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Determination of Some Physical Properties of Jatropha *(Jatropha Curcas)* Oil.

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Abstract :The energy crisis and shortage of fuel emanating from total dependence on mineral oil with resultant socio-economic problems demand the need to explore the use of renewable energy as alternative. This study evaluates the physical properties Jatropha (Jatropha curcas) oil as alternative base oil for lubricant in auto engines.

A quantity of 32 kg dried base decorticated seeds of Jatropha was locally obtained. Volume of 4 litres of Jatropha oil was extracted from the seeds using existing hydraulic press machine, while its physical properties was determined through laboratory analytical procedure of American Society for Testing and Materials analytical standard 960-52 (ASTM,D960-52). The properties determined were: viscosity, density, flash point, pour point, melting point, refractive index, specific heat and thermal conductivity. Comparisons of the properties were also made with the standard lubricant (SAE 40 engine oil). The principles of flow theories were employed to develop heat generated equation in terms of temperature, density and viscosity of the oil and a computer program in C^{++} language was thus written. Sensitivity analysis was performed on the effect of temperature change, (30 ^oC to 100 ^oC) on value of density and viscosity.

The physical properties of Jatropha oil are viscosity (162.8) cst, density (0.920) g/ml, flash point (113)^oC, pour point (7.7)^oC, melting point (4 to 5)^oC, refractive index (1.435), specific heat (0.082) KJ/Kg/K and thermal conductivity (4.250) W/m^oC. Comparative analysis showed that the values of viscosity, density, thermal conductivity and pour point for Jatropha oil were higher than the values of SAE 40 engine oil while specific heat, flash point and refractive index values of Jatropha oil were less than the values of SAE 40 engine oil. The result showed that the average values for density and viscosity of Jatropha oil were 890.75 Kgm^{-3} and 0.1385 $N.S/m^2$. Sensitivity analysis showed that Jatropha oil has highest density and viscosity values at 30^oC and lowest values at 100^oC.

In conclusion, Jatropha oil is suitable as alternative to conventional lubricating oils in auto engines. This study provides baseline information for production of lubricating oils from Jatropha seeds.

KEYWORDS: The physical properties, viscosity, density, flash point, pour point, melting point, refractive index, specific heat capacity and thermal conductivity.

INTRODUCTION

There has been renewed interest in the use of vegetable oils for the manufacture of biodiesel due to their less polluting and renewable nature when compared to conventional diesel. The focus has been mainly on oils from seeds such as soybean, rapeseed, sunflower and safflower (Lang *et al.*, 2001), which are essentially edible in nature. In India, with its abundance of forest resources, there are a number of other non-edible tree borne oil seeds with an estimated annual production of more than 20 million tones, which have great potential for making biodiesel to supplement other conventional sources (Kaul *et al.*, 2003). Among these, Karanja (Pongamia glabra) and Jatropha (Jatropha curcas) have been successfully proved as the potential source for biodiesel (Pramanik, 2003).

With the increasing population today, over 90% of the world entire population depends on petroleum or fossil fuel as the only source of energy. With recent finding, it has been made known that there is gradual depletion of oil and gas reserve that it will get to a time when there will not be enough energy from fossil fuel to serve the world at large. Since the petroleum crises in 1970s, the rapidly increasing prices and uncertainties concerning petroleum availability, a growing concern of the environment and the effect of greenhouse gases during the last decades, has revived more and more interests in the use of renewable energy as a substitute for fossil fuel (Wang *et al.,* 2006).

The use of vegetable oils and animal fats for lubricant oil purpose has been practiced for many years (Lou, 2005). In the field of oil production, agricultural produce are natural endowment which can be used in the production of oil as bio- oil from renewable agricultural waste such as Jatropha seeds which will serve as revenue generation for the country and also create employment for the younger ones in the country as well as enhance technological developments of the nation.

Jatropha belongs to the family of *"euphorbiaceae"*. The word jatropha is derived from two Greek Words 'Jatros' meaning doctor and 'trophe', which means nutrition. Jatropha curcas is a drought-resistant perennial shrub or a small tree. It grows wild in tropical and sub-tropical climatic regions and can be successfully grown in problematic soils and arid regions. It can produce seed for fifty years. *Jatropha curcas* has a wide range of uses and promise various significant benefits to human and industry. Extracts from this plant have been shown to have anti-tumor activity, the leaves can be used as remedy for malaria and the seed can be used in the treatment of constipation and the sap was found to be effective in accelerating wound healing (Barn and Sharma, 2005).

