PRELIMINARY STUDY ON THE PROSPECTS OF USING OF CASTOR OIL (Ricinus communis L.) AS AN ALTERNATIVE AUTOMOBILE HYDRAULIC FLUID

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ABSTRACT
Castor oil (Ricinus communis L.) has been extracted from castor seeds obtained from its plants; grown along the bank of Meme River, Lokoja andthe waterwaysin phase II linking to the River in Lokoja, Kogi state,Nigeria, employing the traditional method of extraction of vegetable oils without chemical additives. The extracted oil appears yellowish in color and it is highly viscous with reasonable yield. Our choice is tied to the fact that castor seed is a renewable resource and has favourable outcome on the environment. In this study, we present the following preliminary results obtained from extraction and physical characterization which includes the extracted oil yield, density, specific gravity, functional groups, dynamic viscosity and activation energy during heat transfer through the extracted castor oil. The percentage yield was found to be 22.3% and the corresponding density and the specific gravity are 964.4kg/m^3 and 0.964 respectively. The moisture content of the extracted castor oil characterized using a standard digital Moisture Analyzer (MA 110) was found to be 0.62%,which is very lowand in conformity with the standard stipulated for hydraulic fluids. The functional groups obtained using Fourier Transform Infra-red spectrophotometer (Agilent Technologies) is in conformity withthe standardfunctional groups for castoroil which includes mainly the alcohol, ester, isothiocyanate, alkane, alkene, amine and carboxylic acid. The dynamic viscosity of the extracted castor oil determined at 40^{o}C using a standard digital Viscometer (RVDV-1) was found to be 376 Pa.s and the corresponding kinematic viscosity is $51.6\times10^{-2}m^2s^{-1}$. The activation energy during heat transfer through the extracted castor oil was found to be 0.88eV.

Keywords: Castor oil, natural resource, biodegradability, hydraulic fluid, dynamic viscosity, heat

1. INTRODUCTION

Hydraulic fluids are a very large class of materials that are used in machines and equipment to transfer pressure from one point to another (Volkhard*et al.,* 2008, Mbah *et al.,* 2014,). They are used for a myriad of applicationsincluding car automatic transmissions, brakes, power steeringand so on. Hydraulic fluids are also used in many machines like tractors and other farm equipment, forklift trucks, bulldozers, and other construction equipment, and airplanes (Ardebili*et al.,* 2012). In addition to this, hydraulic fluids are used in automobiles for lubrication, sealing, cooling and removal of contaminants (Nur*et al.,* 2017). An ideal hydraulic fluid should possess ideal viscosity, low density, good heat dissipation, low volatility and low flammability (Oje*et al.,* 1991, Ogunniyi et *al.,* 2006). In addition to these, it should

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be fire resistant, incompressible, emulsification free, compatible with systems and ecofriendly (Aluyor*et al.,* 2009).Nevertheless, biodegradability of conventional mineral hydraulic fluids has been a major concern to the environment for decades because frequently,the hydraulic fluids breach the containment. Whenever they are spilled or improperly disposed to the environment, certain microorganisms such as bacteria, yeast and fungi that breakdown the molecules for sustenance are grossly affected (Lea cliff,2005).The overall environmental hazard of conventional mineral hydraulic fluids is not entirely determined by the mineral oil basebut by the several additives; used in the production of the finished products, which contribute substantially to the toxicity of the spills. The negative effects of this toxicity can range from mortality to impaired reproduction or growth abnormalities (Exxon Mobil Corporation-HY8014TT, 2012).As such, the Organization for Economic Cooperation Development (OECD) Guideline for Testing of Chemistries proposed that Vegetable-based fluids are generally more readily biodegradable and have less environmental impact because their structures are more susceptible to microbial breakdown than petroleum oils (Exxon Mobil Corporation-HY8014TT, 2012). These attributes and the expensive remediation effort required for pollutant cleaning have paved way for the development of alternative and environmentally benign hydraulic fluids based mainly on vegetable oils such as castor oil.

