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Experimental Investigations on the Use of Preheated Neat Karanja Oil as Fuel in a Compression Ignition Engine

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***Abstract*—**The concerns about clean environment and high oil prices driving forces for the research on alternative fuels. The research efforts directed towards improving the performance of C.I engines using vegetable oil as fuel. The paper deals results of performance of a four stroke, single cylinder C.I. engine by preheated neat Karanja oil is done from 30°C to 100°C. The performance of the engine was studied for a speed range between 1500 to 4000 rpm, with the engine operated under full load conditions. The performance parameters considered for comparing are brake specific fuel consumption, thermal efficiency, brake power, Nox emission of the engine. The engine offers lower thermal efficiency when it is powered by preheated neat Karanja oil at higher speed. The power developed and Nox emission increase with the increase in the fuel inlet temperature and the specific fuel consumption is higher than diesel fuel operation at all elevated fuel inlet temperature.

***Keywords*—**Alternative fuel, Compression ignition engine, neat Karanja oil, preheating.

I. Introduction

NOWADAYS, due to limited resources of fossil fuels, rising crude oil prices and the increasing concerns for environment problems. Using straight 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.Certain edible oils such as palm, sunflower, rapeseed and cottonseed can be used in diesel engines. For longer life of the engines these oils cannot be used straightway. These oils are not cost effective to be used as an alternate fuel in diesel engines at present. Some of the non-edible oils such as Karanja (*Pongamia pinnata*), mahua, castor, neem (*Azadiracta indica*), rice bran, linseed, jatropha (*Jatropha curcas*) etc. can be used in diesel engines after some chemical treatment. [1]-[3]. The viscosity and volatility of these vegetable oils is higher, and these can be brought down by a process known as 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. [4]

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 [5]. 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 [6]. Past investigations showed that preheated vegetable oils in diesel engines resulted in improved brake thermal efficiency and reduced smoke, particulate emissions [6]-[13]. However, literature shows limited analysis on the use of Karanja oil in diesel engines. In India, Karanja (Pongamia Pinnata) is one of the forest-based tree-borne non-edible oil with a production potential of 135,000 metric tons per year in India. It is one of the few nitrogen fixing trees (NFTs), which produce seeds containing 30–45% oil [2]. Hence it finds attraction to use as fuel in diesel engines. The properties of vegetable oil like density, calorific value, etc. are very close to diesel (see Table I).

TABLE I
PROPERTIES OF DIESEL AND VEGETABLE OIL [1]-[7]

Properties	Diesel	Vegetable Oil
Density (kg/m3)	840	900-966
Calorific value (kJ/kg)	42,490	30,000-42,000
Cetane number	45	40-56
Viscosity (!10K6m2/s)@30 °C	2.59	25-60
Carbon (%)	84–87	77.6
Hydrogen (%)	33–16	11.6
Oxygen (%)	00 12	10.8
Sulphur (%)	0.29	0.0

Moreover, the vegetable oil has fixed oxygen in it which can enhance the combustion process. However, the high viscosity and poor volatility of vegetable oil show difficulty in handling by the conventional fuel injection system. Preheating can offer significant reduction in viscosity with improved performance and reduced emissions in a diesel engine fuelled with neat Karanja oil.

In this work, effect of fuel preheating using Karanja oil as fuel in a diesel engine is investigated. Experiments are carried out at the rated speed of 1500 rev/min with under full load conditions. A separate heater arrangement is made to preheat

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the neat karanja oil. The fat is heated to 30, 70 and 100 ^oC. Experiments are conducted at all temperatures Performance, emissions and combustion parameters are analyzed and compared with neat diesel.

II. Experimental Setup And Experimental Procedure

A single cylinder 4-stroke air-cooled diesel engine developing a power output of 3.7 kW is used for the work. Engine specification is given (see Table II). A rope brake dynamometer is used for loading the engine. Computerized diesel engine is observation at different fuel inlet temperatures and up to the maximum value of 120^{o}C. It is also used to determine the temperature, pressure and heat released or transferred at each stroke or crank angle and exhaust analyzer is used for measuring Nox. The parameters related to the performance of the engine, which were evaluated, are: specific fuel consumption, the thermal efficiency, brake power and Nox emissions. These parameters were evaluated for each fuel inlet temperature and at different engine speed.