Jatropha oil is a vegetable oil that has very higher viscosity and density in comparison with fossil fuel. To lower the viscosity and density of the renewable oil, preheating is necessary prior to using (Alamu and Durowoju, 2003).

MATERIALS AND METHOD

The materials used for this study were Jatropha seeds. Four (4) bags of fresh jatropha seeds weighing 25 kg each were sourced from COGA's farm, Bode Saadu, Moro Local Government Area of Kwara State. It was allowed to dry and reweighed to be 15 kg each. This showed a significant weight loss of 10 kg. This means that 25 kg of fresh Jatropha seeds was equivalent to 15 kg of dry seeds with husk. Therefore, 100 kg of fresh jatropha seeds with husk was equivalent to 60 kg of dry jatropha seeds with husk. The seeds were dehusked and the weight reduced to 32 kg of clean jatropha kernels. This was used to produce approximately four (4) litres of extracted oil. This shows that eight (8) kg of the seeds gave approximately one (1) litre of extracted oil.

Some of the physical properties of oil extracted from the jatropha seeds were determined using different kinds of machines such as Temperature assembly to determine flash point, and pour point, Refractometer to determine Refractive index. Viscosity and density of jatropha oil were determined at various temperatures of 30 ^oC, 40 ^oC, 50 ^oC, 60 ^oC, 70 ^oC, 80 ^oC, 90 ^oC and 100 ^oC with different apparatus such as density bottle to determine density, Ostwald viscometer to determine viscosity and thermometer to determine temperature.

The viscosity of the oil was determined by pouring 200 ml of the extracted oil into the Ostwald's viscometer until the two non-reading arms were full. The pressure from the reading arms timed at interval of 35 seconds for the Jatropha Oil. The time was multiplied by the instrument's constant which is 4.697. This gave the viscosity in centistokes. The kinematic viscosity was determined by ASTM D-445.

The density of the oil was determined by using a clean density bottle of 10 g which was dried in the oven with temperature 5 ^oC and kept in dessicator to cool. The density bottle was weighed when empty as 10 g, and was also weighed when it was filled with water (63 g), as well as when it was filled with Jatropha oil (58.7 g), which means water's volume was 53ml, Jatropha oil weight was 48.7 g. The calculation of the density goes thus: Weight of density Bottle empty = a grams, Weight of density Bottle + water = b grams, Weight of density bottle + sample = c grams, the density was determined by ASTM D-1293 method.

Density, $\rho = \frac{c-a}{b-a}$ (1)

Flash point: 150 ml of extracted oils was poured into a metal container and heated at a controlled rate temperature of 36 ^oC after, which, the flame being passed over the surface of the extracted oils was observed at a regular intervals of 5 secs for 1 min. The flash point was determined by ASTM D-93 method.

Pour point: 150 ml of extracted oil was cooled inside an ice pack cooling bath of temperature 70^oC to allow the formation of paraffin wax crystals. At 9^oC above the expected pour point of 12^oC, and subsequently for every 3^oC, the test jar was removed and tilted to angle 45^o to check for surface movement. The oils extracted do not flow after tilted; the jar is held horizontally for 5 sec. 3^oC is added to the corresponding temperature of 0^oC. The pour point was determined by ASTM D-97 method.

Melting point: 150 ml of oils extracted was placed in capillary tube of 92 mm in length and 24 mm in diameter, which was heated at the controlled rate temperature of 36^oC. The temperature at which Jatropha oil melted was 4 to 5^oC.

Refractive index: Two drops of the extracted oil was put into the lens of an Abbe refractometer. Water at 30^oC was circulated round the lens to keep its temperature uniform. Through the eyepiece of the refractometer, the dark portion viewed was adjusted to be in line with the intersection of the cross. At no parallax error, the pointer on the scale pointed to the refractive index which was read against the internal monochromatic source of light in the equipment. This was repeated 3 times and the mean value noted and recorded as the refractive index.

