A comparative study of pongamia pinnata and jatropha curcus oil as diesel substitute

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Absreact *- In the present work a comparative study was performed to test the feasibility of non-edible plant oils derived from two different species as diesel substitute. Oil extracted from the seeds of pongamia pinnata and jatropha curcus were processed in a batch type of transesterification reactor. The straight vegetable oils obtained from these varieties as well as their blends with certified diesel were tested for physical and chemical properties. Further, engine performance as well as emission tests were conducted and compared with certified diesel. Engine performance tests were conducted in a 5 HP single cylinder, water cooled diesel engine coupled to a dynamometer. Transesterification process shows improvement in fuel properties of pongamia pinnata and jatropha curcus oil. Results obtained from 15 to 20% pongamiya pinnata and blends of jatropha methylester with petrodiesel (B15 and B20) shows improvement in brake thermal efficiency and reduction in brake specific fuel consumption in engine especially at higher loads. Emission results indicate significant reduction in percentage of CO and HC for B15 and B20 at medium and higher power output.*

Keywords **- CI Engine, pongamia pinnata Oil, Jatropha curcus Oil, Renewable Energy, Transesterification, Biodiesel.**

1. INTRODUCTION

Gradual depletion of world petroleum reserves, increase in crude oil prices, and impact of environmental pollution have motivated the scientific community all over the world to look for suitable alternative fuels. This results in renewed focus on vegetable/plant oils and other renewable lipid sources. Several researchers have made systematic efforts to use plant oils and their esters (Biodiesel) as fuel in compression ignition (CI) engines [1-4].

It had been reported that major problem associated with straight vegetable oil (SVO) as petrodiesel substitute in CI engine were its high viscosity, low volatility and presence of poly-unsaturated character [4]. These problems are due to large molecular mass and chemical structure of vegetable oils. It was observed that due to polyunsaturated character, in long-term operation, vegetable oils normally introduce the formation of gum, the formation of injector deposits [5], ring sticking, as well as incompatibility with conventional lubricating oils [6]. The problems associated with SVO can be minimized by any one of the four processes viz, pyrolysis, microemulsification, dilution or transesterification [7]. The processed vegetable oil can be used in any existing CI engine without any modification [8-9].

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The use of non-edible vegetable oils as compared to edible oils is very significant in developing countries because of the tremendous demand for edible oils as food and they are far too expensive to be used as fuel at present [7-11]. In the present investigation, the diluted and transesterified non-edible oils of pongamia pinnata and jatropha curcus have been considered as a potential alternative fuels for CI engines. Based on various experimental results a comparative study of both the oil varieties has been presented.

Pongamia pinnata (L.) is an Indo-Malaysian species, a medium-sized sub evergreen tree, common on alluvial and coastal situations from India to Fiji, from sea level to 1200 m [12]. It is found in Australia, Florida, Hawaii, India, Malaysia, Oceania, Philippines, and Seychelles. Pongamia pinnata tree can withstand temperatures slightly below 0°C to 50°C and annual rainfall of 5 to 25 cm, the tree grows wild on sandy and rocky soils, including limestone, but will grow in most soil types, even with its roots in salt water. The oil extracted from seeds of pongamia pinnata is poisonous, oil content in seed kernel (w/w) is 30 to 40 % and seed yield of pongamia pinnata tree is 3 to 10 tons per hectare per year.

Use of pongamia pinnata oil as SVO in CI engine has been reported by Srinivasan [13]. Dhinagar *et al*. [14] tested pongamia pinnata oil on a low heat rejection engine. An electric heater was used to heat the oil. The exhaust gas was also utilized for heating the oil. Efficiency reduction by 1 to 4%, compared to that of petrodiesel, was reported. However, with heating, the efficiency was improved.

It was found out that blends of pongamia pinnata methyl ester with petrodiesel reduced emissions such as CO, smoke density and NO_x on an average of 80%, 50%, and 26%, respectively. However, brake power output increased on an average 6% up to biodiesel blend B40 and with a further increase in the biodiesel percentage in the blend, it reduced [15].