TABLE II
Engine Specification

Item	Technical Data
Model	VRC 1
Make	COMET
Rated BHP/kw	5.0/3.7
Bore x Strok (mm)	80.0/110.0
Swept volume (cc)	553
Compression Ratio	17.5:1
Method of cooling	Air
Bearing type	Bush
Sp.fuel consumption Gm/kwhr	251
Lubrication system	Plunger pump
Crank shaft height (mm)	203

Experiments were performed with diesel fuel and neat Karanja oil preheated up to three different temperatures, namely 30, 70 and 100 ^oC. Another fuel tank used for preheating the Karanja oil. A separate heater arrangement is made to preheat the Karanja oil before it is injected into the engine. A resistance controlled by a thermostat was installed around a fuel reservoir. The thermostat was used for keeping the temperature of the Karanja oil in the reservoir at the required temperatures. The parameters related to the performance of the engine, which were evaluated, are: specific fuel consumption, the thermal efficiency, brake power and NOx emissions. These parameters were evaluated for each fuel inlet temperature and at different engine speed. Experiments are initially carried out on the engine using diesel as the fuel in order to provide base line data. The properties of the diesel fuel and neat Karanja oil are cited in (see Table III).

As expectedly, the specific gravity and kinematic viscosity of the Karanja oil gradually decrease with the preheating temperature. It is seen that the kinematic viscosity is 29.65 cSt at 30 ^{o}C, 10.23 cSt at 70 ^{o}C and decreases gradually to 5.23 cSt at 100 ^{o}C. Additionally, the density decreases from 938 kg/m^3 at 30 ^{o}C, 870 kg/m^3 at 70 ^oC and 850.2 kg/m^3 at 100 ^oC.

TABLE III
Properties of Mineral Diesel And Karanja Oil

Property	Mineral diesel	Karanja oil
Density(Kg/M^3)	840	938
Kinematic viscosity at 30^{o}c(Cst)	2.68	29.65
Specific Gravity At 30^{o}c	0.835	0.912
Cloud Point (^{O} c)	5	7
Pour Point (^{O} c)	5	3
Flash Point (^{O} c)	71	237
Fire Point (C))	103	253
Calorific Value (MJ/Kg)	45.343	38.879
Carbon (%, W/W)	80.33	76.11
Hydrogen (%, W/W)	12.36	10.52
Nitrogen (%, W/W)	1.76	0
Oxygen (%, W/W)	1.19	11.06
Sulfur (%, W/W)	0.25	0
Cetane Number	46	28.93

III. Results And Discussion

A. Fuel Inlet Temperature

The test results show the effect of increasing fuel inlet temperature on the viscosity of neat Karanja oil and its performance in a single cylinder unmodified diesel engine. The fuel inlet temperature was the only parameter that was changed and the shift in engine performance is attributed to these temperature changes. The flow of neat Karanja oil becomes a problem as the temperature drops down Selection of fuel inlet temperature of 100^{o}C was based on the laboratory test results of viscosity-temperature and density-temperature relationships shown in Fig. 1 & 2. The test results showed that heating neat Karanja oil to a temperature above 100^{o}C brings its physical properties close to mineral diesel.

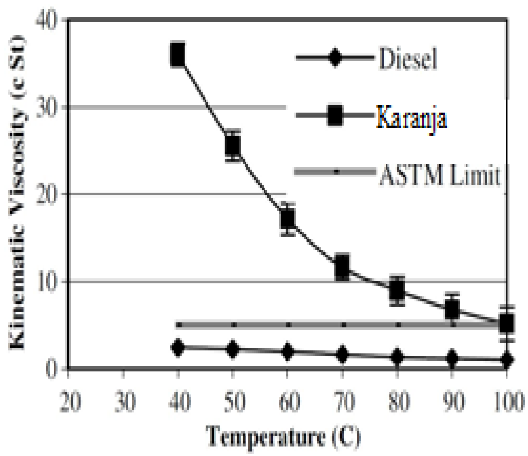

Fig. 1. Effect of temperature on viscosity of Karanja oil.

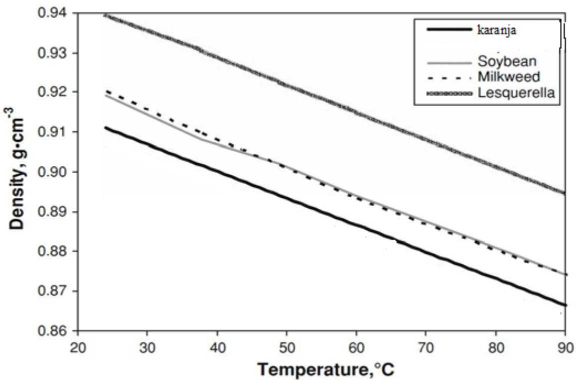

Fig. 2. Density comparisons of Karanja oil with rapeseed, soybean, milkweed, and lesquerella oil

B. Engine Performance

The results obtained under full engine load conditions, are presented in Fig. 1 through fig. 4, with variation in speed for various fuel inlet temperatures. The variation of Brake-specific fuel consumption, Thermal efficiency, effective engine power and Nox emissions with engine speed is shown in Fig. 3-6, respectively. Brake-specific fuel consumption and Nox Emissions are high at low engine speed but when engine speed is increased, the Nox emissions are higher and Brake-specific fuel consumption is quite similar to that of diesel operation. From Fig. 3, it can also be observed that when the power reaches its maximum value, then it decreases. The engine power and thermal efficiency are generally slightly lower than the corresponding values using ordinary diesel fuel.

