Bio-diesel Technology-An Alternative to Fossil Fuels

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1.0. Introduction:

Bio-diesel is fatty acid ethyl or methyl ester made from virgin or used vegetable oils (both edible & non-edible) and animal fats. The main commodity sources for bio-diesel in India can be non-edible oils obtained from plant species such as Jatropha Curcas (Ratanjyo t), Pongamia Pinnata (Karanj), Calophyllum inophyllum (Nagchampa), Hevca brasiliensis (Rubber) etc. . Bio-diesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a bio-diesel blend or can be used in its pure form. Just like petroleum diesel, bio-diesel operates in compression ignition engine; which essentially require very little or no engine modifications because bio-diesel has properties similar to petroleum diesel fuels. It can be stored just like the petroleum diesel fuel and hence does not require separate infrastructure. The use of bio-diesel in conventional diesel engines results in substantial reduction of un-burnt hydrocarbons, carbon monoxide and particulate matters. Bio-diesel is considered as clean fuel since it has no sulphur, no aromatics and has about 10 % built- in oxygen, which helps it to burn fully . Its higher cetane number improves the ignition quality even when blended in the Petroleum diesel.

1.1. Biodiesel an option for Energy Security:

Energy is an essential input for economic development and improving the quality of life. Oil is the major source of energy for the entire world as it is convenient to store and handle. At present, India is the sixth biggest country in the world in terms of energy demands, which is about 3.5 percent of world commercial energy demand and is expected to grow at the rate of 4.8 percent per annum of its present demand (**Kumar, 2003)**. The petroleum import bill is currently about 30 percent of total import bill and the yearly consumption of diesel oil in India is about 40 million tonnes that comes to about 40 percent of the total petroleum product consumption.

The ongoing economic expansion, robust GDP growth, urbanization, agricultural mechanization and increase in vehicular population would increase the demand for transportation fuel at high rates. The crude oil import bill has gone up to Rs. 120,000 crore in the year 2006-07 **(India-2006)** and this has already depleted foreign exchange reserves and made dent in Indian economy. Thus, alternate fuel technology availability and use will become more common for both automobile applications and for stationary power in the coming decades. Another reason motivating the development of alternate fuels for internal combustion engine is concern over the emission problems of gasoline and diesel engines.

1.2. Feasibility of Biodiesel as Engine fuel:

Liquid fuels such as vegetable oils and alcohols & gaseous fuels such as biogas, compressed natural gas (CNG), liquefied petroleum gas (LPG) and hydrogen are found to be promising for use in compression and spark ignition engines. In addition, some of these alternative fuels are seen as potential for lower emissions than are associated with diesel and petrol fuels. This is of a particular significance at a time when many countries of the world are pressured to comply with the air quality standards. Consequently, in recent years, systematic efforts have been made to persuade investigations in technology and utilization of vegetable oils as alternative to diesel fuel in compression ignition engines.

The advantages of using vegetable oils as fuel for diesel engines include better self ignition characteristics, better compatibility with fuel injection system used in the existing CI engines, high energy content and self processing and handling. Above all, these fuels can be readily incorporated in to energy pool, should the need arise due to sudden shortage or disruption in the existing petroleum supply system **(Gupta, 1994)**. Moreover, vegetable oil fuels produce greater thermal efficiency than diesel fuel **(Goering *et al.*, 1982)**. However, the use of vegetable oil in direct injection type diesel engine is limited by an important physical property i.e. viscosity. Viscosities of vegetable oils are reported to be 10 to 20 times more than that of diesel fuel due to which such oils are lower in total energy and higher in density, carbon residue, and particulate matter **(Ali, 1995)**.

Preliminary studies indicate that over short period of time total replacement of diesel by vegetable oil fuels perform satisfactorily in unmodified diesel engines for a number of different vegetable oils. However, the problems associated with their long term use are difficulty with cold start, plugging and gumming of filters, fuel lines and injectors and engine knocking. In the long –term uses, the problems may lead to reduced performance or even complete failure of the engine caused by coking of injector nozzles, carbon deposits on the piston and cylinder head, dilution of the crankcase lubricating oil, excess wear on the rings, pistons and cylinder and failure of the engine lubricating oil due to oxidation and polymerization. These problems have been correlated with several basic properties of vegetable oils, such as naturally occurring gums, high viscosity, acid composition, free fatty acid content, and low cetane rating. It is crucial to understand and anticipate these problems before an attempt is made to use vegetable oils.

