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# Evaluation of Lubricating Performance of Biodegradable Moringa Oleifera Oil

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**Abstract:** Lubricants is mostly used to reduce the friction and wear from the sliding and metal contact surfaces, because of which can smoothly moves in each other. Nowadays, it is important issue to protect the environment and replace the mineral oil due to the increase of the oil prices and reduction of the oil reserves. It is essential to find out an alternative oil for the replacement of mineral oil based lubricants and vegetable oil already meets the requirements. Vegetable oils based biolubricants are non-toxic, biodegradable, renewable and have a good lubricating performance than mineral oil based lubricant. This study evaluated the lubricating properties and tribological characteristics of Moringa oleifera oil and compared with coconut, rice brain and lube oil. The friction and wear characteristics of the oil investigated by using a four ball tester according to ASTM 4172 method. MOO showed higher viscosity and viscosity index compared to other vegetable oils and it is better for boundary lubrication. In thermogravimetric analysis, it was found that MOO remains thermally stable up to 300°C. MOO showed a lower amount of coefficient of friction and wear scar diameter compared to other vegetables oils and lube oil. Therefore, Moringa oleifera oil is very potential to use as a lubricating oil in industrial applications due to better lubricating performance.

**Key words:** renewable energy, biodegradable oil, biolubricant, vegetable oils

## 1. Introduction

In this world, various kinds of lubricants are used as a lube oil such that refined, synthetic oil, mineral oil, and vegetable oils. Mostly, mineral oil used as a lubricant oil in engine oil, motor oil, and so on. Mineral oils are available in the world market and which are derived from the petroleum oil but these are not be convenient for the environment due to their non-biodegradability and toxicity [1, 2].

Biolubricant oil can be used as an alternative of the mineral oil due to the depletion of the crude oil, increase the prices of the oil and environmental protection. Vegetable oils are renewable, less toxic, biodegradable, and thermally stable compared to mineral and commercial oils [1, 3]. Biolubricants have a better lubrication performance due to their higher viscosity, viscosity index, flash and fire point. Vegetable oils are found from both edible and non-edible sources, such as; jatropha, karanja, olive, palm, coconut, sunflower, soybean and so on [4]. Many researchers were used vegetable oils as an alternative fuel for diesel engine but some researchers reported that biolubricant used as a lubricating oil, which are produced from crude vegetable oils or derived from the vegetable oils.

Lubrication is required for reducing the frictional effects and wear from the various types of sliding, moving and rotating components [5]. It can also be reduced the temperature from the metal contacts zone. Many researchers reported that, the vegetables oil could be used as a biolubricant for the industrial and engine lubrication purposes like as coconut oil, olive oil, sunflower seed oil, corn oil, soybean oil, rice brain oil, rubber seed oil and so on. S. Rani et al. [6], evaluated the lubrication and tribological properties of rice brain oil, which used as a biolubricant oil for the

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industrial applications. They reported that, rice brain oil had a good thermal and tribological properties.

The viscosity and oxidation stability of the rice brain oil can be improved by adding the proper additives. The suitable additives such as organo-zic compounds, aromatic amine compounds and sulphur phosphorous compounds were mostly used for improving the oxidation stability property of the oil. *M.oleifera* oil has a higher oxidation stability compared to other vegetable oils such as; soybean oil, sunflower oil, coconut oil, cotton seed oil, olive oil and so on. This result could be attributed by the presence of natural antioxidant compounds (gamma oryzanol) in *M.oleifera* oil [7]. The aim of this study is to evaluate the lubricating and triobological properties of *M.oleifera* oil used as a biodegradable lubricant for industrial purposes. And also compare with lube oil. This study presents the biolubricant used as an alternative lubricating oil in industrial applications including with vegetable oil properties, DSC, TGA, wear and friction analysis.

## 2. Materials and Methods

### *2.1 Materials*

The *M.oleifera* and rice brain oil collected from Indian market by the personnel communication with foreign suppliers. The oil extracted from *M. oleifera* seeds, which contained 41% oil. The refined oil is very clear, odorless and rancidity. Coconut oil and SAE20W40 collected from local suppliers in Malaysia.

### *2.2 Determination of Fatty Acid Composition*

The fatty acid composition is the most important parts of the vegetable oils when these used as a lubricant. FAC of M. oleifera oil (MOO) and other oils were measured using by gas chromatography (GC) analysis according to ASTM D7797 method. FAC of MOO, COCO and RBO are shown in Table 1. MOO contained 73.5% oleic acid compared to rice brain and coconut oil, which can be used as lubricant base stock.