Jatropha curcus (Linnaeus) or Ratanjyot is a multipurpose bush/small tree. It is a native of tropical

America, but now thrives in many parts of the tropics and sub-tropics in Africa and Asia. It has few pests and diseases and can grow under a wide range of rainfall regimes from 200 to over 1500 mm per annum [16]. In low rainfall areas and in prolonged rainless periods, the plant sheds its leaves as a counter to drought. Jatropha curcus is easy to establish, grows relatively quickly and is hardy, being drought tolerant. It is not browsed, because its leaves and stems are toxic to animals. The oil extracted from jatropha curcus is viscous and poisonous; the oil content in seed kernel (w/w) is 40 to 60% and seed yield of jatropha curcus shrub is 1.5 to 12 tons per hectare per year.

Jatropha curcus oil and it's blend with diesel were tested by some researchers as CI engine fuel. It was reported [17] that up to 50% jatropha curcus oil can be substituted for petrodiesel for use in CI engine without any major operational difficulties. Kumar *et al*. [8] found that100% jatropha curcus oil resulted in a slightly reduced thermal efficiency, ignition delay, lower heat release rates and higher HC emission as compared to petrodiesel and with100% methyl ester of jatropha curcus oil the brake thermal efficiency was comparable to petrodiesel values, but there was ignition delay and lower heat release rate.

In the present work, efforts were made towards the comparative study of SVO of pongamia pinnata and jatropha curcus and of their methyl esters as petrodiesel substitute with minimal fuel processing without engine modification. Test of SVO and their blends were carried out in a 5 HP single cylinder water-cooled CI engine at rated speed of 1500 RPM under variable load conditions with different blending ratio of pongamia pinnata and jatropha curcus oil, and of their methylesters with petrodiesel. The performances of the engine characteristic were evaluated using different proportions and were compared using certified petrodiesel. Further, emission of CO and HC were studied with various biodiesel blends and compared.

2. EXPERIMENTAL INVESTIGATION

To compare the fuel potential of non-edible oils of pongamia pinnata and jatropha curcus as a substitute of petrodiesel various experiment were performed by standard methods. The details of all experiments performed in this study are described in the following subsections.

2.1. Dilution and Catalytic Transesterification

Dilution or blending of vegetable oils with alcohol or petrodiesel brings their viscosity close to the petrodiesel specifications [4, 16]. Therefore, the pongamia pinnata and jatropha curcus oil were diluted with petrodiesel in different proportions to reduce their viscosity close to that of the diesel fuel. Simple mixing gives homogeneous and stable mixture for all blends of SVO and petrodiesel.

The "catalytic transesterification" process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of acidic, alkaline or lipase as catalyst to form mono alkyl ester (i.e. biodiesel) and glycerol.

It is reported [4] that alkaline catalyzed transesterification is fastest and require simple setup therefore, in current study the SVO of pongamia pinnata and jatropha curcus were transesterified with methyl alcohol in the presence of strong alkaline sodium hydroxide catalyst in a batch type transesterification reactor (shown in figure 1).

To prepare biodiesel from SVO of pongamia and jatropha, first the sodium hydroxide was added in to the methyl alcohol to form sodium-methoxide, simultaneously oil was heated in a separate vessel to remove moisture. Moisture free oil was kept in to the inner vessel of transesterification reactor, and subjected to heating and stirring. When temperature of the oil reached at 60 ^{0}C then sodium methoxide was mixed in to the oil and reaction mixture was stirred for more than one hour until separation of glycerol is not started. Separation of glycerol was checked by taking a small sample of reactant in test tube. When separation of glycerol started than stirring was stopped and reaction mixture was transferred to a separate container. After 8 hour the reaction mixture was separated into the methyl esters as upper layer and the glycerol as lower layer. The methyl esters were decanted and were washed three times with warm distilled water to remove traces of soap and other impurities. The final product was good quality biodiesel. The values of various variables of transesterification reaction of pongamia and jatropha are given in table 1.

