Biodiesel Production and Investigations on the Performance of Diesel Engine Using Jatropha Oil

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***Abstract*—Biodiesel has become a key source as a substitution fuel and is making its place as a key future renewable energy source. The current scenario for higher GHG emissions has persuaded the policy makers, investors and researchers to think more of the substitution of fossil fuels to save the planet. The environmental impacts and the agronomic properties of oils have not been thoroughly investigated. In this paper production of biodiesel from Jatropha oil and the emission analysis was made. Effect of alcohol was checked by varying the amount of catalyst. The higher amount of catalyst 1% w/w although gives rapid increase in the yield initially but after some time the yield decreases because of the hindrance in reaction due to emulsion formation. Various blends of biodiesel with fossil diesel were tested on an engine. The engine was run at 50% throttle opening for various samples with varying engine speed and power curves were drawn. The engine speed was varied from 1200 to 2500 rpm and the exhaust gas samples were analyzed for CO, NOx and HC emissions. Initial tests propose a nice start for studying engine performance. Although it describes the information for comparison of biodiesel with fossil diesel however, further working is required for the development of statistical models. These initial tests are promising in regard of emissions analysis and engine power.**

Key Words
Biodiesel, Jatropha, Diesel engine, Performance characteristics.

1. Introduction

Reservoirs of fossil fuels are depleting day by day as a result of which interest for alternate energy sources is becoming higher. Different alternate energy sources like wind energy, geothermal energy, solar energy, energy from biomass etc. are under focus these days. According to general belief hydrogen-fueled cars and buses cannot be expected to account for alternate energy vehicles before 2040 because of high cost of these demonstration projects. About 95% of the world market is based on compression ignition engine propulsion technologies consuming fossil fuels [1].

Research is still in progress for finding better ways of making less emissions emitting and fuel efficient engines for the reduction in emission of toxic gases while brining fuels. The research on internal combustion engine is of more than 150 years maturity. This can be used by finding alternate fuel which is renewable in nature, economically viable and is capable of burning in the internal combustion engine. Due to various challenges faced in the use of petroleum fuel, researchers are working for the development of other fuel sources [2].

Different renewable sources can be used as alternate energy sources. Among these different clean burning sources biodiesel seems to be more efficient because of its renewable and clean burning property. The burning of biodiesel generates very less toxic emissions. It can be used as pure biodiesel in the engine or by making different blends with the fossil diesel. These blends can be used either making a minute or no modification in a diesel engine. Biodegradability, less toxic emissions, easy to handle and environmental green fuel are the main advantages for using biodiesel as an alternate energy source [3].

Different plants like cottonseed, sun flower, canola, Pongamia pinnata etc. are being used for biodiesel production. The characteristics for these fuels have been well evaluated. However the effect of engine performance and emissions analysis for these fuels have not been yet evaluated thoroughly, hence there is thirst in this field to be worked out [4, 5].

Feedstock for biodiesel production can be classified into three main categories [6] which are vegetable oil; animal fat and used cooking oil. In addition to these categories algal oils are also being considered for biodiesel production because of their high oil content [7, 8, 9, 10, 11]. Currently more than 95% of biodiesel is being produced from edible sources [12]. Vegetable oils can be attractive raw materials for biodiesel production due to their renewable nature. They can also be mass propagated because of environment friendly nature [13, 14, 15]. In spite of all this there are serious observations on using edible oils for biodiesel production. Since the use of edible oils for biodiesel production may enhance the edible oil prices and hence it will disturb the whole biodiesel economy [16]. Large scale use of edible oils for biodiesel production may result imbalance to the supply and demand for food [17]. The vegetable oil is continuously running short because of its use in the biodiesel production. Fig. 1 shows the ending stock of vegetable oils because of the production of biodiesel from 1991 to 2005[18].

