CASTOR OIL : A BIODEGRADABLE EXTREME PRESSURE AND ANTIWEAR LUBRICANT

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ABSTRACT

Castor oil, extracted from natural castor seed and mineral extreme pressure and antiwear lubricant, HD-90 gear oil were tested on a four ball machine. The test modes include : load, temperature, wear and seizure tests in sixty (60) seconds duration. The assessment criteria are: friction transients, surface temperature, flash temperature, wear scar diameter, and load capacity.

The results showed that natural castor oil apart from being biodegradable possessed extreme pressure and antiwear properties superior to one mineral gear oil HD 90 (A), though inferior to HD 90 (B). Also, the results suggests that the lubricant film in castor oil consisted of jelly brush-like polar molecules of fatty-acid (mainly recinoleic acid) oriented vertically to the surface - giving rise to static friction values which decreased with increasing load unlike the mineral gear oil. In the latter, lubricity is derived from the extreme pressure and antiwear additives in the mineral oil adhering to and / or reacting with the surface to form a protective laminar independent of the load, except transition is attained.

1.0 BACKGROUND

Environmental pollution, a threat to global peace and health is compounded by the craze for industrialisation and technological advancement in recent times. The disposition of the wastes derived from mineral oil lubricants is not unconnected with this pollution toll. This has encouraged researches into the re-refining of these wastes with a view of re-cycling and re-using them. This aposteriori investigation is directed at fighting the effect rather than the cause of this pollution menace. This has spurred recent researches into biodegradable lubricating oils which could be consumed by aquatic and terrestrial life; such oils pose far less waste disposal problems.

Clayton (1937) showed that vegetable oils possessed interesting extreme and antiwear properties. Bowden and Tabor (1974) indicated that the use of vegetable oils as lubricant dates back to the 3500 BC in the lubrication of chariot wheels. Infact, lubrication practice started with man's realisation that it is easier to move heavy objects on rollers or by pouring oil between the moving parts to reduce body-to body contact and hence the resistance to motion.

Odi-Owei (1989) showed that some natural oils possessed tribological properties superior to those of mineral oils. In the study, coconut and groundnut Oils have superior fatigue resistance compared to HD 90 mineral gear oil. The antiwear characteristics of Palm kernel (distilled fatty acid) oil are comparable to that HD 90 mineral gear oil. Hydrogenated fats of palm oil and soyabean oil have antiwear properties superior to HD 90 gear oil. The load capacity for hydrogenated soyabean, palm fats and top fraction fat are 90 Kg, 94 Kg and 140 Kg respectively, as compared to 90 Kg for HD 90 gear oil.

The investigations of Odi-Owei and Ebere (1990) revealed interesting results on the lubricity of palm-oleine as a potential boundary lubricant. In another study, Ossia et al (1996) obtained results which showed that castor oil possessed extreme pressure, antiwear and lubricity properties superior to a typical SAE 90 mineral oil. In the present study, the prospects of natural Castor oils in extreme pressure and antiwear applications are further examined.

2.0 METHODOLOGY

The tests were performed to IP 239 / 79 standards. Firstly, the upper collet ball is mounted on the machine spindle after connecting the motor and autograph to the supply grid. The machine is run without load for about fifteen (15) minutes while test balls and ball-housing are washed with petroleum spirit. The lower balls are locked in the steel cup housing and the test oil is introduced therein to sufficiently cover the balls.. The ball housing is mounted on the lower bearings attached to the piston of the hydraulic loader. The recorder spring is connected to the torque arm and tensed in the opposite direction by a 10 gm weight suspended through a small pulley.

