Dependence of Viscosity and Density of Nigerian *Lophira lanceolata* Oil (Ochnaceae) on Temperature

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Authors' contributions

This work was carried out in collaboration between all authors. JBY designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. JSM managed the analyses of the study and correction after review. PT and YMD managed the literature searches. All authors read and approved the final manuscript.

Research Article

ABSTRACT

The viscosity at constant shear rate of 30 rpm and density of *Lophira lanceolata* oil (LLO) were measured at different temperatures. The viscosity at constant temperature, 285 K was measured at different shear rates. The results show that viscosity decreases with both shear rate and temperature and density decreases with temperature as well as while the cubic expansivity increases with temperature. From viscosity measurements, the following parameters: molar activation energy (G = 5.1 kJ/mol), molar volume ($V_m = 11.91 \times 10^{-3}$ m^3), intermolecular distance ($\delta = 2.71 \times 10^{-9}$ m), consistency index (k = 148.4 Pa) and power index (n = 0.9886 ± 0.0054) were determined. Our results and that from previous works show that LLO may be a non-Newtonian liquid, a good lubricant and coolant in non-vehicle engines, desirable inhibitor of corrosion, and has bio-fuel potentials.

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1. INTRODUCTION

A liquid is a body which has definite volume but do not have elasticity of form (absence of a shear modulus). Liquids are distinguished for their strong molecular interactions and as a result, low compressibility. The low compressibility of liquids is evident since small reduction in the already small intermolecular distances give rise to large intermolecular forces of repulsion. In the laboratory, liquids of like colour or odour are usually distinguished by studying their physical properties such as viscosity, density, melting and boiling points.

Lipids or fats are naturally occurring inorganic or organic substances that are not soluble in water. Most fats containing organic materials are made up of carbon, hydrogen, oxygen and some elements like phosphorus. Oils are mostly extracted from living animals and plants as well as their dead remains in rock underground. Viscosity is known to be a good parameter for oil quality control because it is sensitive to small changes in temperature, concentration, homogeneity, shape and size of molecules. For example, the viscosity and density of some pure vegetable oils decrease with temperature (Tabor, 1979; Gyani and Murari, 1956). As the temperature is increased, thermal fluctuations reduce intermolecular cohesion and hence the viscosity. In most organic liquids, the intermolecular forces are Van der waal's forces, which depend on the shape and sizes of the molecules (Finar, 1975; Ekpe, 1975). Liquid flow can be hindered by strong intermolecular attractions and molecular shapes. Long chain liquid polymers resist flow because the chains become entangled with one another during flow. The viscosity of lubricants and their blending agents affects the rate at which the sensitive components suffer oxidation at the surface of the liquid (Adeosun et al., 1997). In this study, we consider the viscosity and density of one of the Nigerian vegetable oils known as *Lophira lanceolata* oil (LLO) at various temperatures.

Nigeria enjoys different kinds of vegetable oils notably palm, peanut, cottonseed and *Lophira lanceolata* oils and has potential to be self-sufficient in these products. The traditional use of the oils has been restricted to cooking and providing fuel for lighting. Occasionally, they are applied as ointment and for medicinal purposes.

Nigeria was a major world exporter of peanut, a major source of peanut oil. Unfortunately, the production of peanut since the early seventy's to date has steadily declined over the years. Consequently, in the markets abound imported vegetable oils instead of the local products. The reason for high demand for imported vegetable oils is that some unpleasant characteristics such as unstable colour and taste, odour, sticky nature, smoky when frying and the source of irritation on the digestive track, have been labeled against the local oils (Perkins and Kummerow, 1958; Utah et al., 1989) Also, it has been reported that when these oils are heated to high temperatures especially in the presence of air, they undergo complex series of reactions that generate volatile and nonvolatile products (Chang et al., 1978; Manji et al., 2007). Among these nonvolatile products are the polymers and the polar compounds (Federico et al., 2003). Other studies show that their risk of health hazards (e.g. hypertension) associated with the intake of cooking oil containing polymers and polar compounds (Supran, 1978). The functional sensory and nutritional quality of fats and oils are also changed during frying and a rejection point may be reached where high quality foods can no longer be prepared in them (Fritsch, 1981).

