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# INVESTIGATION OF TRIBOLOGICAL PROPERTIES OF VEGETABLE OIL BLENDS

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**ABSTRACT**

Lubricants are commonly used to reduce friction and wear from the sliding and metal contact surfaces, so as to allow the smooth movement of parts in each other, the calls for green ecology and legislations to protect environment and replace the mineral oil with bio-lubricant oils necessitated for this study. It is essential to find out alternative oil for the replacement of mineral oil based lubricants and vegetable oil already meets the requirements. Vegetable oils based bio-lubricants are non-toxic, biodegradable, and renewable and have a good lubricating performance than mineral oil based lubricant. The present study evaluates the tribological properties of Castor (C) and Neem (N) oil and their blends and this was compared to the conventional mineral oil. The friction and wear characteristics of the formulated oils were investigated by using four ball tribo tester according to ASTM D4172 method. 60N+40C showed higher viscosity and viscosity index compared to other formulated lubricants and it is better for boundary lubrication. Physico-chemical analysis showed that 100N oil exhibited high saponification value of (194.69MgKOH/g) which confirms its good quality for lubricant production, as compared to 100C oil of 179.23MgKOH/g. In thermal stability analysis, it was found that 60N+40C remains thermally stable than other formulated oils and 60N+40C showed a lower amount of coefficient of friction and wear scar diameter compared to other formulated oils and conventional mineral oil. Therefore the 60N+40C formulated oil from Castor and Neem oil has the potential of replacing the conventional mineral oil for industrial applications.

**KEYWORD:** Tribology, bio-lubricant, vegetable oils, friction, viscosity, wear scar diameter.

## 1.0 INTRODUCTION

The concept of tribology was introduced in 1966 in a report of the UK Department of Educational Science. It encompasses the interdisciplinary Science and Technology of interacting surface in relative motion and associated subjects and practices [1]. It includes part of physics, chemistry, solid mechanics, heat transfer, materials science, lubricant rheology, reliability and performance. Lubrication is a constituent of tribology which is one of the powerful means of reducing friction resistance of surface having relative motion under load. It includes hydrodynamic, hydrostatic and elasto-hydrodynamic lubrication (EHL) utilizing either oils or liquids or gases as lubricants while tribology is the science and technology of the interaction between surfaces moving relative to each other.[1,2] The principal function of lubricants are to control friction, wear, temperature, corrosion, insulate (electric), transmit power (hydraulic), dampen shock ( viz- dashpot, gear), remove contaminants (flushing action) and form seal.

Lubricating oils are selected considering the various operations condition like temperature rise, working load, normal working temperature, pressure, extreme conditions.[2,3] Lubricating oils are categorized by either composition or end use. They are divided into two groups – minerals oils and vegetable or animal oils, but end users prefer names that reflect the use of the lubricant. Mostly, mineral oil based is commonly used as lubricants but their uses have been questioned as regards to cost, environmental impacts and sustainability. Bio-lubricant oil can be used as an alternative to the mineral oil considering the depletion of the crude oil, increase in price and environmental pollution associated with engines run on mineral oil. Vegetable oils are renewable, less toxic, and biodegradable and thermally stable compared to mineral and commercial oils. Bio-lubricants have better lubrication performance due to their higher viscosity, viscosity index, flash point and fire point.[4] Vegetable oil are found from both edible and non-edible sources, such as Jatropha, Karanja, Neem,Castor, Palm e.t.c.