The chemical composition of vegetable oil is directly related to problems with failure of engine lubrication. Some oils are more likely to polymerize or oxidize in the crankcase than others, notably those high in unsaturated acids. The problem arises due to the triglyceride composition of the oils. All unsaturated triglycerides have a tendency to polymerize, depending on the degree of saturation. Polymerization is accelerated by high temperature, pressure and the presence of certain metal-conditions often found in the crankcase of an internal combustion engines. The same problem of polymerization of crankcase oil in diesel engines occurred with petroleum based fuels in 1950s. The solution was to put additives into motor oils. This problem, combined with the viscosity of vegetable oils presents the greatest difficulty in using vegetable oils in diesel engines. Therefore, several techniques are being used to reduce the viscosity. These include heating the vegetable oil to sufficient temperature to lower the viscosity to near specification range, diluting the vegetable oil with other less viscous liquid fuels to form blends that have been termed as hybrid fuels, micro emulsifying the vegetable oil and esterification process i.e. chemically converting the vegetable oil to simple esters of methyl, ethyl or butyl alcohols. Esterification process has been preferred because it reduces viscosity and maintains the heat of combustion. Moreover, this process also enhances volatility of the fuel which in turn helps in its better atomization. The esters produced from esterification process present a very promising alternative to diesel fuel since they are renewable, non-volatile, and safer due to increased flash point and biodegradability. They also contain little or no sulfur and can be produced easily in rural areas where there is an acute need for such form of energy. Moreover, they have been demonstrated to burn in unmodified diesel engines **(Gateau and Staat, 1995) in** contrast to natural gas such as CNG and LNG **(Sharp *et al.,* 1983 and Mott *et al.*, 1995)**. The various aspects of using vegetable oils as fuel include development of high oil bearing crops, their production, oil processing and storage, filtration, blends and additives, esterification, engine performance, problem with engine deposits and injector coking, use of byproducts and their overall economics.

1.3. Feed stock available for Biodiesel Production in India:

Edible oils such as soybean, rapeseeds, canola, sunflower, cottonseed etc. and non-edible oils like jatropha, karanja, neem, mahua etc. have been tried to supplement diesel fuel in various countries. In U.S., biodiesel programme is based on their surplus edible oils like soybean and in Europe it is based on rapeseed and sunflower oils. Under Indian conditions, an emphasis is being laid by the government to explore the possibility of using non edible oils as biodiesel as the country is already short in production of edible oils. Non-edible oils such as neem, mahua, karanja, babassu, Jatropha, etc. are easily available in many parts of the world including India, and are very cheap compared to edible oils. The potential availability of some non-edible oils in India is given in Table 1.

Table 1: Non-edible oil sources of India

Oil	Botanical Name	Potential (million tonnes)	Utilised (million tonnes)	Percent Utilisation
Rice bran	*Oryza Sativa*	474,000	101,000	21
Sal	*Shorea robusta*	720,000	23,000	3
Neem	*Melia azadirachta*	400,000	20,000	6
Karanja	*Pongamia glabra*	135,000	8,000	6

(Source: Anjana Srivastava and Ramprasad).

1.4. Feasibility of Jatropha and Pongamia as feedstock for Biodiesel production:

During the last few decades, researchers tried all edible and non-edible vegetable oils in compression ignition and spark ignition engines for different utilities. Since India cannot afford the usage of edible vegetable oils for power requirements to feed its huge population, planners have suggested the use of non-edible vegetable oils like Pongamia, Jatropha, etc as alternative fuels.