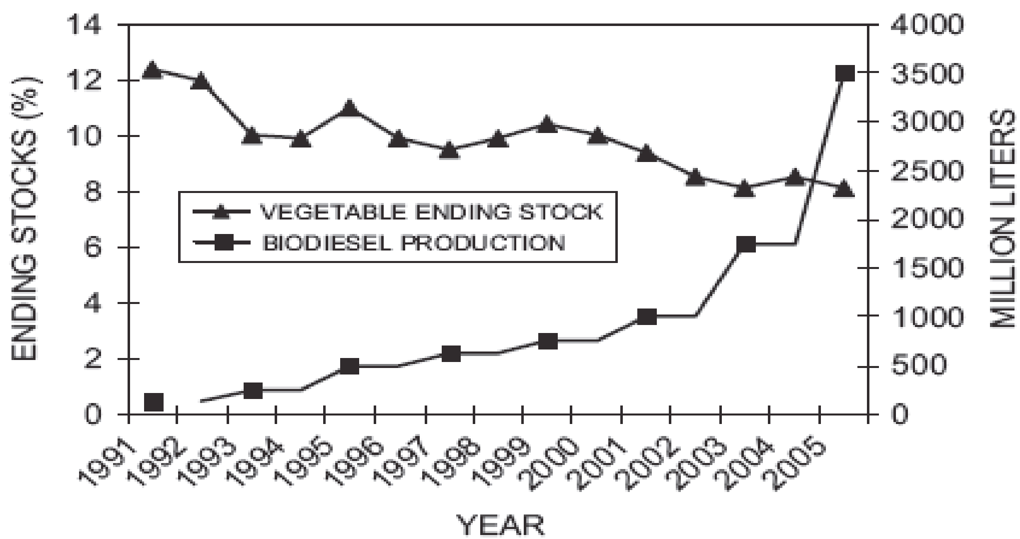

Fig. 1 Global vegetable oil ending stock and biodiesel production [18]

Almost 60-80% cost of biodiesel comes from raw materials. The cost of biodiesel will increase higher if edible oil is used as raw material. Also edible oil may become more expensive for human consumption if used for biodiesel production [14]. The animal fats are not feasible as they create problems during production process due to their property of becoming solid wax at room temperature [19]. Waste cooking oil is impure because it is a mixture of oils and fats. It also gets contaminated from several impurities during the cooking process [20].

In order to overcome these issues researchers have found production of biodiesel from non edible oils. Different non edible oils can be employed for biodiesel production like Jatropha curcas, Madhuca indica, Pongamia pinnata etc. [21, 22]. Oil crops with higher oil content are always preferred for biodiesel production. Table 1 shows the oil content in seeds and kernels for some non edible oil plants.

Table 1: Oil Content (%) for some non edible plants (23, 24)

Sr. No.	Type of Oil	Oil Content, %	
		Seed, wt%	Kernel wt%
1	Jatropha curcas	20-60	40-60
2	Castor	45-50	-
3	Pongamia Pinnata	25-50	30-50
4	Rubber Seed	40-60	40-50
5	Neem	20-30	25-45

Among these different non edible sources Jatropha curcas are the best because of their ease of use and sufficient oil content in the seed and kernel. Jatropha curcas can also grow almost anywhere on sandy, saline and waste soils and even under different climatic conditions. The properties of Jatropha are comparable to diesel like cetane number and calorific value [25]. The only issue with the use of Jatropha oil is its toxicity [26], it is also resistant to grow in waterlogged land. The drought-resistant property of Jatropha plant makes it a good applicant for eco-restoration in wastelands. The major groups of fatty acids in Jatropha oil are Stearic acid, Palmitic acid, oleic acid and Linoleic acid which can be easily converted to esters using alcohol and alkali.