The desired test load is applied on the lower balls by means of the plunger of the hydraulic loader. The load thus applied is read on a gauge as the load pressure, P and the true load, W is determined by the relationship

$$W = 0.1816P - 7.0 \qquad (1)$$

The recorder is started and allowed to run for 5 seconds to create the friction base line. The motor and autographic recorder are started simultaneously and run for 60 seconds . At the end of the test, the load is released; autographic recorder is disconnected from the torque arm and the steel cup housing is dismantled. The test balls are washed with the solvent before wear scars are marked with an indelible ink. The three lower balls are removed from the housing and the wear scars are measured with the optical microscope in two orthogonal directions. The oil temperature is also recorded just at the end of the test. The procedure is repeated with a fresh load on a new set of balls. All the tests were performed at a sliding speed of 0.59m/s and initial oil temperature of 30^0 C

3.0 RESULTS AND DISCUSSIONS

3.1 LUBRICITY

Good lubricant lubricity is characterised by low friction coefficients. Rozeanu (1975) showed that friction transients are associated with very dangerous damage on the surfaces of the mating pairs. The scholar indicated that the severity of conditions during these transients could be 2-3 times greater than that of the steady state. Friction transients in tribological investigations are indicative of lubricant film breakdown (onset of seizure).

From figures 1, 2, and 3 there is a negative linear correlation between static friction coefficient and load. The product moment of correlation coefficient (r) being -0.66 and -0.17 for castor oil and HD 90 (B) mineral gear oil respectively. This suggests that shearing of lubricant films, rather than adhesive metallic junctions and plastic deformation is responsible for this phenomenon. There is stronger cohesion between the metallic soap (lubricant) film molecules adhered to the friction pairs such that the film behaves like a sponge, making asperity penetration more difficult at higher loads. Hence, real contact area decreases instead of increasing with load. The reverse is the case at lower loads since low cohesion between the lubricant film molecules make asperity penetration easier with consequent increase in the real metal-to-metal contact area.

3.2 EXTREME PRESSURE AND ANTIWEAR PROPERTIES

From figures 4 and 5 mineral gear oil - HD 90 (B) showed superior antiwear properties compared to castor oil. However, this property is more stable in castor oil than the mineral gear oil; illustrated by the smaller slope of wear curves in the mild wear regimes. Of the test oils in figure 4 castor oil antiwear property is the most stable, followed by the mineral gear oils HD 90 (A) and (B). The two mineral gear oils exhibited the same antiwear stability. Previous investigations by Ebere (1988) had shown that Palm oleine gave the worst antiwear stability characteristics. Utilisation of this oil in variable load conditions could be very dangerous. It is worthy to note that castor oil showed antiwear property superior to the mineral gear oil HD 90 (A).

From figure 6, there is a remarkable difference in load capacity of the two mineral gear oils which are of the same make. The difference is attributable to age; HD 90(A) being ten (10) years older than HD 90(B). This effect of age on lubricant behaviour or performance, particularly in the tropics provides enough scope for further research. Figures 1, 2, 3, 4, 5, 7, and

8 show that seizure is associated with increased wear, wear rates, flash and surface temperatures, as well as steady state friction; but reduced contact pressure. The maximum hertzian pressure, P_H and hertzian diameter, D_H are derived from hertzian theory as :

$$P_H = 0.9954W^{\frac{1}{3}} \quad (2)$$

$$D_H = 0.0876W^{\frac{1}{3}} \quad (3)$$

The contact pressure P_C is derived as :

$$P_c = 5.0992\frac{W}{d^2} \quad (4)$$

The flash temperature, ΔT_f and surface temperature, T_S for figures 7 are derived from Archard (1959) theory as :

$$\Delta T_f = \frac{0.435NL}{\sqrt{L}+0.87} \quad (5)$$

$$T_s = T_o + 1.11\Delta T_f \quad (6)$$

where $L = 0.86277W^{\frac{1}{2}}$ .... (7)

and $N = 217.3205\mu$ .... (8)

In the derivations above, relevant physical and mechanical properties of the steel test balls are as given in tables 1 and 2. The wear volume, V and wear rates, K_r in figure 5 are given by equations 9 and 10 respectively

$$V = 0.0465d^4 - 1.31048Wd \quad (9)$$

$$K_r = 7.02965*10^{-6}\frac{V}{W} \quad (10)$$

Earlier, Ebere (1988) tested some other natural oils using the same machine, type of balls and test duration. The load capacities of the test and those of the present investigation are in shown in figure 6

3.4 EFFECT OF BOND ENERGY

Figure 9 indicates that castor oil has the highest bond energy while HVI 500 N had the least among the non-additive oils studied. From the figure, there is a positive linear correlation between bond energy of the test oils and load capacity. The product moment of correlation coefficient (r) is 0.81. The higher the bond energy of the non-additive test oils, the higher its load bearing capacity. This explains how hydrogenation can improve the load capacity through saturation (hence, Iodine value reduction) of the natural oil.