Industrial uses of the oils have been mainly in the areas of margarine, soap and detergent manufacture. Other uses as in cooling, insulating and lubricating machinery are rare. For example, tailors in Mapeo village, Ganye local government of Nigeria use *Lophira lanceolata* oil as lubricant in their sewing machines and for treatment of skin diseases. The oil

properties will vary according to their use. The wide varieties of industrial applications of LLO have motivated us to study some fluid properties of LLO at various temperatures with the aim to establish whether our theory favours viscosity prediction. It is against this background that the viscosity and density of *Lophira lanceolata* oil (LLO) were measured at different temperatures.

2. EXPERIMENTAL DETAILS

2.1 Measurement of Viscosity at Various Temperatures and Shear Rates

The viscosity, η of *Lophira lanceolata* oil (LLO) at various temperatures (285-343 K) was measured using a computerized rotary viscometer (NDJ-85 model) with its rotor immersed in LLO inside a cylinder C placed in a temperature controlled circulatory water bath. The cylinder containing LLO sample was placed in the bath with its brim above the level of water in the bath but the level of LLO below the water level. Ice was used to cool the sample below room temperature and automatic electric heater H with stirrer attached to the temperature regulator was used to heat it above room temperature. The values of the viscosity of LLO against temperature were determined at a shear rate of 30 rpm. For high accuracy (± 0.5⁰ C), a calibrated thermocouple was placed in the oil to ascertain that the oil was at the same temperature with the water in the bath before readings were taken and contamination of LLO with water and other impurities was avoided.
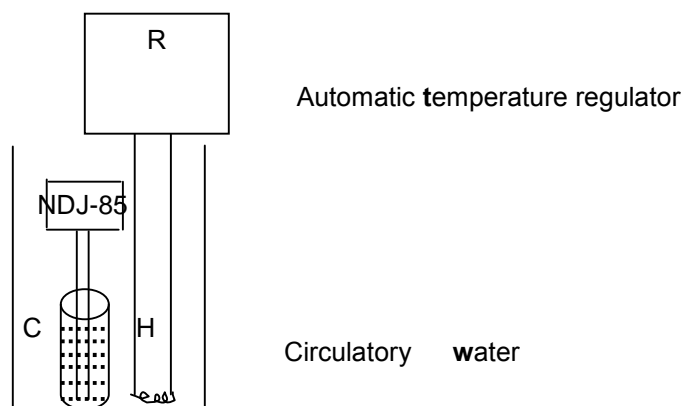

Fig. 1. Schematic diagram for viscosity measurement

The values of the viscosity of LLO at different shear rates in the range 0.3-60 rpm were measured at room temperature (303 K) using the same rotary viscometer described in the experiment. Rotor 1 and 30 rpm were chosen because the viscometer was calibrated by a similar viscometer with type of rotor 1 at 30 rpm for high accuracy.

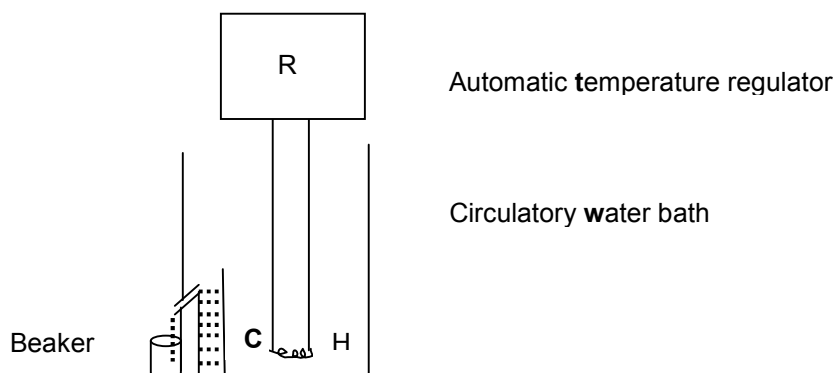## 2.2 Measurement of Density at Different Temperatures

Fig. 2. Schematic diagram for density measurement

The circulatory water bath is in form of an open rectangular box containing an electric heater H with automatic stirrer and temperature regulator R. The small cylinder C of fixed volume (65 ml) is sample container with slanting short open tube connected to the outside through one side of the box. A beaker is placed on top of automatic digital balance of accuracy ± 0.01 g directly below the opening of the slanting tube to collect any excess liquid flowing out from C. On heating, the temperature regulator was set at a particular temperature and the heater connected to power source was used to heat the water in the bath until the LLO in C ceased to overflow into the beaker. The excess mass of LLO collected due to its expansion at this temperature was measured and hence the mass of LLO remaining in C was calculated. The density ρ of LLO at this temperature is calculated from the ratio $\rho = m/V_o$ where m is mass of LLO remaining in C of volume V_o i.e. volume of C. This procedure was repeated for several other temperatures.