2.2 Physical and Chemical Properties

The important fuel properties of SVO of both the varities and of their methyl ester were studied by performing various tests using standard methods. Most of the fuel properties were tested in the laboratories of Indian Institute of Technology Guwahati, Assam. However, biodiesel samples were tested in Bongaigaon Refinery and Petrochemicals Limited, Assam.

2.3 Engine Performance and Emission Tests

The schematic of experimental setup used for the present work is shown in figure 2. The set up consists of a 5 HP water-cooled, direct-injection, four-stroke diesel engine coupled to a water dynamometer. The specifications of engine are given in table 2. The fuel supply system is modified. To allow rapid switching between the petrodiesel oil used as a standard and the test fuels, an additional two-way control valve was used in the test rig. At each loading, the speed of the shaft was measured using a handheld tachometer. The fuel was fed to the injector pump under gravity and the volumetric flow rate was measured by noting the time taken for 50 ml of fuel to flow through a graduated measuring device. The petrodiesel/SVO of pongamia pinnata, petrodiesel/ SVO of jatropha curcus, petrodiesel/pongamia pinnata methylester blends and petrodiesel/jatropha curcus methylester blends were tested successfully in this set up.

Test runs were also carried on certified petrodiesel fuel in order to make comparative assessments. In all the cases, the engine speed was almost constant at 1500 RPM while power output was varying by external loading through hydraulic dynamometer. An infrared exhaust gas analyzer was used for the measurement of CO and HC % in exhaust gases for petrodiesel, B15, and B20 fuel of pongamia pinnata and jatropha curcus methylesters.

3. RESULTS AND DISCUSSION

3.1 Physical and Chemical Tests Results

The results of tests for various physical and chemical properties of different fuels are presented in tables 3 to 6.

The fatty acid composition of vegetable oils can affect fuel properties of biodiesel therefore fatty acid compositions of pongamia and jatropha oil were studied and results are shown in table 3. It can be observed from table 3 that SVO of pongamia and jatropha have high percentage of unsaturated fatty acid. Unsaturated character of fatty acid will result in gum formation when SVO will come in contact to atmospheric oxygen. Saturated fatty acid methyl esters increase the cloud point, cetane number and improve stability whereas more poly-unsaturated fatty acid ester reduce the cloud point, cetane number and stability.

Various physical and chemical test results for both SVO,s and of their methylesters are compared with petrodiesel in table 4.

One can noticed from table 4 that petrodiesel has low viscosity (2 to 5 cSt) whereas viscosity of SVO of pongamia pinnata and jatropha is15.2 cSt and 52.76 cSt respectively (very high for a CI engine fuel). The value of viscosity of pongamia pinnata methylester is 5.75 cSt and for jatropha curcus methylester the value is 6.7 cSt. It shows that viscosities of methylesters of pongamia pinnata and jatropha curcus oil are comparable to petrodiesel specification. The specific gravity and calorific value of pongamia pinnata oil and its methyl ester are compatible with petrodiesel but jatropha curcus oil and its methylester have higher specific gravity as compare to petrodiesel. One can also observed that pongamia pinnata oil, jatropha curcus oil and their methylesters have higher flash point than petrodiesel which makes sure that SVO and of their methylesters blend with petrodiesel will improve flash point of petrodiesel and can be transported with less hazard.

The effects of dilution of vegetable oils with petrodiesel were studied and results are shown in table 5. It can be observed that blends up to 10% SVO have viscosity comparable to petrodiesel. Even 30% SVO blend shows almost 50% reductions in viscosity. Thus blends up to 30% can be considered for thermo-mechanical study. Variation in density for up to 30% blend is very less and comparable to petrodiesel. One can also observe that calorific value of blends decreases with increase in percentage of SVO. However, these variations are low compared to petrodiesel up to 30% blend.

