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Experimental Investigation of Karanja Oil as a Fuel for Diesel Engine-Using Shell and Tube Heat Exchanger

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Abstract**—**This paper presents experimental investigation carried out on an unmodified four stroke diesel engine running with preheated straight vegetable oil (SVO) of Karanja. The viscosity of straight karanja oil was reduced by preheating the oil up to 1600C under different load condition. The preheating was done with the help of a Shell and Tube heat exchanger equipment without using any external power source. The heat exchanger was designed in the lab and the heating source was by waste exhaust gas from engine. The experimental results data were analyzed by using 20% blends of svo of Karanja with 80% diesel by volume and 100% preheated svo of karanja for various parameters like specific fuel consumption, brake thermal efficiency and emission of exhaust gas like CO, CO_2, HC and NOx. The results indicated that by using straight karanja oil, the emission parameter increases as compared to diesel but regarding engine performance it was found to be very close to that of diesel. All total it can be a replacement of diesel with a small efficiency drop.

Keywords**—**Karanja oil, Performance analysis, Shell &Tube heat exchanger, SVO.

I. Introduction

AT the 5th OPEC International Seminar in Vienna the report said that between 2010-2011 and 2011-2012, India the world's fourth largest oil importer saw its average cost of imported crude oil rising by $27 per barrel, "making India's oil import bill rise from $100 billion to $140 billion dollars".

This higher international oil prices lead to domestic inflation increased input costs, an increase in the budget deficit which invariably drives up interest rates and slows down the economic growth. Current position of India's crude oil import bill jumps 40% to $140 billion in FY 12, resulting 1.5% reduction in the GDP. According to 5th Renewable Energy India 2011 Expo report 75% of crude liquid fuels were imported resulting in a larger import bill.

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Diesel is one of the main liquid fuels used in India. The consumption of diesel is many times higher than that of petrol as the prime use of diesel is in agriculture and transport. Efforts are being made to develop a sustainable alternative fuels which can be a replacement of diesel. Much research activity has been carried out in this area and researchers are going for renewable energy source for a alternative fuel which will reduce the gap between the demand and import of hydrocarbons. India is endowed with a number of vegetable oils like groundnut, cotton seed, sunflower, coconut etc. and many non-edible vegetable oil producing trees like karanja, neem, jatropha, mahua which are renewable sources of energy can be used as an alternative fuels. These trees can thrive in heat, low water, sandy and rocky areas [1]. As there is a high demand of edible oils for food, so it is justified to concern on non –food based feedstock.

It has been found that non edible vegetable oils have properties similar to that of diesel which can be easily extracted from their seeds. In the present investigation fuel was prepared from karanja seeds.

Experiments study shows that, Navindgi M. C. et al. [2] have carried an investigation with non-edible straight vegetable oils of Neem, Mahua, Linseed and Castor oil on a C.I. Engine and concluded that these neat oils with preheating can be substituted as fuel for diesel engine. Rampure P. B. et al. [3] have tested non-edible Rice bran oil in a diesel engine and found that by using rice bran oil the engine runs on without any problem, the nozzle orifices were not clogged and no major carbon deposits were observed on the combustion chamber. Acharya S. K. et al. [4] have tested Kusum oil as fuel for small horse power diesel engine and concluded that the preheated oil's performance was slightly inferior in efficiency but pollution point of view it can perform well for the unmodified engine for a long period of operation without any ignition problem. The Use of Vegetable oils results in increased volumetric fuel consumption and BSFC [5]-[7]. Some fuels can be used directly to the engine while others need to be formulated to bring it to the relevant properties close to conventional fuels [8], [9].

A. *Karanja Oil*

Karanja oil is derives from the seeds of *Pongamia pinnata* tree, is common throughout India. Karanja is a legume tree that grown to about 15-25 meters in height with a large canopy which spreads equally wide. Flowering starts generally after 3-4 years. Cropping of brown seed pods and single almond sized seeds can occur by 4- 6 years. The tree grows wild on sandy and rocky soils withstanding a temperature between 0^0C up to about 50^0C with a humid and subtropical climate. Each fruit contains 1-2 red kernels and the yield of kernels per tree is reported between 8 to 24kg. The oil content is 30% to 40%.