Castor (*Ricinus communis* L.) is a nonedible oilseed, belonging to the *Euphorbiaceae* family (Kirk-Othmer, 1979). Castor oil is highly viscous and pale yellow in color and is usually produced from castor seeds. It is paraded with inherent rare quality because of its physical properties and the innate unequal structure. The uniformity and reliability of its physical properties are demonstrated by the long-term use of castor oil as an absolutestandard for viscosity. Castor Oil also has excellent emollient and lubricating properties (Akpan *et al.,* 2006). The high polar hydroxyl groups makes castor oil a natural polyol providing oxidative stability to the oil, a relatively high shelf life compared to other oil by preventing peroxide formation and a functional group location for performing a variety of chemical reaction including halogenation, dehydration, alkoxylation, esterification, sulfation, epoxidation, hydrogenation, etc.,(G. R. O'Shea Company).It is known to contain about 40 to 60% oil (Olaoye, 2000). Castor oil is unique among all fats and oils in that it is the only source of an 18-carbon hydroxylated fatty acid with one double bond andthe ricinoleic acid (12-Hydroxyoleic Acid) comprises approximately 90% of the fatty acid composition. It is a naturally occurring resource that is nontoxic, biodegradable and renewable. The remarkably constant composition of castor oil fatty acids includes 89.5% ricinoleic acid, 4.2% linoleic acid, 3.0% oleic acid, 1.0% stearic acid, 1.0% palmitic acid, 0.7% dihydoxystearic acid, 0.3% linolenic acid and 0.3% eicosanoic acid(G. R. O'Shea Company).In Nigeria, castor seedcan be grown to maturity between 4-6 months in all parts of the country due to its resistance to drought conditions giving it an additional opportunity to increase its exploitation and developing regional economies without competition with traditional oilseeds (Falasca*et al.,* 2006). Due to global sustainable environment concerns on mineral oil pollution, chemically modified castor oil may possess addedeconomic value as a potential environmentally benign hydraulic oils for automobiles, many machines and airplanes leading to an increase in theper capital income of Nigeria.In this research, our overall goal is tomodify castor oil via one of the favorable chemical reactions and eventually use the chemically modified castor oil for the production of alternative and biodegradable hydraulic fluid with optimum properties comparable to the conventional hydraulic fluids produced from mineral oils. Our choice is tied to the fact that castor seed is a renewable resource because it can be planted all the year round with great endurance under harsh weather conditionsand it also has favourable consequence on the environmentbecause they are biodegradable and non-toxic. Preliminary results on the moisture content, the functional groups, the dynamic viscosity and the activation energy during heat transfer through the extracted castor oil are presented.

2. MATERIALS AND METHODS

The major material used for this project is Castor seeds obtained from Castor plants(Ricinus communis L.) along the bank of Meme River, Lokoja and the waterways linking to the River in Phase II, Lokongoma, Lokoja, Kogi State. The extraction procedure and the techniques employed for the characterization of the extracted castor oil (Ricirus communis)are presented herein.The castor seeds were allowed to dry for 7 days for easy de-hulling. The castor seeds were then de-hulled with stone and were cleaned from dirt. The mass of the raw castor beans was measured using a top loading weighing balance with accuracy of *0.1g*. Subsequently, the castor beans were roasted and then pulverized using a pestle in a mortal until a paste is formed. As a follow-up to this, the castor pastry was then placed on fire for 1hr and as the water evaporates sticky oil was formed on the cake. The sticky oil wasscooped into a separate container (pot), then heated for 30 minutes to reduce the moisture and almost moisture free and yellowish castor oilwas obtained. The mass of the extracted castor oil was then measured using a top loading weighing balance with accuracy of *0.1gwhile the volume was measured using a volumetric flask*. Finally, the percentage yield of the extracted castor oil was calculated by comparing the mass of the extracted castor oil with the mass of the roasted castor seed using:

$$\%\ yiled = \frac{mass\ of\ the\ extracted\ castor\ oil}{mass\ of\ the\ roasted\ castor\ seeds} \times 100$$

The Moisture content of the extracted castor oil was evaluated using a top loading Moisture Analyzer (Model MA *50/110*). Few drops of castor oil were put into the sample container, the initial and the final masses were obtained automatically with the Moisture Analyzer.The heating temperature and the heating time used were 110^oC and 156srespectively. Finally, the percentage moisture content of the extracted castor oil was calculated by comparing the initial mass of the extracted castor oil with the residual mass after heating using:

For the determination of the functional groups, a drop of castor oil was put on the sample holder and exposed to infrared radiation using Fourier Transform Infrared (FTIR) Spectrophotometer (Agilent Technologies) to elucidate the functional groups of the extracted castor oil. The sample was scanned *30* times with a resolution of $8\ cm^{-1}$and the spectral range was $4000\text{-}650cm^{-1}$.The positions and intensities of the IR band were processed with "Spectral Analysis software". Finally, for the measurement of the dynamic viscosity, about 45 ml of the castor oil was poured into a sample container and a spindle which rotates at a velocity of *20rpm* was inserted into the sample.The percentage torque of the spindle was *40.2*, the shear rate was $4.280s^{-1}$and the room temperature was 27.4^oC. The whole set up was put in a water bath maintained at 100^oC.The viscosity and temperature ($30^oC\text{-}60^oC$) of the system were monitored and recorded automatically using a Digital Viscometer (Model RVDV-1) operating at*220V*.The temperature dependence of the of dynamic viscosity was then fitted with the Arrhenius equation given in the logarithmic form as;

$$\ln(\eta) = \ln(A) + \frac{E_a}{R}\left(\frac{1}{T}\right)$$

where R, E_a, η and A are the gas constant, the Arrhenius activation energy, dynamic viscosity and the pre-exponential (entropic) factor of the Arrhenius equation for castor oil respectively. The plot of equation (3) is given in figure 3 and the activation energy was obtained from the slope of the Arrhenius plot.

