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Performance and Emissions of CI Engine Fuelled With Preheated Vegetable Oil and Its Blends – A Review

P. P. Sonune, H. S. Farkade

Abstract—The research on alternative fuels for compression ignition engine has become essential due to depletion of petroleum products and its major contribution for pollutants, where vegetable oil promises best alternative fuel. Vegetable oils, due to their agricultural origin, are able to reduce net CO2 emissions to the atmosphere. But major disadvantage of vegetable oil is its viscosity, which is higher than that of mineral diesel. Hence neat vegetable oil does not give better performance. In the present paper preheated mahua oil and its blend with diesel has been introduced as an alternative fuel to overcome the above problems. Various fuel inlet temperatures, blending ratio, viscosity and various loading conditions are some of the parameters that need to be analyzed for better engine performance and reduced emissions. In this study, a review of research papers on various operating parameters have been prepared for better understanding of operating conditions and constrains for preheated mahua oil and its blends fuelled compression ignition engine. Only experimental study is not sufficient to understand the best combination of parameters improving the performance, hence analysis is carried out using mathematical relations available from the literature.

Index Terms— **Alternative Fuel, CI Engine, Elevated Temperature, Engine Emission, Vegetable Oil.**

I. INTRODUCTION

Nowadays due to limited resources, rapid depletion of fossil fuels and as pollutant resulting from these categories are massively expelled to ruin the healthy climate is demanding an urgent need of alternative fuels for meeting sustainable energy demand with minimum environmental impact. Diesel engines are used to power automobiles, locomotives, ships and irrigation pumps. It is also used widely to generate electric power. A lot of research is being carried out throughout the world to evaluate the performance, exhaust emission and combustion characteristics of the existing engines using several alternative fuels such as hydrogen, compressed natural gas, alcohols, liquefied petroleum gas, biogas, producer gas, biodiesels developed from vegetable oils. Using neat vegetable oils in diesel engines is not a new idea. Rudolf Diesel first used peanut oil as a fuel for demonstration of his newly developed compression ignition (CI) engine in year 1910 [11]. Certain edible oils such as palm, sunflower, rapeseed and cottonseed and some of the non-edible oils such as Karanja (Pongamia pinnata), mahua (Madhuca Indica), castor, neem (Azadiracta indica), rice bran, linseed, jatropha (Jatropha curcas) etc. were tested to their performance in diesel engine. Since straight vegetable oils are not suitable as fuels for diesel engines, they have to be modified to bring their combustion related properties closer to diesel. This fuel modification is mainly aimed at reducing the viscosity to eliminate flow or atomization related problem. The fuel injection system of new technology engines is sensitive to fuel viscosity changes. High viscosity of the vegetable oil leads to poor fuel atomization, which in turn may lead to poor combustion, ring sticking, injector chocking, injector deposits, and injector pump failure. Viscosity of the vegetable oils must be reduced in order to improve its engine performance. Different methods have been tried to use vegetable oils efficiently. Some of them are given below with brief explanation like

1) Heating
2) Transesterification with alcohols,
3) Blending with diesel or alcohol and
4) micro-emulsion [4].

Moreover, the vegetable oil has fixed oxygen in it which can enhance the combustion process. A preheating of vegetable oil increases the poor cold-flow properties and improves the atomization of fuel.

