Performance and Characteristics Study of the Use of Environment Friendly Pongamia Pinnata Methyl Ester in C. I. Engines

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Abstract

The use of increasing fossil fuels in the recent years is the chief contributor to the urban air pollution and a major source of Green House Gases (GHGs) and considered to be the prime cause behind the global climate change. Biofuels are renewable, can supplement hydrocarbon fuels and mitigate the adverse effects that result from fossil fuel combustion. The present work deals with the preparation of pongamia pinnata methyl ester (PPME) i.e. biodiesel from raw pongamia oil through transesterification process, estimation of the properties of the blends of diesel and PPME in varying proportions from 20%, 40%, 60%, 80% and 100% (B20, B40, B60, B80 and B100), performance and exhaust emission analysis in a 3.68 kW Compression Ignition (C. I.) engine. In the experimental investigation, it was found that 40% substitution of biodiesel with petro diesel resulted in reduced emissions and improved efficiency with out loss in the engine power. This would go a long way in solving the basic problems of energy crisis and environmental pollution leading to sustainable development.

Introduction

Energy crisis and environmental air pollution are of alarming concern worldwide. Exponentially increasing population, rapid growth of industrialization and the global trend of urbanization have totally disturbed the eco-balance and the balance of resources on earth. In particular, transport vehicles greatly pollute the environment through emissions such as CO_2, CO, NO_x, SO_x, compounds consisting of organic unburnt or partially burnt HC and particulate emissions. Energy is an essential and vital input for economic activity. Building a strong base of energy resources is a pre-requisite for the sustainable economic and social development of a country. Indiscriminate extraction and increased consumption of fossil fuels have led to the reduction in underground based carbon resources. Further environmental degradation due to fossil fuel combustion includes Global warming, Ozone depletion, Acid precipitation etc. resulting in gradual increase in global temperature, acidification of lakes, streams and ground waters, damage to fish and aquatic life, damage to forests and agricultural crops and deterioration of materials. In addition, with the rising prices of crude oil and petroleum products in the world market and increasing dependence on imports, countries like India are becoming more vulnerable in the matters of energy security.

Biofuels will mitigate the vulnerability and the adverse effects of use of fossil fuels. Several developed countries have introduced policies encouraging the use of biofuels made from grains, vegetable oil or biomass to replace part of their fossil fuel use in transport. This measure is to prevent environmental degradation by using cleaner fuel, to reduce dependence on import of finite fossil supplies by partially replacing them with renewable, domestic sources and to provide new demand for crops to support producer income and rural economics.

The biofuels can be suitably converted into biodiesel using methyl/ethyl alcohol through a process called transesterification. In this process the density of the biofuels are brought down to that of diesel so that it can be easily blended and other properties like viscosity are also changed to meet the requirements.

A detailed review on the production and characterization of biodiesel and a review of various experimental works with biodiesel were carried out by Ayhan et al [1]. In this work, it was reported that the transesterification of triglycerides by methanol, ethanol, propanol and butanol proved to be the most promising process for converting the vegetable oils into biodiesels. Sanjib et al [2] prepared biodiesel from Pongamia pinnata by transesterification of the crude oil with methanol and KOH as the catalyst and reported that properties such as viscosity, flash point compare well with accepted standards. Burnwal et al [3] reported that triglycerides (vegetable oils / animal fats) are promising alternate fuels for diesel engines. They also reported two different methods for improvement in fuel properties (i) catalytic transesterification of triglycerides with alcohols to form mono alkyl esters of long chain fatty acids (ii) the supercritical method of producing biodiesel, which is quite similar to hydrocarbon based diesel fuels.

Diesel engine fueled with rapeseed oil methyl ester at three different pressures and reported that the droplet size of methyl ester was more than that of diesel due to higher viscosity and resulted in increased combustion duration. Recep et al [4] conducted performance and emission tests in a diesel engine fueled with methyl esters of various vegetable oils. The oils tested include, sunflower oil, cotton seed oil, soya bean oil, refined corn oil, distilled opium poppy oil and refined rape seed oil. They observed a small reduction in power produced and increase in particulate matter emission. But NO_x emissions were lower. The authors conclude that, vegetable oil methyl esters are acceptable substitute for diesel. Kumar et al [5] tested a constant speed diesel engine with jatropha oil methyl ester and reported a higher ignition delay as compared to diesel. Darado et al [6] tested a 3 cylinder, 4 stroke, 2500 cc Direct Ignition (D. I) diesel engine with olive oil methyl ester and reported a constant combustion efficiency for methyl ester of olive oil and diesel. They also reported a slight reduction in Brake Specific Fuel Consumption (BSFC), reduction of 58.9% in CO, 8.9% in CO_2, 37.5% in NO and 32% in NO_x for olive oil methyl ester. Sukumar et al [7] tried Mahua Oil Ethyl Ester (MOEE) in a four stroke naturally aspirated D. I diesel engine and reported an increase in BSFC, a slight increase in Brake Thermal Efficiency (BTE). They also reported reduction in CO, HC, NO_x emissions and increase in CO_2 emission.