2.0. Extraction of Oil from Pongamia and Jatropha Seeds:

To prepare biodiesel, the oil is expelled from the seeds through the process of solvent extraction, enzymatic extraction, etc. If the seeds are processed at rural level in a decentralized way by oil extraction at small scale level, it will reduce the processing cost compared to the biodiesel manufactured at a large scale Industry. In other words, Biofuel processing needs to be shifted to small scale/medium scale industry at rural level. This in-situ extraction process brings together the energy source and energy consumer reducing unnecessary transport of fuel. In addition to that the nutrition rich cake meal that is a waste product at Industry can be used as biofertilizer source to the rural farms if extraction is done at village level. In this regard, the mechanical expulsion seems to be advantageous for the rural conditions.

Processing of Jatropha and Pongamia seeds for biodiesel application involves two major steps, which include expelling the oil from the seeds and preparing biodiesel with transesterfication process. Unfortunately there is no specific oil expeller available in the market for Jatropha and Pongamia seeds. The expellers, which are commonly used for groundnut and other products of small size seeds having high oil content, are normally used for extracting the oil from Jatropha and Pongamia seeds. In addition to this, these seeds consist of more gums and wax when compared to other conventional edible seeds and obstruct cake movement inside the cage chamber. Due to all these reasons, only 20-24 % of the oil is extracted from the Pongamia seeds and 24-27 % of oil extracted from the Jatropha seeds making it uneconomical apart from oil loss (around 8-12%) through cake, which finally restricts the cake usage as bio fertilizers. The efficiency of the oil expeller depends on the compression ratio of the expeller and screw configuration which include the angle of helix worm geometry etc **(Jaswant singh 1999)**. Hence modifications are necessary in expeller mechanism to increase the oil recovery and reduce the gums and waxes so as to make the oil more engines friendly.

Apart from the low recovery of oil from these seeds, the specific energy consumption was around 450 W/kg of oil which was higher than the compared to conventional seeds **(Pathak et. al. 1988)**. Hence any modification in expeller design will definitely bring down the energy consumption so that the farmer will get the end benefit.

The development of oil expellers for on-farm processing of Pongamia and Jatropha seeds specifically for self-sustainability in a decentralized manner for rural application is envisaged. A mini expeller is fabricated by the Central Research Institute for Dryland Agriculture (CRIDA) under the Union Ministry of Agriculture and and compared the performance with conventional expeller after modification. The configuration of the screw, compression ratio in the capacity range of 40 kg/hour is modified to obtain optimal oil yield with low energy consumption. Specifications of the conventional and modified oil expellers are as follows:

Item	Specifications of oil expellers	
	Conventional oil expeller	**Modified oil expeller**
Capacity of the oil expeller	70-100 kg/hr	40 kg/hr
Power of the motor	10 h.p.	3 h.p.
Size of the main frame	1500mmX700mmX300mm	1100mmX500mmX150mm
Diameter of the driving wheel pulley	800mm	450 mm
Total Length of the screw	900 mm	600 mm
Diameter of the screw	75mm	45 mm
Rpm of the screw	32	Variable (35 to 65 rpm)
Hopper dimensions	700mm dia. and 400mm depth	35mm dia and 250mm depth
Compression ratio of the expeller	14:1	Variable (14:1 to 21.5:1)

Existing oil expeller

Modified oil expeller

The compression ratio of modified oil expeller is varied in the range of 14:1 to 21.5:1 with the screw shaft speed in the range of 25 to 65 rpm. The worm helix angle of screw is varied in the range of 35-85 degrees. The cake breakers are also fixed to increase the oil recovery by restricting the cake movement. The cake breakers angle is also varied in the range of 10-90^0.

It is observed that these parameters significant impact on the oil recovery and energy consumption during Pongamia and Jatropha oil extraction. It is observed that the optimum compression ratio of 18.5:1 at 45 rpm speed gave maximum oil recovery with minimum energy for Pongamia. Similarly the maximum oil recovery with minimum energy is obtained at 20:1 compression ratio and 45 rpm shaft speed for Jatropha seed. The Worm helix angle of 65^0 for Pongamia and 75^0 for Jatropha enhanced the oil recovery and decreased the energy consumption considerably. Fixing of cake breakers at 70^0 helped the smooth movement of cake inside the oil chamber and reduced the choking problem, resulted in increase of oil recovery up to 30.16 % in case of Pongamia and 32 % in case of Jatropha by saving 38 % of overall energy.

