

RHEOLOGY OF GMELINA AND RUBBER SEEDS OIL LUBRICANTS

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ABSTRACT: Rheological behavior of gmelina (*Gmelina arborea*) and rubber (*Hevea brasiliensis*) seed oil was investigated. Oil samples were generated from gmelina and rubber seeds. Dynamic viscosity of the oil samples was measured using Baird Brookfield rotational viscometer at different shear rates and temperatures. Rheological properties were obtained by transforming the viscosity values obtained using the formalized equations of state for oil lubricants. Results obtained showed that the oil samples were shear rate thickening and dilatant fluids; a common feature of oil lubricants of mineral oil origin. Gmelina and rubber seed oil can be used as alternative lubricants in light engineering applications and may also be upgraded for normal engineering applications.

Keywords: energy market, reactive power market

INTRODUCTION

The lubricant, which is an intermediate material separating two interacting surfaces, is amenable to technological substitution. Mineral oil base lubricants predominantly in use have well-established rheological behavior, which is suited for lubrication of engineering mechanisms. Substitution of these lubricants with natural oils such as gmelina and rubber oils will lead to increased consumption of widely cultivated agricultural crops. The study addresses oil lubricants from natural oils obtained from botanical plants. Natural oil source is considered regenerative and renewable through improved agricultural techniques.

The natural oils of interest are, oil from para rubber seeds (*Hevea brasiliensis*) and oil from gmelina seeds (*Gmelina arborea*). The choice was informed by abundance of rubber and gmelina plantations in the southern and middle belt parts of Nigeria (Onucheyo, 1998). Rubber and gmelina trees are useful economic trees that provide logs for the building and electricity industry, and rubber for automobile and other industries.

An oil lubricant should maintain the integrity of interacting surfaces under operating conditions of sliding speed, contact pressure, temperature and humidity, and atmospheric cleanliness (Czichos, 1978). Ability of the oil lubricant to perform this function is determined by its viscosity that changes with temperature, load, speed and pressure. Oil lubricants are classified by the response of viscosity to shear stress at any given temperature. Oil lubricants are classified into Newtonian (constant shear stress to shear rate at any given temperature) and non-newtonian flows. Rheology which is the science that deals with the deformation and flow of materials is used to characterize oil lubricants behavior.

The rheology of oils are highly influenced by changes in temperature emphasized by a variant of Arrhenius equation based on the idea that flow will occur if a molecule has sufficient thermal energy to change its site relative to neighboring molecules (Hutton, 1973 and Tabor, 1982). Thus;

$$\eta = K \exp \left(-\frac{E_a}{RT} \right) \text{-----(1)}$$

Where,

η - Measured viscosity

K – Apparent viscosity at reference temperature

T – Absolute temperature

Ea – Activation energy

R – Universal gas constant (8.3143 Jk⁻¹ mol⁻¹)

Activation energy which is the energy required to activate molecular flow can be determined according to (Tabor, 1982) from the slope of viscosity-reciprocal absolute temperature curve for the oil.

A lubricant during the lubrication process will be subjected to high shearing stresses and velocity gradients. The plain journal bearing model adapted for this study is characterized by the rheological relationship (Fuller, 1984).

$$\tau = \eta \, dv/dh \text{ -----(2)}$$

Where,

τ - Shear stress

V – Velocity

dv/dh – Velocity gradient or shear rate

h – Radius of channel

η - Dynamic viscosity

For the plain journal bearing, the rotating journal drags oil into the wedge shaped clearance by virtue of oil viscosity and the shear stress, τ .

$$\tau = 2 \pi r N \eta / C \text{ -----(3)}$$

Where, N – Speed of shaft

r – Shaft radius

η – Dynamic viscosity

C – Diametrical clearance between shaft and bearing

Torque generated by the shaft is

$$T = 4 \pi^2 r^3 L N \eta / C \text{ -----(4)}$$

Newtonian flow is characterized by the Newtonian equation

$$\tau = \eta r \text{ -----(5)}$$

where,

τ - Shear stress

η - Dynamic viscosity

r – Shear rate i.e. dv/dh.

Non –Newtonian flow is subdivided into the following groups, Bingham plastics, quasi-viscous flows and quasi-plastic flows.

Quasi - viscous flow has non-linear relationship between shear stress and shear rate and is represented by the following Ostwald –de Waele equation (Mc Cabe et al., 1985).

$$\tau = K r^n \text{ -----(6)}$$

Where,

K - Apparent viscosity;

n– Flow behavior index or power-law

Flow can be pseudoplastic or dilatant. In pseudoplastic flow, the curve passes through the origin, is concave downwards at low shears and becomes linear at high shears. The power – law is less than one ($n < 1$).