Many researchers have tested the diesel engine with blends of diesel and biodiesel in varying proportions. Investigation on a C. I. engine fueled with blends of diesel and methyl soyate in varying proportions showed no reduction in power up to 30% methyl soyate and resulted in reduced emissions except NO_x [8]. C.I. engine fueled with blends of soya bean methyl ester and diesel exhibited reduction in Total Heat Content (THC) and Specific Fuel Consumption (SFC). Increase in NO_x and reduction in CO and particulate emissions were also recorded [9]. Use of blends of marine diesel and two types of biodiesel (sunflower and olive oil) showed a reduction in SFC and an appreciable reduction in CO, HC, NO_x and particulate matter emissions [10]. C. I. engine fueled with blends of diesel and rubber seed oil (up to 80%) resulted in acceptable BTE, SFC and better overall performance [11].

In the present research, biodiesel is prepared from the raw pongamia oil by the transesterification process. The kinematic viscosity value of raw Pongamia oil is 37.12 mm^2/s compared to the kinematic viscosity of 2.6 mm^2/s for diesel at 40 ^0C. Thus kinematic viscosity of the biofuel is almost 14 times that of diesel. This leads to many problems in pumping, atomization etc. necessitating the transesterification process. Further, investigations are made to study the various effects of the use of the blends of PPME and diesel in diesel engines. The experiments are conducted in a diesel engine coupled with an exhaust gas analyzer to study the performance characteristics and the extent to which the biodiesel could replace petro-diesel in order to overcome the basic problems of energy crisis and environmental pollution.

Experimental Investigation

Biodiesel preparation and characterization

Pongamia pinnata is a non-edible species capable of growing in almost all types of land (sandy, rocky including oolitic limestone). It grows even in salt water and can withstand extreme weather conditions with a temperature range of 0 ^0C to 50 ^0C and annual rainfall of 50 to 250 cm. The annual production potential is about 9000 kg per hectare. In India the estimated oil from seeds is about 50,000 tones. The yield from a single tree would be around 25 to 100 kg of seed containing around 27 to 50% of oil. The comparison of various properties of raw pongamia oil with respect to other raw oils is presented in Table 1.

Table 1 Properties of raw pongamia oil in compassion with diesel and other raw oils [12]

Property	Ponagamia oil *	Diesel	Soya bean oil	Cotton seed oil	Sun Flower oil	Rap seed oil	Rubber seed oil
Fatty acid composition							
Palmitic acid $C_{16:0}$	3.7-7.9		11.75	11.67	6.8	3.49	10.2
Stearic acid $C_{18:0}$	2.4-8.9	-NA-	3.15	0.89	3.26	0.85	8.7
Oleic acid $C_{18:1}$	44.5-71.3		13.26	13.27	16.93	64.4	24.6
Linoleic acid $C_{18:2}$	0.8-18.3		55.33	57.51	73.73	22.3	39.6
Linoleic acid $C_{18:3}$	---		6.31	0	0	8.23	16.3
Specific gravity	0.912	0.830	0.92	0.912	0.918	0.914	0.91
Kinematic Viscosity (mm^2/s at 40ºC)	37.12	2.6	65	50	58	39.5	66.2
Flash point (ºC)	263	49	230	210	220	280	198
Calorific Value (MJ/kg)	34.0	41.86	39.6	39.6	39.5	37.6	37.5
Acid Value (mg KOH/gm)	0.62	---	0.2	0.11	0.15	1.14	34

*Experimentally determined property values

The characteristics of these oils fall within a fairly narrow band and are quite close to those of diesel. The pongamia oil has less calorific value than that of diesel due to the oxygen content in their molecules. Previous research works show that high viscosity, density, iodine value and poor non volatility are the problems associated with the use of vegetable oils in diesel engines leading to problems in pumping, atomization and gumming, injector fouling, piston and ring sticking and contamination of lubricating oils in the long run operation. Hence it is highly essential to reduce the viscosity of the vegetable oils by methods like preheating, thermal cracking and transesterification etc. Transesterification is the best way to convert the vegetable oils to suit for the use in diesel engines.

Transesterification of pongamia oil is composed of heating of oil, addition of KOH and methyl alcohol, stirring of mixture, separation of glycerol, washing with distilled water and heating for removal of water. The biodiesel (PPME) so produced was mixed with diesel in varying proportions from 20% to 100% by volume (B20, B40, B60, B80 and B100) with the help of a magnetic stirrer. The blends were stirred continuously to achieve stable property values. Fuel properties such as flash point, fire point, kinematic viscosity and calorific value were determined for the PPME and the different blends.

Experimental set up and test procedure

The experimental set up consists of a single cylinder four stroke, water-cooled and constant speed (1500 rpm) compression ignition engine. The detailed specification of the engine is given below.