Natural vegetable oils properly blended are good substitutes for mineral based lubricants. In this regard, the choice of natural oils and hence their percentage composition should be governed by the bond energy and molecular weight as well as the fatty acid percentage composition. Blending of natural oils with higher percentage of long chains saturated fatty acids or higher bond energy fatty acids could be yield satisfactory lubricating oils.

These results agree with those other investigations. Arizmendi et al (1985) studied the effect of chain length of hydrocarbons on their lubricating properties. In the study, friction and wear values found by the use of mineral oils with the same nominal viscosity at 38° C and similar viscosity index depends on the molecular weight distribution of the oil constituents. The results showed that oil blends with higher percentage weight of light component (low molecular weight component) exhibited higher friction coefficient and lower load capacity. In a similar study Jahanmir (1985) used carboxylic acids and normal alcohol with 12 - 18 carbon atoms in the chain as additives in n-hexadecane base lubricants. The results showed that the friction coefficient of the test oils reduced as the sliding speed increased regardless of the presence of an additive. For particular speeds the friction coefficient reduced with increasing concentration of hexadecanol in hexadecene until a steady state value is attained at lower speeds than for higher ones. Friction coefficient was observed to decrease with increasing number of carbon atoms of the acid or alcohol.

All the above results could be explained by the role of marangoni effects in lubrication. Marangoni effects promote the migration of heavier components with higher surface tension away from the contacts. The proportion of lighter components at the contacts area increases with substantial viscosity reduction and subsequent lubricant film breakdown. Unichema (1987) showed that the viscosity of a mixture of fatty acids depends on the average chain length. Therefore, there is oxide film formation (with lubrication film breakdown) which inhibits wear at the contact area. The superiority of the extreme pressure and antiwear properties of castor oil over those of other natural oils studied is therefore derived from its high bond energy; which in turn is due to the high percentage of the high molecular weight ricinoleic acid present in it.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The foregoing results and discussion informs the conclusions that:

- Natural castor oil possesses lubricity characteristics just below transition which are superior to mineral gear oils HD 90(A) and HD 90(B).
- Natural castor oil is more stable in tribological applications than mineral gear oil HD 90 (A) and HD 90 (B).
- The extreme pressure and antiwear properties of castor oil exceeded that of mineral gear oils.
- Natural vegetable oils with higher bond energy, chain length and higher percentage of high molecular weight component showed better extreme pressure properties. The load capacity correlates linearly positive with bond energy of the test oils.
- Two wear regimes (mild and severe) are observed with a transition associated with increased wear, wear rates, friction coefficient, contact pressure, flash and surface temperatures.
- The load capacity of lubricating oils could reduce appreciably with the age of the oil.
- Natural Castor oil (non-additive), a biodegradable oil is a good substitute for heavy duty mineral lubricating gear oils. Its extreme pressure and antiwear performance could however be boosted further by hydrogenation and other additives.

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NOTATIONS

Symbols	Nomenclature	Units
D_H	Hertzian diameter	mm
K_r	Wear rate	mm^2/N
L	Dimensionless speed parameter	—
N	Archard's proportionality constant	^oK
P	Load pressure	KN/m^2
P_c	Contact pressure	MN/m^2
P_H	Maximum hertzian pressure	GN/m^2
T_o	Bulk oil temperature	^oC
T_s	Surface temperature	^oC
ΔT_f	Flash Temperature	^oC
V	Wear Volume	mm^3
W	Applied Load	Kg
d	Wear scar diameter	mm
r	Product moment of correlation coefficient	--
m	Coefficient of friction	--
CO	Castor oil	
NPO	Natural palm oil	
RPKO	Refined palm kernel oil	
NCO	Natural coconut oil	
PO	Palm oleine	