The thermo physical and chemical properties of the Karanja oil fuel such as low heating value and high viscosity as compared to diesel fuel and improper air and karanja oil fuel mixture cause inefficient combustion due to improper atomization of vegetable oil fuel.

C. Brake-Specific Fuel Consumption

Brake-specific fuel consumption (bsfc) is the ratio between mass fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to thermal efficiency. The results for the variation in the brake specific fuel consumption (bsfc) with increasing fuel inlet temperature on the engine at various speed range studied are presented in Fig. 3. For all fuel inlet temperatures, the specific fuel consumption varies with increasing speed. For 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. The brake specific fuel consumption (bsfc) becomes equal at the maximum speed for both neat Karanja oil fuel and diesel fuel (within the speed range studied).

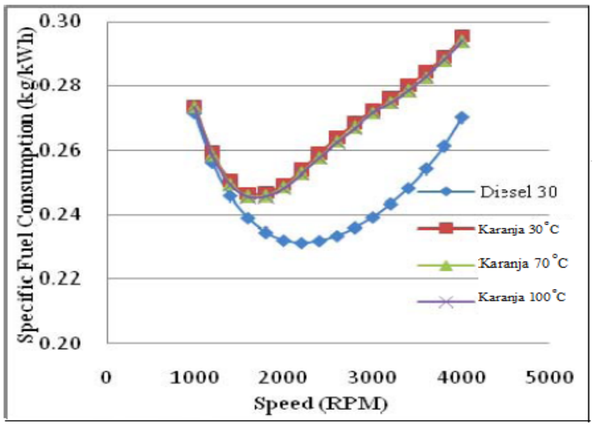

Fig. 3. Variation of specific fuel consumption with Speed at elevated fuel inlet temperatures

D. Thermal Efficiency

Thermal efficiency is the ratio between the power output and the energy introduced through fuel injection, the latter being the product of the injected fuel mass flow rate and the lower heating value. Thus, the inverse of thermal efficiency is often referred to as brake-specific energy consumption. Since it is usual to use the brake power for determining thermal efficiency in experimental engine studies, the efficiency obtained is really a brake-specific efficiency. Hence it is more appropriate to consider the brake-specific energy to compare the performance of different fuels instead of using their heating values. It is observed that the brake thermal efficiency is slightly lower than that of the corresponding diesel fuel, at higher fuel inlet temperature and at higher speed of the engine. It can be seen from the Fig. 4 that the efficiency is quite close to that of a diesel at very high speed of the engine. This means that the increase of brake specific fuel consumption is lower than the corresponding decrease of the lower calorific value of the neat vegetable oil, which could have been caused by reductions in friction loss associated with higher lubricity of neat Karanja oil.

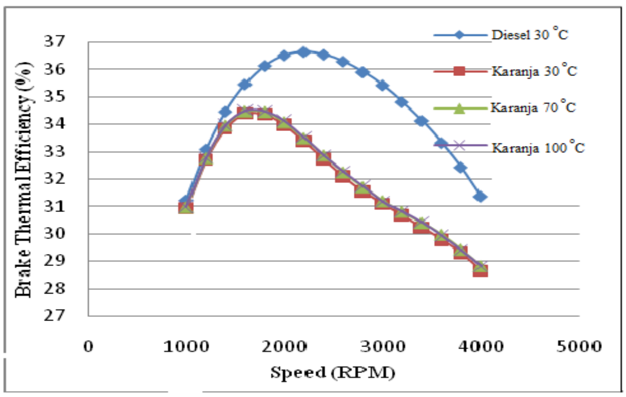

Fig. 4. Variation of engine thermal efficiency with speed at elevated fuel inlet temperatures

E. Engine Power

Fig. 5 shows the variation of the engine power with speed for diesel and neat Karanja oil at elevated temperature. As expected and as a general trend, initially the engine power increases with a speed to a maximum value at a engine speed of 3500 rpm, and decreases thereafter for speeds higher than 3500 rpm. The decrease in engine power after reaching its maximum value is an expected phenomenon as the speed further increases. Further, it may be noticed that the power produced is slightly higher than that of ordinary diesel fuel with the increasing speed of the engine for neat vegetable oil at higher speed of the engine and at high fuel inlet temperature.