Specific heat capacity: A copper calorimeter was weighed and recorded. 150 ml quantity of oil was also weighed and its temperature which is 15^oC was noted and transferred to the calorimeter. A known volume of water (53 ml) was heated to a temperature of 20^oC above that oil, the hot water was transferred to the oil in the calorimeter, which was closed and stir until it reaches the equilibrium temperature and it was recorded. Specific heat capacity was calculated using equation 2.

$$c = t/m, \quad (2)$$

where C = SHC of calorimeter, (kJ/kg/K), t = heat loss, (^oC), m = mass of oil, (ml)

Ambient temperature, T_a = 20.1 ^oC (degree to minimize error due to heat transfer to or from the surroundings).

Thermal conductivity: **S**ato-Riedel method is the most popular method used for liquid thermal conductivity. This method is one of the corresponding state theories and it was estimated with the following scheme below:

$$\lambda_l = \frac{2.64\times10^{-3}}{\sqrt{M}} \times \frac{3+20(1-Tr)^{2/3}}{3+20(1-Tbr)^{2/3}} \quad (3)$$

Where: λ = Thermal Conductivity (W/m^oC)

Tr = Reduced Temperature, (^oC)

Tbr = Boiling Point/Critical Temperature, (^oC)

M = Molecular Weight, (g)

Related equations on the effect of Temperature Changes on Values of Density and Viscosity for Jatropha Oil through Computer Simulation

The values obtained from the analysis of properties were developed into a computer program written in C^{++} language for a quick and precise estimate of the temperature to which highly viscous fluid can be heated at minimum value of density and viscosity. The surrounding temperature for the fluid was assumed to be 20 ^oC in the computer code developed. The program was structured in a way that output of the heating temperatures, corresponding to the varied density and viscosity values were put into consideration. Analysis of fluid flow theories and cost concept are as follow:

For flow of any incompressible fluid through a closed conduit, the power delivered to the fluid by the pump is given in equation 4 (Alamu and Eweremadu, 2001).

$$W = P_d M_f / 10^3 \rho \qquad (4)$$

Where: W = pumping power, *(kW)*

P_d = pump pressure drop, *(Nm^{-2})*

m_f = mass flow rate, *(kgS^{-1})*

The total pressure low along a closed conduit is given, through Darcy-Weisbach formular, as shown in equation 5 (Eweremadu and Olafimihan, 2000).

$$p = (\rho u^2 / 2 [f\, L/d + \sum k]) \qquad (5)$$

Where: f = friction factor

L = pipe length, *(m)*

d = diameter of pipe, *(m)*

u = linear fluid velocity along the pipeline, *(m/s)*

For laminar flow (high viscosity), friction factor (f) is givens as:

$$f = 16 Re^{-1} \qquad (6)$$

Where: $$Re = \rho u\, d/\mu \qquad (7)$$

Re = Reynolds Number (< 2100) is given in equation 6 and equation 7 (Peters and Timmerhaus, 1968)

Substituting equations (7), (6) and (5) in equation (4), the power developed by the pump becomes:

$$w = (m f u^2 / 2 \times 10^3 [16\mu\, L/\rho u\, d^2 + \sum k]) \qquad (8)$$

Using plot of Lewis and squires, a set of practical data of known temperature values with corresponding viscosities and fluid density for various fluids can be obtained in equation 8 (Coulso and Richardson, 1999).

The overall pump efficiency is given in equation 9 (Theodore and Lionel, 1967)

$$\eta = P_2 / P_1 \qquad (9)$$

Where: P_2 = output power of the pump, (W)

P_1 = the pump power input, (W)

Combining equation (8) and (9) the pump power input takes the form as shown equation 10 (Theodore and Lionel, 1967):

$$p_1 = (m f u^2 / 2 \times 10^3\, \eta\, [16\mu\, L/\rho u\, d^2 + \sum k]) \qquad (10)$$

While the linear fluid velocity, u, along the pipeline is given as shown in equation 11

$$u = 4^m{}_f / \pi d^2 \rho \qquad (11)$$

Pumping Cost

Let C_e = Cost per kw/h of electrical energy, *(#kWh^{-1})*

C_1 = Cost of electrical energy needed for pumping, *(#h^{-1})*

C_3 = Any other cost associated with pumping, *(#h^{-1})*

The cost of electrical energy consumed by the pump to generate the power, P_1, can be written as obtained in equation 12.