**Table 1 Fatty acid composition of different types of MOO, COCO and RBO.**

| Carbon Structure | Fatty acid name | MOO | COCO | RBO |
|---|---|---|---|---|
| C8:0 | Caprylic | --- | 9 | --- |
| C10:0 | Capric | --- | 7 | --- |
| C12:0 | Lauric | --- | 49 | --- |
| C14:0 | Myristic | --- | 16 | 0.3 |
| C16:0 | Palmitic | 6 | 8 | 20.74 |
| C16:1 | Palmitoleic | 1.3 | --- | --- |
| C18:0 | Stearic | 5.4 | 2 | 2.6 |
| C18:1 | Oleic | 73.5 | 7 | 42.63 |
| C18:2 | Linoleic | 2.8 | 2 | 31.59 |
| C20:0 | Arachidic | 3.6 | --- | --- |
| C20:1 | Eicosenoic | 1.4 | --- | --- |
| C22:0 | Behenic | 6 | --- | --- |
| Saturated | | 22.3 | 91 | 23.64 |
| Monounsaturated | | 74.9 | 6 | 42.63 |
| Polyunsaturated | | 2.8 | 2 | 31.59 |

### *2.3 Physical and Chemical Properties*

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 based oil, these properties could be enhanced a better lubricating performance.

The lubrication performance depends on the oxidation stability of the oil, which may change the physical and chemical properties of the oil. All of the chemical properties were measured for MOO, COCO and RBO according to ASTM standard methods. Table 2 shows the physical and chemical properties of MOO, COCO and RBO. The dynamic and kinematic viscosity were measured by stabinger viscometer (SVM 3000) according to ASTM D445. The viscosity index was estimated as followed by ASTM D2270 method. The rheological properties of MOO, COCO, RBO and SAE20W40 are shown in Table 3.

### *2.4 Thermal Properties*

The flash point and fire point were measured by Pensky-martens flash point tester and Cleveland open cup equipment according to ASTM D92 and 93 methods respectively. Thermal properties of MOO, COCO, RBO and SAE20W40 are shown in Table 4. Pour point is the most important property for the lubricating oil, when it is used in the winter season and cold countries.

The pour point and cloud point temperature were measured by cloud and pour point tester according to ASTM D97 and D2500 methods respectively. RBO showed a lower pour point compared to MOO and COCO. TA DSC (Q200) was used for DSC analysis with a temperature range -90°C to 550°C. In TGA analysis, TGA Q500 instrument was used with a temperature range 0°C to 600°C and the nitrogen flow rate was maintained 20 L/min with 10°C/min heating range.

**Table 2 Physical and chemical properties of MOO, COCO and RBO.**

| Properties | MOO | COCO | RBO |
|---|---|---|---|
| Density (gm/m$^3$) | 920.2 | 918 | 924.1 |
| Iodine value | 66.1 | 8 | 97 |
| Saponification value | 171 | 258 | 182 |
| Acid value | 8.670 | 0.3 | 1.314 |
| Oxidation stability (110 ℃, h) | 43.75 | 31.2 | 4.40 |

**Table 3 Rheological properties of MOO, COCO, RBO and SAE20W40.**

| Properties | Units | MOO | COCO | RBO | SAE20W40 |
|---|---|---|---|---|---|
| Dynamic Viscosity at 40°C | mPa.s | 37.301 | 19.172 | 33.364 | 92.134 |
| Kinematic Viscosity at 40°C | cSt | 42.004 | 26.327 | 39.225 | 103 |
| Kinematic Viscosity at 100°C | cSt | 9.657 | 5.863 | 8.393 | 16.09 |
| Viscosity index | -- | 225 | 177 | 198 | 167 |

**Table 4 Thermal properties of MOO, COCO, RBO and SAE20W40.**

| Properties | Units | MOO | COCO | RBO | SAE20W40 |
|---|---|---|---|---|---|
| Cloud point | ℃ | -7 | 25 | -6 | -18 |
| Pour point | ℃ | -7 | 21.5 | -13 | -23 |
| Flash point | ℃ | 263.7 | 323.2 | 303.5 | 205.7 |
| Fire point | ℃ | 268 | 328 | 309 | 208 |

*2.5 Friction and Wear Test Procedure*

The friction and wear test conducted with TR-30H four ball tribo tester. The friction and wear characteristics of MOO, COCO, RBO and SAE20W40 were tested according to ASTM D4172 method.

At first of all, the tested steel balls were washed with n-heptane and then wiped with tissue, it to be confirm that the balls are dry to use. These dry balls were placed in a steel cup and poured with 10 ml tested oil into the cup. Three balls are placed as stationary and another ball was rotated on these stationary balls. Fourth ball was adjusted within a collet and it placed in a rotating arm. Fig. 1 shows the schematic diagram of four ball tribo tester and Table 5 shows the experimental test conditions and tested ball configuration. According to ASTM D4172 method, the wear scar diameter (WSD) of the tested balls were