Dhandapani et al. made extensive work on the compression ignition engine for its performance and emissions analysis. He used different blends of biodiesel from Jatropha oil with the fossil diesel like B20, B40, B60, B80 and B100. In their study they used port injection method and injected 5% ethanol into the intake manifold with the use of mechanical fuel injection pump. This may be taken as homogenous charge combustion after premixing with intake air. An improved combustion process was achieved with the assistance of this ethanol injection in diesel and biodiesel blends as well. They concluded that 3-5% of engine performance is increased with the addition of 5% ethanol in compression ignition engine along with blends of fossil diesel and Jatropha biodiesel blends. They also found that there is reduction in emissions for CO, smoke and total hydrocarbons up to 51%, 43% and 40% respectively. However at high engine load, 47% increase in NO_x emissions was noted [27].

Shah et al. reported different combustion parameters like maximum pressure, equivalent piston position relative to cylinder head in terms of crank angle and ignition delay / Lang angle. They described important source of fundamental approach for studying basic combustion parameters in the diesel engine [28]. Crookes studied the compression ignition engines running on different biofuels and examined their performance and emissions data. He used different biofuels including commercial seed oil and simulated biogas. He described brake power and specific fuel consumption along with emissions [29]. Different researchers made a comparison for engine performance and emission characteristics for different fuels. They reported their findings in terms of rate of fuel consumption, brake thermal efficiency, brake specific fuel consumption (bsfc) and emissions of CO, CO_2 and NO_x. They analyzed the effect of per oxidation process on engine performance and emissions [29, 30, 31, 32].

Among the different sources, biomass derived sources are preferred for alternate fuels because of their renewable nature and plentiful availability. In the transportation sector ethanol and methanol have been proved and are being used on large scales. In this study, emissions, performance and combustion characteristics of single cylinder, constant speed and direct ignition diesel engine were studied and results were compared with fossil diesel fuel operation. The initial results seem promising for engine power and emissions. Increase in thermal efficiency shows that this fuel is completely burnt as compared to fossil diesel (reduction of carbon-mono-oxide (CO) and hydrocarbon (HC) [3, 4]). Reduction of nitrogen oxide (NO_x) as a result of using blended biodiesel is reported [33, 34, 35, 36]. This needs to be investigated and confirmed for Jatropha.

2. Selection of Chemical Process

The transesterification reaction of Jatropha oil may be carried out using different catalysts. This depends upon the percentage of free fatty acids present in the oil. This is because of the formation of soap for higher FFA oils if alkaline catalyst is used. For such cases either enzyme catalyst or two step transesterification is practical. Transesterification of oil using various catalysts is shown in the figure 2 [37]:

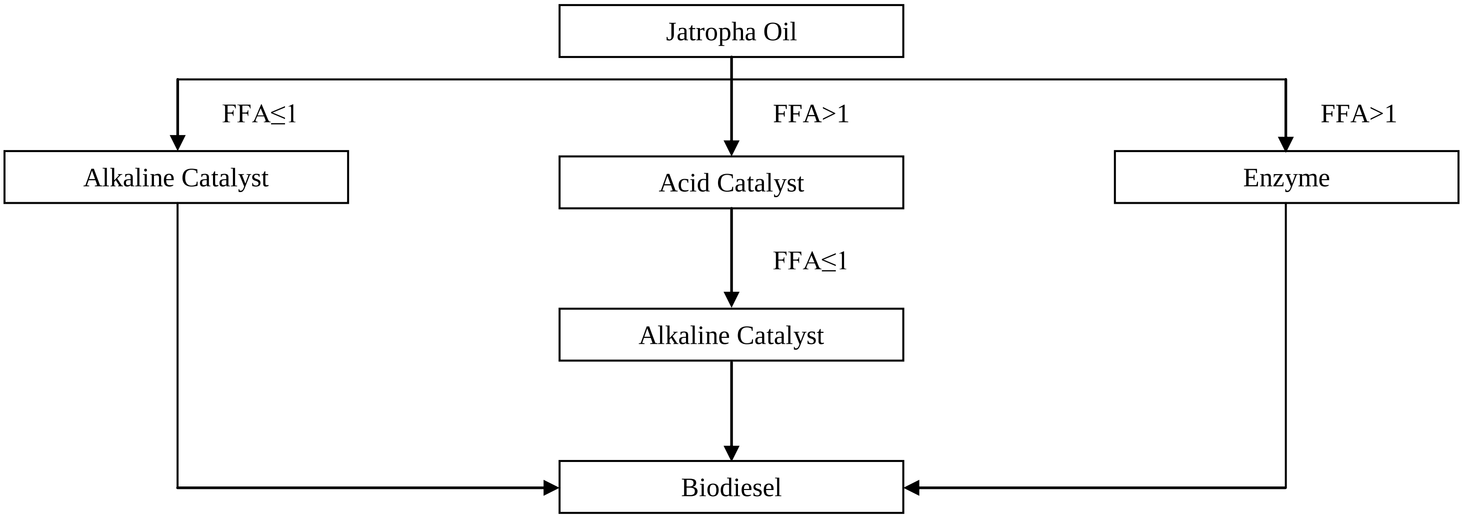

Fig. 2: catalytic production of biodiesel based on FFA content in Jatropha oil [37]

Mostly the common method used to prepare Fatty acid methyl acid (FAME)/Biodiesel is by esterification of Jatropha oil using alkaline catalyst and alcohol. The stoichiometry of reaction shows that 3 moles of alcohol react with 1 mole of triglyceride to yield three moles of esters and 1 mole of glycerol as shown in fig. 3. As the reaction is reversible, excess alcohol is used in practice to shift the equilibrium to the products side and result in higher ester yield.

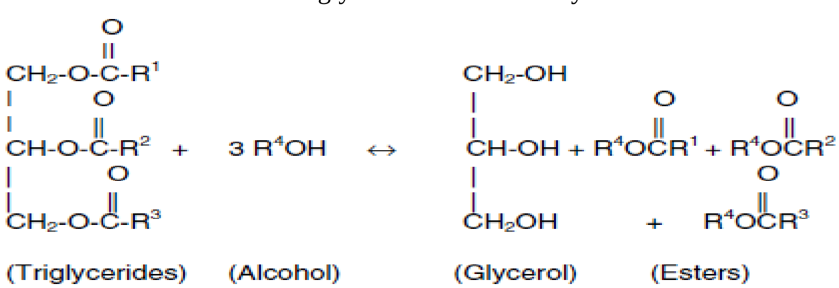

Fig. 3: Transesterification Reaction

Glycerol is recovered from as bottom product. Biodiesel is washed with water and stayed for sedimentation to avoid any impurities. A comparative study of the different catalyzed reactions for biodiesel production is given in table 2.

Table 2: Comparison of different catalyzed reactions

Properties	***Enzyme Catalyzed Reaction***	***Acid Catalyzed Reaction***	***Alkali Catalyzed Reaction***
Molar Ratio	4:1 Methanol to Jatropha	*30:1* Methanol to Jatropha	6:1 Methanol to Jatropha
Time & Temp.	Not available	69 hours & 65ºC	45-80 Min & 65ºC
Catalyst/enzyme	30 wt% of lipase	Sulphuric acid	NaOH or KOH
Conversion	85%	90%	93-98%
Advantages	Because of very less amount of organic solvents is used there is very little down-stream treatment.	The reaction is unresponsive to the Free Fatty Acid therefore no pretreatment is required	High yield in a relatively small reaction period.
Disadvantages	Rate of Reaction is very slow with high cost catalyst (Lipase)	Reactor size will be high as the methanol needed in high quantity and downstream treatment is required	Catalyst is low cost and easily available
Remarks	Not Recommended	Recommended for raw materials with higher fatty acids	Recommended (selected for our process)

3. Materials and Methods

3.1. Materials

Jatropha Curcas were taken from Alternate Energy Development Board (AEDB). Jatropha oil was obtained by grinding the seeds. Oil was filtered to remove the solid impurities. The main fatty acid compositions Jatropha oil are Palmitic acid (14.1%), oleic acid (40.1%) and linoleic acid (31.3%). Methanol (99.8%), potassium hydroxide and other chemicals were purchased from Dawn Scientific (Lahore, Pakistan). All the chemicals were of analytical grade.