TABLE 1 : Composition and Specifications of EN 31 steel ball (Madhi, 1981)

Surface roughness (Ra)	0.04		
Hardness (H)	$8.041 * 10^9$ [N/m^2]		
Poisson ratio (n)	0.28		
Young's modulus (E)	$208.9 * 10^9$ [N/m^2]		
Chemical composition:			
Carbon (C)	1.05;	Sulphur (S)	0.028
Silicon (Si)	0.23;	Phosphorous (P)	0.03
Manganese (Mn)	0.73;	Nickel (Ni)	0.23
Chromium (Cr)	1.50;	Molybdenum (Mo)	0.21

TABLE 2 : Physical Properties of Steel Balls (Fein, 1959; Popov, 1989; Ebere, 1988)

Thermal diffusivity (k)	$0.12 * 10^{-4}\ m^2/s$
Yield strength (P_m)	$1035 * 10^6\ N/m^2$
Density (ρ)	$7.83 * 10^3\ Kg/m^3$
Specific Heat Capacity (C)	$0.456 * 10^3\ J/kg^oC$
Mechanical Equivalent of Heat (J)	4.1868 J/cal

Figure 1 : Static Friction Coefficient (U) of the Castor Oil [CO] and Mineral Oil HD90 (B) Oil [HDB]

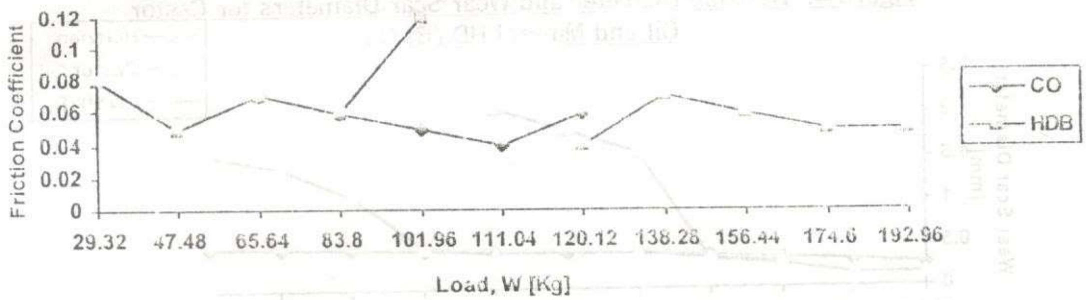

Figure 2 : Friction Transients Versus Load Curve

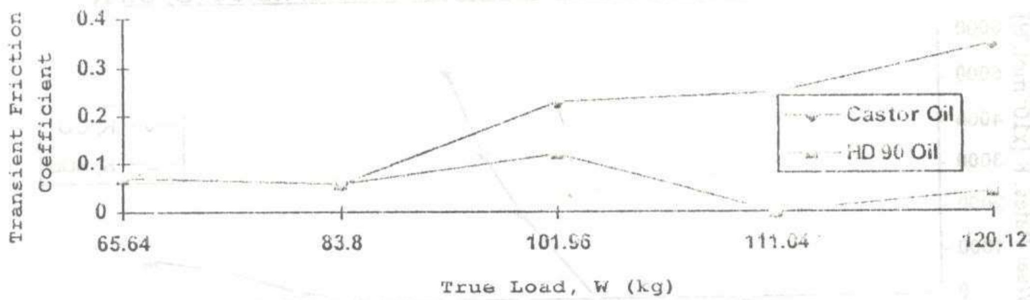

Figure 3 : Steady state friction coefficient (u) of the Castor Oil[CO] and mineral HD90 (B) oil [HDB]