## 2.0 Review of related works[5]

Investigated the performance of different types of cutting fluids (Karanja oil and Neem oil, conventional fluid) as compared to dry cutting condition during turning of AISI304 stainless. The use of vegetable based cutting fluid improves surface quality to dry turning and conventional cutting fluid. Similarly,[6] used vegetable based cutting fluids coconut oil, palm kernel oil and shear butter oil during turning of mild steel, aluminum, copper and measure cutting force. Although it was found that the effect of vegetable based cutting fluids were material dependent, coconut oil showed the best performance among the three based vegetables based cutting fluid investigated, in the same way[7] carried out analysis of some local vegetable oils (such as tallow and rape oil) and their fatty acid composition confirmed. Presence of: palmitic, oleic and linoleic acid was confirmed in reasonable quantities. In similar study conducted by[8] where the effects of vegetable based oil on cutting parameters in turning operations were investigated. The force and the apparent coefficient of friction effects of three based vegetable oils, palm kernel oil, cotton seed oil, and palm oil were assessed from values obtained from cutting dynamic by considering the cutting parameter of rake angle, depth of cut, and chip thickness in the orthogonal cutting of aluminum at various cutting speed and feed rates. The results showed that the vegetable based-oil exhibited better lubrication potentials than the soluble oil, normally employed in most machining operations based on their ability to reduce chip compression, apparent coefficient of friction and cutting force. Furthermore[8,9] investigated the effect of vegetable based cutting oil on cutting forces and power of an AISI 316C stainless steel work piece were machined by drilling, core drilling, reaming and tapping using HSS-E tools. The results showed that vegetable based cutting oil demonstrating cutting performance than the commercial oil. Therefore, this study evaluated the tribological properties of blended Castor and Neem oil and their blends in comparison with conventional mineral oils.

## 3.0 MATERIALS AND METHODS

### 3.1 Extraction of Neem and Castor Seed Oils

The Neem and Castor seeds used for this work were obtained in Bichi local Government, Kano State, in view of its abundant in the area. The fruits were collected in a drum, and the kernels were separated to obtain the seeds. Later the seeds were oven dried at temperature of 105$^{o}$C and then fed into the oil extracting machine using mechanical pressing method.[10,11] The oil was obtained by pressing it mechanically and then collected in a drum. Filtration was then done to remove the various unwanted particles left in the extracted oil.

### 3.2 Formulation of the Oil Blends.

The formulation of oil blending was conducted in a seven 250ml necked round bottom flask connected to a overhead motor stirrer, a thermometer and an open separating funnel, Castor oil in various proportions were blended with Neem oil. The formulated oils in their various proportions as shown in Table 1 were charged into the round bottom flask. The mixture was allowed to stir for 30 minutes at 40$^o$C room temperature.

**Table 1: Method of formulating oil blends.**

| % Oil sample | Oil quantity ml | Blend ratio | Additives | % Formulation | Remark |
|---|---|---|---|---|---|
| 100Neem | 250 | 100:1 | - | 100Neem oil | Lubricant |
| 100Castor | 250 | 100;1 | - | 100Castor oil | Lubricant |
| 90N+10C | 250 | 90:10 | - | 90Neem+10castor | Lubricant |
| 80N+20C | 250 | 80:20 | - | 80Neem+20castor | Lubricant |
| 70N+30C | 250 | 70: 30 | - | 70Neem+30Castor | Lubricant |
| 60N+40C | 250 | 60: 40 | - | 60Neem+40Castor | Lubricant |
| 50N+50C | 250 | 50: 50 | - | 50Neem+50Castor | Lubricant |

### 3.3 Determination of Fatty Acids Profile of Castor and Neem Seed Oil

The fatty acid composition is an important component of vegetable oils when used as a lubricant. Fatty acid composition of the Castor and Neem oil samples were measured using gas chromatography (GC) analysis according to ASTM D7797 method.

### 3.4 Physical and Chemical Properties of Oil Samples.

The density of the oil was measured by using stabinger viscometer (SVM 3000) according to ASTM D1298 method. Iodine, saponification, and acid value are the main chemical properties of the lubricant that could enhance its lubricity performance. The lubricating performance depends on the oxidation stability of the oil, which may change the physical and chemical properties of the oil. The dynamic and kinematic viscosity was measured by stabinger viscometer (SVM 3000) according to ASTM D445.The viscosity index was estimated according to ASTM D2270. The chemical properties were analyzed for 100% Castor oil, 100% Neem oil, and the formulated blended oil samples according to ASTM standard methods.