3.0. Production of Biodiesel (methyl ester) from Jatropha and Pongamia at CRIDA:

The oil collected from the oil expeller is filtered using suitable filter paper and made into different samples based on the treatment.Evaluation of biodiesel properties obtained from Pongamia and Jatropha oil is essential to determine their adaptability as fuel in I.C engine. For this, established procedure of single stage transesterification for low fatty acid oil and two-stage transesterification for high fatty acid oils is used. For transesterification, methanol is commonly used on the farm for obtaining biodiesel. Though there are many catalysts available for methonolysis reaction, Potassium hydroxide (KOH) is selected due to its suitability for Pongamia and Jatropha oils.The biodiesel from raw Pongamia and Jatropha oil is made by two-stage acid-base catalyst transesterification process since the percentage of free fatty acids is more than 2 % in the samples. The acid esterification reaction is carried with 0.30 volume of methanol per unit volume of oil for duration of one hour. After the reaction, the mixture is allowed to settle for 1 hour and the methanol–water fraction formed at the top is removed in a separating funnel. The bottom product having acid value less than 2 mg KOH/g is used for the main transesterification reaction. The main transesterification reaction is carried out with 0.25 v/v methanol (6:1 molar ratio) varying KOH concentration in the range of 0.75 to 2.75 % w/v to optimize the catalyst concentration and to standardize the process in terms of quantity of catalyst required for smooth reaction to obtain higher biodiesel recovery. Minimum KOH amount is arrived based on 0.5% for catalyst plus the amount needed to neutralize the un-reacted acids (i.e. 2 mg KOH/g) in the acid esterficiation product.

The parameters like reaction temperature, molar ratio of methanol-oil, settling time, separation method, etc are kept constant to restrict the study for obtaining optimal value of catalyst concentration which is found as very critical parameter (Foidl 1996). The flow chart of the reaction process is given in below fig1.