II. VEGETABLE OIL AS AN ALTERNATIVE FUEL

Vegetable oils mainly contain triglycerides (90% to 98%) and small amounts of mono and di-glycerides. Triglycerides contain three fatty acid molecules and a glycerol molecule. They contain significant amounts of oxygen. Commonly found fatty acids in vegetable oils are stearic, palmitic, oleic, linoleic and linolenic acid [4]. Due to the agricultural origin, they are able to reduce net CO_2 emissions. They have a reasonably high cetane number. The CO emission decreased with preheating due to the improvement in spray characteristics and better air fuel mixing. In principle, vegetable oil is carbon neutral. Vegetable oil is biodegradable, safe to store and transport due to high boiling point and does not cause environmental or health problems. However, the high viscosity and poor volatility of vegetable oil show difficulty in handling by the conventional fuel injection system. Transesterification and emulsification are found as effective methods for improving performance and reducing emissions of a diesel engine fuelled with vegetable oils. However, transesterification is a more expensive, time consuming and complex process due to the chemical and mechanical processes involved. Emulsions can be made by mixing water and surfactants with oil in a simple process. However, making stable emulsions with suitable surfactants is a difficult task. In addition to that use of emulsions in diesel engines results in inferior performance at part loads. Fuel preheating technique offers the advantage of easy conversion of the normal diesel engine to work on heavy fuels. It needs no modifications in the engine. Engine with fuel preheating has indeed in principle superior characteristics to that of normal fuel operation. The experimental result as shown in fig. 1 shows preheating of Karanja oil resulted in decreases in viscosity. At the temperature above 100°C the viscosity value reaches to ASTM limits from 35cSt [11]. Fig. 2 shows that general type of set up used for the preheating of vegetable oil. As the viscosity of these oils is more, their viscosity should be reduced in order to their use in CI engine. Preheating can be done by using heat of exhaust gases or by using thermostatic heating arrangement to tank. Fuel at elevated temperature injected in combustion chamber for better performance of engine as shown in Fig. Table 1 and 2 are shown in Appendix.

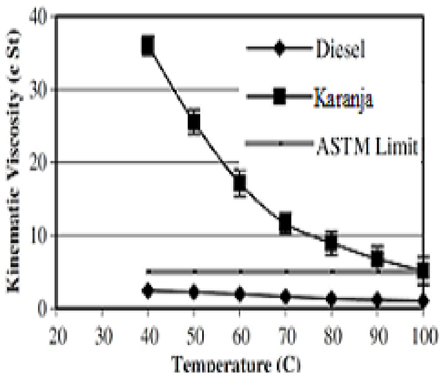

Fig 1: Effect of Temperature on Viscosity of Karanja Oil

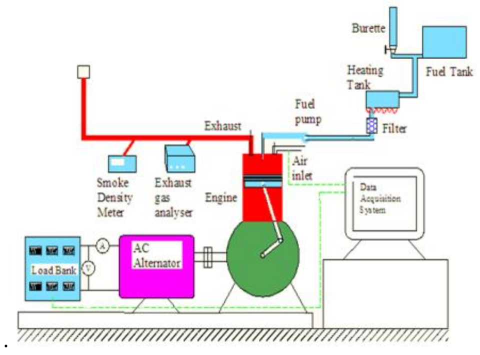

Fig 2: General Set Up for Preheating Of Vegetable Oil

Preheating is one of the simplest methods for using vegetable oil in CI engine. The CO emission decreased with preheating due to the improvement in spray characteristics and better air fuel mixing. Preheating can offer significant reduction in viscosity with improved performance and reduced emissions in a diesel engine fuelled with mahua oil. Mahua oil is of significance because of the great need for edible oil as food. However, literature shows limited analysis on the use of mahua oil in diesel engines. In India, mahua (Madhuca Indica) is one of the forest-based tree-borne non-edible oil. Mahua oil has an estimated annual production potential of 181 thousand tons in India [12]. Hence it finds attraction to use as fuel in diesel engines. The properties of vegetable oils summarized in table no. 1 are minimum and maximum values [3, 8, 9, 11 and 13]. It is found that the fuel properties of several vegetable oils are widely different according to climate, soil, variety, etc. Compared to diesel fuel, higher density and kinematics viscosity, lower cetane number and calorific value of vegetable oils are noted. Table no. 2 shows the fuel properties of several methyl esters obtained from vegetable oils and American standards. The physical properties of biodiesel fuel depend on the structure and type of the fatty acid esters present [9, 10, 11, 12 and 13].

III. PERFORMANCE CHARACTERISTICS

The various performance parameters such as brake thermal efficiency, brake power, torque, and brake Specific fuel consumption under study is summarized as follows.