### 3.5 Thermal Properties of Oil Samples.

The flash point and fire point were measured by Pensky- Martens flash point tester and Cleveland open cup experiment accordance with ASTM D92 and D93 methods respectively. Pour point is the most important property for the lubricating oil, when it is used in the winter and cold countries. The pour point and cloud point temperature were measured by cloud and pour point tester according to ASTM D97 and D2500 method respectively. 50%N+50%C, showed a lower pour point as compared to 100%N, 100%C and SAE20W40.

### 3.6 Co-efficient Friction and Wear Test Procedure

The four ball tester is used to determine wear preventive (wp), Extreme pressure properties (EP) and friction behavior of lubricants. In four ball tester, a rotating ball is pressed against three steel balls held together and immersed in lubricant under test. The test load, duration, temperature and rotating speed are set in accordance with standard test schedule. The co-efficient of friction and wear scar test was conducted with TR-30H four ball tribo- tester (refer to figure 1). The friction and wear characteristics of 100%C, 100%N, SAE20W40 and the blends were tested according to ASTM D4172 method. Wear evaluation was performed at 25kg loading and 1200 rpm for 60 minutes at 35$^{o}$C temperature of the lubricants. The standard balls used in this experiment are made from AISI-5200 chromium alloy steel, with the following specifications: diameter 12.7mm, extra polish (EP) grade 25, hardness 64-66 HRC (Rockwell C Hardness). Four new balls were used for each test. Each time before starting a new test, the tested steel ball were washed with n-heptane and then wiped with tissue, it is to be confirmed that the balls are dry to use and a base line was run without any lubricant sample to check the actual friction generated between the balls and steel cup. These dry balls were placed in a steel cup and 10 ml of formulated Castor and Neem oil was poured into the cup. Three balls were placed as stationary and another ball was rotated on these stationary balls. Fourth ball was adjusted within a collet and placed in a rotating arm, the wear scar diameter (WSD) of the tested balls were evaluated by optical micrometer (C2000, IKA, UK) to determine the lubricity performance of the tested lubricants. After completing the measurement of WSD of the tested balls and then average WSD was calculated from the obtained results. The co-efficient of friction (COF) was expressed as: COF, μ = $\frac{Frictional\ Torque\ (Kg-mm)\sqrt{6}}{3x\ Applied\ loadxDistance\,(mm)} = \frac{T}{3Wr}\sqrt{6}$, Where T is the friction torque in kg-mm, w is the applied load in kg and r is the distance from the centre of the contact surface on the lower balls to the axis of rotation.

At the end of each test the ball in the chuck was discarded and the other three balls were taken from the cup in order to examine the diameter of the wear scar. The wear scar diameter was used to calculate the load wear index, with each load applied in a stepped series with the first being 25kg. The load series used are: 25, 50, 75, 100, 125, 150, 175 and 200 kg. The wear scars were optically measured and the other parameters were calculated according to ASTM D2397. A series of 20-second runs were made at pre-selected load. The first run was made with a load of 25kg (marked base) and subsequent runs at successively higher load until welding of the four balls occur. Two check runs at the welding load were made, and if welding did not occur in both of the check run, the next higher load was applied until welding occurred.