In dilatant flow, the curve is concave upward at low shears and becomes linear at high shears. The power – law is greater than one ($n > 1$).

Pseudoplastics are said to be shear rate thinning, dilatant and shear rate thickening (Hutton, 1973, Taylor, 2002, Spence and Middleton, 1973 and Scales, 1999).

The behavior of the lubricant in actual service depends strongly on the presence and influence of the boundary layer hence oil lubricant flow is also referred to as boundary layer flow with the boundary layer effect assumed across the entire flow channel. The significance of rheology in lubrication is partly because many lubricating oils manifest elasto-viscous (i.e. non- Newtonian) behavior under operating conditions based on previous rheological history and present response. The viscosity will decrease rapidly with time of shearing and the behavior will become non-

Newtonian even when it was not so originally (Walters, 1973 and Barnes et al., 2003). Rotational viscometers, capillary viscometers, falling sphere viscometers and efflux viscometers are commonly used to measure viscosity.

Mineral oil base lubricants predominantly in use are often scarce as a result of difficulties in exploitation and processing. So, research on natural oils for possible replacement is desirable. Most work done in the rheology of natural oils has culinary relevance and not lubrication. It is therefore necessary to establish the rheological behavior of rubber seeds and gmelina seeds oil with relevance to lubrication if these oils are to successfully replace conventional mineral base lubricants.

MATERIALS AND METHODS

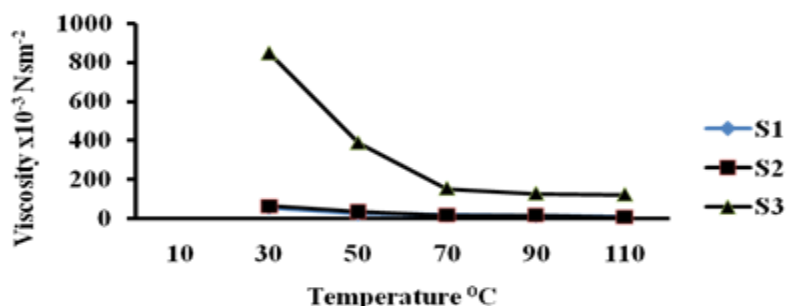
The following test oil samples were generated from gmelina and rubber seeds oil for determination of rheological behavior of oils. A reference standard mineral oil lubricant (EPSAE85W/140) was also used in the ratio proportions.

The samples were individually placed in the sample holder of a Brookfield rotational viscometer (model LV8). The spindles (No 1 and No 4) were immersed to the set points. The temperature of the samples was normalized at 30°C, 50°C, 70°C, 90°C and 110°C each in a hot water bath for 30 minutes before switching on the viscometer. Five spindle speeds (3rpm, 6rpm, 12rpm, 30rpm and 60rpm) were used to achieve five different shear rates and the viscosity was recorded. Rheological relationships were determined using equations 1-6.

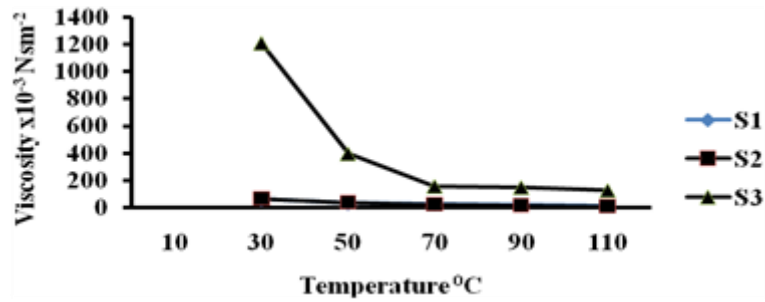
RESULTS AND DISCUSSION

The results obtained for rheological behavior of oil samples for five speeds and temperature ranges are presented in Figs. 1– 3. Dynamic viscosity values were transformed to obtain the three relationships of interest including, viscosity – temperature, shear stress - shear rate and viscosity - shear rate. Various degrees of relationships were established for the deformation and flow behavior of the oil samples shown in Figs. 1-3. In the figures, viscous shear stress and dynamic viscosity increased with rise in shear rate for the natural and reference oils.