3.2. Apparatus

A lab scale rig was developed for the transesterification. This consisted of reaction flask, water bath, hot plate along with r.p.m. controller for controlling the speed and condenser. The capacity of glass reactor is 500 ml which consists of three necks. Among these three necks; one was for thermometer, second for condenser and the third one was for the entrance of chemicals and reactants. For measuring the reaction temperature, a temperature indicator was used.

3.3. Pretreatment and Transesterification

200 ml of Jatropha oil was heated till 80^{o}C at atmospheric pressure to remove any moisture content. This was filtered under vacuum to eliminate the suspended impurities. The free fatty acid content of the oil was measured using titration method and was found less than1%. Potassium hydroxide was

introduced into the system to complete the transesterification reaction. The oil mixture along with 10-50ml amount of methanol was placed in a reaction flask containing reflux condenser and magnetic stirrer. Mixture was heated till 50°Cand stirred at a constant speed of 400 r.p.m. for 60 minutes until a straw yellow color came in mixture. The mixture was transferred to separating funnel and crude ester layer was removed as the top product from the bottom glycerol layer after giving a settling time of 8 hours. The upper biodiesel layer was washed with warm water to remove unreacted oil, impurities, excess methanol, catalyst residue and small amount of soap produced. The biodiesel was again kept in separating funnel to remove any other impurities present and clear biodiesel was achieved for subsequent analysis.

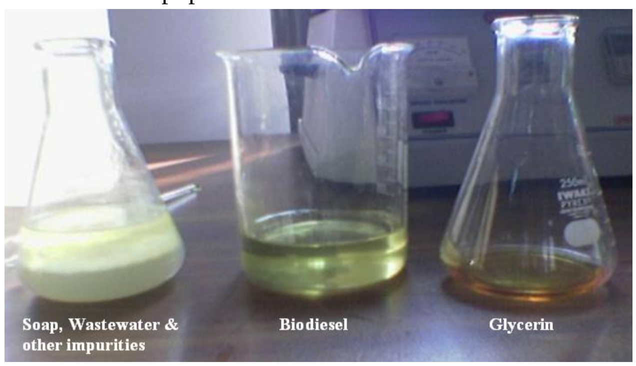

Fig. 4: Biodiesel Sample produced

4. Results & Discussions

4.1. Effect of Alcohol on % Yield

Alcohol to oil molar ratio is one of the most important factor that affects the yield of ester. According to stoichiometry of reaction 3 moles of alcohol and one mole of oil are required as shown in fig. 3. But in practice excess alcohol is required to shift the reaction to right side. Amount of alcohol was changed from 10 ml till 40 ml. the effect of methanol was observed keeping other parameters fixed. It was found that ester yield shows a rise with increase in the alcohol. The incremental gain in ester yield showed a decrease with the increase in methanol. Linear increase in conversion was achieved from 10-30 ml alcohol. After 30-40 ml there was no significant change in the conversion hence yield was same. This is shown in fig. 4.