3. RESULTS AND DISCUSSION

In this section, the obtained results for the yield, density, specific gravity and moisture content of the extracted castor oil are analyzed and discussed. This is followed by the discussion on the FTIRcharacterization of the extracted castor oil. The section ends with the analysis and discussion of the results obtained from the dynamic viscosity for the extracted castor oil in the

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temperature range 30°C-60°C and thecalculated activation energy from Arrhenius plot during heat transfer through the extracted castor oil.

The mass of the castor seed upon removal of the shells was found to be 195.0g.The mass of the oil extracted was 43.4g which corresponds to 48 ml. The percentage yield was calculated using equation (1) to be 22.3%.The corresponding density and the specific gravity are 964.4kg/m3 and 0.964 respectively. The moisture content (% water loss) was also calculated using equation (2) to be *0.62%*.When a molecule interacts with infrared radiation, its chemical bond vibrates. The bond can either stretch or bend. Also, the molecules vibrate at a different frequency because their structures are different. In view of this, the functional groups which are finger prints for the associated molecules are assigned absorption frequency band in the spectra presented in figure 1 and the corresponding band assignment extracted from the spectral are given in the following table 1. In this work the prominent functional groups are alcohol, ester, isothiocyanate, alkane, alkene, amine and carboxylic acid.

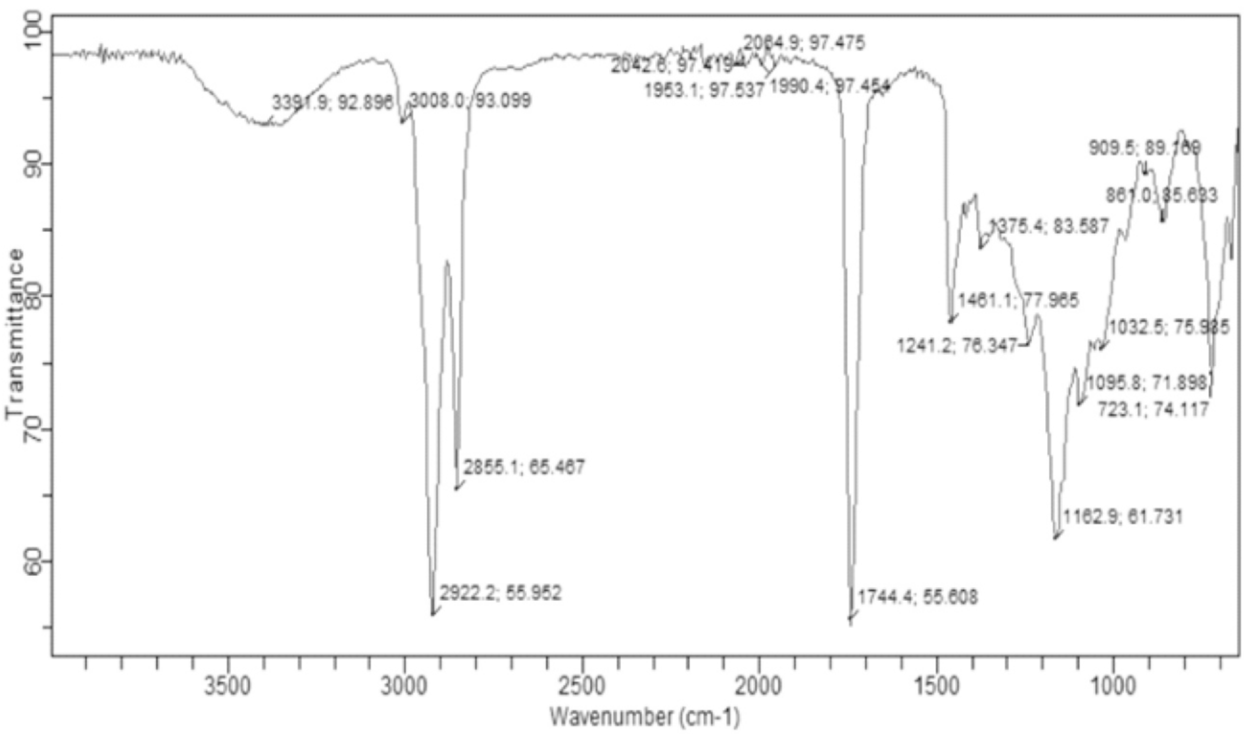

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Figure 1: FTIR Spectra of the extracted castor oil.