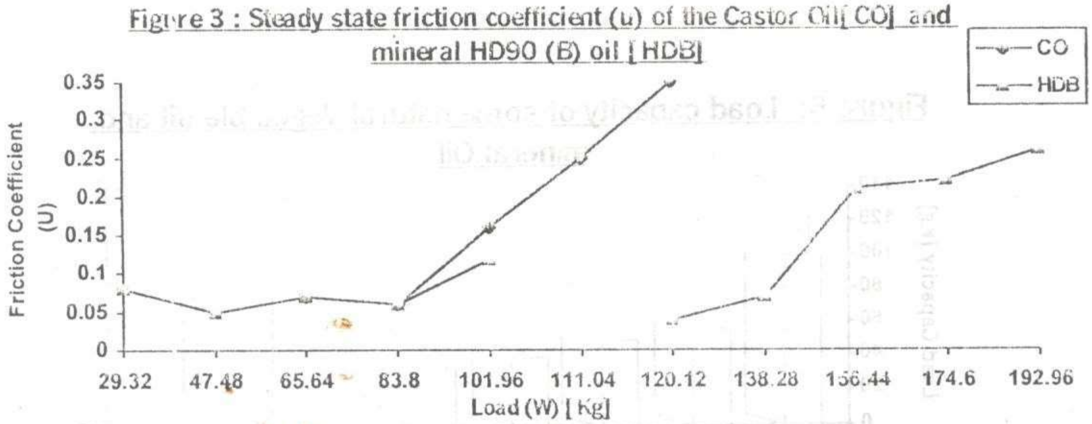

Figure 4: Hertzian Diameter and Wear Scar Diameters for Castor Oil and Mineral HD (B) Oil