$$C_1 = C_e P_1 + C_3 \qquad (12)$$

Cost of Heating

Let Q = quantity of the heat consumed by the fluid, *(JS^{-1})*

C = specific heat capacity of the fluid, *($Jkg^{-1}K^{-1}$)*

T_2 = temperature to which the fluid has been heated to ease pumping, *(^oC)*

m_s = mass of steam used in heating the fluid per second, *(kgs^{-1})*

L_s = latent heat of vaporization of steam

C_s = unit cost of steam, *(#kg^{-1})*

The quantity of heat gained per seconds by the fluid while being heated from the room temperature to the required pumping temperature can be obtained from equation 3.13 (Kurmi, 1991).

$$Q = m_f C (T_2 - T_1) \qquad (13)$$

Neglecting heat losses to the surrounding, this quantity of heat is supplied to the fluid the steam is given in equation 14. Hence:

$$Q = m_s L_s \qquad (14)$$

The cost of generating steam therefore can be written as shown in equation 15

$$C_h = C_s m_s \qquad (15)$$

The total pumping and heating cost is therefore given by the sum of equation (12) and (15) thus;

$$C_p = C_e P_1 + C_3 + C_s m_s \quad (16)$$

RESULTS AND DISCUSSION

The results of real values, average values and variation values for the physical properties of oils extracted from jatropha seeds using Hydraulic press machine and mechanical oil extraction method is shown in Table 4.1.

Comparison of Some Oil Properties

Some properties of standard base oil 500 Solvent Neutral were compared with the extracted oil with emphasis on its possible use as lubricants. Properties considered were viscosity, density, thermal conductivity, specific heat capacity, flash point, pour point and refractive index (Table 4.2). Comparative analysis showed that the values of viscosity, density, thermal conductivity and pour point for Jatropha oil were higher than the values of standard base oil of 500 Solvent Neutral while specific heat, flash point and refractive index values of Jatropha oil were less than the values of standard base oil of 500 Solvent Neutral.

However jatropha seeds have high viscosity hence, there is a need to reduce the viscosity because it is an important and vital property when considering the lubricating characteristics of the engine for high performance. Hence the viscosity reported herein was higher than ASTM D-445 standard this could be as a result of variation in temperature. The lower the temperature value, the higher the viscosity value. This can be achieved through temperature varying method before usage. The analysis showed that the viscosity value for jatropha oil was 162.8 centistoke while standard base oil of 500 Solvent Neutral was 95.0 centistoke.

Density of a material is defined as the measure of its mass per unit volume (e.g in g/ml). The density of vegetable oil is lower than that of water and the difference in density of vegetable oils are quite small, particularly amongst the common vegetable oils. Generally, the density of oil decreases with molecular weight, yet increase with unsaturation level. From the experiment conducted, the density of jatropha seed oil is 0.9200 g/ml, while the value of base oil of 500 Solvent Neutral was 0.9000 g/ml.

The flash point is related to the safety requirement in handling and storage of fuel however, Jatropha oils have very high flash point values. This makes them safer to handle and store. When compared with standard base oil, it was discover that base oil of 240 ^oC was higher than the two extracted oils of 145 ^oC and 113 ^oC respectively. But the two sampled oils are good and can be use.

The value of pour point for Jatropha oil was 7.7 ^oC which was higher than base oil 500 Solvent Neutral value of -6.0 ^oC. To meet with the ASTM D-97 standard the vegetable oil sampled (Jatropha oil) need some adjustment to ensure that its pour point is reduced to the bearest minimum, in order to suit for the purpose of its utilization.

Refractive index analysis showed that there was little difference between the values obtained for Jatropha oil, 1.435. Comparing this result with the ASTM values that ranges from 1.476 – 1.479, a little difference is noticed. However, this little difference can be considered being within an acceptable experimental error range that can be attributed to the presence of some impurities and other component of the extracted oil mixture. Thus, the refractive index of Jatropha oil was in agreement with ASTM specification.

The specific heat capacity for the sampled oil is far lower than that of base oil of 500 Solvent Neutral which was 1.270 kJ/kg/K, compared with jatropha oil that was 0.082 kJ/kg/K. Thermal conductivity value obtained in this study was 4.250 W/m^{o}C for jatropha oil, while for base oil of 500 Solvent Neutral the value was 0.875W/m^{o}C, which was lower compared with the value obtained from the vegetable sampled oils.