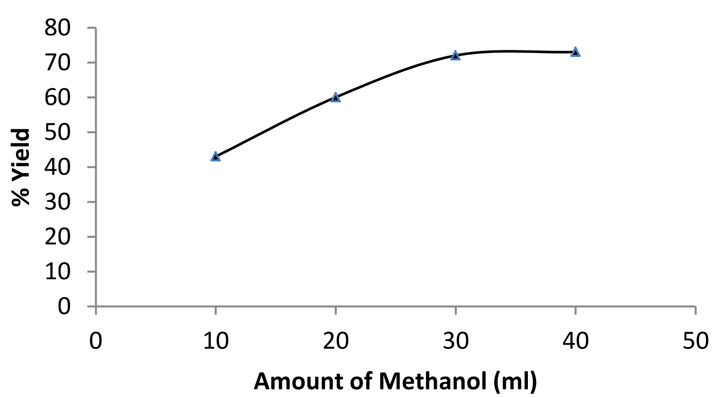

Fig. 4: Influence of methanol on % yield

Effect of Catalyst Amount

The amount of catalyst used in the reaction also affects the percentage yield of the process, though not to large extent. The catalyst amount was taken as 0.4 and 0.5 w/w % of oil. With the increase in the catalyst amount the yield was increased. It was observed that conversion was affected for both the cases and as a result of this yield was changed. At the start there was an increase in conversion which became constant for higher molar ratios of alcohol. For 1 gm KOH; there was more rapid rise in the conversion than for 0.8 gm KOH. But after 30 ml methanol there was decline in the conversion. Excess amount of catalyst started to form emulsion which increased the viscosity and started the formation of gels. This formation of emulsion hence blocked the reaction and as a result reduction in yield is apparent. This effect is shown in fig. 5.

Biodiesel produced was analyzed for use as fuel according to ASTM standards. The results obtained are given in table 3.

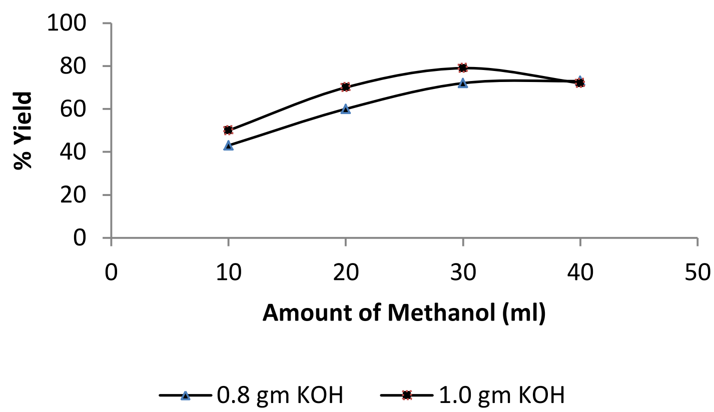

Fig. 5: Effect of catalyst on yield

Table 3: Biodiesel Test Result

Property	**Method**	**ASTM D6751-02**	**Jatropha Biodiesel**
Flash Point, closed cup	D 93	>130^{0}C	148.2^{0}C
Density	D 1298	-	0.878 (gm/cm^3)
Kinematic Viscosity, 40^{0}C	D 445	1.9-6.0 (mm^2/s)	4.6 (mm^2/s)
Total Sulfur	D 5453	<0.05 wt%	0.024%
Cetane Number	D 613	>47 min	50 min
Cloud Point	D 2500	No est. limit	-10^{0}C

The above test results shows the properties calculated are almost in the limits of ASTM standards. The Flash point of the Biodiesel is quite high as compare to diesel. Due to this it’s safer to store, handle and use than conventional diesel engine. As the viscosity of Biodiesel is higher than diesel; higher the viscosity, the greater the tendency of the fuel to cause problems but biodiesel blends improve such problems.

The quality and quantity of both Methanol (MeOH) and Potassium Hydroxide (KOH) should be checked very carefully as they directly affect the production rate of biodiesel. A large quantity of soap will be produced if we use mush quantity of KOH and the quality and quantity of biodiesel reduced. Temperature, agitation, exact quantity and quality of KOH and Methanol are key parameters for the best quality biodiesel production.

4.2. Engine Tests

The experimental setup was made using the existing facilities and equipments. These were modified according to the need and requirement for experimental work.

The biodiesel produced above was used for engine test in the form of different blends with petro diesel. The test was performed for each sample using hydra engine test bed. The hydra engine test bed is composed of single cylinder multi-fuel engine with changeable compression ratio. The rating of dynamometer incorporated with hydra engine test bed is 37kW continuous absorbing having maximum speed 6500 rev. /min using Thyristor drive control.

Both CAP 3200 gas analyzer and Dynomite gas analyzer can be used to analyze exhaust gas from internal combustion engine. Smoke meter was used to measure smoke from the diesel engine exhaust. In this study Dynomite gas analyzer was used to measure exhaust gas while vehicle is in running on roads.