Engine specification:

Manufacturer:	Kirloskar
Rated speed:	1500 rpm
Brake power:	3.68 kW
Stroke length:	110 mm
Cylinder bore:	87.5 mm
Compression ratio:	16.5 : 1
Fuel used:	diesel

Generator specification:

Rated voltage:	220 V
Efficiency:	82 %

The engine is equipped with a D.C swinging field generator and a salt-water rheostat in order to apply the required load. An exhaust gas analyzer is coupled to this engine for measuring the various emission parameters. This analyzer is capable of measuring CO, HC, CO_2 using NDIR technique with the range of 0-20%, 0-10,000 ppm, 0-20 respectively. The analyzer can also measure O_2 and NO_x using electrochemical technique in the range of 0-25% and 0-5000 ppm respectively. A separate fuel tank of capacity 5 liters is fitted with the diesel engine for the biodiesel and its blends. The schematic arrangement of the experimental set up is shown in Fig. 1.

A series of experiments were carried out using diesel, biodiesel and the various blends. All the blends were tested under varying load conditions (no load to 75% of the rated maximum load) at the rated speed. During each trial, the engine was started and after it attained the rated speed, important parameters related to thermal performance of the engine such as the time taken for 20 cm^3 of fuel consumption, the ammeter and voltmeter readings were measured and recorded. Also the engine emission parameters like CO, CO_2, HC and NO_x from the online exhaust gas analyzer were noted and recorded.

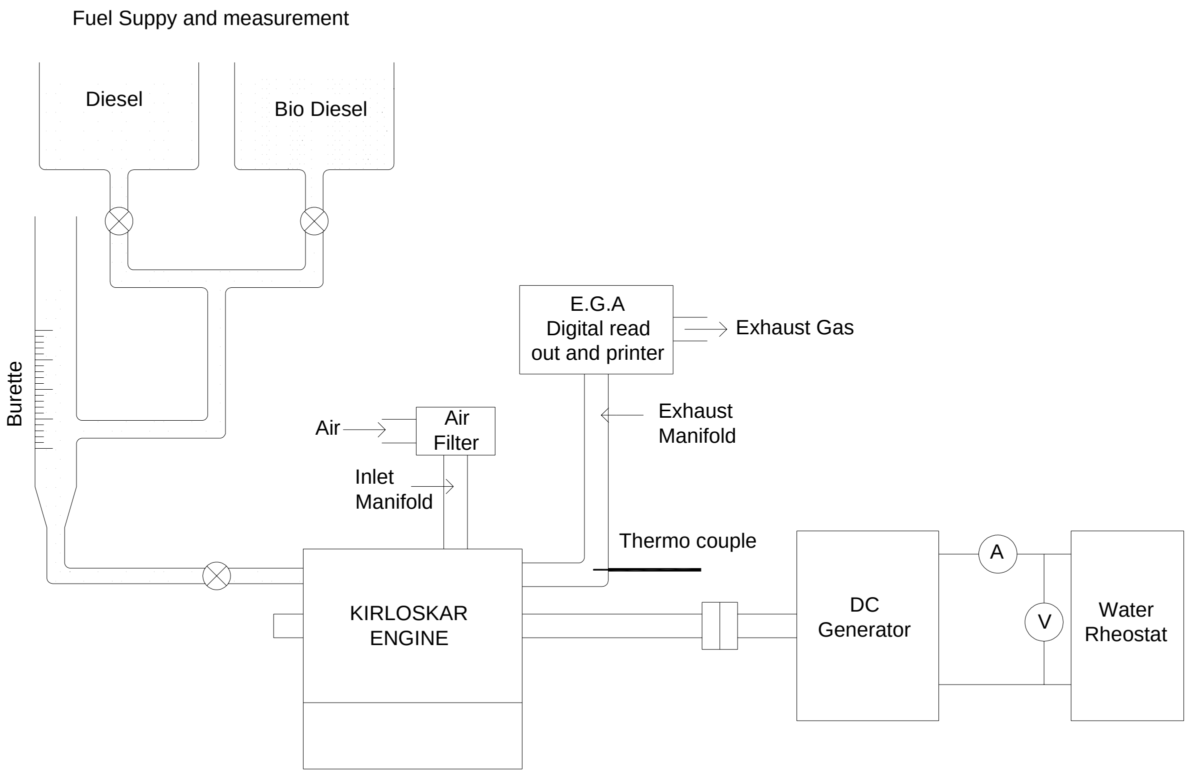

Fig. 1 Experimental set up

Results and Discussion

Characteristics of biodiesel and its blends

After the transesterification process, the colour of the biodiesel changed from deep brown to reddish yellow. Transesterification decreased the kinematic viscocity by a factor of 3.5. The calorific value of biodiesel was slightly increased and specific gravity was slightly decreased. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulphur and aromatics. Biodiesel contains 10–11% oxygen, thereby enhancing the combustion process in an engine. The comparison of the measured property values of PPME with those of biodiesel derived from other vegetable oils is presented in Table 2.