Aliphatic primary has an absorption band of *3391.9*cm^{-1} with a medium appearance and the vibration stretches. Alcohol has an absorption band of *3008.0*cm^{-1}, whose appearance ranges from weak to medium. The presence of hydroxyl makes the castor oil a natural polyol providing oxidation stability and preventing peroxide formation with a relatively high shelf life compared to other oils. Alkane has an absorption band that ranges from *2855.1*cm^{-1} to *2922.2*cm^{-1} with an appearance that is strong and the vibration is stretching. Isothiocynate has an absorption band of *2042.6*cm^{-1} to *2064.6*cm^{-1} with a strong appearance and stretching vibration. Allene has an absorption band of *1990.4*cm^{-1} with a medium appearance and a stretching vibration.

TABLE 1: Band assignment of the peaks obtained from the FTIR spectra for castor oil.

Absorption Band (cm^{-1})	Types of Bond	Functional group	Appearance	Vibration
3391.9	Aliphatic primary	N-H	Medium	Stretching
3008.0	Alcohol	O-H	Weak to Medium	Stretching
2922.2	Alkane	C-H	Medium	Stretching
2855.1	Alkane	C-H	Strong	Stretching
2064.6	Isothiocynate	N=C=S	Strong	Stretching
2042.6	Isothiocynate	N=C=S	Strong	Stretching
1990.4	Allene	C=C=C	Medium	Stretching
1953.1	Aromatic compound	C-H	Weak	Bending
1744.4	Lactone	C=O	Strong	Stretching
1461.1	Alkane	C-H	Medium	Bending
1375.4	Alkane	C-H	Medium	Bending
1241.2	Amine	C-N	Medium	Stretching
1162.9	Ester	C-O	Strong	Stretching
1095.8	Secondary alcohol	C-O	Strong	Stretching
1032.5	Sulfoxide	S=O	Strong	Stretching
909.5	Alkene	C=C	Strong	Bending
861.0	Alkene	C=C	Strong	Bending
723.0	Alkene	C=H	Strong	Out-of-plane bending

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Aromatic compound has an absorption band of *1953.1cm*$^{-1}$with weak appearance and has bending vibration.Lactone has an absorption band of *1744.4cm*$^{-1}$with strong appearance and has stretching vibration. Alkane also ranges from *1375.4cm*$^{-1}$to *1461.1cm*$^{-1}$with a medium appearance and the vibration bends. Amines have an absorption band of *1241.4cm*$^{-1}$ with a medium appearance and a stretching vibration. The secondary alcohol with absorption band of*1095.8cm*$^{-1}$appears strong with a stretching vibration. Sulfoxide has an absorption band of *1032.5cm*$^{-1}$ with a strong appearance and stretching vibration. Finally, alkene absorption band ranges from*723cm*$^{-1}$to *909.5cm*$^{-1}$witha strong appearance and bending vibration.

The dynamic viscosity values obtained by scanning the temperature from *30^{o}C -60^{o}C are presented* in figure 2. It is an established fact that all vegetable oils are considered to be Newtonian fluid. In view of this, the results obtained for the viscosity of the extracted castor oil are in good agreement with the established fact in the literatures and it decreases with increasing temperature (Massey *et al.,* 2006). It is noteworthy that the shear rate did not have significant effect on the viscosity for the temperature range considered.The dynamic viscosity of a fluid is directly related to its heat transfer coefficient and dependent on temperature change (Abdelmalik *et al.,* 2016). In view of the above, the viscosity of the extracted castor oil with temperature change is depicted graphically in figure 2. The viscosity decrease of the extracted castor oil with temperature is systematic and it is owed to the increase in the thermal kinetic energy of the constituent molecules of the oil. This in turns reduces the cohesive energy between the constituent molecules and the resistive frictional force acting between the layers of these molecules travelling at different speeds(Abdelmalik *et al.,* 2016).