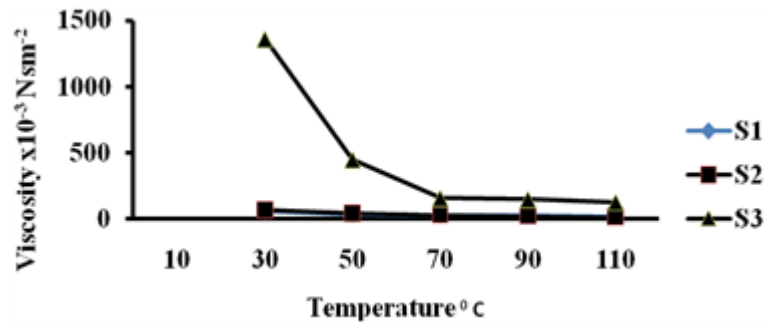
Rheograms of viscosity against temperature for oil samples are shown in Fig. 1. Values obtained for the gmelina and rubber seeds oils were so close that the rheograms assumed the same profile. Viscosity dropped with rise in temperature as the hydrocarbon molecules interacted less and vibrated more. The viscosity of the reference oil (a polymer treated oil) at higher temperature was higher than for natural oils. The viscosity difference was maintained at higher shear rates. Response of viscosity to change in temperature was lower for gmelina and rubber seeds oil i. e. viscosity index was apparently higher than that of the reference oil that had an initial viscosity of $850 \times 10^{-3} \text{ Nsm}^{-2}$ for 3rpm at 30°C and dropped to $120 \times 10^{-3} \text{ Nsm}^{-2}$ at 110°C. At the same speed of 3rpm, rubber seed oil started with a viscosity of $55 \times 10^{-3} \text{ Nsm}^{-2}$ at 30°C and ended with $6.5 \times 10^{-3} \text{ Nsm}^{-2}$ at 110°C. Gmelina seed oil had a viscosity of $61 \times 10^{-3} \text{ Nsm}^{-2}$ at 30°C and ended with $4.8 \times 10^{-3} \text{ Nsm}^{-2}$ at 110°C. The rapid drop in viscosity of the reference oil as the temperature rose was possibly due to the presence of polymer molecules in the oil lattice that experienced atomic segregation once their activation energy level was reached giving the oil lubricant the viscosity-temperature behavior of the base oil. Rheograms obtained at 6rpm and 12rpm gave the same profile. The natural oils would perform better during machine start up as activation energy required is lower with lower interlayer friction in the oil lubricant. Boundary lubrication regime during start up is expected to be longer for gmelina and rubber seeds oils and shorter for the reference oil.



(a)



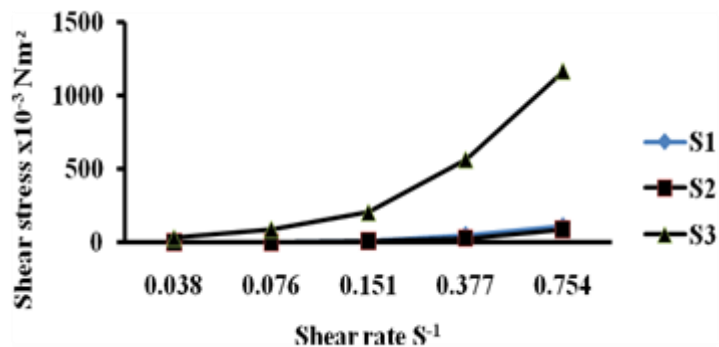
(b)



(c)

Figure 1. Dependence of viscosity on temperature for rubber (S1), gmelina (S2) and EPSAE 85W/140 (S3) oil samples at (a) 3rpm (b) 6rpm (c) 12rpm

Fig. 2 shows rheograms of shear stress against shear rate for natural and reference oils. All oil samples showed an increase in viscous shear stress with rise in shear rate. The increase was attributed to increase in molecular interaction and decrease in vibration of the molecules as shear rate increased (Walters, 1973). The oils therefore belonged to the shear rate thickening grade/group. This is an important characteristic in lubrication as it shows the ability of the lubricant to retain a hydrodynamic film at increasing shear rates. Power law index increased with rise in viscous shear stress and shear rate at different test temperatures. The higher the power laws, the higher the deviation of the fluid from Newtonian behavior. Thus, this deviation possibly caused by atomic stacking is a source of interlayer friction in the oil. Atomic stacking and molecular segregation accounts for some failures experienced in actual service lubrication especially when using multigrade lubricating oils.