Table 2: Properties of PPME and esters (biodiesel) of other vegetable oils [12]

Property	PPME*	Soya bean	Cotton seed	Sun Flower	Rap seed	Rubber seed
Specific gravity	0.878	0.885	0.874	0.878	0.882	0.874
Calorific Value (MJ/kg)	35.56	39.76	40.32	40.56	37.0	36.5
Kinematic Viscosity at 40ºC (mm^2/s)	10.64	4.08	4.0	4.5	4.5	5.81
Flash point (ºC)	172	69	70	85	170	130

*Experimentally determined property values

It is seen from the Table 2 that the specific gravity and calorific values of PPME are in closer agreement with the other biodiesel and the kinematic viscosity and flash points are comparatively higher. On comparison with diesel, the flash point and fire point were found to be around three times more than that of pure diesel, facilitating safe transport and storage. The colorific value of biodiesel was measured to be 36 MJ/kg, which is less than that of diesel (41.86 MJ/kg) but greater than that of raw pongamia oil (34.1 MJ/kg). The kinematic viscosity of the biodiesel was measured to be around four times that of diesel at 40^0C.

The property values of the different blends of diesel and biodiesel (PPME) in varying proportions from 0 to 100% (pure diesel to 100 % biodiesel) are shown in Figs. 2 and 3. It is observed that increasing concentration of biodiesel in the diesel (B0) resulted in the corresponding increase in the kinematic viscosity. A similar phenomenon in specific gravity is also noted. The flash point of the various blends with increasing biodiesel concentration is found to increase, due to the higher value of flash point for the biodiesel than diesel. Conversely, a decreasing trend is observed for the calorific value in the fuels with increasing biodiesel concentration.

The variation of kinematic viscosity with temperature for the different blends is shown in Fig.4. It is observed that for all the blends, the kinematic viscosity decreases with increase in temperature. The kinematic viscosity of the blends B20, B40 and B60 are closer to that of diesel at 70^0 C. In the case of B80 and B100, the kinematic viscosity is very high at lower temperature and this value decreases appreciably at higher temperature.

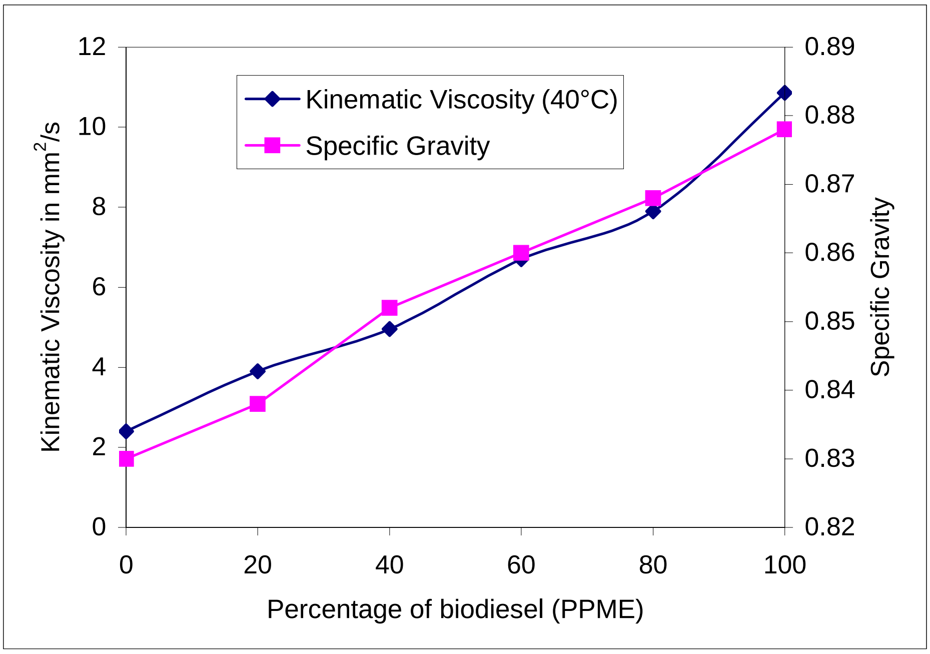

Fig. 2 Variation of kinematic viscosity and specific gravity with percentage of biodiesel (PPME) in the blend

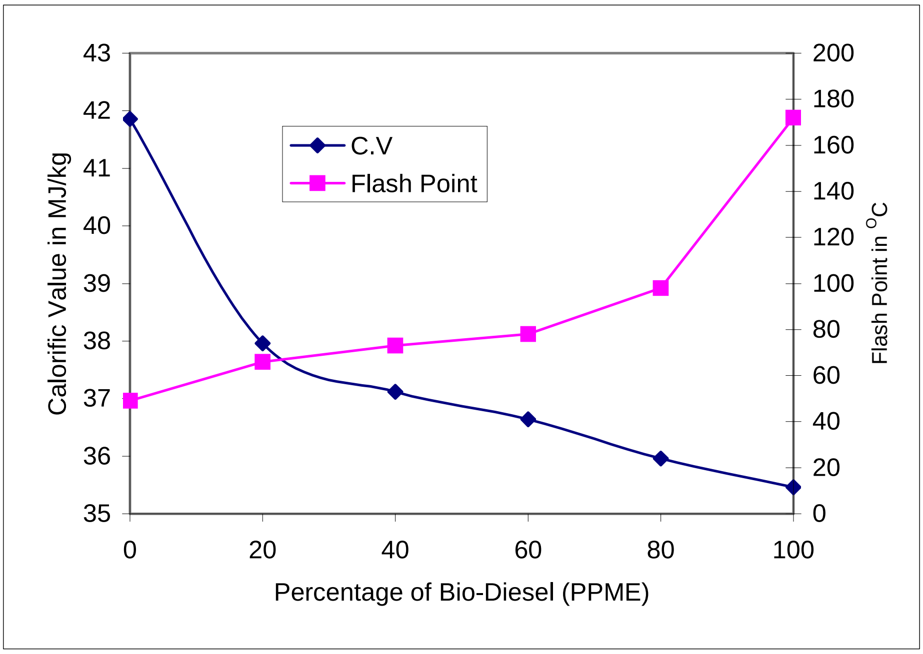

Fig. 3 Variation of calorific value and flash point with percentage of biodiesel (PPME) in the blend