3. RESULTS AND DISCUSSION

3.1 Viscosity and Temperature

Table 1 shows the values of the viscosity of LLO against temperature measured at shear rate of 30 rpm. The viscosity of LLO in the temperature interval 285-345 K lies in the range 7.81-0.011 Pa·s. It could be seen that viscosity decreases with increasing temperature.

Table 1 shows that the viscosity of LLO for a given shear rate (30 rpm) decreases nonlinearly with increasing temperature, T. The decrease is very sharp 5 K above and below the room temperature 303 K. This sharp change is more pronounced on cooling 5 K below room temperature than that of heating. This signifies that LLO is very sensitive to temperature. Considering the enormous amount of lubrication performed by the engine oils and the rapid fall of viscosity of LLO with temperature, it is evident that LLO cannot meet the required specification as engine oil. However, for temporary and light duty work e.g. softening textile fabrics and sawn timber LLO should find ready use (presently it is used in sewing machines by tailors in Mapeo-Ganye, Nigeria). Also recent studies (Samuel and Maimuna, 2007) have reported that LLO has bio-fuel/biomass potentials and low flash point. Since it is dangerous for oil in a motor engine to ignite and burn, its low flash point makes LLO unsuitable as engine oil. It has been reported that LLO is non-drying oil and has low

pour point which makes it ready for use as good inhibitor of corrosion and oxidation even at low temperatures. These properties are also good signature that LLO can be used as coolants in transformers and rheostats.

Table 1. Viscosity of LLO (Rotor 1, R = 30 rpm)

T (K)	y (Pa·s)
285	7.81
288	7.21
293	7.02
298	5.81
303	1.41
308	0.10
313	0.098
323	0.061
333	0.032
343	0.011

The viscosity (η) can be related to the temperature (T) by a decreasing exponential function of the form (Barrow, 1960; Berry et al., 1980; Moore, 1983).

$$y = y_o e^{\frac{E}{kT}}$$

where η_o is the viscosity at T =   , E is the activation energy and k is Boltzmann's constant. We can easily deduce from above equation that change in activation energy is given by $\Delta E = k[T_2 \ln\eta_2 - T_1 \ln\eta_1 + (T_1 - T_2)\ln\eta_0]$ or in terms of   G, $G = R[T_2\ln\eta_2 - T_1\ln\eta_1 + (T_1 - T_2)\ln\eta_0]$. Using this equation the values of ΔE were computed and recorded against the mean of temperatures T_1 and T_2 in Table 2. The negative values of ΔE in Table 2 indicates that the activation energy E_2 at higher temperature is less than E_1 at a lower temperature i.e. activation energy decreases with temperature. This means that the energy barrier a layer of LLO needs to overcome to flow over another layer decreases as the temperature increases. However, the value of ΔE for mean temperature 290.5 K (17.5ºC) is positive and this means ($E_1 > E_2$) is likely signature of transition point (probably freezing point) of LLO at about 17.5ºC.

Table 2 shows that change in activation energy decreases sharply to a minimum at 305.5 K and increases to maximum at 310.5 K and again appears to decrease to another minimum beyond the temperature interval. This could mean that on heating the oil decomposes to smaller products with lower activation energy until a new phase or equilibrium is reached. Heating beyond the equilibrium (transition) temperature, the activation energy of the new phase again decreases with temperature seeking a possible second equilibrium temperature.