The fuel properties of pongamia and jatropha biodiesel blends with petrodiesel were determined and results are shown in table 6. It can be observed from these results that 15% and 20% blends of pongamia pinnata and jatropha curcus methylesters (i.e. B15 and B20) have density, viscosity, and pour point and Cu strip corrosion within specified limits for petrodiesel. The improvement in cetane index and flash point can also be observed. The most valuable result is reduction in percentage of total sulphur that will result in reduction of SO_X in exhaust gases which is one of the reasons of acid rain.

3.2. Engine Performance Test

One 5 HP single cylinder water-cooled CI engine at rated speed of 1500 RPM was tested to check its performance under variable load condition with different blending ratio of pongamia pinnata, jatropha curcus oil, and of their methylesters with petrodiesel. The plots of performance results are shown in figure 3 and figure 4.

The results of variation in the Specific Fuel Consumption (SFC) with brake power for 5 to 30% blends of SVO of pongamia pinnata and jatropha curcus and for B15 and B20 fuel of their methylesters are plotted in figure 3. For comparison, results with petrodiesel as standard fuel are also plotted. Results show that fuel consumption increases with increase in percentage of SVO of pongamia pinnata and jatropha curcus in blend. This is mainly due to the combined effects of the relative fuel density, viscosity and heating value of the blends. However, at higher load fuel consumption is comparable to petrodiesel for up to 30% SVO blend. Blends of SVO of jatropha curcus and petrodiesel results in higher fuel consumption as compare to corresponding blends of SVO of pongamia pinnata. It can also be observed that B15 and B20 results in slight reduction in fuel consumption as compared to petrodiesel and SVO blend. Throughout the entire load range, minimum fuel consumption is obtained with B20.

The variation of brake thermal efficiency of the engine with brake power was evaluated for various blends of pongamia pinnata oil/petrodiesel and for B15 and B20 of both oils and results are plotted in figure 4. It can be observed that the brake thermal efficiencies increase with brake power for all fuels. The brake thermal efficiencies of the pongamia pinnata SVO, jatropha curcus SVO blends were lower than that with petrodiesel fuel, B15 fuel, and B20 fuel for entire range of loading. It can be noticed that B15 and B20 show increase in efficiency as compared to petrodiesel; highest efficiency is obtained with B20. The drop in thermal efficiency with increase in proportion of SVO of pongamia pinnata and jatropha curcus must be attributed to the poor combustion characteristics of the SVO's due to their high viscosity and poor volatility with subsequent higher SFC.

The increase in thermal efficiency with B15 and B20 can be attributed to 10% built-in oxygen that is present in all methylester of vegetable oils (i.e. biodiesel). Extra oxygen causes better combustion inside the combustion chamber.

3.3 Engine Emission Test

The emission characteristic of the engine was studied by using an infrared exhaust for measurement of CO and HC % in exhaust gases of the engine running with petrodiesel, B15, and B20 fuel of pongamia pinnata and jatropha curcus methylesters. The emission results are presented in figure 5 and 6.

Emission of CO (% volume) is shown in figure 5. It can be noticed that for petrodiesel, B15 and B20 fuels of pongamia pinnata and jatropha curcus; CO emission first decreases with increase in load and after reaching some minimum value it starts to increase. This behavior can be explained by the fact that at lower output, engine gets lean mixture and at a higher output, rich mixture is supplied to the engine that results in incomplete combustion and, therefore, higher % of CO. One can also notice that at low power output, CO emission is less with petrodiesel as compare to B15 and B20 fuels. However, at higher power output, CO emission reduces drastically with increasing amount of methylester. This phenomenon can be explained from the fact that at higher temperature, part of methyl esters in B15 and B20 plays significant role for better combustion of fuel due to presence of built-in oxygen. Results show that B15 and B20 fuels of pongamia pinnata methylester gives better results as compare to B15 and B20 fuels of jatropha curcus methylester, which can be attributed to higher viscosity and specific gravity of jatropha curcus methylester as compare to pongamia pinnata methylester.