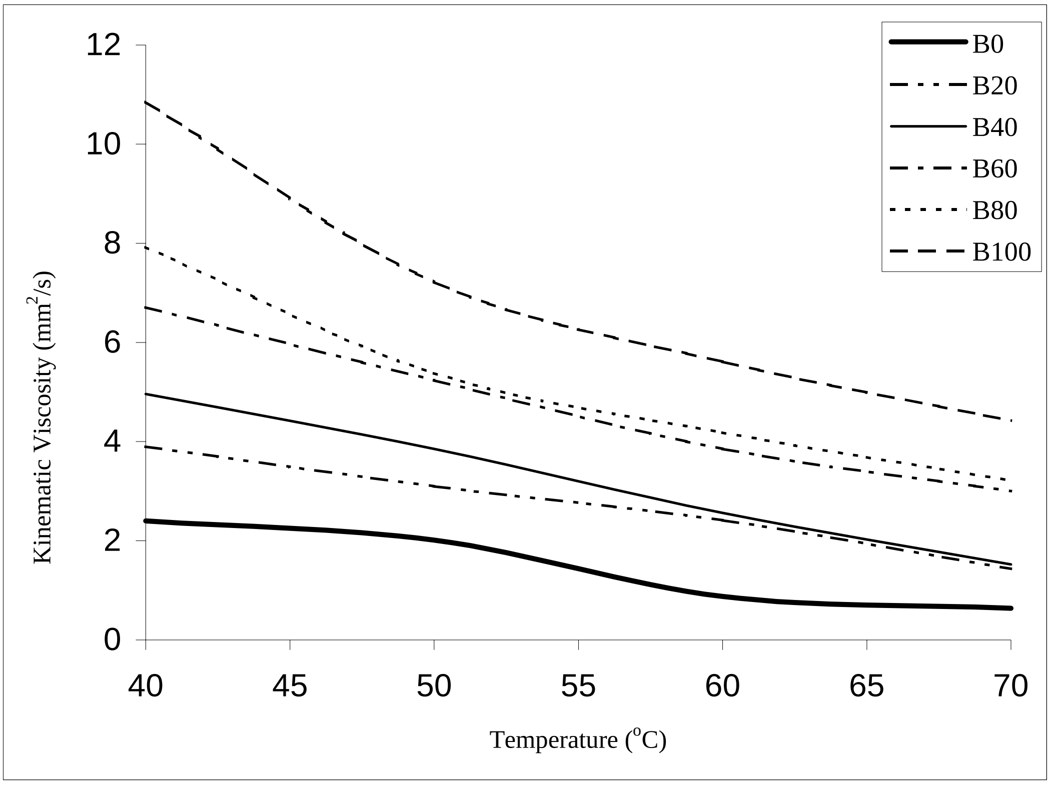

Fig. 4 Variation of kinematic viscosity with temperature for different blends

Engine performance

The engine performance was evaluated based on Break Specific Fuel Consumption (BSFC) and Break Specific Energy Consumption (BSEC) to compare the effects of various biodiesel blends and diesel. BSFC is the amount of fuel required to develop unit brake power and BSEC is the energy input required to develop unit brake power. BSEC is independent of the fuel used and hence the brake specific energy consumption is a good measure to compare the performance of the engine with different fuels.

BSFC and BSEC

The variation of BSFC and BSEC with load for different blends and diesel are presented in Figs. 5 and 6. It is observed from Figs. 5 and 6 that the BSFC and BSEC for all the fuel blends and diesel tested decrease with increase in load. This is due to higher percentage increase in Break power with load as compared to increase in the fuel consumption. For B20 blend the BSFC is lower than diesel for all loads. For B40, the BSFC is almost same as that of diesel. For blends with biodiesel grater than 40%, the BSFC was observed to be grater than that of diesel, the difference being maximum at 25 % of load.

Hence it is concluded that the fuel is completely burnt at the right time in the engine cylinder. This could be due to the presence of dissolved oxygen in the biodiesel that enables complete combustion and the negative effect of increased viscosity would not have been initiated. However as the biodiesel concentration in the blend increases further, the BSFC and BSEC increase for all loads and the percentage increase is higher at low loads. This could be due to the high mass flow of fuel entering into the engine (specific gravity of biodiesel is 6% more than diesel). In addition, the high viscosity of the blends may also inhibit the proper atomization of the fuel, which in turn affects the combustion process.