A. Brake Thermal Efficiency

The brake thermal efficiency of CI engine is lower than that of the corresponding diesel fuel at all the engine speed. Thermal efficiency of preheated Jatropha oil was found slightly lower than diesel. The possible reason may be higher fuel viscosity. Higher fuel viscosity results in poor atomization and larger fuel droplets followed by inadequate mixing of vegetable oil droplets and heated air. However, Thermal efficiency for preheated Jatropha oil was higher than unheated Jatropha oil. The reason for this behavior may be improved fuel atomization because of reduced fuel viscosity [4]. Fig 3 gives the percentage change of brake thermal efficiency with the engine speed. An experimental study on preheated COME proved that for each heated COME usually yields higher BTE compared to diesel fuel. The energy of the COME entering the engine is considerably low due to its lower heating value, which results in higher BTE for COME operations compared to diesel fuel. The BTE with the COME were on averages of 3–14% higher than that of diesel fuel [9].

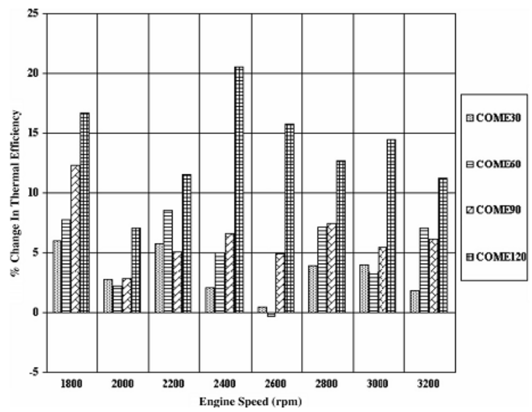

Fig 3: Changes in the Brake Thermal Efficiency with Engine Speed

B. Brake Specific Fuel Consumption

Brake-specific fuel consumption is the ratio between mass fuel consumption and brake effective power, for a given fuel, it is inversely proportional to thermal efficiency. The fuel consumption rates for the test fuels decreased when the fuel (RRO and diesel) was preheated, the mass fuel consumption decreased around 5.14%, 7.25% and 5.18% for diesel, O20 and O50, respectively. However, in all test the mass fuel consumption rates for blends were higher than that of DF. The loss of heating value of RRO is compensated with higher fuel consumption to maintain the similar trend of power. Thus, the aforementioned increase in fuel consumption was not caused by any loss in thermal efficiency but rather by the reduced heating value of oil [5]. An experimental study on mahua oil methyl ester-diesel blends shows that the BSFC was found to increase with increasing proportion of biodiesel in the fuel blends with diesel, whereas it decreases sharply with increase in load for all fuels. The main reason for this could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads [12]. For preheated neat Karanja oil fuel, brake specific fuel consumption has high value at low speed but decreases as the speed increases, and then it reaches the value to that of a diesel fuel operation as shown in above fig 4. For all fuel inlet temperatures, the specific fuel consumption varies with increasing speed. The brake specific fuel consumption becomes closer at the maximum speed for both neat Karanja oil fuel and diesel fuel within the speed range 1500 to 4000 rpm [11].

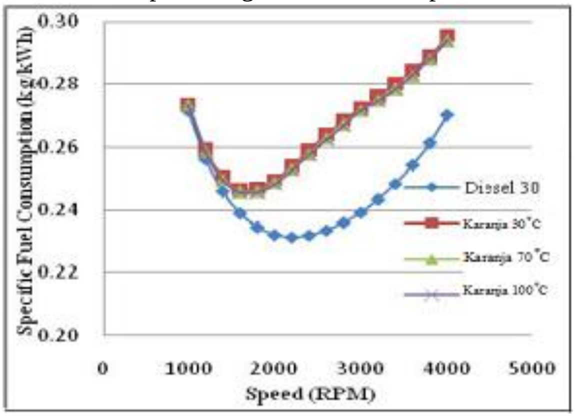

Fig 4: Variation of Specific Fuel Consumption with Speed at Elevated Fuel Inlet Temperature