Karanja oil is toxic and having disagreeable taste and odor due to flavonoid constituents. Oil made from the seeds has been used as lamp oil, in soap making, and as a lubricant. Karanja oil is composed of the following fatty acids listed in Table I.

TABLE I
FATTY ACID % IN KARANGA OIL [10]

Sl.No	Fatty Acid	%
1	Palmitic	3.7-7.9
2	Stearic	2.4-8.9
3	Oleic	44.5-71.3
4	Linoleic	10.8-18.3
5	Lignoceric	1.1-3.5
6	Eicosenoic	9.5-12.4
7	Arachidic	2.2-4.7
8	Behenic	4.2-5.3

Karanja tree, seeds, and oil are shown in Fig. 1.

Fig. 1 Karanja Tree, Seeds and Oil

II. MATERIALS AND METHODS

A. Karanja Oil Extraction

Karanja seeds were collected from local market. Two methods were adopted for extraction of karanja oil from kernel. By mechanical extraction method these karanja seeds were mechanically processed by using mechanical Expeller to extract oil followed by filtration. The recovery of oil was calculated to be near about 27%. In n-hexane Solvent extraction method by using a Soxlet apparatus the oil recovery was 35%. The extraction was carried out in the Renewable Energy Lab. of Odisha University of Agriculture and Technology (OUAT), Bhubaneswar. Petroleum diesel was purchased from nearby fuel filling station. Apparatus used for oil extraction are shown in Fig. 2.

Mechanical Expeller Soxlet Apparatus

Fig. 2 Apparatus used for Karanja oil extraction

Experiments were conducted by using 20% of blended vegetable oils i.e. 20% filtered karanja vegetable oil mixed with 80% diesel by volume. The other form was preheated filtered karanja vegetable oil after analyzing its fuel properties. Properties of *Pongamia pinnata* (Karanja oil) are listed in Table II.

TABLE II
PROPERTIES OF KARANJA OIL

Fuel Blend	Calorific Value (Mj/Kg)	Flash Point (^{0}C)	Fire Point (^{0}C)	Kinemetic Viscosity (cSt) at 40^0C	Specific gravity
Diesel	43.40	64	75	2.9	0.828
Karanja Oil	38.00	210	219	28.3	0.914
10% of karanja oil blend	42.80	83	90	3.94	0.838
20% of karanja oil blend	42.20	112	120	8.0	0.841
Preheated oil at 130^0C	38.00	---	---	4.2	0.835

The Physical and Chemical properties of Karanja oil and its blends used for the engine testing were determined according to ASTM methods at the Renewable Energy Laboratory of Odisha University of Agriculture and Technology (OUAT), Bhubaneswar. The various instrument used for determining the properties were Hydrometer for density, Red wood Viscometer for Kinetic viscosity, Pensky-Martens closed cup tester for flash point and Bomb Calorimeter for Calorific Value etc are shown in Fig. 3.

Kinetic Viscometer Pensky-Marten

Hydrometer Bomb Calorimeter

Fig. 3 Apparatus used for determining various properties

B. Effect of Temperature on Viscosity of Karanja Oil

The kinematic viscosity of karanja oil was found 28.3 cSt at 40^0C, which was not acceptable for a diesel engine. The higher viscosity of karnja will leads to oil ring sticking, thickening of lubricating oil, causes an increased mechanical stress on fuel and injection pumps and impacts the fuel delivery characteristics as a result incomplete fuel combustion and carbon deposition on the valve seat and injector which caused chocking of injectors. In order to keep the viscosity of karanja oil with in engine allowable range, the heating of karanja oil was carried out in a shell and tube type heat exchanger. This higher viscosity of karanja oil was reduced up to 3.5 cSt at 130^0C by heating the oil by shell and tube heat exchanger in a range of 40^0C to 130^0C, which was slight higher than that of diesel. As the temperature increases the viscosity of karanja oil decreases considerably. Variation of Kinematic Viscosity with temperature of Karanja Oil is shown in Fig. 7 by using the heat exchanger.

