoke opacity of CPOME was found to be higher at entire load range in comparison to diesel fuel. It may be due to poor combustion in comparison with the diesel fuel. As a lot of studies, smoke density increases with increasing power for all the test fuels due to the engine characteristic for which incomplete fuel combustion is taking place. As for CPOME, higher density and viscosity was resulted more smoke emissions as compared to neat diesel. The high viscosity of pure biodiesel deteriorates the fuel atomization and increases exhaust smoke.

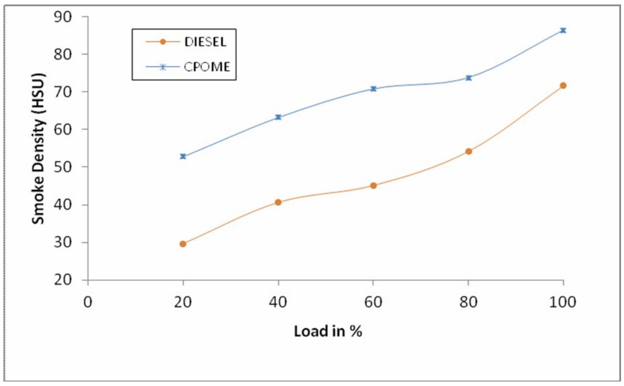

Fig.5. Variation of Smoke density with Load

Nitogen Oxides (NO_x)

Fig. 6. shows oxides of nitrogen (NO_x) emission for diesel and CPOME. In a DI natural aspirated 4-stroke diesel engine, NO_x emissions are sensitive to oxygen content, adiabatic flame temperature and spray characteristics. It is well known that vegetable based fuel contains a small amount of nitrogen. This contributes towards NO_x production[8]. In case of CPOME, NO_x emission is lower than in diesel. It was observed that as load

increases the NO_x formation increases and attains maximum at maximum load. This may be due to higher combustion temperature inside the cylinder at higher load.

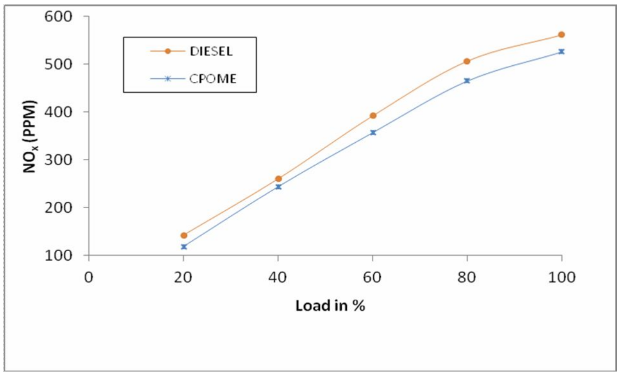

Fig . 6. Variation of NO_x emission with Load

Carbon Monoxide (CO)

Fig.7. shows the carbon monoxide (CO) emission with load for CPOME and diesel. Carbon emissions depend upon the combustion efficiency and carbon content of the fuel, which during combustion undergoes series of oxidation and reduction reactions [9]. Carbon content in the fuel oxidized with O_2 available in the air to CO and then to CO_2. Carbon which is not converted into CO_2 will come back as CO in the exhaust. The methyl ester based fuel contains small amount of oxygen and that acts as a combustion promoter inside the cylinder[9]. This results in better combustion for CPOME than diesel fuel. Hence CO, which is present in the exhaust gas due to incomplete combustion, is lower in comparison to diesel.

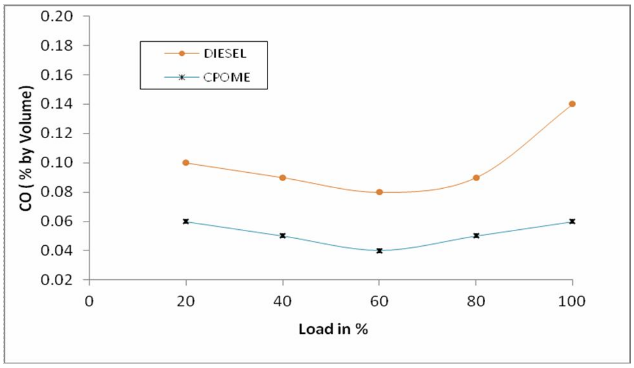

Fig.7. Variation of CO emission with Load Carbon Dioxide (CO_2)

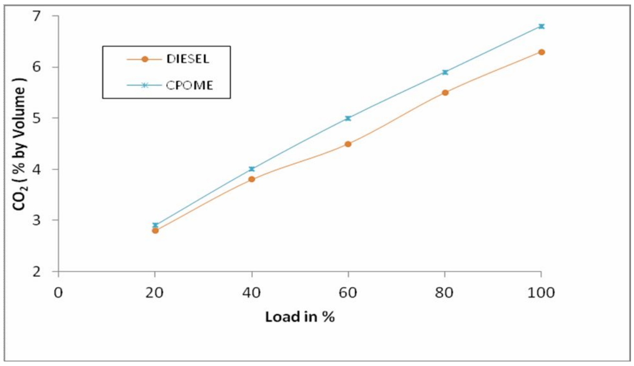

Fig.8. Variation of CO_2 emission with Load

The variations of carbon dioxide (CO_2) emission with load for CPOME and diesel is shown in Fig.8. The CO_2 emissions indicate how efficiently the fuel burnt inside the combustion chamber.