C. Brake Power and Torque

An experimental study on preheating raw rapeseed oil shows that the torque was almost not affected with preheating. As expected there is slight increase in torque with the increase in temperature. The average torque differences with preheating were 1.2%, 0.8% and 0.14% for DF, O20 and O50, respectively. Also the output power of DF is higher than O20 and O50 for all engine operations either with preheating or not, as the DF fuel has higher caloric value than those of both O20 and O50 blends [5]. Study on with and without preheating of cotton seed oil methyl ester (COME), shows that the maximum brake power values were obtained in the case of diesel fuel operation. The minimum and maximum power obtained with COME90 and COME120 was on averages of 1.92% and 7.59% lower than that with diesel fuel. A moderate change in the break power is observed for the cases from COME30 to COME90 due to heating [9].

D. Exhaust Gas Temperature

Experimental study of preheated Jatropha oil shows the variation of exhaust gas temperature for diesel and Jatropha oil (unheated and preheated). Result shows that the exhaust gas temperature increases with increase in brake power for each fuel. Highest value of exhaust gas temperature of 389 °C was observed with the PJO100 and lowest was achieved with JO (Jatropha oil) of about 345°C whereas the corresponding value with diesel was found to be 359°C [4]. Figure 5 shows the effect of engine speed on EGT. The exhaust gas temperature for O50 showed a fairly higher trend when compared with O20and DF, as RRO contains constituents of poor volatility, which burn only during the late combustion phase. It can be mainly due to delayed combustion [5]. An experiment study on mahua oil methyl ester proved that the EGT increased with increase in engine loading for all the fuel tested. The mean temperature

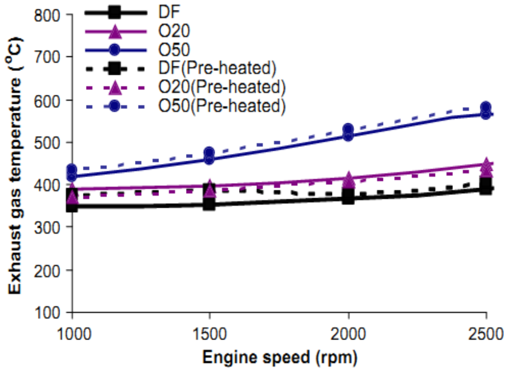

Fig 5: The Exhaust Gas Temperature Variation with Preheated Diesel Fuel, O50 Mixtures O20 and O50 Mixtures

Increased linearly from 180°C at no load to425°C at full load condition with an average increase of 15% with every 25% increase in load. The mean EGT of B20, B40, B60 and B100 were 7%, 9% 10% and 12%, respectively, higher than the mean EGT of diesel [12].Study on MOEE shows that the exhaust gas temperature increased with BMEP for both diesel and MOEE. The highest value of exhaust gas temperature of 439°C was observed for MOEE, whereas for diesel it was found to be 249°C only. The higher exhaust gas temperature may be because of better combustion of PMOEE [14].

IV. EMISSION CHARACTERISTICS

Due to agricultural origin, vegetable oils are able to reduce net CO_2 emissions. It is proved that blend of Karanja oil up to 20% gives lower CO emissions than diesel. Blends higher than 20% showed higher CO emissions compared to mineral diesel at high engine load [1]. Due to the high viscosity, the air-fuel mixing process is affected by the difficulty in atomization and vaporization of Karanja oil and blends. The resulting locally rich mixtures cause more incomplete combustion products such as CO, HC and PM because of lack of oxygen. Higher the engine load, richer air-fuel mixture is burned, and thus more CO is produced.