C. Design and Development of Shell and Tube Heat Exchanger

A heat exchanger is an equipment to transfer the energy from a hot fluid to a cold fluid with maximum rate and minimum investment and running cost.

The shell and tube heat exchanger was designed and manufactured for preheating the neat karanja vegetable oil by using waste exhaust gas of the engine. The heat exchanger usually extracts the waste heat of engine gas to preheat the neat vegetable oil before it is fed to the engine.

The shell is an encloser and the passage of the waste gas, inside which tubes are fitted. It has a circular cross section. By considering the corrosiveness of the fluid, working temperature and pressure, mild steel was chosen as shell material. It consists of an air tight cylindrical shell closed at each end. A number of Copper tubes are fixed in the tube plates which are located between each cover head and shell.

The hot waste gas flow path was arranged in such a way that maximum heat of waster gas should be transferred to the neat vegetable oil flowing through the tubes. The waste hot exhaust gas from the engine entered the shell at one end and surrounds the copper tubes through which neat karanja vegetable oil was circulating under force. Heat energy lost by exhaust gas was utilized for heating the neat karanja vegetable oil. It provides a relatively large area of heat transfer for a given volume of the equipment.

Cupper as a tube material was selected by considering the corrosion resistant factor, thermal conductivity, thermal expansion etc. Also copper **tubes diameter** was considered by taking the fouling factor and economical part. **Tube thickness** was determined by taking into consideration the internal tube pressure and over pressure in the shell i.e. hoop strength and buckling strength. **Tube length** was designed by considering the economical part, space available at the site, and production capabilities. While designing the tubes, it is practical to ensure that the **tube pitch** is not less than 1.25 times the tubes' outside diameter. Development of Shell and Tube heat exchanger disassembled and assembled are shown in Figs. 4 and 5 respectively.

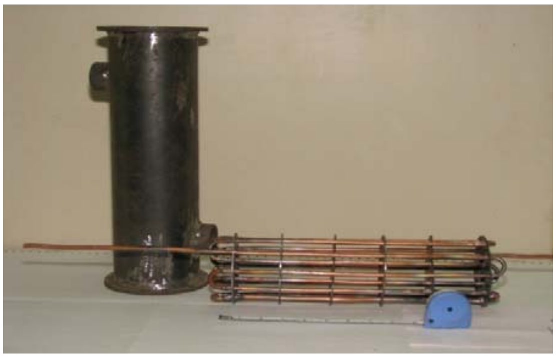

Fig. 4 Disassembled of Heat exchanger

Fig. 5 Assembled Heat exchanger

By considering the thermo economic optimization the baffles were spaced no closer than 20% of the shell's inner diameter. Baffles were used to direct hot gasses across the tube bundle. They run perpendicular to the shell and hold the tube preventing the tubes from sagging and vibrating. Segmental types baffle were used. The semicircular segmental baffles were oriented at 180 degree to the adjacent baffles forcing the hot gasses to flow upward and down wards between the tube bundles so that the hot gasses did not take a short cut through the shell side leaving ineffective flow volumes. The baffles were attached to the tube bundle rather than the shell in order that the bundle will be removable for maintenance. Specifications of shell and tube exchanger are given in Table III.

TABLE III
SPECIFICATION OF SHELL AND TUBE HEAT EXCHANGER

Details of shell and tube heat exchanger	Specifications
Shell material	Mild Steel
Tube Material	Copper
Shell Diameter	150 mm
No. Of Baffles	04 no's
Type of Baffles	Semicircular
No. Of shell passes	01 no's
No. Of tube passes	15 no's
Tube length	4.5 meter
Tube outer diameter	6.5 mm
Tube inner diameter	6 mm
Pitch of the tubes	(1.25 6.5)mm

D. Design Analysis of Shell and Tube Heat Exchanger

The fluids are not undergoing the phase change, according to 1^{st} law of Thermodynamics the rate of heat transfer from the hot gasses be equal to the rate of heat transfer to the neat karanja vegetable oil.