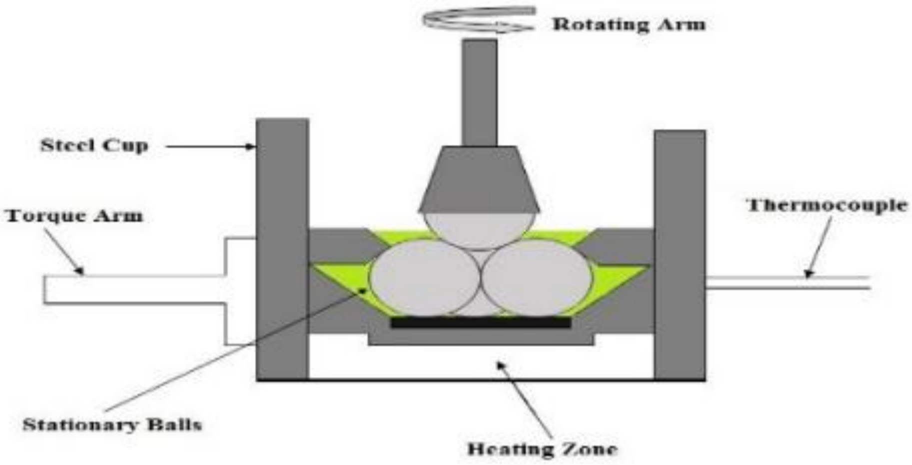


**Figure 1: Schematic diagram of four ball tribo-tester.**

## 4.0 RESULTS AND DISCUSSION

### 4.1 Fatty Acid Profile of Oil Samples

**Table 2: Fatty acid profile of Castor and Neem seed oil (ASTM D97).**

| Fatty acid | % composition (Neem oil) | % composition (Castor) |
|---|---|---|
| Oleic acid (C18:1) | 42.20 | 2.8 |
| Linoleic acid (C18:2) | 19.50 | 4.4 |
| Linolenic acid ( C18:3) | 0.09 | 0.2 |
| Erucic acid (C22:1) | 0.28 | - |
| Palmitoleic acid (C16:1) | 1.88 | - |
| Palmitic acid (C16:1) | 15.55 | 0.69 |
| Stearic acid (C18:0) | 18.32 | 0.72 |
| Arachidic acid (C20:0) | 0.18 | - |
| Behenic acid(C22:0) | 0.11 | - |
| Lignoceric acid(C24:0) | 0.71 | - |
| Dihydroxy stearic acid | - | 0.43 |
| Ricinoleic acid(C18:1) | - | 90.58 |
| Total | 100 | 99.82 |

From the results of fatty acid (refer to Table 2) analysis of seed oil, only unsaturated fatty acids such as : oleic acid, linoleic acid and linolenic acids that imparts the most on the quality of seed oil based lubricating oils will be discussed. The oleic acid content suggests the degree of oiliness of seed oil samples.[12] Therefore, it could be seen that oleic acid content of Neem oil is higher than that of Castor oil and therefore, when blending the oil together it would naturally provide better boundary lubrication for two contacting metallic surfaces. It could also be seen from the Table 2 that the linolenic acid content of Castor oil is higher. According to.[13] a correlation exists between linolenic acid content and the stability of seed oil. The stability is highest for the oils containing the smallest amount of linoleic acid; hence, this explains why 100C oil is more stable than other formulated oils.

### 4.2 Physico-chemical Properties of Oil Samples

**Table 3: Determination of physico-chemical properties of the blended Castor and Neem.**

| Oil sample (%) | Density at 26.3 °C ASTM D97 | Refractive index ASTM D97 | Saponifiion no. ASTM D 93 | Iodine value ASTM D482 | Specific gravity ASTM D93 | Viscosity at 23.6° C ASTM 189 | Flash point °C ASTM D92 | Pour point °C ASTM D97 | Emulsion stability | Acid value Mg KOH/g ASTM D95 | Viscosity index |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 neeem | 4.83 | 1.466 | 194.69 | 88.83 | 0.917 | 12.00 | 329 | -38 | Good | 8.415 | 50 |
| 100 Castor | 0.945 | 1.465 | 179.23 | 83.50 | 0.961 | 65.33 | 368 | -39 | Excellent | 17.952 | 53 |
| 90neem+ 10 Castor | 0.934 | 1.467 | 39.55 | 86.29 | 0.961 | 21.33 | 367 | -37 | Excellent | 15.708 | 56 |
| 80neem+ 20 Castor | 0.923 | 1.468 | 9.817 | 30.46 | 0.927 | 10.00 | 368 | -37.5 | Excellent | 7.854 | 55 |
| 70neem+ 30 Castor | 0.892 | 1.468 | 5.049 | 63.45 | 0.929 | 20.67 | 370 | -35.1 | Excellent | 21.879 | 54.5 |
| 60neem+ 40 Castor | 0.835 | 1.469 | 39.83 | 81.23 | 0.933 | 27.33 | 375 | -33 | Excellent | 24.123 | 56 |
| 50neem+ 50 Castor | 0.795 | 1.470 | 31.416 | 116.75 | 0.937 | 25.33 | 354 | -42 | Excellent | 22.40 | 50 |