A. Un-burnt hydrocarbon (HC) emission

For preheated jatropha oil HC emissions are lower at partial load, but tend to increase at higher loads for all fuels. This is due to lack of oxygen resulting from engine operation at higher equivalence ratio. Preheated jatropha oil produced lower HC emissions compared to Jatropha oil but higher than diesel fuel [4]. An experimental study on mahua oil methyl ester shows decrease in the HC emission level with blends of methyl ester of mahua oil as compared to pure diesel operation as shown in fig. There is a reduction from 74 ppm to 50 ppm at the maximum power output of 96 kW. These reductions indicate that more complete combustion of the fuel takes place and thus, HC level decreases significantly [12]. An experimental study on various CR and IT for biodiesel (linseed oil) blended diesel shows that increased CR reduced the HC emissions by 4.39% and reduced CR increased them by 35.50% for B20 when compared with ORG CR. The increased IT reduced the HC emissions by 13.54% and the decreased IT raised it by 1.21% compared to results of ORG IT for B5 [2].

B. Nitrogen Oxides (Nox) Emission

An experimental study on preheating raw rapeseed oil shows that the NOx emission increases with the increase in the fuel inlet temperature shown in fig 6. The average NOx emission was increased by 19%, 18% and 15% using DF, O20 and O50, respectively. The increase in NOx with preheating may be attributed to the increase in the combustion gas temperature with an increase in fuel inlet temperature [5]. The increase in NOx emissions with preheated COME may due to various reasons, such as improved fuel spray characteristics, better combustion of biodiesel due to its high oxygen content and higher temperatures in the cylinder as a result of preheating. The NOx emission for COME increases approximately 11.21-39.1% as compared to diesel fuel. The maximum increase in NOx emissions were obtained in the case of COME 90 [9].

Experimental work on preheated neat karanja oil revealed that the NOx emission increases with the increase in engine speed and reaches its maximum value at a speed of 3500 rpm and further goes on decreasing and there is no significant change with increased fuel inlet temperature. To reduce NOx emission, the temperature in the cylinder should be reduced [11].

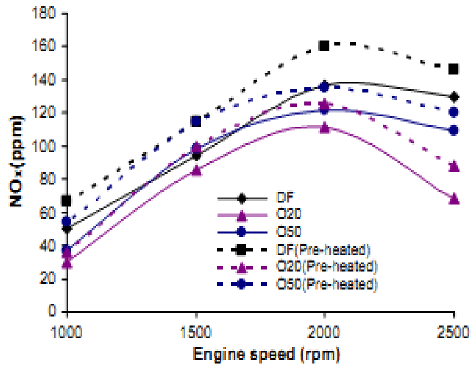

Fig 6: The Effect of Preheating On Nox Emissions of RRO Blends and DF.

C. Carbon Mono-Oxide (CO) and CO_2 Emissions

Preheating of raw rapeseed oil shows the effect on CO emission. CO emission of RRO blends was not sufficiently lower than those of DF. The high viscosity of the RRO causes poor spray characteristics, forming locally rich air-fuel mixtures during the combustion process thus leading to CO formation. CO emission was decreased for all test fuels with preheating due to the improvement in spray characteristics and better air-fuel mixing. When preheated, CO emissions were decreased by 20.59%, 16.67% and 25.86% for DF, O20 and O50, respectively [5]. Preheated Jatropha oil shows marginal increase in CO_2 emission compared to diesel fuel. Unheated fuel operation gives higher CO_2 emissions compared to preheated fuels. At lower loads, CO emissions were nearly similar but at higher loads, CO emissions were higher for Jatropha oil compared to that of diesel. This is possibly a result of poor spray atomization and non-uniform mixture formation with Jatropha oil. For preheated jatropha oil blends CO_2 emissions for lower blend concentrations were close to diesel [4].

D. Smoke Emission

Smoke emission using Jatropha oil was greater than that of diesel. Heating the Jatropha oil result in lower smoke emission compared to unheated oil but it is still higher than diesel [4].