The rate of heat transfer by hot fluid

$$Q_h = m_h \times C_{p,h} \times (T_{h,i} - T_{h,o}) \quad (1)$$

The rate of heat transfer by cold fluid

$$Q_c = m_c \times C_{p,c} \times (T_{c,o} - T_{c,i}) \quad (2)$$

where Q_h and Q_c are the heat transfer rate of exhaust gas and neat karanja vegetable oil. m_h and m_c are the mass flow rate of exhaust gas and neat karanja vegetable oil. $C_{p,h}$ and $C_{p,c}$ are the Specific heat of exhaust gas and neat karanja vegetable oil. $T_{h,i}$ & $T_{h,o}$ are the inlet and outlet temperature of hot exhaust gas. $T_{c,o}$ & $T_{c,i}$ are the outlet and inlet temperature of neat karanja oil.

By using the energy conservation we know that

$$Q_h = Q_c = Q$$

where **Q** = Heat transfer rate between the exhaust gas and neat karanja vegetable oil.

Now Q can be calculated in terms of overall heat transfer coefficient.

Thus

$$Q = U A \Delta T_m \quad (3)$$

where

U = Over all heat transfer coefficient

A = Surface area for shell and tube heat exchanger

ΔT_m=Log mean value of temperature difference(**LMTD**)

We know that by introducing correction factor for single shell pass and multi tube pass flow heat exchanger equation (3) becomes

$$Q = F U A \Delta T_m \quad (4)$$

where **F** is the correction factor and can be obtained from the chart corresponding to thermal effectiveness (P) as in (5) and heat capacity (**R**) as in (6)

P is expressed as

$$P = \frac{t_2 - t_1}{T_1 - t_1} \quad (5)$$

The parameter **R** on curve equal to heat capacity can be expressed as

$$R = \frac{T_1 - T_2}{t_2 - t_1} \quad (6)$$

where, T represents to shell side temperature, t represents the tube side temperature and subscripts **1** and **2** for inlet and outlet conditions, respectively.

U is the Overall heat transfer coefficient is the amount of heat transferred by means of conduction or convection through heat transfer barriers. It usually involves two flowing fluids separated by a solid wall. The heat is first transferred from hot fluid to wall by convection, through the wall by conduction and from the wall to cold fluid by convection again.

A is the area of the heating surface

ΔT_m is the log mean temp difference (**LMTD**) can be expressed as

$$\Delta T_m = \frac{\Delta T_2 - T_1}{\ln\left[\frac{\Delta T_2}{\Delta T_1}\right]} \quad (7)$$

where $\Delta T_1 and \Delta T_2$ represent the temp difference between hot and cold fluids at two ends.

The **total thermal resistance** associated with this heat transfer process involves two convection and one conduction resistance. The total thermal resistance of heat exchanger can be expressed as

$$\sum R_{th} = R_{total} = R_i + R_{wall} + R_o = \frac{1}{h_i A_i} + \frac{\ln(d_o / d_i)}{2\pi L k} + \frac{1}{h_o A_o} \quad (8)$$

where A_i is the area of the inner surface of the tube wall and A_o is the area of its outer surface.

If all the thermal resistance in the path of heat flow from hot gas to neat karnja oil cold fluid is combined then heat transfer rate can be expressed as

$$Q = \frac{\Delta T_m}{R_{th}} = UA\Delta T_m = U_i A_i \Delta T_m = U_o A_o \Delta T_m \quad (9)$$

where **U is overall heat transfer coefficient, which is measured in W/m^2.K.**

From (8) we get

$$\sum R_{th} = R_{total} = \frac{1}{UA} + \frac{1}{U_i A_i} + ... + \frac{1}{U_o A_o} \quad (10)$$

Overall heat transfer coefficient based on outside tube surface can be expressed as

$$U_o = \frac{1}{\sum R_{th} A_o} = \frac{1}{\frac{1}{h_o} + \frac{A_o \ln(d_0 / d_i)}{2\pi L k} + \frac{A_o}{h_i A_i}} \quad (11)$$

where U_o= Overall heat transfer coefficient

h_o = Outer heat transfer coefficient

h_i = Inner heat transfer coefficient

d_o = Outer diameter of the tube

d_i = Inner diameter of the tube

L = Length of the tube

k =Thermal conductivity of the material

Effectiveness of heat exchanger is a dimensionless parameter and can be expressed as

$$\in = \frac{Q_{actual}}{Q_{\max imum}} = \frac{T_{h,i} - T_{h,o}}{T_{h,i} - T_{c,i}} \quad (12)$$