The emission of Hydrocarbon (HC) in ppm is shown in figure 6. It can be noticed that the HC emission has almost the same behavior as that of CO emission. This can be explained with the same reasoning including an additional fact of the absence of aromatic compound in methyl ester of pongamia pinnata oil. The absence of aromatic compound results in better combustion and therefore, less emission of HC. For most of the loading range the hydrocarbon emission with B15 and B20 fuels of jatropha curcus methylester is slightly higher as compare to B15 and B20 fuels of pongamia pinnata methylester.

4. FIGURES AND TABLES

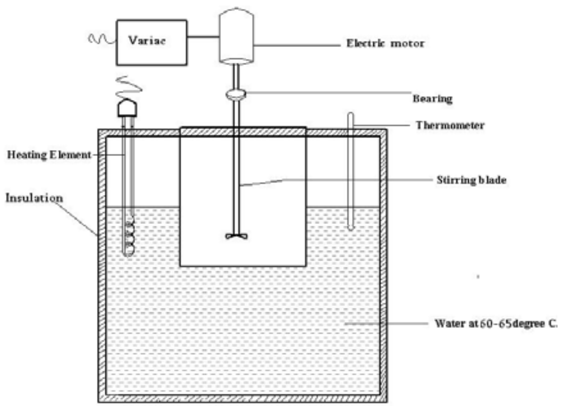

Fig. 1. Transesterification reactor.

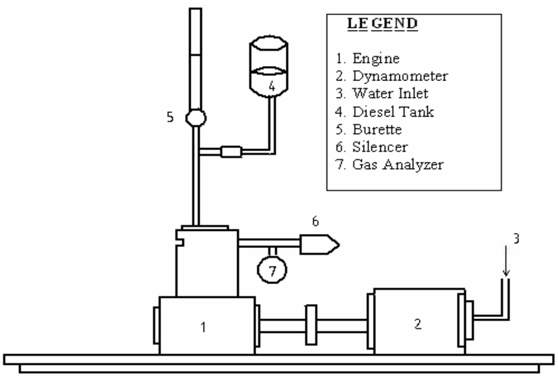

Fig. 2. Engine set-up.

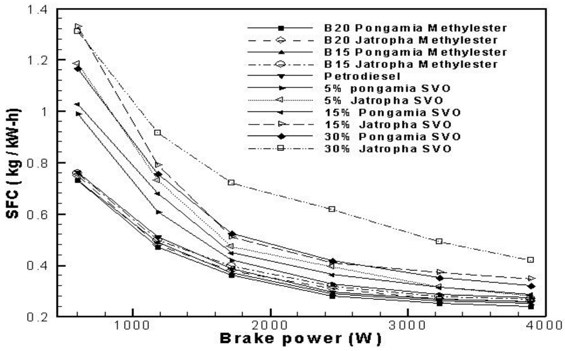

Fig. 3. Variation of specific fuel consumption with brake power for different fuels.

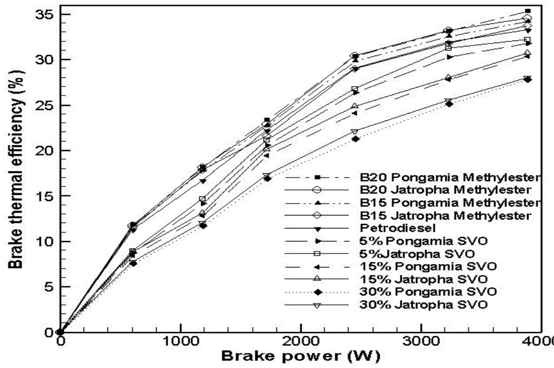

Fig. 4. Variation of brake thermal efficiency with brake power for different fuels.

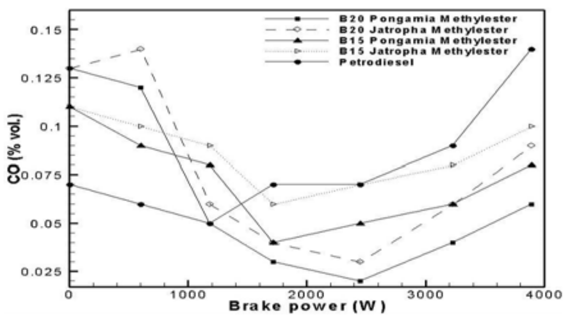

Fig. 5. Variation in CO emission with brake power.