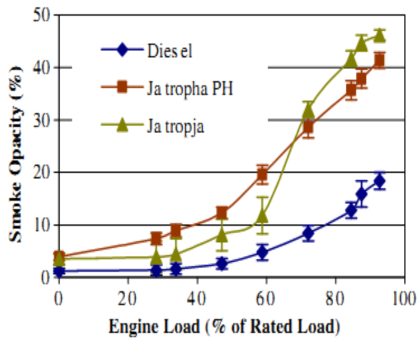

Fig 7: Smoke Opacity of Preheated Jatropha Oil with Load.

For preheated RRO blends the smoke emissions decrease with the preheating. The most sufficient decreases were observed for rapeseed oil blends. The lowest smoke densities were obtained with preheated O50 and O20. The average smoke densities were decreased by 9.4%, 20.1% and 26.3% for DF, O20 andO50, respectively. This may be due to the reduction in viscosity and subsequent improvement in spray [5].

V. CONCLUSION

Based on the reviewed paper for the performance and emissions of preheated vegetable oil, it is concluded that the preheated vegetable oil represents a good alternative fuel for diesel and therefore must be taken into consideration in the future for transport purpose. Thus a number of conclusions are drawn from the studies of various experimental results. Thermal efficiency, and exhaust temperature increases while other performance parameter like BSFC is decreased for preheated vegetable oil fuelled engine compared to unheated vegetable oil. Except NOx the other emission characteristics such as HC, CO and CO_2 are decreased due to preheating of the fuel. Preheating by exhaust gases could be one feasible solution to overcome the problem of high viscosity which is being the major cause of many problems identified by several researchers. Straight vegetable oils have the potential to reduce NOx emissions which is one of the major concerns of the world today. Thus straight vegetables and their blends fuelled engines have a great capability to be comparable to that of diesel fuel. To reach the optimum performance further research can be carried out in this field.

VI. NOMENCLTURE

Abbreviation	Meaning
BSFC	Brake specific fuel consumption
CI	Compression Ignition
CO	Carbon Monoxide
CO_2	Carbon dioxide
COME	Cotton seed oil methyl ester
CR	Compression ratio
DF	Diesel fuel
EGT	Exhaust gas temperature
HC	Hydrocarbon
IP	Injection pressure
IT	Injection timing
JOME	Jatropha oil methyl ester
KOME	Karanja oil methyl ester
LHV	Lower heating value
MME	Mahua oil methyl ester
NOx	Nitrogen oxide
O20	20% Rapeseed oil with diesel
O50	50% Rapeseed oil with diesel
RRO	Raw rapeseed oil

VII. ACKNOWLEDGMENT

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APPENDIX

Table 1: Thermodynamic Properties of Diesel and Vegetable Oil

Properties	Diesel	Karanja Oil	Mahua oil	Jatropha oil	Cottonseed oil	Linseed oil	Rapeseed oil
Density (kg/m3)	840	938	924	917	909.5	923.6	911.5
Calorific value (kJ/kg)	42490	38879	37,614	39071	39500	39300	39700
Cetane number	45	28.93	40	23	41.8	34.6	41.3
Viscosity@40 ^oC	3.05	35.98	39.45	35.98	33.5	27.2	37
Oil content wt%	-	25-50	35-50	20-60	17-25	35-45	25-35
Flash point ^oC	85	237	276	229	23	241	246
Pour point ^oC	-4	3	14	4	-4	-15	-31.7

Table 2: Thermodynamic Properties of Biodiesel

Properties	JOME	KOME	M0ME	COME	LOME	ASTM
Density (kg/m3)	862-886	865-898	828-865	872-885	874-920	870-900
Calorific value(MJ/kg)	37.2-43	36-42.1	36.8-43	40.1-40.8	37.5-42.2	-
Cetane number	43-59	36-61	47-51	45-60	48-59	47 min
Viscosity@40 ^oC	3-5.65	3.8-9.6	2.7-6.2	3.6-5.9	3.36-8.9	1.9-6
Flash point ^oC	180-280	110-187	5-208	70-200	161-181	>130
Pour point ^oC	2-6	-6-10	1-6	-15-6	-18-14	-15 - 10