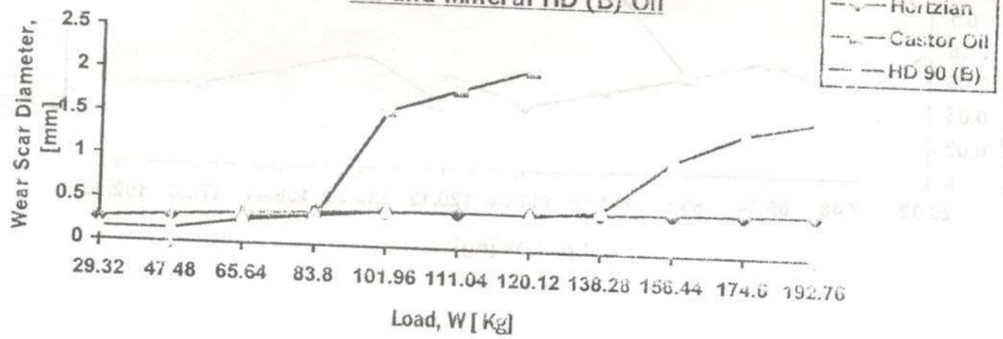

Figure 5: Wear Rates of Castor Oil and Mineral HD 90 (B) Oil K,

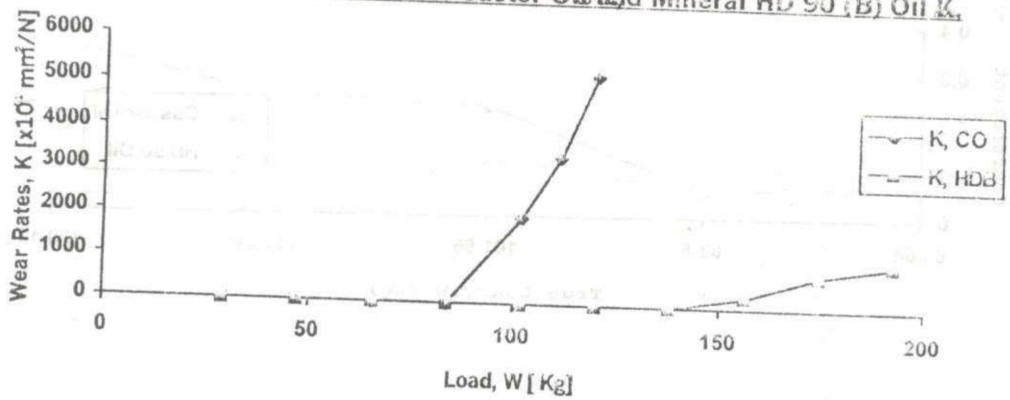

Figure 6: Load capacity of some natural Vegetable oil and mineral Oil

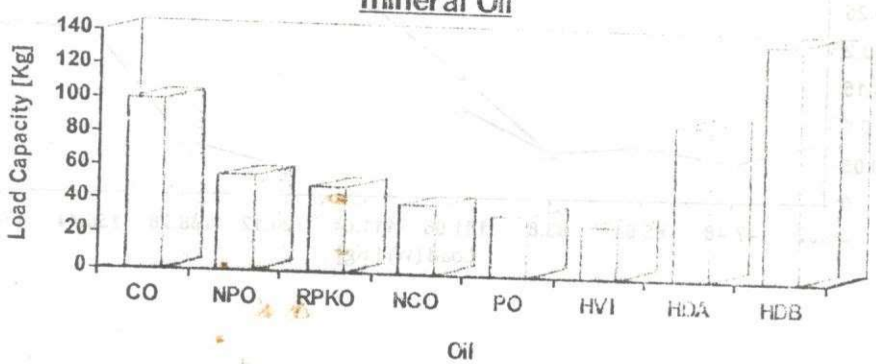

Figure 7: Flash Temperature,(T) and Surface Temperature,(T) of test Oils

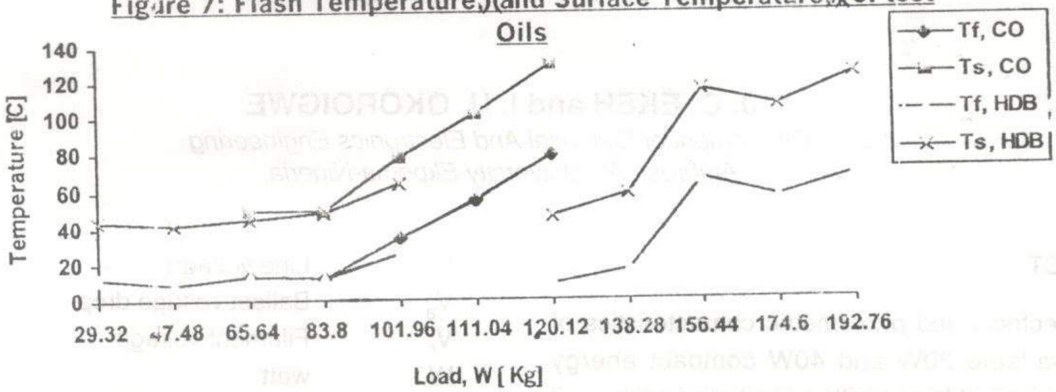

Figure 8: Hertzian Pressure, and Average Contract Pressure of test Oils

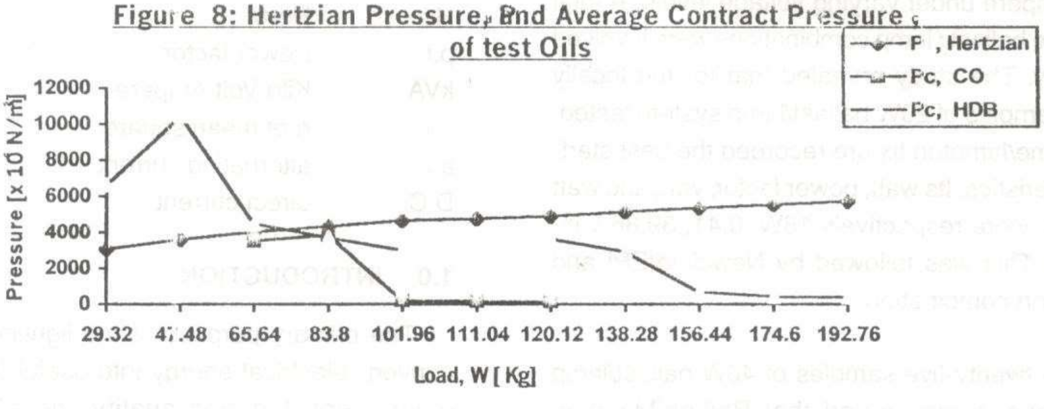

Figure 9: Bond Energy of Some Natural Vegetable Oil and Mineral Oil