For 90% Neem and 10% Castor (refer to Table 3), the result obtained showed an improvement in the viscosity value of the blends from 12.0 cps for 100N oil to 21.33cps.This blend ratio is also characterized with high acid value (15.708MgKOH/g) and high viscosity index value of 56.The emulsion stability for this blend was excellent, when compared with 100 N oil which showed acid value of 8.415MgKOH/g and viscosity index of 50.The emulsion stability obtained for 100N oil was good. For 80N + 20C oil, the physico-chemical analysis showed decrease in viscosity value to 10.0cps from 12.00cps obtained for 100 N oil but an increase in viscosity index to 55 from 50 obtained for 100 N oil was recorded, this blend is also characterized with an increase in flash point temperature from $329^0$C for 100N oil to $368^0$C. A considerable decrease in saponification value number was recorded from 194.69MgKOH/g for 100N oil to 9.817MgKOH/g .For this blend the overall emulsion stability was excellent. For 70 N + 30C oil, the result obtained indicated an increase in viscosity value to 20.67cps from 12.0cps for 100N oil showed a better lubricity property for the blend. This blend is also characterized with an increase in flash point temperature of 370$^0$C from 329$^0$C for 100 N oil, an increase in viscosity index from 50 for 100N oil to 54 but a considerable decrease in saponification value to 5.049MgKOH/g from 194.69MgKOH/g for 100N oil, for 60N+40C oil showed an increase in viscosity value to 27.33cps from 12.00cps for 100 N oil, this result shows that as the quantity of castor oil is increasing in the blend, the lubricity properties of the blend is improving. This blend shows the highest values in the critical properties needed in lubricating oil.

### 4.3 Thermal Properties of Oil Samples.

**Table 4: Determination of thermal properties of oils.**

| Properties | Unit | 100%C | 100%N | SAE20W40 | 90N+10C | 80N+20C | 70N+30C | 60+40C | 50N+50C |
|---|---|---|---|---|---|---|---|---|---|
| Cloud point | $^0$C | -37 | -35 | -23 | -34 | -35 | -33 | -31.5 | -29.5 |
| Pour point | $^0$C | -39 | -38 | -35 | -37 | -37.5 | -35.1 | -33 | -42 |
| Flash point | $^0$C | 368 | 329 | 295 | 367 | 368 | 370 | 375 | 354 |
| Fire point | $^0$C | 378 | 383 | 305 | 376 | 384 | 354 | 377 | 365 |

Viscosity is the most important property of the oil to identify the individual grades of the lubricating oil. If the oil has a higher value of viscosity, it indicates the lubricant is being deteriorated by either contamination or oxidation and a lower viscosity value indicates a decrease in the dilution property of the oil.[14] The kinematic viscosity of 100%N, 100%C, SAE20W40 and the blends are presented in Table 4 at 100$^o$C and 40$^o$C. From Table 4, 60N+40C and 50N+50C displayed higherviscosity value than other blends except SAE20W40.The lower amount of viscosity produced more wear and a higher viscosity can cause more friction loss in moving and sliding metal components.[15] Hence, 60N+40C and 50N+50C can reduce more wear from the metal contact surfaces compared to other blends and therefore, they are suitable for boundary lubrication applications.