(a)

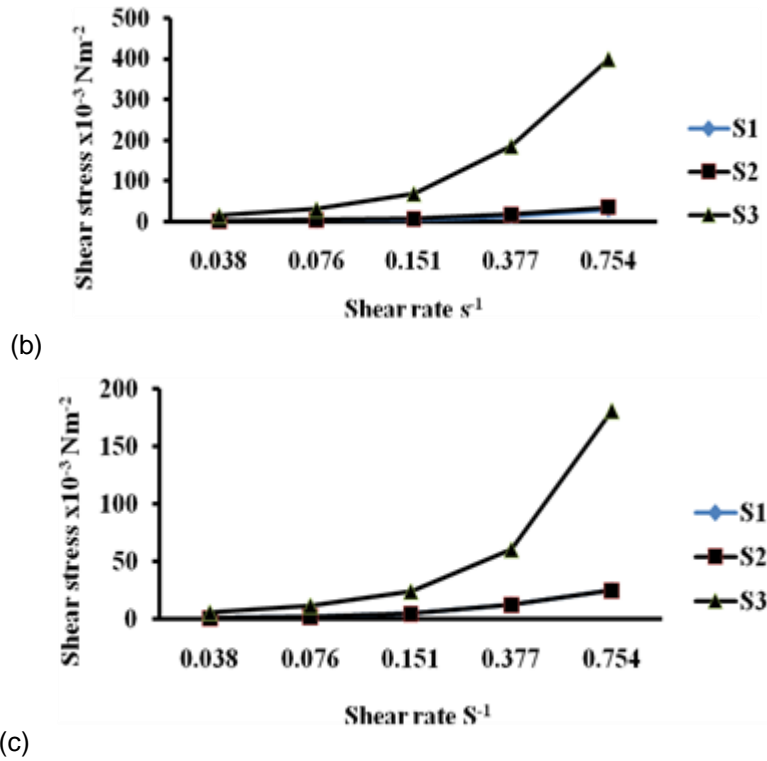
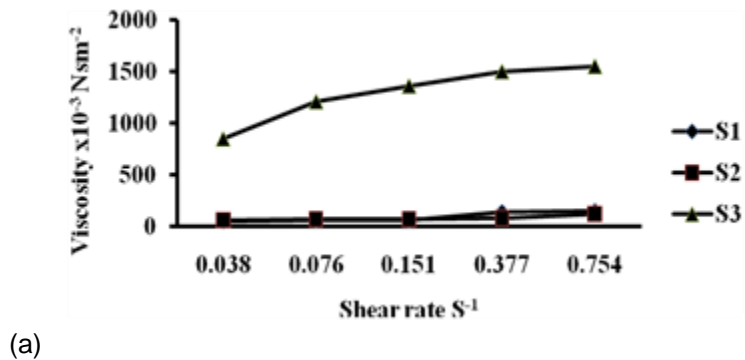


Figure 2. Dependence of shear stress on shear rate for rubber (S1), gmelina (S2) and EPSAE 85W/140 (S3) oil samples at (a) 30°C (b) 50°C (c) 70°C ($n > 1$ for all oil samples)

Fig. 3 shows rheograms of viscosity relationship to shear rate for the oil samples at different temperatures. Increase in viscosity with rising shear rate of the oil samples resulted in increase in viscous shear stress. Similar results were obtained with mineral base colloidal oil lubricants by references (Mc Cabe et al., 1985 and Barnes et al., 2001). The reference oil had initial higher viscosity of $850 \times 10^{-3} Nsm^{-2}$ at 30°C and rose at about the same rate as the natural oils as the shear rate increased. However, at 70°C a rise in viscosity of the reference oil from $160 \times 10^{-3} Nsm^{-2}$ at $0.377s^{-1}$ to $420 \times 10^{-3} Nsm^{-2}$ at $0.754s^{-1}$. This could also be attributed to atomic stacking and molecular segregation due to centrifugal effect. In actual service, adverse operating condition could lead to degrading of the polymer in the polymer-treated multigrade lubricating oil and consequent increase in the oil's apparent viscosity (Slimming et al., 1973).