4.1: Physical Properties of Jatropha Oil Extracted

	Properties	Castor Oil			
		Real Values	Average Values	Standard Deviation	Deviation
1	Viscosity (centistokes)	897.1			
		887.7	889.27	7.18	2.68
		883			
2	Density (g/ml)	0.96			
		0.96	0.96	0	0.02
		0.96			
3	Thermal Conductivity(w/m^{0}C)	0.09			
		0.09	0.09	0	0.06
		0.09			
4	Specific Heat (kJ/kg/K)	4.72			
		4.66	4.73	0.07	0.27
		4.8			
5	Flash Point (^{o}c)	145			
		145	144.67	0.58	0.76
		144			
6	Pour Point (^{o}c)	3			
		2	2.67	0.58	0.76
		3			
7	Refractive index	1.48			
		1.48	1.48	0	0
		1.48			

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Table 2: Compared Properties of Jatropha Oil Extracted with Base Oil of 500 Solvent Neutral

S/No	**Properties**	**Name of Oil Used**	
		500 Solvent Neutral	Jatropha Oil
1.	Viscosity (centistokes)	95 (30^{o}C)	162.8 (30^{o}C)
2.	Density (g/ml)	0.9000	0.9200
3.	Thermal conductivity (W/m^{o}C)	0.875	4.250
4.	Specific heat (kJ/kg/K)	1.270	0.082
5.	Flash Point (^{o}C)	240	113
6.	Pour Point (^{o}C	-6.0	7.7
7.	Refractive index	1.483	1.435

Viscosity and Density Behaviour at varying Temperatures for Jatropha oil

Both viscosity and density were varied at different temperature range from 30^{o}C to 100^{o}C and the results obtained were shown in Table 3 and 5 through the statistical method of average determination values and deviation values. Tables 4.4 and 4.6 shows the values of densities and viscosities at different temperature values for oils extracted from castor and jatropha seeds.

Characteristic Curves for Castor oil

The result presented shows that as the pipe diameter increased from 0.042m to 0.062m, the heating temperature decreased from 100^{o}C to 30^{o}C as shown in figure 1 - 6.

Figure 1 shows the relationship between the frictions of fluid and heating temperatures which is the surface movement between two moving parts that caused the engine to overheat. As the heating temperature changes to lower value, the friction increase but when temperature increases the friction become reduced which bring about good working condition for an oil with less wear on moving parts, less pressure loss, less leakage and high film strength.

Figure 2 revealed that as the friction of fluid increases, there was also an increase in fluid viscosity which shows that the internal friction or shear of the fluid was increased which can cause less precision control and slower responses of an engine or machine. But to have good and acceptable friction at which the lubricant can be applied the viscosity need to be reduced.

Figure 3 shows that the coefficient of friction increased with a linear increase in fluid density which shows that the volumetric efficiencies were too high and the performance of the fluid was sluggish. To neutralize this, the density of the oils needs to be reduced through increase in the heating temperature of the fluid.

The relationship between power and temperature in Figure 4 shows that as the power which is output performance of oil increases, the heating temperature of the fluid was reduced and the temperature need to be increased in order to make the oil effective and have required working efficiency in lubricating moving parts of an automotive engine.

Figure 5, shows power and fluid viscosity relationship. As power increases the fluid viscosity also increases which shows that the power consumption will be more and less mechanical efficiency. But with the increase in the temperature both the power consumption and efficiency will be moderate.

Figure 6 shows the relationship between power and fluid density. As the power increases there was also a corresponding increase in the density value which leads to increase and decrease movement of the fluid and cause the fluid to be categorized as heavy weight oil that brings about excessive heat generation and higher pressure drop due to the friction. But with an increase in the temperature of the fluid it will reduce the heaviness of the oil and makes it more useful.