**Table 5: Determination rheological properties of oils.**

| Properties | 100%C | 100%N | SAE20W40 | 90N+10C | 80N+20C | 70N+30C | 60N+40C | 50N+50C | Units |
|---|---|---|---|---|---|---|---|---|---|
| Dynamic viscosity @ 40$^0$C | 54.56 | 34.55 | 82.14 | 49.13 | 52.56 | 55.67 | 59.45 | 57.45 | Mpa.s |
| Kinematic Viscosity@ 40$^0$C | 37.34 | 26.76 | 94.11 | 30.23 | 33.78 | 36.15 | 40.18 | 40.85 | cSt |
| Kinematic Viscosity @ 100$^0$C | 15.69 | 11.34 | 12.03 | 12.11 | 13.91 | 14.28 | 17.34 | 15.33 | cSt |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Viscosity index | 53 | 50 | 74 | 56 | 55 | 54.5 | 57 | 50 | cSt |

**4.4 Friction Characteristics**

A lubricant can create and maintain a stable lubricating film at the metal contact zone, it is the main ability of all lubricating oils. Vegetable oils provide excellent lubricating performance due to their ester functionality.[15] Table 5 shows different values of Co-efficient of Friction (COF) for different types of formulated lubricants under different loads and temperature rise. COF of vegetable oil reaches a steady state condition after 20 seconds for each oil. It was clear that, 60N+40C and 50N+50C had a lower amount of COF compared to other formulated lubricants. This is evident with a higher amount of unsaturated and lower amount of saturated fatty acid compositions, this may cause lower COF compared to other formulated lubricants.

Vegetable oils showed the lowest amount of COF compared to mineral oil (refer to table 5). Vegetable oils contained a higher amount of fatty acid composition which enables them to reduce friction from the metal contact surface. 60N+40C and 50N+50C have reduced friction from sliding surfaces due to the presence of free fatty acid composition.[16] However, 60N+40C and 50N+50C oil samples contain higher amount of oleic acid which could reduce friction due to the tendency of the oils to form metallic soap between contacting metallic surfaces during boundary lubrication.

**Table 5: Determination of co-efficient of friction and wear scar diameter.**

| Sample | Co-efficient of friction | Wear (mm) |
|---|---|---|
| 100% Neem | 0.25 | 0.29 |
| 100% Castor | 0.20 | 0.16 |
| 90% Neem and 10% Castor | 0.21 | 0.17 |
| 80% Neem and 20% Castor | 0.26 | 0.23 |
| 70% Neem and 30% Castor | 0.19 | 0.18 |
| 60% Neem and 40% Castor | 0.14 | 0.13 |
| 50% Neem and 50% Castor | 0.17 | 0.15 |
| SAE20W40 | 0.32 | 0.38 |

**4.5 Wear Scar Diameter**

The use of the four-ball meter tester was informed to determine the load carrying capacity and weld point of formulated lubricant samples without the introduction of extreme pressure additives. The values of wear scar diameter (WSD) for different types of formulated lubricants are shown in Table 5 and 6 respectively. 60N+40C and 50N+50C formulated lubricants showed average WSD of 0.13mm and 0.15mm respectively, the value which are lower than those obtained for other formulated lubricants and SAE20W40. The minimum amount of WSD was found by 60N+40N and it has a maximum ability to protect the metal to metal contact surface area. WSD of 60N+40C is less compared to other formulated oils and commercial lubricant. This result may be attributed to the presence of natural anti-oxidants compound found in vegetable oils. The fatty acid chain length has a tendency to absorb film thickness and if the length of fatty acid increases it will increase the protective area of the metal contact surface.[17] However, 60N+40C has a maximum ability to retain the lubricating film and suspend the particles of wear between the contact areas to avoid the metal surface interactions. Therefore, 60N+40C has the lowest WSD compared to other formulated oils, and so 60N+40C formulated lubricants have demonstrated the potential of blended Castor and Neem oil as a possible replacement to the conventional mineral oil for lubrication applications.