Three blends of biodiesel A, B, C and a pure diesel sample were analyzed for emission behavior and following curves were achieved.

It was observed that exhaust CO decreased with engine speed for pure diesel. At the start there was higher percentage of exhaust CO for pure diesel. Using higher blends of biodiesel the exhaust CO decreased rapidly. At low speed the CO percentage for biodiesel was found lower as compared to fossil diesel as shown in fig. 6.

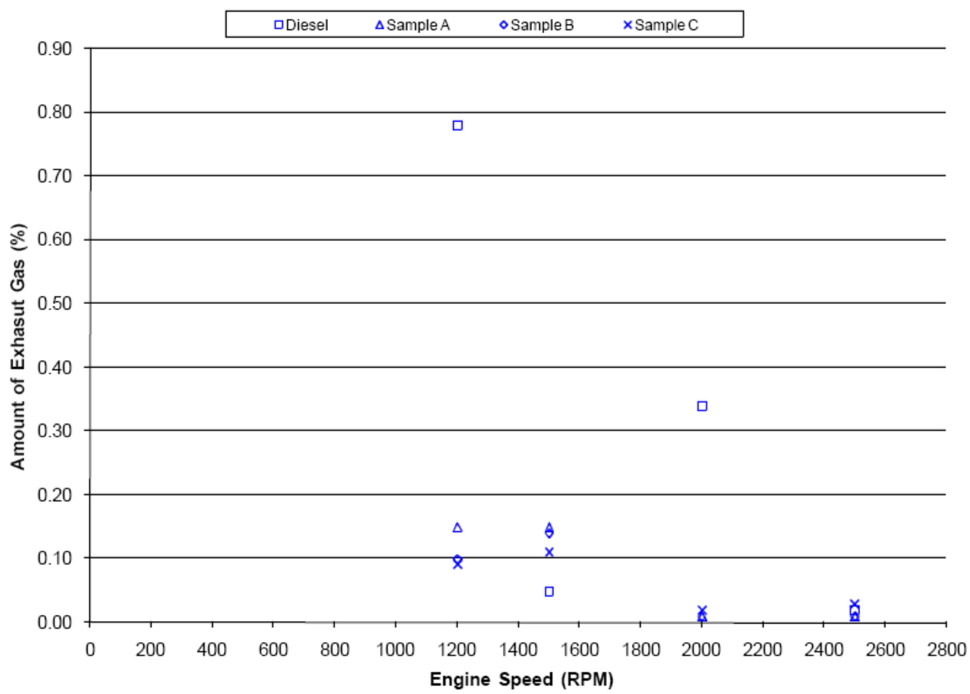

Fig. 6: Regulated Exhaust Gases-CO

The effect of regulated exhaust hydrocarbons with the change in speed is given in fig. 8. It was observed that at low speed 1200 RPM, the exhaust hydrocarbons were higher for fossil diesel and were the lowest for sample A. This behavior is shown in fig. 7.