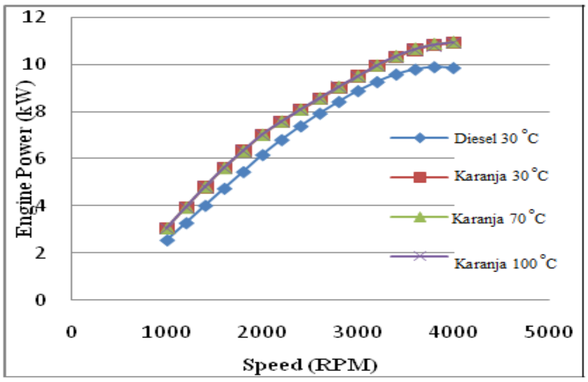

Fig. 5. Variation of engine power with speed at elevated fuel inlet temperatures

F. NOx Emissions

Although most of the literatures reviewed show a slight increase in NOx emissions when using biodiesel fuel, some works showing different effects have been found. Some of them found increase in NOx emission only for certain operating conditions, some others did not report differences in NOx emission between diesel and biodiesel fuels, and others reported even decrease in NOx emissions when using biodiesel [15].

There are combustion models reporting simulated results of increase in NOx emissions when using biodiesel fuels. As against this, Sundarapandian and Devaradjane (2007) reported the decrease in nitric oxide formation from the comparison of predicted result of nitric oxide formation with respect to engine load condition for different vegetable oil esters and diesel fuel [16]. Choi and Reitz (1999) presented a model on auto-ignition delay times, and temperature distributions in the combustion chamber using biodiesel from soybean oils as well as diesel fuel. They obtained reduced auto-ignition times and higher extension of the high-temperature areas when using biodiesel fuels and used the results obtained by their model to explain the typical increase in NOx emissions[17]. Diesel engine combustion generates large amounts of NOx because of high flame temperatures (1800^{o}K) in the presence of abundant oxygen and nitrogen in the combustion chamber (Avinash Agarwal et al., 2009)[2]. The variation of NOx emissions for both the fuels with engine speed is shown in Fig. 6. 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. The NOx emission increases with the engine load at higher combustion temperature. This proves that the most important factor for the emissions of NOx is the combustion temperature in the engine cylinder and the local stoichiometry of the mixture. From Fig. 6, it can be seen that within the range of tests, the NOx emissions from the neat vegetable oil are higher than that of diesel fuel. This is probably due to the increased fuel inlet temperature.

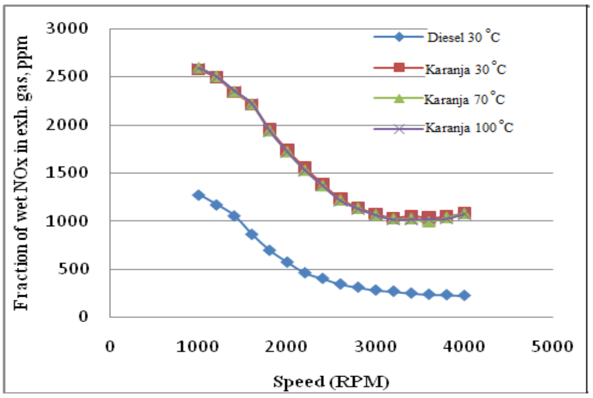

Fig. 6. Variation of NOX Emissions with speed at elevated fuel inlet temperatures

IV. Conclusions

In this work a computerized single cylinder four stroke compression engine when it is powered by neat Karanja oil at different fuel inlet temperatures. The fuel inlet temperatures and kinematic viscosity coefficients were the only parameters which were varied, and the shifts in engine performance must be attributed to these temperature and viscosity variations only. The results obtained can be summarized as under:

1. At higher speed there is no significant difference in BSFC when the engine is operated with preheated and unheated vegetable oil fuels. In other words, BSFC is not affected due to temperature of fuel at inlet conditions.
2. The Karanja oil fuel produced the same brake thermal efficiency at high speed and low speed of the engine and slightly deviating in the mid of the speed range studied. The heated fuel showed a marginal decrease in brake thermal efficiency as compared to diesel fuel operation.
3. Engine power increases with speed to a maximum value at an engine speed of 3500 rpm. At speeds more than 3500 rpm the power produced is slightly higher than that of ordinary diesel fuel. This clearly indicates that at higher engine speed conditions the performance of Karanja oil fuel can exceed that of diesel fuel operation.
4. There was significant increase in Nox emissions when running on neat vegetable oil fuel compared to diesel fuel operation. The overall test results showed that fuel heating was not beneficial at low speed operation. The higher combustion temperatures become the dominant factor at higher speed operations, making both heated and unheated vegetable oil fuels to acquire the same system temperature before fuel injection.

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