Fig.1: Flow chart of Biodiesel preparation from Pongamia and Jatropha oils

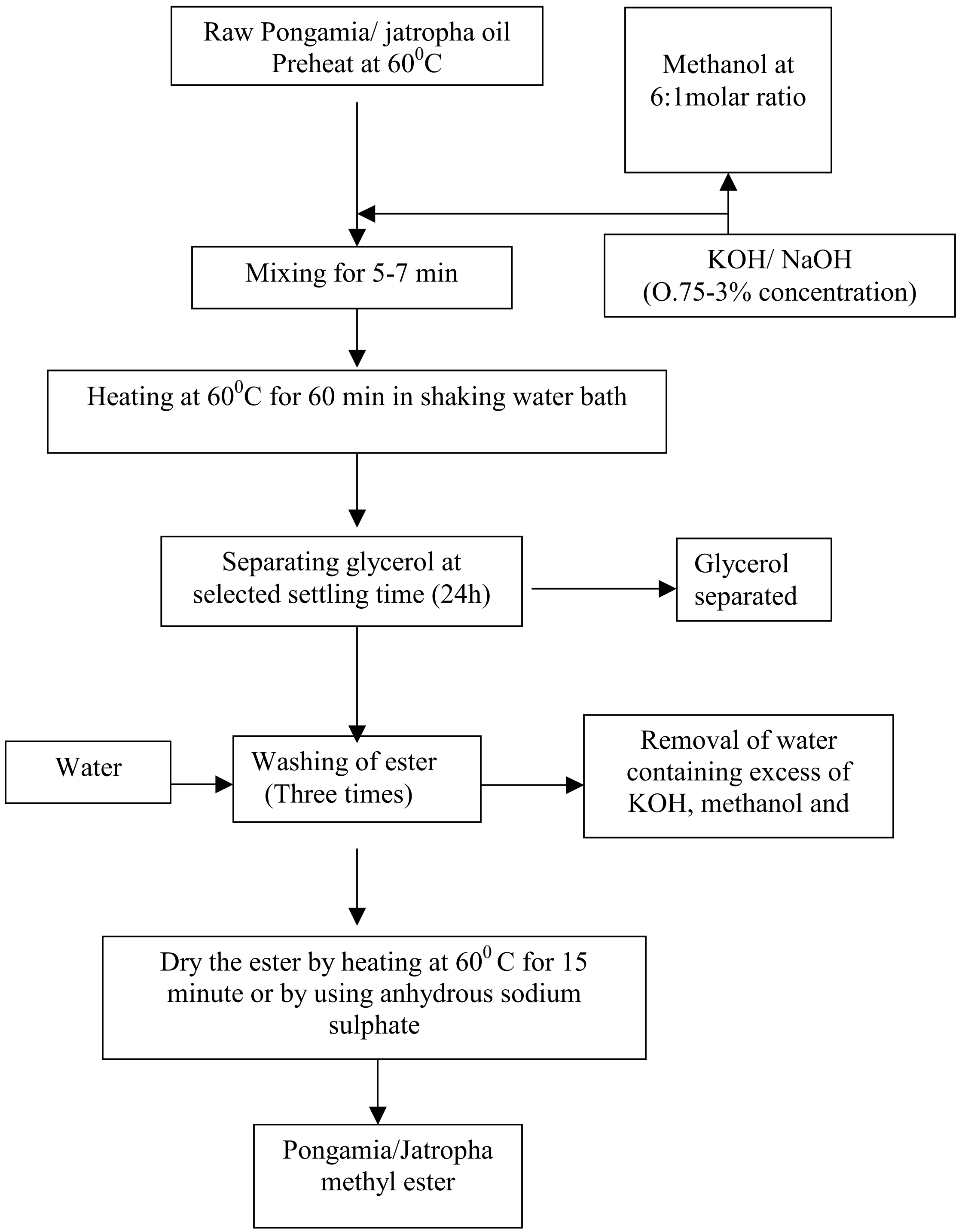

Table.2: Characteristic fuel properties of Pongamia and Jatropha methyl esters

Fuel Property	Pongamia oil	Pongamia Methyl ester	Jatropha oil	Jatropha Methyl ester
Kinematic viscosity (cst)	45.22	3.92	36.44	3.02
Relative density	0.912	0.882	0.894	0.858
Gross heat of combustion (MJ/kg)	34	37.12	37.5	39.87
Cloud and pour point (^{0}C)	17 & 7	15.5 & 6	7 & 4.5	3.5 & 1
Flash and fire point (^{0}C)	217 & 223	161 & 157	197 & 204	148 & 153
Acid value	14.08	1.05	6.23	0.98

4.0. Performance evaluation of CI Engine with different blends of Pongamia and Jatropha methyl ester with diesel

Different fuel blends are prepared by blended the biodiesel in the range of 20-80 % with diesel for testing in the CI engine. The characteristic fuel properties such as kinematic viscosity, relative density, gross heat of combustion, cloud and pour point, flash and fire point, carbon content, ash content and total acidity were measured for different fuels to assess their compatibility with diesel fuel according to ISI Standards.

All characteristic fuel properties of different fuel blends of Jatropha and Pongamia methyl ester with diesel up to 40% are almost similar to diesel.

The performance evaluation of a 3.73 kW diesel engine with selected fuels and their blends is carried out as per **IS: 10000 [P: 8]: 1980**. at CRIDA, Hyderabad. A 3.73 kW [5 HP) single cylinder four stroke Kirloskar engine, water cooled, direct injection compression ignition engine operating at a constant speed 1500 rpm is selected for study and connected with Eddy Current Dynamometer for taking observations. The observations of fuel consumption, load applied, rpm of the engine etc using the test-rig are taken and the engine characteristics like Brake specific fuel consumption, Brake power and Brake thermal efficiency are recorded. The specifications of the engine and Eddy Current Dynamometer are given below

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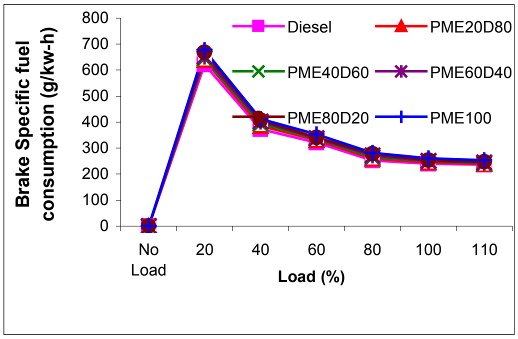
4.1. Brake Specific fuel Consumption:

The variation of brake specific fuel consumption with load for different types of fuel is studied for evaluating the engine performance. It is observed from fig.1&2 that the brake specific fuel consumption at rated power with diesel is found to be 239.1 g/kW-h. It can be observed that similar trend can be observed for Pongamia and Jatropha methyl ester fuel blends. It can also be observed that BSFC increased with increase in methyl ester content in the diesel blends for both Pongamia and Jatropha methyl esters due to higher relative density and more fuel consumption of the esters. The higher specific fuel consumption can also be contributed to the high viscosity of methyl esters compared to the diesel.



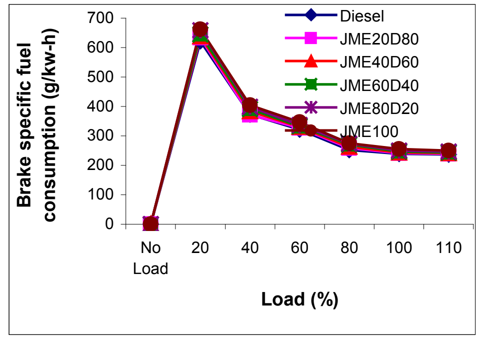


Fig.1: Effect of Blend on brake Specific fuel Consumption of Pongamia methyl ester blends

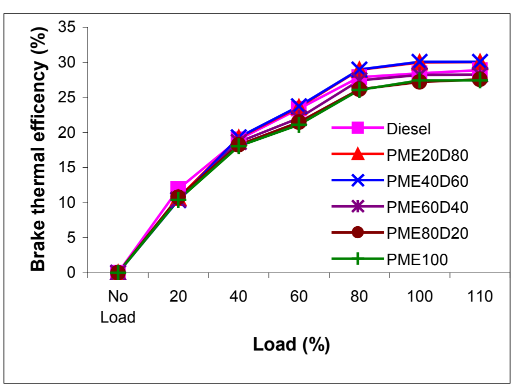
Fig.2: Effect of Blend on brake Specific fuel Consumption of Pongamia methyl ester blends

BSFC values of all Jatropha methyl ester blends with diesel are found to be lower than the values of respective Pongamia methyl ester blends. This is because of higher calorific value of Jatropha methyl esters than the Pongamia methyl esters, which influenced the fuel consumption at various loads.

4.2. Brake Thermal Efficiency:

The relation between brake thermal efficiency with load for various Pongamia and Jatropha methyl ester blends with diesel is shown in Fig. 3&4. Brake thermal efficiency of the engine increases with load for all fuel blends. It can also be observed that at for 20% rated load, higher BTE is obtained with diesel compared to other blends, which is due to the lower BSFC of the diesel at lower loads.

The observed readings of brake thermal efficiency (BTE) of the engine at 100% rated load with Pongamia methyl esters blends are higher than that of diesel. This can be due to availability of oxygen in the biofuels, which help in better ignition of the fuel in combustion chamber. As the blend percentage of methyl esters in diesel increases, BTE decreases when compared with that of diesel. This may be due to the increase in viscosity of the fuel that increase the droplet size of the fuel affecting proper combustion and also due to lower heating value of the fuel. Similar trend is observed with the Jatropha methyl esters as fuel.



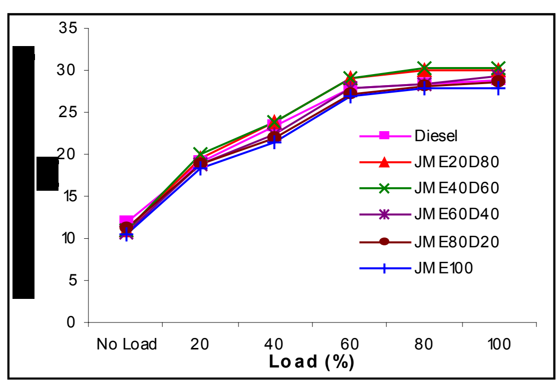


Fig.3: Effect of Pongamia methyl ester blends with diesel on brake thermal efficiency