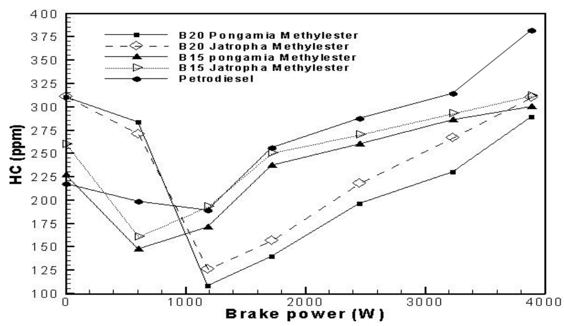

Fig. 6. Variation in HC emission with brake power.

Table 1. Variables of Transesterification Reaction

Reaction Variable	Pongamia Pinnata Oil	Jatropha Curcus Oil
Amount of NaOH catalyst (g/litre oil)	7.3	8.1
Ratio of Methyl alcohol/Oil (v/v%)	20	25
Reaction Temperature (^{0}C)	60	60
Stirring Speed (Range in RPM)	350-500	350-500

Table 2. Specifications of the Engine

Manufacturer	Kirloskar
Number of cylinder	1
Power	5 HP
Stroke	110 mm
Volume Displaced	553 cc
Compression Ratio	16:1
Loading device	Hydraulic dynamometer
Cooling system	Water Cooled

Table 3. Fatty Acid Distribution of Pongamia Pinnata and Jatropha Curcus SVO

Fatty Acid	Structure and molecular wt. of fatty acid	Fatty acid %by weight for Pongamia pinnata oil	Fatty acid %by weight for jatropha curcus oil
Capric	C10:0 (172)	--	0.1
Myristic	C14:0 (228)	--	0.1
Palmitic	C16:0 (256)	3.7-7.9	15.1
Stearic	C18:0 (284)	3.7-7.9	7.1
Arachidic	C20:0 (326)	--	0.2
Behenic	C22:0 (354)	--	0.2
Lignoceric	C24:0 (368)	1.1-3.5	--
Palmitoleic	C16:1 (254)	--	0.9
Oleic	C18:1 (282)	44.5-71.3	44.7
Linoleic	C18:2 (280)	10.8-18.3	31.4
Lenolenic	C18:3 (278)	--	0.2

Table 4. Physical and Chemical Properties of Different SVO, Methylesters and Certified Diesel

Properties	Pongamia pinnata oil	Methyl Ester of Pongamia pinnata Oil	Jatropha curcus oil	Methyl Ester of Jatropha curcus Oil	Petrodiesel
Viscosity (cSt) at 30 ^{0}C	15.2	5.75	52.76	6.7	2-5
Flash point, ^{0}C	205	110	240	126	35-50
Specific gravity at 30 ^{0}C	0.870	0.865	0.932	0.890	0.830-0.850
Calorific value, (kJ/kg)	37,255	36,540	39,774	38,584	42,000-46,000

Table 5. Physical and Chemical Properties of SVO-Petrodiesel Blends

SVO / Petrodiesel (%)	Properties of blends of SVO of Pongamia pinnata and Petrodiesel at 30 ^{0}C			Properties of blends of SVO of Jatropha curcus and Petrodiesel 30 ^{0}C		
	Viscosity (cSt)	Specific gravity	Calorific value(kJ/kg)	Viscosity (cSt)	Specific gravity	Calorific Value(kJ/kg)
5	3.23	0.832	41256	4.21	0.851	41624
15	4.83	0.840	41180	5.41	0.861	41415
20	5.41	0.843	41063	6.23	0.867	43289
25	6.15	0.846	40904	8.21	0.873	42731
30	7.42	0.851	40577	9.15	0.881	42413
50	12.3	0.872	39745	15.20	0.890	41162