Table 3: Determination of Averages and Deviations from real value obtained from Varied Density at Different Temperatures

Temperature, ^{o}c	Jatropha Oil			
	Real Value	Average Values	Standard Deviation	Deviation
30	0.92			
	0.92	0.92	0.00	0.00
	0.92			
40	0.91			
	0.91	0.91	0.00	0.00
	0.91			
50	0.89			
	0.89	0.89	0.00	0.00
	0.89			
60	0.89			
	0.89	0.89	0.00	0.00
	0.89			
70	0.89			
	0.89	0.89	0.00	0.00
	0.89			
80	0.88			
	0.88	0.88	0.00	0.00
	0.88			
90	0.88			
	0.88	0.88	0.00	0.00
	0.88			
100	0.87			
	0.87	0.87	0.00	0.00
	0.87			

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Table 4: Varied Density at Different Temperatures Jatropha Oil

Temperature (^{o}C)	**Jatropha Oil**
30	0.920
40	0.907
50	0.893
60	0.891
70	0.887
80	0.881
90	0.876
100	0.871

Table 5: Determination of Averages and Deviations values from real values obtained from Varied Viscosity at Different Temperatures

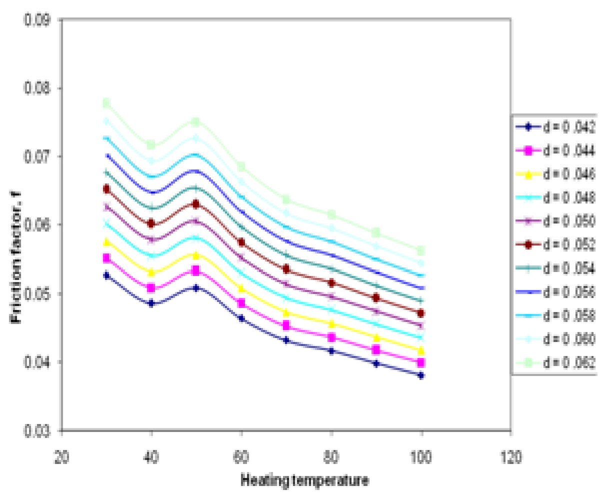
	Jatropha Oil			
Temperature,^{o}c	Real Value	Average Values	Standard Deviation	Deviation
30	169.1			
	155	162.83	7.18	2.68
	164.4			
40	150.3			
	151.2	150.3	0.9	0.95
	149.4			
50	148			
	146.5	147.33	0.76	0.87
	147.5			
60	145.6			
	143.3	143.57	1.91	1.38
	141.8			
70	133.9			
	134.8	133.73	1.16	1.08
	132.5			
80	129.2			
	126.8	128.87	1.92	1.39
	130.6			
90	122.1			
	124.5	123.23	1.21	1.1
	123.1			
100	117.4			
	117.4	117.87	0.81	0.9
	118.8			

Table 6: Varied Viscosity at Different Temperatures for Jatropha Oil

Temperature (^{o}C)	**Jatropha Oil**
30	162.8
40	150.3
50	147.3
60	143.6
70	133.7
80	128.9
90	123.2
100	117.9

Characteristic curves for Jatropha Oil

Data obtained from computer simulation for jatropha oil were used to plot different graphs shown in figure 7 to 12. These graphs were plotted to depict the behaviour of both Jatropha oil in relation to its physical characteristics such as friction factor, heating temperature, fluid density, power and fluid viscosity. From the analysis performed, it was discovered that friction decreases with increased temperature, viscosity increases with increase in friction, while fluid density increases linearly with increased friction in Jatropha oils. Thus they have similar and related characteristic with each other as shown in the plotted graphs.



, ^{0}c\

Fig. 1: Plot of Friction factor versus Heating temperature for Jatropha Oil

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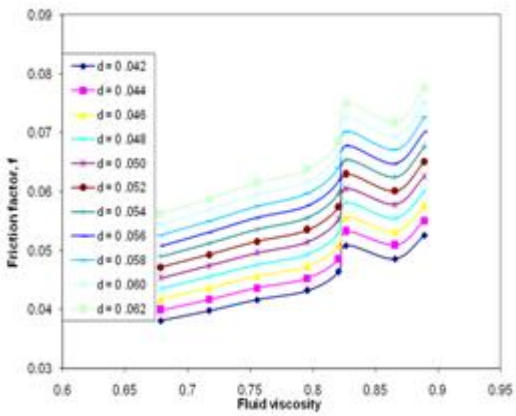
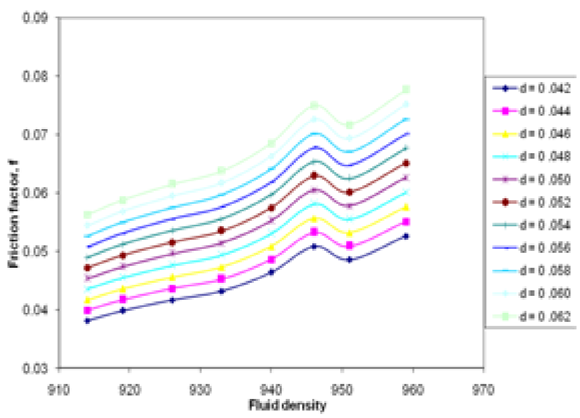