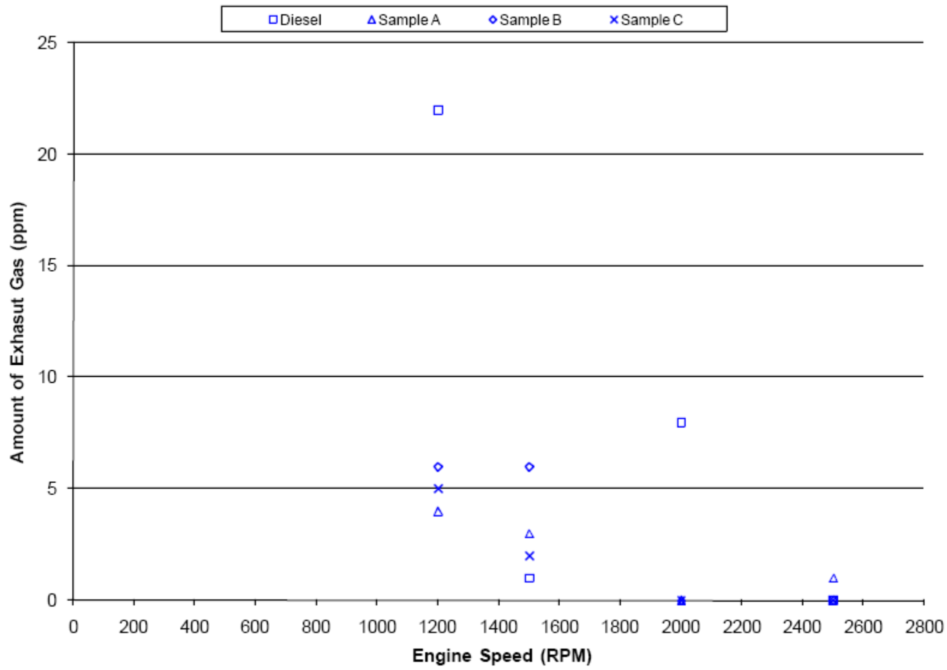

Fig. 7: Regulated Exhaust Gases-HC

The exhaust NO_x effect by changing the speed of engine is shown in fig. 9. It is observed that that emission of exhaust NO_x is lower at low speed but it increases as the speed increases. The lowest exhaust NOx is for sample C at 2500 RPM engine speed as shown in fig. 8.

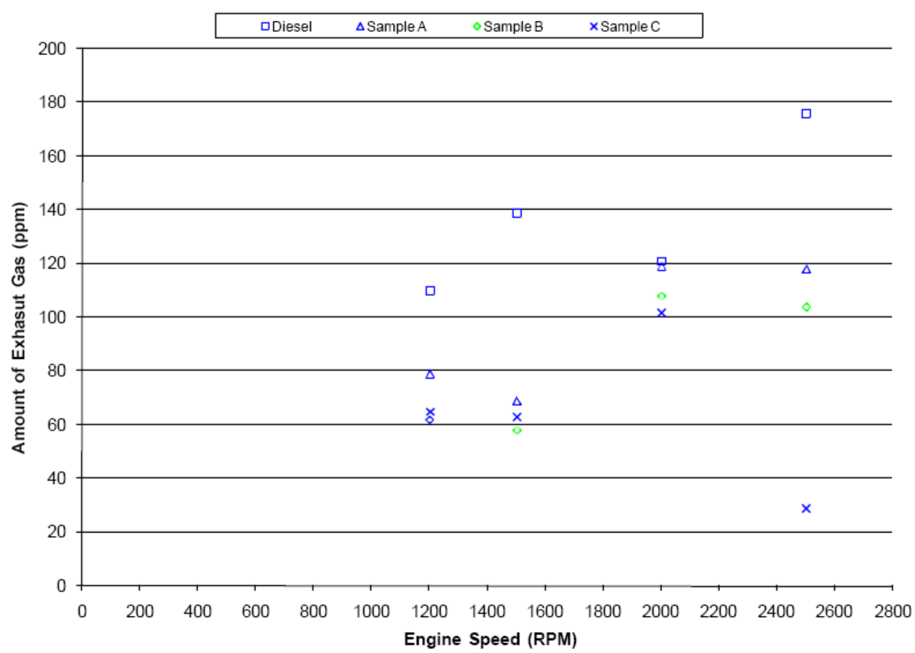

Fig. 9: Regulated Exhaust Gases-NO_x

Fig. 8: Regulated Exhaust Gases-NO_x

5. Conclusion:

This all-round study of biodiesel production from Jatropha oil has been carried out. Overall results confirm that Jatropha oil is a good source for transesterification. There was high exhaust when the only diesel was used but when the blends were used the exhaust gas was much less. This shows that different blends of biodiesel are good to use in the compression ignition engine without any engine modifications. This will also limit the release of toxic gases and use of alternate fuel.

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