By putting the measured and calculated values in the above equations the Results obtained were

Heat Exchanger effectiveness ($\in$) = 0.5-0.55

Over all Heat transfer Coefficient (U_0) = 5.4-6.8 W/m^2.K

III. Engine Experimental Set Up

A single cylinder four stroke, constant speed, liquid cooled, direct injection diesel engine was used to investigate the performance and emission characteristics by using preheated karanja oil. Experiments were performed at the Department of Farm Machinery and Power, Odisha University Agriculture and Technology (OUAT), Bhubaneswar. By using multi-gas analyzer (NETEL India Pvt. Ltd.) CO_2, CO, NOx gases were analyzed. 20W40 lubricating oil was filled in oil sump. Engine detailed specification is shown in Table IV. Experimental Setup is shown in Fig. 6.

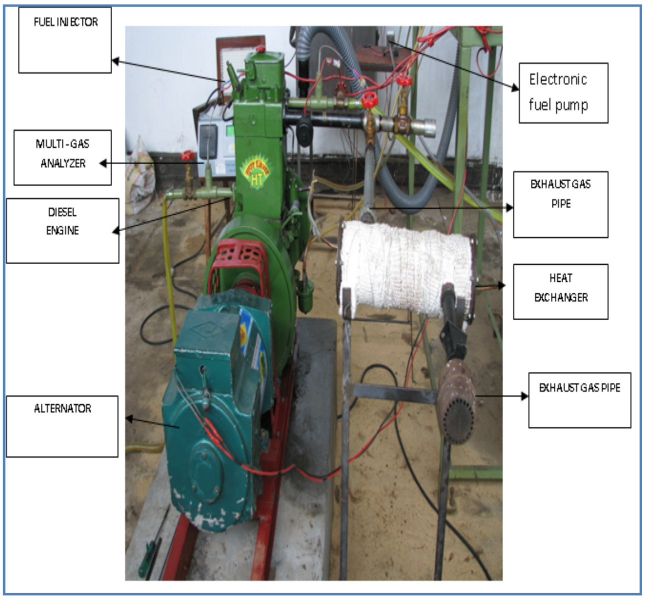

Fig. 6 Experimental Setup

TABLE IV
ENGINE SPECIFICATION

Engine Parameters	Specifications
Manufacturer	Kirloskar oil Engine Ltd, India
Rated Power	3.74 Kw
Bore and Stroke	0.08m x 0.11m
Compression Ratio	16.5:1
Engine Type	Vertical, 4 stroke, single cylinder, constant speed
Cooling system	Water cooled
Speed	1500 rpm

IV. Results and Discussion

By using preheated karanja oil all the experiments were conducted by using the above engine. The performance and characteristics of svo were compared with diesel.

A. Effect of Kinematic Viscosity of Karanja Oil with Temperature

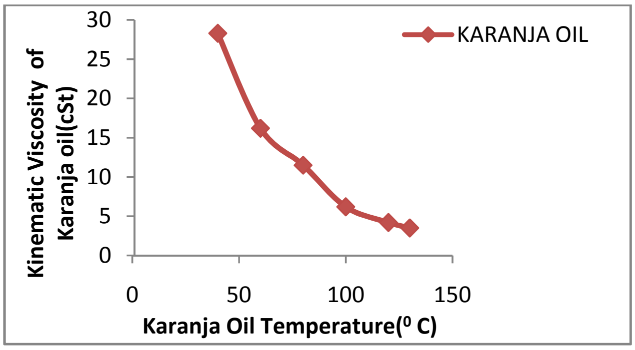

Fig. 7 Variation of Kinematic Viscosity with temperature of Karanja Oil

Fig. 7 shows the variation of kinematic viscosity characteristics of karanja oil was effected by temperature. The graph indicates that as the temperature increases the Kinematic Viscosity of karanja oil decreases. The viscosity of Karanja oil at 120^{0}C is best suited for engine allowable range.