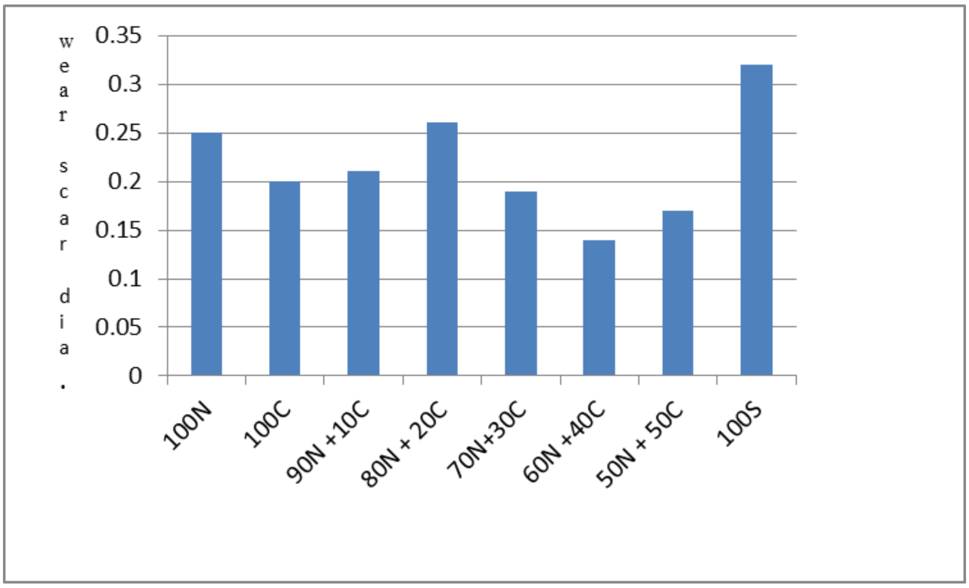


**Figure 2.0:** ***Wear Scar Diameter (WSD) versus lubricating oil sample.***

**Table 6: Determination of load-carrying capacity of the formulated lubricants.**

| Oil samples | load (kg) | Temp ($^0$C) | Time (s) | Min. scar dia.(mm) | Remarks |
|---|---|---|---|---|---|
| 100C | 25 | 25 | 20 | 0.29 | LNSR/L |
| 100N | 50 | 27 | 20 | 0.16 | ISR/L |
| 90N+10C | 75 | 29 | 20 | 0.17 | IMSR/L |
| 80N+20C | 100 | 31 | 20 | 0.23 | JBWR/L |
| 70N+30C | 125 | 33 | 20 | 0.18 | WR/L |
| 60N+40C | 150 | 35 | 20 | 0.13 | ISR/L |
| 50N+50C | 175 | 37 | 20 | 0.15 | ISR/L |
| SAE20W40 | 200 | 39 | 20 | 0.38 | LNSR/L |

## 5.0 CONCLUSION

The lubricant and tribological properties of formulated oils from Castor and Neem oil were compared to commercial oil. 60N+40C has the highest oleic acid content and its oxidation stability is better that other formulated oils and the conventional lubricant, therefore, 60N+40C formulated oil possess the minimum requirements of an ideal lubricant, and hence represents the optimum blend. 60N+40C showed a comparatively higher amount of viscosity compared to other formulated oils. The average co-efficient of friction of 60N+40C is less compared to other formulated oils and mineral oil, this is because 60N+40C contains higher amount of unsaturated fatty acid composition which enable it to reduce friction likely caused by contacting metallic surfaces. 60N+40C showed the least WSD compared to other formulated oils and conventional mineral oil. It is hereby recommended that future study should be on how to sustain the oils effectiveness against spoilage and rancidity usually associated with short shelf life of vegetable oil.

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