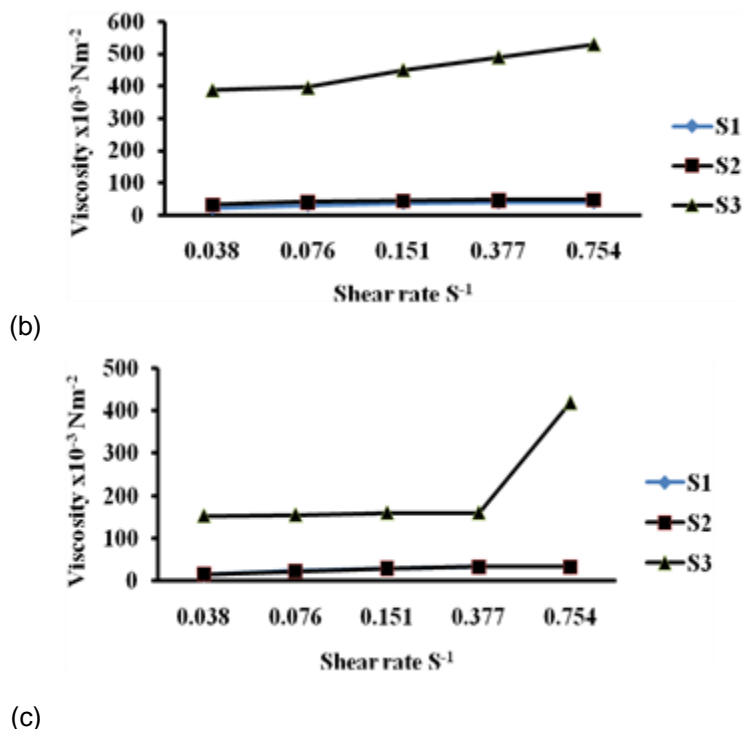


Figure 3. Dependence of viscosity on shear rate for rubber (S1), gmelina (S2) and EPSAE 85W/140 (S3) oil samples at (a) 30°C (b) 50°C (c) 70°C

Table 1. Power laws (flow indices) for rubber (S1), gmelina (S2) and EPSAE 85W/140 (S3) oil samples at different temperatures and shear rates

Temperature °C	Shear Rate S ⁻¹	S1	S2	S3
	0.038	1.0109	1.0098	1.1286
	0.076	0.0111	1.0125	1.2416
	0.151	1.0139	1.0162	1.3746
	0.377	1.0703	1.0351	1.7489
	0.754	1.2616	1.2084	3.5672
0.038		1.0082	1.0092	1.1197
0.076		1.0098	1.0114	1.2263
0.151		1.0129	1.0153	1.3508
0.377		1.0655	1.0311	1.7027
0.754		1.2476	1.1902	3.4086
0.038		1.0082	1.0095	1.1132
0.076		1.0093	1.0119	1.2128
0.151		1.0125	1.0143	1.3313
0.377		1.0597	1.0339	1.6620
0.754		1.2243	1.1813	3.2609

CONCLUSION

Viscosity-temperature, shear stress-shear rate and viscosity-temperature rheograms for rubber and gmelina seeds oils established the proximity of these oils to that of mineral reference oil. The natural oils and reference oil are shear rate thickening and therefore

amenable to upgrading for better lubrication performance under boundary and hydrodynamic lubrication conditions.

REFERENCES

Barnes HA, Hutton JF and Walters K. 2001. An Introduction to Rheology, Oxford, Elsevier Science.
 Czichos H. 1978. Tribology; A systems Approach to the Science and Technology of Friction, Lubrication and Wear; Tribology Series 1, New York, Elsevier Scientific Publishing Company. 200Pp.

- Fuller DD. 1984. Theory and Practice of Lubrication for Engineers, New York, John Wiley and Sons. 180pp.
- Hutton JF. 1973. A Limitation on the Use of Cone-and-Plate Rheometers For the Study of Grease Rheology. In: The Rheology of Lubricants, ED Davenport, T. C., England, Applied Science Publishers Limited. Pp 108-117.
- McCabe WL, Smith JC and Harriott P. 1985. Unit Operations in Chemical Engineering, 4th Ed, New York, McGraw-Hill Book Company. Pp. 447 – 559.
- Onucheyo E. 1998. Political Decisions in the Nigerian Agricultural Industry, Zaria, Nigeria, Tamaza Publishing Company. 10p
- Scales LE. 1999. Quantifying the Rheological Basis of Traction Fluid Performance, SAE 1999- 01-3610.
- Slimming PN, Craill IR and Hattersley PJ. 1973. Low Temperature Rheological Properties of Polymer Treated Lubricating Oils. In: The Rheology of Lubricants, ED Davenport T.C., England, Applied Science Publishers Limited. Pp. 48 – 65.
- Spence JA and Middleton DES. 1973. The Rheological Stability of Crank-Case Lubricants. In: The Rheology of Lubricants, ED Davenport, T.C., England, Applied Science Publishers Limited. Pp.42 – 47.
- Tabor D. 1982. The role of surface and intermolecular forces in thin film Lubrication. In : Microscopic Aspects of Adhesion and Lubrication, Tribology, series 7, ED Georges, J.M. New York, Elsevier Scientific Publishing Company. Pp. 651 – 679.
- Taylor I. 2002. Car Lubricants: Fact And Fiction, Physics World, IOP Publishing Limited, UK.
- Walters K. 1973. New Concepts in Theoretical and Experimental Rheology. In: The Rheology of Lubricants, ED, Davenport, T.C., England, Applied Science Publishers Limited. Pp1-15.