B. Effect of Exhaust Gas Temperature with Engine Load Using Preheated Karanja Oil

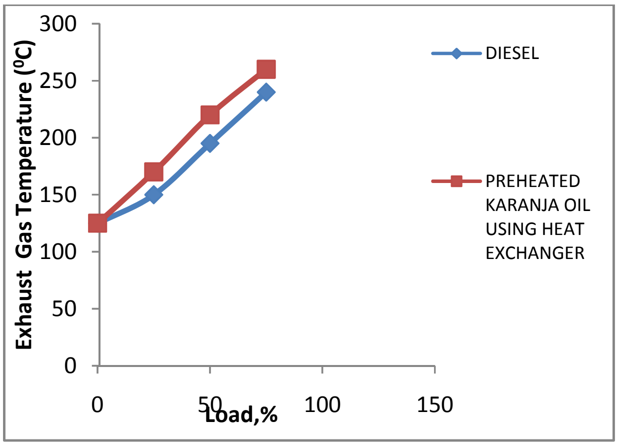

Fig. 8 Effect of Exhaust gas temperature on engine load of karanja oil

Fig. 8 indicates that the exhaust gas temperature gradually increases with the increase in engine load. This is due to as load increases the fuel consumption increases as a result the combustion temperature also increases. With comparison with diesel the exhaust gas temperature of preheated karanja oil using heat exchanger is more than diesel.

C. Effect of Outlet Karanja Oil Temperature from Heat Exchanger with Inlet Exhaust Gas Temperature into Heat Exchanger

Referring to Fig. 9 it is observed that the oil coming out from the heat exchanger varies from 75^{0}C to 160^{0}C. The maximum exhaust temperature from the engine is found to be 300^{0}C. For safety purpose a by-pass system was fitted to control the oil temperature with in 120^{0}C to 130^{0}C.

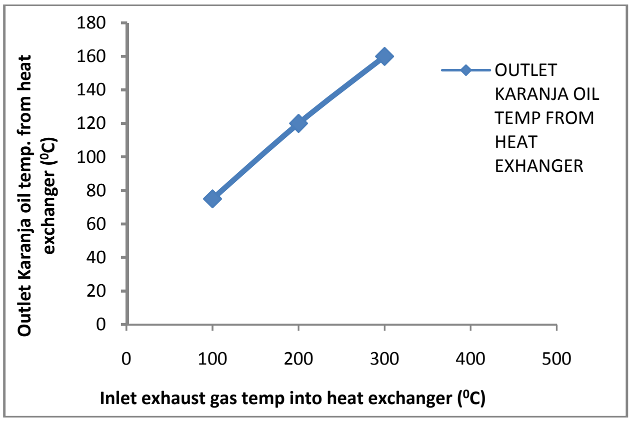

Fig. 9 Effect of outlet karanja oil temp. from heat exchanger with inlet exhaust gas temp into heat exchanger

D.Effect of Engine Load on Brake Specific Fuel Consumption (BSFC) Using Karanja Oil

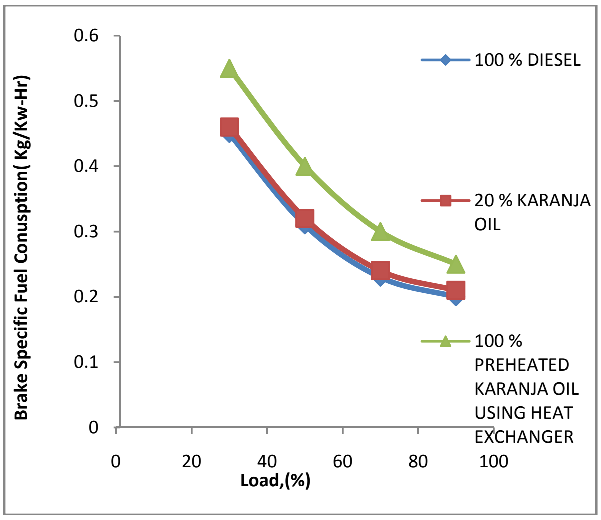

Fig. 10 Variation of Brake Specific fuel consumption with load of karanja Oil

Fig. 10 indicates that in all cases BSFC reduces with increase in load. BSFC of preheated oil was higher than diesel; this may be due to low heating value and inferior in combustion. Calorific value is the net heat content of fuel and it affects brake thermal efficiency and specific fuel consumption of the diesel engine [11]. However 20% blends of Karanja oil is more or less equal to that of diesel.