Table 6. Comparison of Physical and Chemical Properties of B-15 and B-20 with Diesel

Sl. NO.	Properties	Petrodiesel	Jatropha curcus		Pongamia pinnata	
			B15	B20	B15	B20
1.	Density(g/cc at 15 ^{0}C)	0.820-0.870	0.862	0.868	0.849	0.857
2.	Kinematic viscosity (cSt at 40^{0}C)	2.0-5.0	3.67	3.68	3.29	3.73
3.	Total sulphur (% Wt.)	0.25 max /0.20 (defense)	0.034	0.023	0.036	0.036
4.	Pour point (^{0}C)	+6 max (Nov-Jan)	+4	+4	+6 max (Nov-Jan)	+6 max (Nov-Jan)
5.	Cetane Index	43 min	45	46	46	48
6.	Copper strip corrosion (3 hrs. at 100^{0}C)	Not worse than one	2-A	2-A	1-A	1-A
7.	Flash point (^{0}C)	35 min	61	66	59	65
8.	Calorific value (kJ/kg)	42000-46000	42,134	40,893	42201	41868
9.	ASTM Distillation (%v/v)					
	a) Recovered @ 350 ^{0}C	85 min	84	85	85	84
	b) Recovered @ 370 ^{0}C	95 min	90	91	94	93

4. CONCLUSIONS

An experimental investigation was conducted to assess the suitability of pongamia pinnata and jatropha curcus oil as petrodiesel substitute. From the experimental results following conclusions were made:

1. The straight vegetable oils of pongamia pinnata and jatropha curcus have higher specific gravity; higher viscosity and low volatility as compared to petrodiesel therefore straight vegetable oil can not be used directly in CI engine.
2. Significant reduction in viscosity was achieved by dilution of straight vegetable oils of pongamia pinnata and jatropha curcus with petrodiesel invarying proportions, which can be further reduced by heating the blends.
3. The blends of both pongamia pinnata oil and jatropha curcus oil with petrodiesel were compatible with diesel oil at higher load from the perspective of engine performance.
4. Physical and chemical properties test revealed that the pongamia pinnata methylester and jatropha curcus methylester (B15 and B20) have almost similar or better physical and chemical properties than the diesel oil, except the viscosity which is slightly higher than that of specified range for petrodiesel fuel. Both the blends are suitable as fuel for CI engines without any enginemodification.
5. Brake thermal efficiency and SFC results show improvement for B15 and B20. Thermal efficiency was found to be highest with B20.
6. Emission test shows reduction in % of CO and HC in exhaust gases for B15 and B20 fuels with respect to petrodiesel at medium and higher power output.

From all of the results it can be concluded that both pongamia pinnata and jatropha curcus oils have substantial prospects as a long-term substitutes for petrodiesel fuels. The 95% petrodiesel and 5% SVO of pongamia pinnata or jatropha curcus blend competed favorably with petrodiesel fuel and offer a reasonable substitute although blend of 85% diesel and 15% SVO of pongamia pinnata or jatropha curcus can also be used without any significant loss in engine output and without any major operational difficulties. The properties of the blends can be further improved to make use of higher percentage of SVO in the blend by preheating the blend. However long time engine running study is needed to established the suitability of SVO of pongamia pinnata or jatropha curcus-petrodiesel blend for CI engine. Finally it can be concluded that B15 and B20 could be used as alternative to petrodiesel fuel for operating the CI engine with less emission of CO and HC and better engine performance. However, further research is needed to check NO_X emission (which is one of the problems with most of the biodiesel), cold starting and carbon deposit on combustion chamber walls and
injectors tips in long time running of engine.

5. NOMENCLATURE

Bxx	xx% Biodiesel and (100-xx) % petrodiesel blend
Cl	Compression Ignition
CO	Carbon Monoxide
HC	Hydrocarbon
HP	Horse Power
NO_x	Nitrogen Oxides
RPM	Revolution Per Minute
SFC	Specific Fuel Consumption
SVO	Straight Vegetables Oil

6. ACKNOWLEDGEMENT

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