Fig.4: Effect of Jatropha methyl ester blends with diesel on brake thermal efficiency

5.1. Hydrocarbon Emissions:

The variation in HC emission at different loads for different fuels is shown in Fig. 5 & 6. It is observed that HC emission is reduced at all blends of Pongamia and Jatropha methyl esters compared to diesel. It also observed that as the percentage of biodiesel is increased in the fuel, the HC emissions are reduced for both PME and JME fuel blends. This may be due to in-built oxygen enabling complete combustion of carbon and HC in biodiesel. It is observed that the emission at higher blends is lower than at lower blends. This may be due to lower oxidation reaction due to lower temperature in the combustion chamber and lean fuel mixture resulting less variation in HC emission for diesel and other fuel blends.

At rated load, the HC emissions of PME100 and JME100 are 49 and 46 ppm respectively, which are lesser than diesel by 40 and 42.5 % respectively. It is evident that HC emissions of Jatropha methyl ester fuel are lower than Pongamia methyl ester fuel blends at the same load for respective blends.

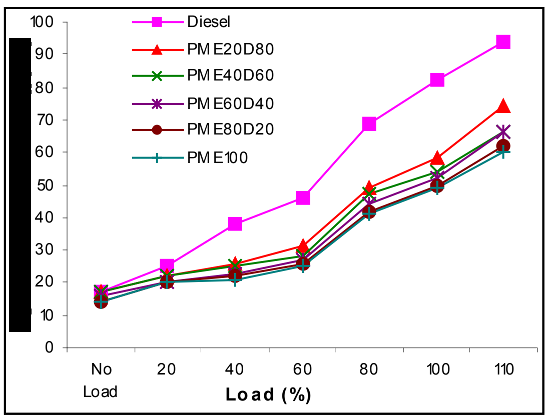


Fig.5: Effect of Pongamia methyl ester blends with diesel on HC emissions

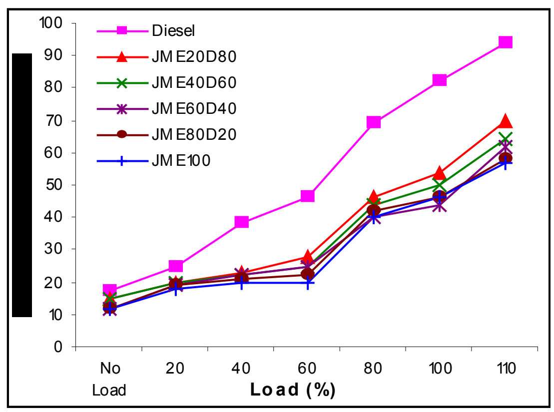


Fig6: Effect of Jatropha methyl ester blends with diesel on HC emissions

5.2. Carbon Monoxide emissions

The carbon monoxide (CO) emissions from the engine with diesel for the selected Pongamia & Jatropha methyl ester blends at various loads are shown in Fig.7 & 8. As the load increased the CO emissions also increased. This may be due to the reason that at higher loads the air/fuel ratio comes down as more fuel is injected in to the combustion chamber limiting the oxygen availability for combustion process. It is observed that CO emissions of Pongamia and Jatropha methyl ester blends are lower than diesel emissions at all loads. This may be due to complete oxidation of biodiesel blends and possible conversion of CO into Carbon dioxide by taking up the extra oxygen molecule present in the biodiesel chain. It can also be observed the CO increased as the ester blend is increased in diesel. The CO emissions of PME100 and JME100 are found to be 0.085, 0.095 which are 43 and 31 % less than the diesel at rated load.

It is evident that CO emissions of Jatropha methyl ester fuel are lower than Pongamia methyl ester fuel blends at the same load for respective blends.