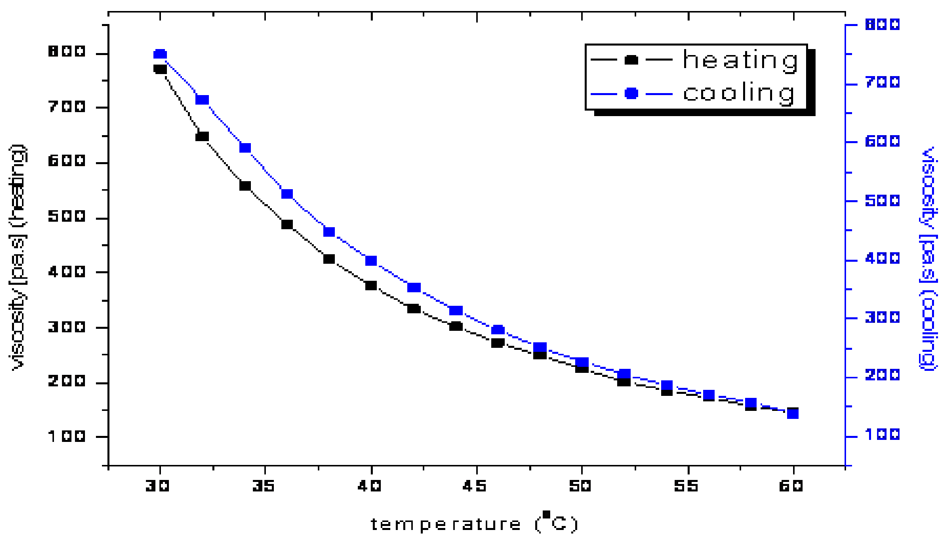

Figure 2: Viscosity against temperature measured during heating and while cooling

The degree of heat transfer through the extracted castor oil with change in its viscosity is illustrated with figure 3 using Arrhenius plot. The calculated activation energy during heat transfer through the extracted castor oil is *0.88eV*. Thus, the influence of temperature on the viscosity of the oil is minimal as evident from the low activation energy during heat transfer through the extracted castor oil. This shows that the thermal velocity acquired by molecules of the oil is small. As such the influence of temperature on the thermal kinetic energy of the molecules is marginal thus revealing that the extracted castor oil is highly viscous.

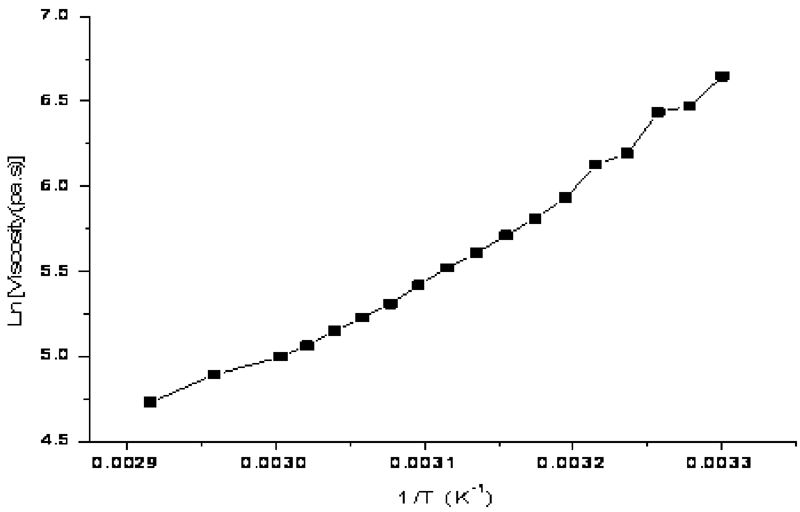

Figure 3:Arrhenius plot for Viscosity change with temperature for Castor oil

4. CONCLUSION

A review of the literatures on mineral and vegetable oils for use as hydraulic fluids has revealed with established facts that vegetable oils are better as hydraulic fluids when benign additives are included because they have good lubricating characteristics compared to mineral oils. Furthermore, it is of great interest to notethat castor oil is a renewable resource because it can be planted all the year round with great resistance to drought and has a favourable outcome on the environment because they are biodegradable and non-toxic. Ultimately, traditional methodhas been employed for the extraction of castor oil and the yield obtained was 22.3% which is equivalent to48ml.As such, it is recommended that for commercial production, this method should be modified to give optimum yield. The moisture content (% water loss) of the extracted castor oil was found to be *0.62%*.The FTIR study revealed the major functional groupsof the extracted castor oil to be in conformity with the standard chemical structure for castor oil. At 40^oC, the dynamic viscosityfor extracted castor oilduring heating was found to be *376 Pa.s* and the corresponding kinematic viscosity is

While during cooling at 40°C, the dynamic viscosity for extracted castor oil was *399 Pa.s* *a*nd the corresponding kinematic viscosity was obtained from the Arrhenius plot to be*0.88eV*.

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