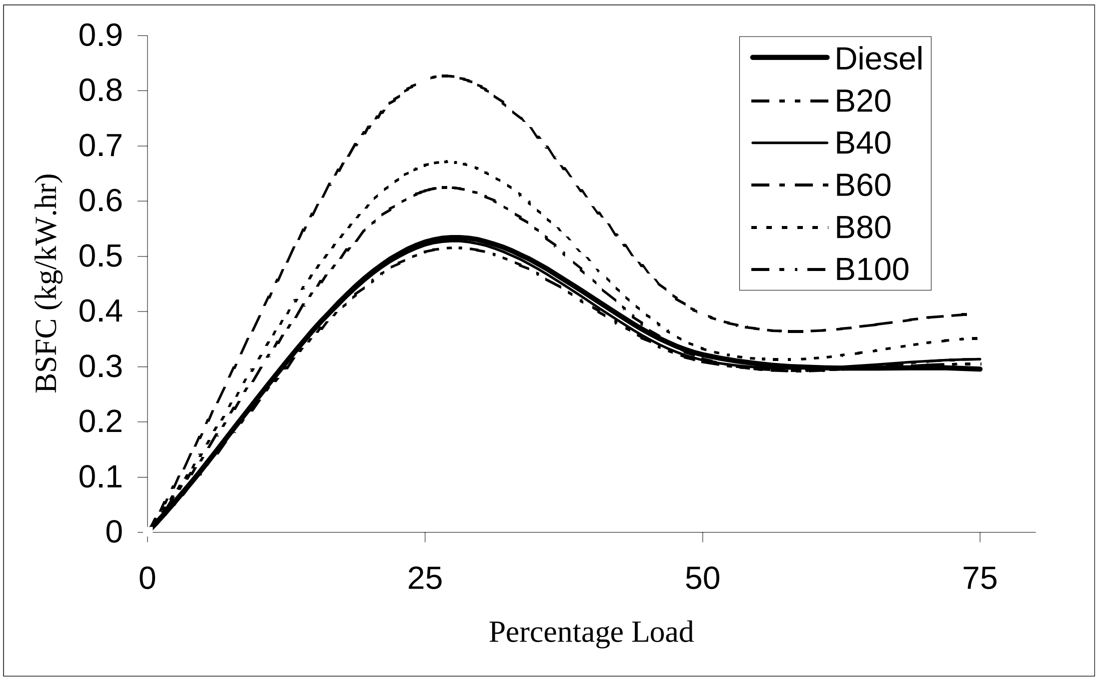

Fig. 5 Variation of BSFC with load for different blends

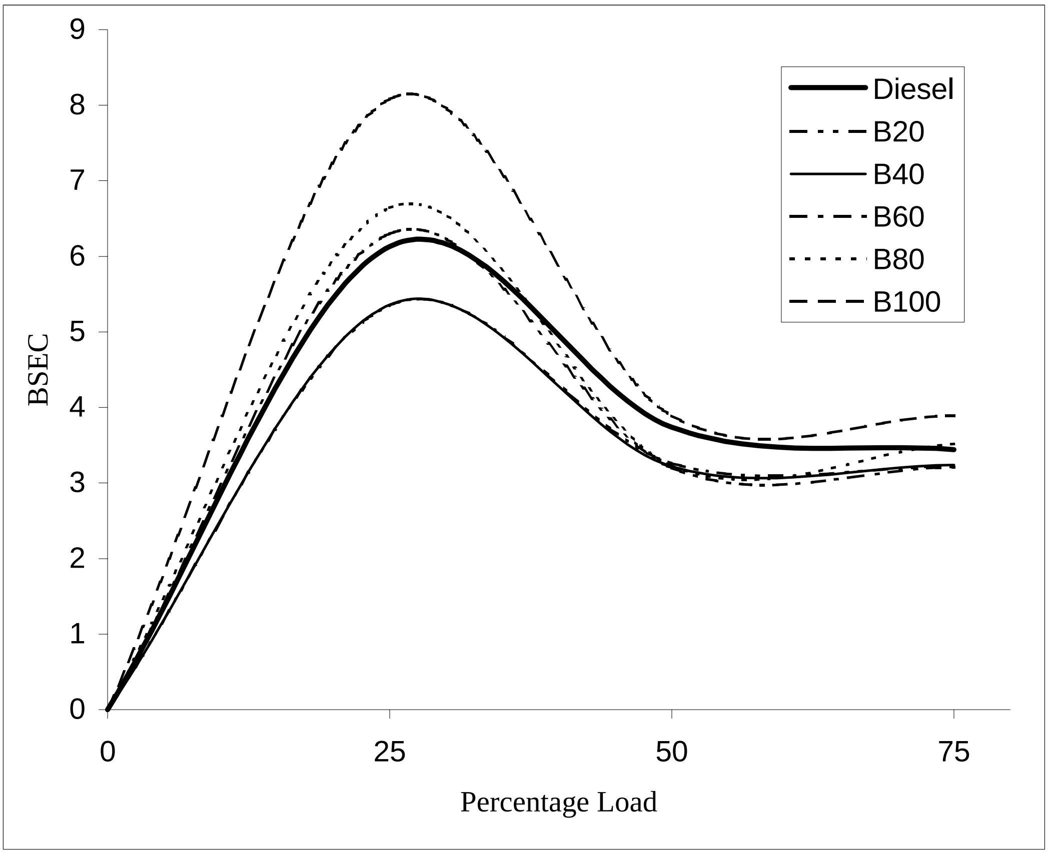

Fig. 6 Variation of BSEC with load for different blends

Engine emission studies

CO emission

It is interesting to note that the engine emits more CO for diesel as compared to biodiesel blends under all loading conditions. It is seen from the Fig. 7 that the CO concentration is totally absent for the blends of B40 and B60 for all loading conditions and as the biodiesel concentration in the blend increases above 60%, the presence of CO is observed. At lower biodiesel concentration, the oxygen present in the biodiesel aids for complete combustion. However as the biodiesel concentration increases, the negative effect due to high viscosity and small increase in specific gravity suppresses the complete combustion process, which produces small amount of CO. The reason explained above is also confirmed from the effects shown in Figs. 3 and 4 for BSFC and BSEC.

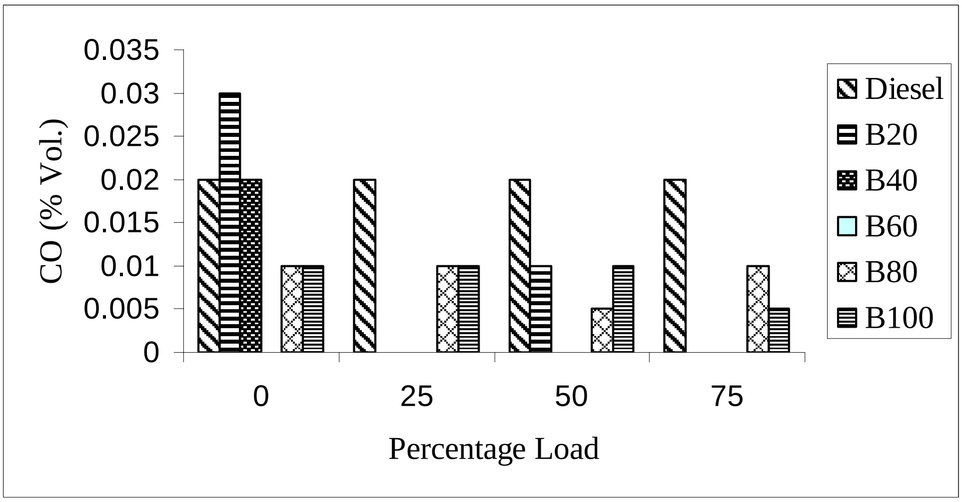

Fig. 7 Variation of CO emission with load

CO_2 emission