Table 2. Change in activation energy

Mean Temperature (K)	Change in activation energy ∪E (meV)	Change in molar free energy G (meV)
286.5	3.0	24.9
290.5	7.6	63.2
295.5	3.4.	28.3
300.5	-28.9	-239.6
305.5	-62.3	-521.5
310.5	5.9	-48.9
318	-0.4	-3.9
328	-6.1	50.7
338	-19.7	-163.9

Considering one mole of LLO, the equation relating η and T can be rewritten as (Bird et al., 1960; Das and Rehere, 1983; Rakshit, 1983).

$$\eta = \eta_{om} e^{\frac{G}{RT}}$$

Where η_{om} is the viscosity at T = 0, G is the molar free energy and R is the universal gas constant. Here $\eta_{om} = \dfrac{N_A h}{V_m}$ where N_A is Avogadro's number, h is Planck's constant and V_m is the molar volume with intermolecular distance, $\delta = (V_m/N_A)^{1/3}$. Using least squares, we calculated molar free energy, G = 5.1 kJ/mol, molar volume V_m = 11.91 $\times 10^{-3}$ m^3 and intermolecular distance, $\delta = 2.71 \times 10^{-9}$ m.

3.2 Viscosity and Shear Rate (285 K)

Table 3 clearly shows that the viscosity of LLO decreases with increasing shear rate at constant temperature (285 K).

Table 3. Shear rate (R) and viscosity (η) at 285 K

R (rpm)	η (Pa·s)
0.3	320.8
0.6	209.6
1.5	118.0
3	59.99
6	29.10
12	14.28
30	7.81
60	2.34

The viscosity (η) and the shear rate (dv/dx or simply R) can be related by the equation $\eta = kR^{n-1}$ (Y. David, unpublished results of undergraduate project, Federal University of Technology Yola, 2008) whose linear form is $\log\eta = \log k + (n-1)\log R$, where k is the consistency index and n the power index. Using least squares, we obtained the power index,

n = 0.9886 ± 0.0054 and consistency index, k = 148.4 Pa. Since the power index n = 0.9886 ± 0.0054, it means that LLO is a non- Newtonian liquid within experimental errors.

3.3 Density and Temperature

Table 4 shows that the density of LLO decreases linearly with increasing temperature up to 333 K above which the linearity is no longer perfectly smooth. In contrast, the calculated cubic expansivity, β from density measurements (Table 4) increases with T. This is to say that in the temperature interval studied, the behaviour of β is the mirror image of density. Since β maintains fairly linear relationship within the said temperature interval, it means that in this interval the oil can still be safely and effectively used as lubricants in light machines. However, even though both density and viscosity decrease with temperature, we can clearly see from our results that the viscosity of LLO is a more sensitive physical parameter that can be used to test quality of LLO than its density. The dependence of viscosity of oil on temperature, shape/size of molecules and their arrangement makes it a better parameter for oil quality control than density which depends only on temperature. This implies that the effect of the change in shape/size of molecules of LLO and their configuration due to thermal degradation is more than that of expansion. That is, on heating, both expansion and alignment of molecules affect viscosity unlike density which is affected by only expansion (increase in intermolecular distance).

Table 4. Density of LLO (V_o = 65 ml = $6.5 × 10^{-6}$ m^3)

T (K)	Δm (g)	M (g) = M_o - Δm ± 0.01	ρ (kgm^{-3}) ± 0.31	$\beta × 10^{-5}$ (K^{-1})
303	0.00	110.32	1696.92	-
315	0.06	110.26	1695.38	7.5
319	0.27	110.05	1693.85	46
323	0.53	109.97	1689.23	113
328	0.85	109.47	1684.62	146
333	1.17	109.15	1680.00	201
338	1.37	108.95	1675.38	257
343	1.52	108.80	1673.85	275
348	1.97	108.35	1667.69	351
353	2.00	108.32	1666.15	369
358	2.24	107.92	1660.00	445

4. CONCLUSION

We have measured the viscosity of *Lophira lanceolata* oil (LLO) at varying shear rates and temperatures as well as density at different temperatures using standard laboratory methods for comparative studies. The density and viscosity decrease with increasing temperature. On the other hand, the calculated volume expansivity from observed values of density increases with temperature. Other parameters deduced from measured viscosity values include change in activation energy, molar activation energy, molar volume, intermolecular distance, consistency index and power index. There is still room to improve on the results. Therefore, we recommend investigations of chemical properties of LLO such as its saponification value, iodine value, percentage of free fatty acids, peroxide value and so on.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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