E. Effect of Engine Load on Brake Thermal Efficiency (BTE) Using Karanja Oil

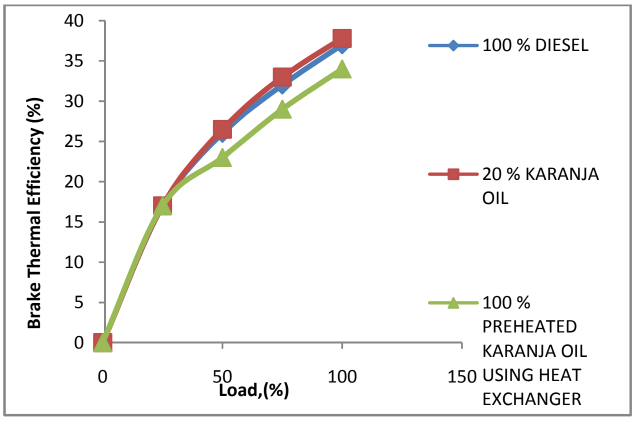

Fig. 11 Variation of Brake Thermal efficiency (BTE) with load of karanja Oil

Fig. 11 shows that at lower load, Brake Thermal efficiency is more or less equal to that of diesel. For all cases the BTE increases with load. The BTE of preheated karanja oil was found lower than that of diesel but 20% blends shows more or less equal to that of diesel due to better combustion.

F. CO Emission

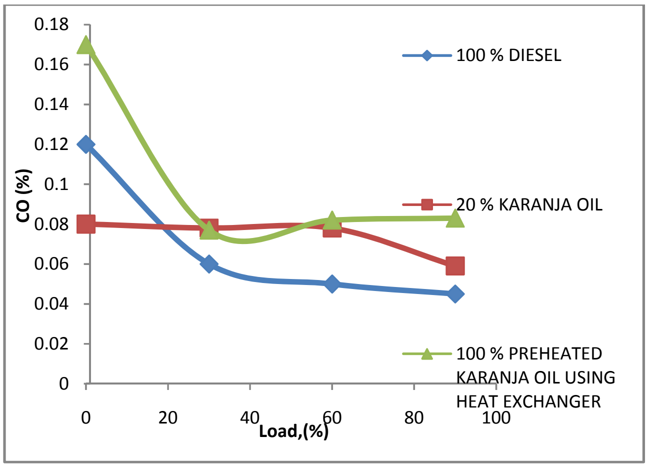

Fig. 12 Variation of CO concentration with Engine load of karanja Oil

Fig. 12 indicates that with the increase in blending concentration of karanja oil, the percentage of CO in exhaust gas was found to be higher. Due to rich mixture at higher load condition the percentage of CO increases.

G. CO_2 Emission

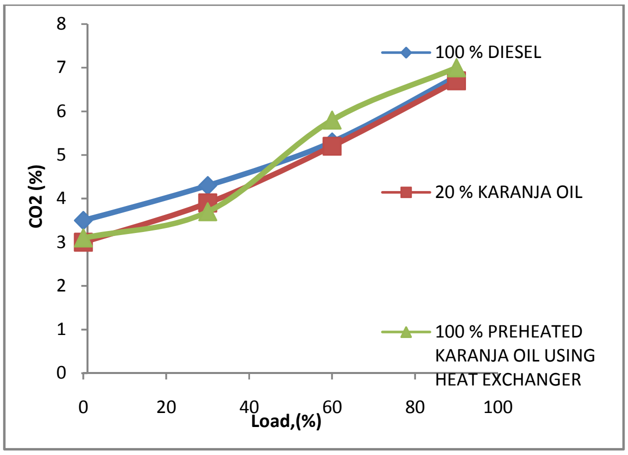

Fig. 13 Variation of CO_2 concentration with Engine load of karanja Oil

Fig. 13 indicates that the composition of CO_2 was found higher as the load increases may be due to oxygenated fuel.