Fig. 8 depicts the CO_2 emission of various fuels used. The CO_2 emission increased with increase in load for all blends. The lower percentage of biodiesel blends emits less amount of CO_2 in comparison with diesel. Blends B40 and B60 emit very low emissions. This is due to the fact that biodiesel is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel. Using higher content biodiesel blends, an increase in CO_2 emission was noted, which is due to the incomplete combustion as explained earlier. Though at higher loads, higher biodiesel content blends emit CO_2 almost at par with diesel, biodiesels themselves are considered carbon neutral because, all the CO_2 released during combustion had been sequestered from the atmosphere for the growth of the vegetable oil crops.

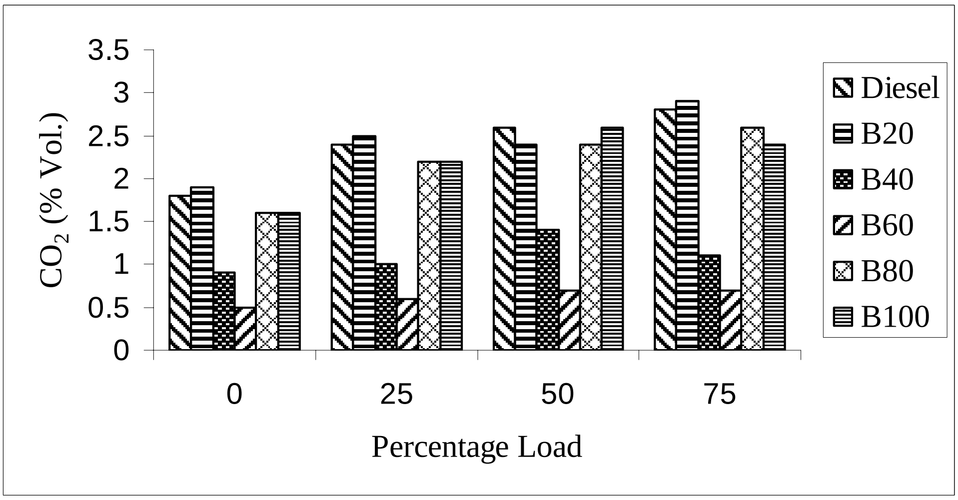

Fig. 8 Variation of CO_2 emission with load

HC emission

The HC emission variation for different blends is indicated in Fig. 9. It is seen from the Fig. 9 that the HC emission decreases with increase in load for diesel and it is almost nil for all biodiesel blends except for

B20 where some traces are seen at no load and full load. As the Cetane number of ester based fuel is higher than diesel, it exhibits a shorter delay period and results in better combustion leading to low HC emission. Also the intrinsic oxygen contained by the biodiesel was responsible for the reduction in HC emission.