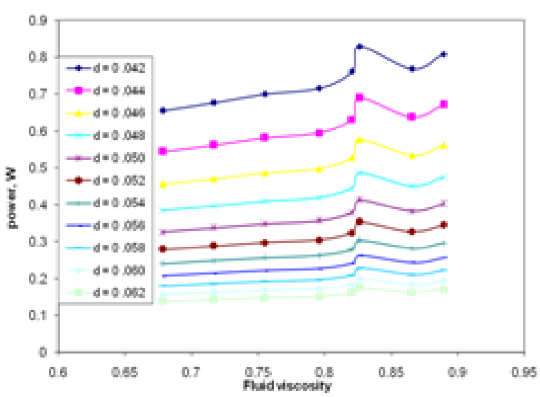
, N.S/m^2

Fig. 2: Plot of Friction factor versus Fluid Viscosity for Jatropha Oil



, g/ml

Fig. 3: Plot of Friction factor versus Fluid Density for Jatropha Oil



, N.S/m^2

Fig. 4: Plot of Power versus Fluid viscosityfor Jatropha

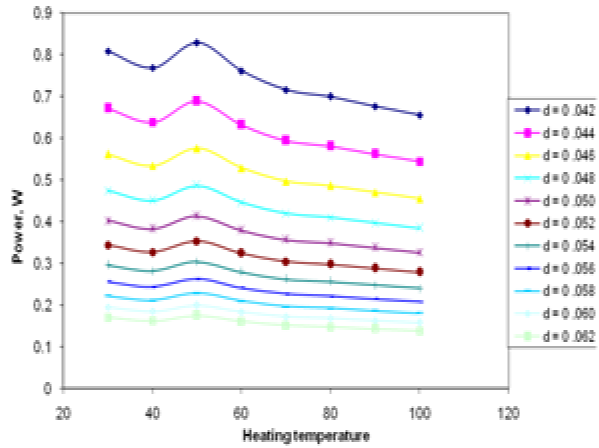
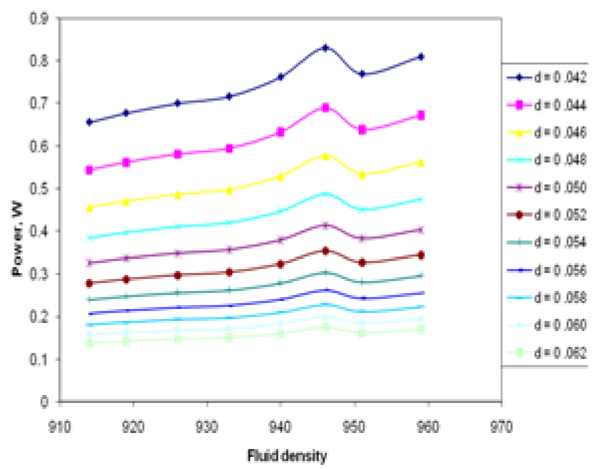


Fig. 5: Plot of Power versus Heaing temperature for Jatropha Oil



,g/ml

Fig. 6: Plot of Power versus Fluid Density for Jatropha Oil

CONCLUSIONS

Oil extracted from non-edible seeds of Jatropha were analyzed and simulated to determine the physical properties, varied density and viscosity with respect to change in temperature. The result showed that the average values for density and viscosity of Jatropha oil is 890.75 kgm^{-3} and 0.1385 N.S/m^2 which compare favourably with 500 solvent neutral that is bright and clear in appearance (see Table 2)

Viscosity of a fluid is an important property to consider in the selection of oil for any engine. The viscosity of Jatropha oils reduces substantially after all the necessary treatment and the sampled oils can perform the required functions much better with increase in temperature. The temperature was found to remain constant as the diameter of pipe increases for the jatropha oil. Most of the values complied with the standard specified by American Standards and Testing Materials (ASTM) hence; the oils are of good quality and could be recommended for suitable industrial usage or exported to generate revenue.

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