H. Unburned Hydro Carbon Emission

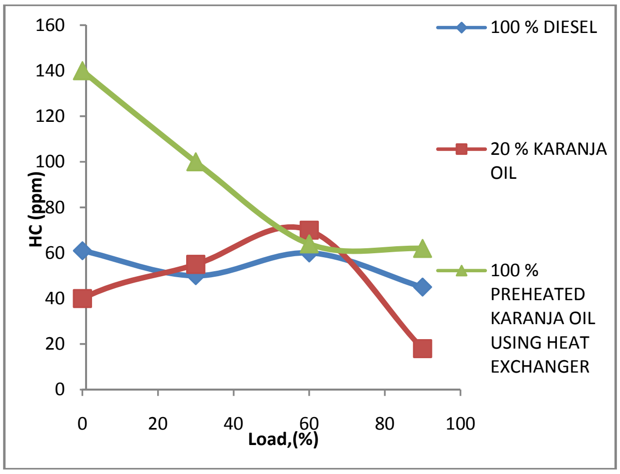

Fig. 14 Variation of HC concentration with Engine load of karanja Oil

Fig. 14 indicates that the composition of hydrocarbon was found higher as blending concentration of the oil increases may be due to atomization problem.

I. NO_x Emission

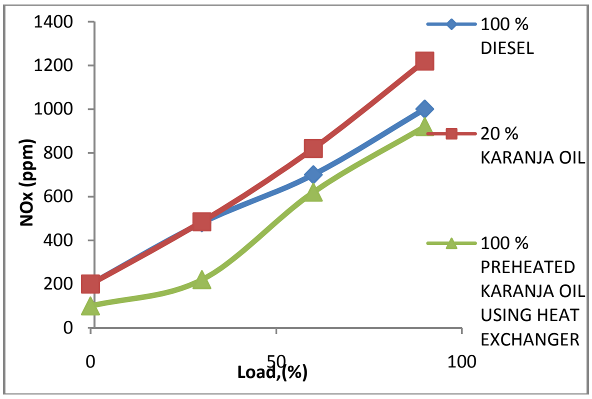

Fig. 15 Variation of HC concentration with Engine load of karanja Oil

Fig. 15 indicates that NO_x composition increases due to increase in load. It was observed that 100% preheated karanja oil from heat exchanger shows better result than diesel and other blends. In Case of KOME the NO_x was found to be more [12].

V. Conclusion

Performance and emission tests were conducted by using a four stroke diesel engine. The major conclusion was drawn based on the tests.

- The oil extraction was found 35 % by n-hexane method.
- The viscosity of straight karanja oil was reduced by preheating the oil by a Shell and Tube Heat Exchanger up to 160^0C under different load condition.
- Engine performance was found to be very close to that of diesel by using preheated straight karanja oil.
- By using preheated straight karanja oil the emission parameter like CO, CO_2, HC increases as compared to diesel but NO_x emission shows better result than diesel and other blends.

Therefore it can be concluded that preheated karanja oil can be used in diesel engines particularly for stationary application like electric generation, agricultural use etc.

Further investigation should be carried out on other non-edible oil as svo by using heat exchanger as per the availability on non –food based feedstock. Government should include the heat exchanger as subsidiary equipment for agriculture use.

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[2] M. K Mohanty, S. R. Mishra, N. Panigrahi. "Biodiesel production from various Tree- Borne Oils". Journal of Biofuels, 2012; 3(1):10-16
[3] N Panigrahi, M K Mohanty, A K Pradhan, "Non-Edible karanja Biodiesel – A sustainable Fuel for C. I Engine". International Journal of Engineering Research and Application (IJERA) ISSN: 2248-9622 Vol.2, Issue 6, Nov-Dec 2012, pp.853-860.

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