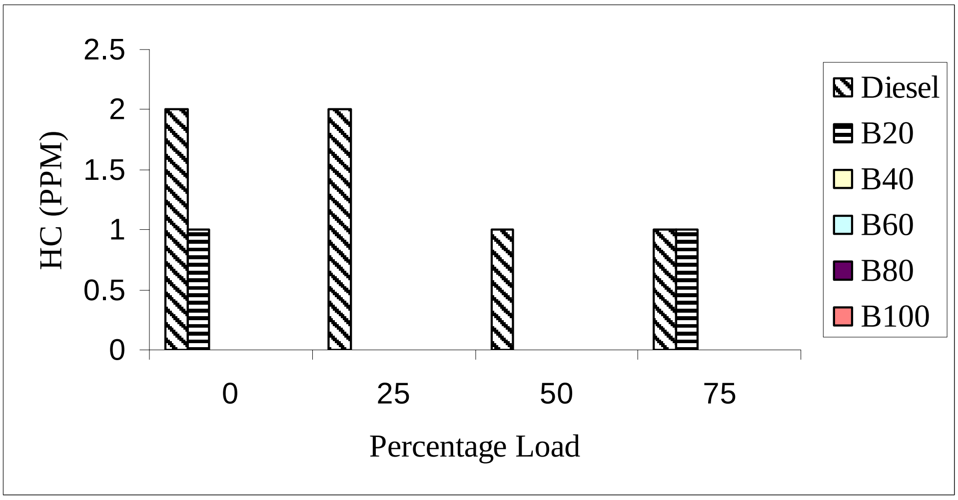

Fig. 9 Variation of HC emission with load

NO_x emission

The variation of NO_x emission for different blends is indicated in Fig. 10. The NO_x emission for all the fuels tested followed an increasing trend with respect to load. The reason could be the higher average gas temperature, residence time at higher load conditions. A reduction in the emission for all the blends as compared to diesel was noted. With increase in the biodiesel content of the fuel, corresponding reduction in emission was noted and the reduction was remarkable for B40 and B60. The maximum and minimum amount of NO_x produced were 230 ppm and 48 ppm corresponding to B20 and B60.

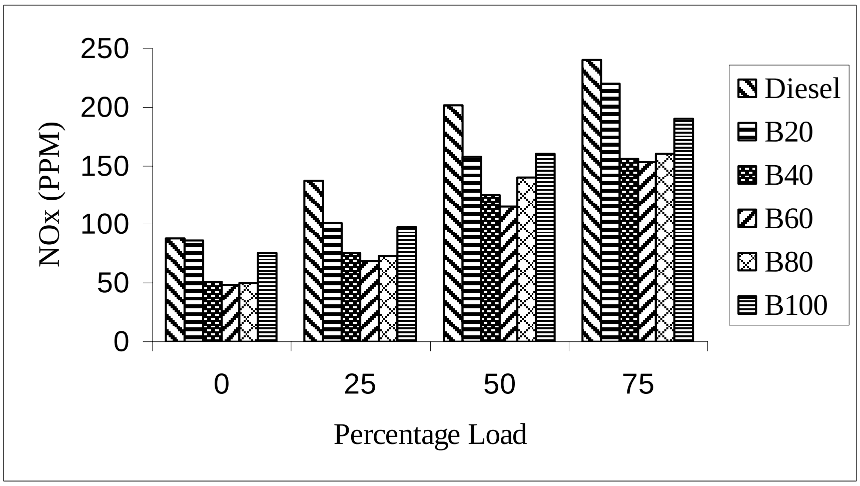

Fig. 10 Variation of NOx emission with load

Conclusion

Biodiesel with higher flash point, biodegradability and nontoxic nature are safe to handle, store and create lesser problems in case of accidental release or spillage and hence superior to diesel oil. Based on the above experimental investigations, it was found that blends of PPME and diesel could be successfully used in diesel engines without any modification, with acceptable performance and better emissions. Based on the engine performance, the blends B20 and B40 are comparable and better in some aspects than that of fossil diesel, and from emission point of view, blends B40 and B60 are superior to diesel. Hence it is concluded that the biodiesel up to 40% (B40) could replace the diesel in diesel engine applications of transport sector, remote rural electrification for getting the expected power output with less emissions leading to energy economy and environmental protection.

It is clearly evident that biodiesel with several desirable characteristics would allow modern diesel engines to use biodiesel without engine modifications and without any reduction in the engine performance. Much attention should be focused on the use of biodiesel to replace fossil fuel in order to prevent environmental degradation due to fossil combustion. In the near future conventional fuels would be fully replaced by biodiesel and would provide a viable solution for the much threatening energy crisis and environmental pollution problems.

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