HydroCarbon (HC)

The variation of hydrocarbon (HC) emission with load is plotted in Fig.9. The HC emission increases with increase in load. Unburned hydrocarbon (HC) is an important parameter for determining the emission behavior of the engines. It is observed that neat biodiesel (B100) CPOME gives relatively lower HC as compared to the neat diesel. This is because of better combustion of biodiesel inside the combustion chamber due to the availability of oxygen atom in biodiesel.

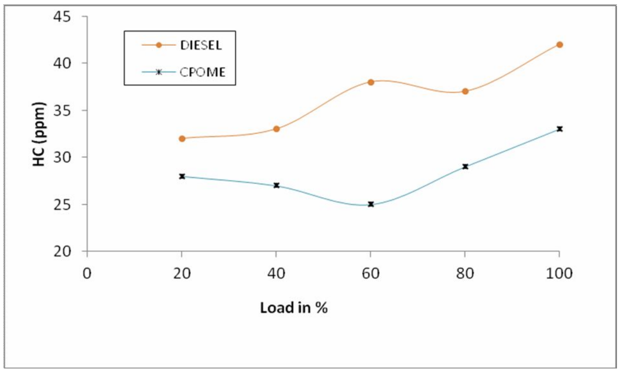

Fig.9. Variation of HC emission with Load

Combustion Pressure

Fig.10. shows the variation of cylinder pressure with crank angle. It has been observed that the CPOME produce similar in-cylinder pressure patterns as conventional diesel fuel. However, the CPOME alone produce slightly low cylinder pressure due to advanced combustion at the initial stage and low net heat release rate. It was found that the CPOME and diesel fuel produce peak pressure within 5-15 crank angle after top dead centre, due to its high rate of burning at the initial stage. Hence, it may be concluded that, engine operation with CPOME and diesel fuel should not pose any problem related to knock, combustion or partial burn. For diesel the peak cylinder pressure of diesel is 69.92 bar and that of CPOME is 67.86 bar.

Heat Release

Fig.11. shows maximum heat release rate curve for CPOME and compared with that of diesel fuel at varying crank angles -30^{o} to 90^{o}. Comparison of the maximum heat release rates of diesel and CPOME alone are observed to be almost similar but the traces differed from the heat release observed for the diesel fuel. The occurrence of the peak net heat release rate is advanced by approximately two degrees in case of CPOME than with diesel run.

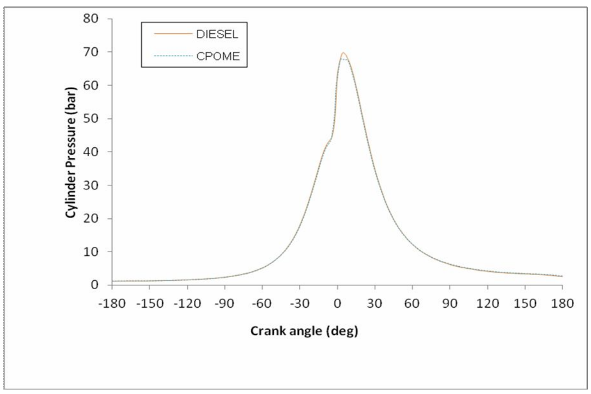

Fig.10. Variation of cylinder pressure with crank angle

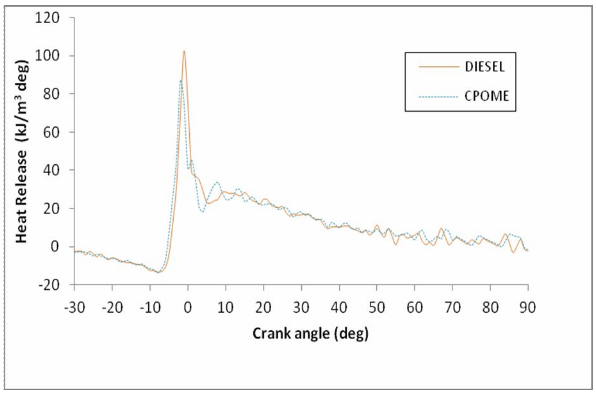

Fig..11. Variation of heat release with crank angle

Conclusion

The crude ceiba pentandra seed oil was transesterified in two stage process using methanol in the presence of acid and alkali catalyst to obtain the renewable bio-fuel. The viscosity and calorific value of neat biodiesel is closer to that diesel. The flash point of biodiesel is greater than that of diesel which offers safe storage. The engine performance reveals that neat biodiesel does not fluctuate much from that of diesel. A neat biodiesel produces slight decline in break thermal efficiency and marginal raise in fuel consumption.This may be due to the lower heating value of the methyl ester. Emissions of CO, CO_2, HC are low for CPOME. Oxides of nitrogen were slightly low for B100 compared with diesel. It was found that the CPOME and diesel fuel produce peak pressure within 5-15 crank angle after TDC, due to its high rate of burning at the initial stage. The CPOME could be used as a renewable substitute bio-fuel in a diesel engine instead of diesel fuel.

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