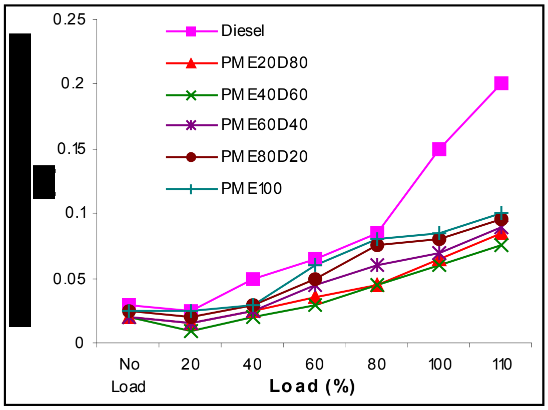


Fig.7: Effect of Pongamia methyl ester blends with Diesel on CO emissions

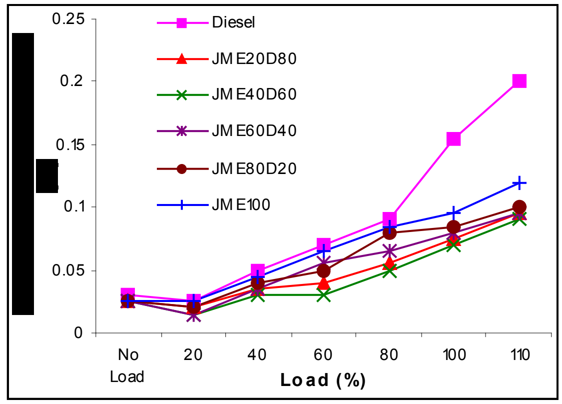


Fig.8: Effect of Jatropha methyl ester blends with diesel on CO emissions

5.3. N0$_x$ emissions

N0$_x$ emissions for selected blends of Pongamia and Jatropha methyl ester with diesel fuels are shown in Fig. 9 & 10. It is observed that the NO_x emissions increase with increase in load. This is due to higher combustion temperatures developed at higher loads as more fuel is injected. It can also be observed that all Pongamia and Jatropha methyl ester blends gave higher NO_x emissions than from diesel fuel. This is due to the presence of higher quantities of biodiesel enhances combustion temperature generating more NOx **(Peterson *et al.*, 2000)** compared to emission from diesel combustion.

At the rated load NO_x emissions of PME and JME are 122 and 112 ppm respectively, which is 18 and 6 % higher than diesel. It is evident that NO_x emissions of Jatropha methyl ester fuel are lower than Pongamia methyl ester fuel blends at the same load for respective blends. This may be due to lower nitrogen in the Jatropha seed than in Pongamia seed.

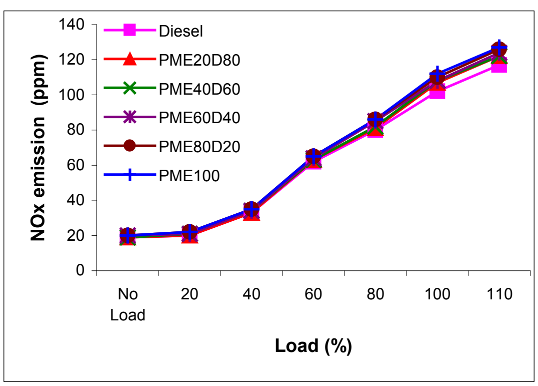


Fig.9: Effect of Pongamia methyl ester blends with Diesel on NOx emissions

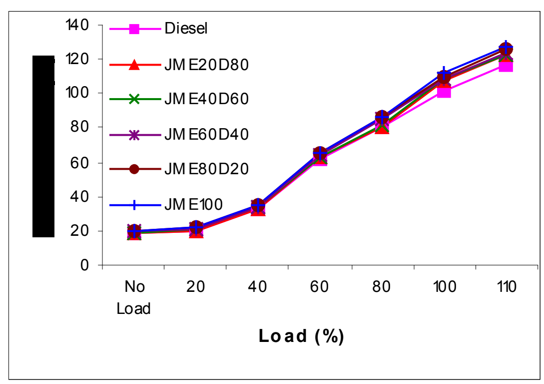


Fig.10: Effect of Jatropha methyl ester blends with diesel on NOx emissions

Performance of a stationery engine is evaluated with Pongamia and Jatropha biodiesel blends with diesel in terms of specific fuel consumption, brake thermal efficiency and exhaust emissions and found comparable with diesel up to 40% of methyl ester blends with diesel. How ever, for the safer side, it is recommended that we can use up to 20 per cent of methyl ester blend with diesel in conventional CI engines with out any modifications.

7.0. References

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