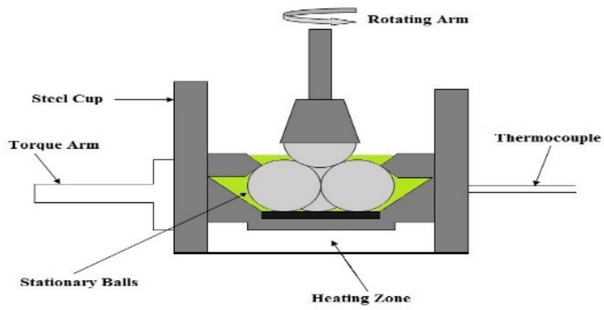


**Fig. 1 Schematic diagram of four ball tester.**

**Table 5 Experimental test condition of four ball tribo tester.**

| | Parameters | Condition |
|---|---|---|
| Operating conditions | Applying load & speed | 40 kg & 1200 rpm |
| | Temperature & duration | 75 °C & 3600 seconds |
| Testing ball | Materials & size | Chrome alloy steel (SKF) &$\varphi$12.7 mm |
| | Hardness & roughness | 62 HRc & 0.1 μm (C.L.A) |
| | Tensile and yield strength | 325,000 psi & 295,000 psi |

evaluated using by optical microscope (C2000, IKA, UK) within ±0.01 mm resolutions. After completing the measurement of WSD of the tested balls and then calculate the average WSD form the obtaining results.

### *2.6 Coefficient of Friction (COF) Calculation*

The frictional torque was measured by a load cell. In this experiment, the lower ball was created maximum torque. COF can be expressed as:

$$\text{COF, } \mu = \frac{Frictional\,Torque\,(kg{-}mm)\times\sqrt{6}}{3\times Applied\ load\ (kg)\times Distance\ (mm)} = \frac{T\sqrt{6}}{3Wr} \quad (1)$$

Where, frictional torque can be expressed as T in Kg-mm, applied load can be expressed as W in Kg, and distance can be expressed as *r* in mm. The distance (d) was measured from the center of the lower ball contact surface to the axis of rotation, and it was found 3.67 mm.

## 3. Results and Discussion

### *3.1 Viscosity*

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 the decreasing the dilution property of the oil [8].

The kinematic viscosity of MOO, COCO, RBO and SAE20W40 at 40°C and 100°C temperature are shown in Fig. 2. MOO showed a higher viscosity value than COCO and RBO, except SAE20W40. These vegetable oils have been satisfied international standard organization (ISO) requirements as well used as bio-lubricant. The lower amount of viscosity produced more wear and a higher viscosity can be caused more friction loss in moving and sliding metal components [9]. Hence, MOO can be reduced more wear from the metal contact surfaces compared to COCO and RBO and it is suitable for the boundary lubrication application.

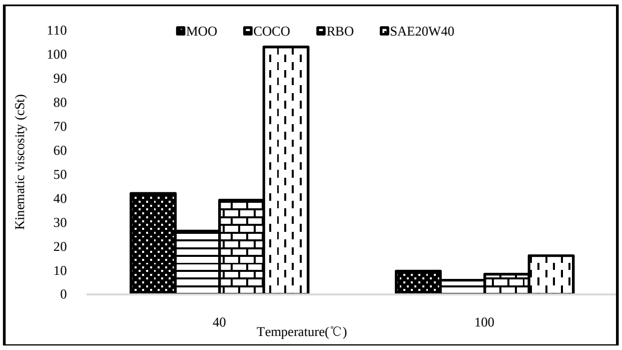


**Fig. 2 Viscosity of various vegetable oils for different temperature.**

### *3.2 Differential Scanning Calorimetry (DSC) Analysis*

Differential scanning calorimetry (DSC) analysis has been successfully used to evaluate the crystallization behavior of the vegetable oils by analyzing the exothermic changes associated with this process [10]. DSC curve provides a qualitative and quantitative information about the physical and chemical changes of the oil and that involves with the endothermic processes (heat absorption), exothermic (releasing heat) or change in heat capacity of the oil [11].

DSC analysis for MOO, COCO, RBO and SAE20W40 are shown in Fig. 3. The peaks of DSC indicate the physiochemical properties changes of the oil during the heating process. The endothermic onset temperature of MOO, COCO and RBO are found -26.79°C, 8.13°C and -20.06°C respectively. MOO showed lower endothermic peak temperature due to the nature of the fatty acid constituents namely oleic and linoleic acid. The endothermic peaks of melting temperature for MOO, COCO, and RBO showed -20.19°C, 22.29°C and -12.08°C respectively. The changes of enthalpy for MOO, COCO and RBO were found 43.61 J/g, 89.08 J/g and 43.06 J/g respectively. This result could be attributed by the presence of unsaturated triacylglycerol groups in the oil [12].

### *3.3 Thermogravimetric Analysis (TGA)*

Thermal stability is the most important parameter of the oil, when it will be used as a lubricating oil at high temperature condition and which are formulated from the vegetable oils [13, 14]. Thermogravimetric analysis used to observe the thermal stability of the oil. Thermogravimetric analysis (TGA) of MOO, COCO, RBO and SAE20W40 are shown in Fig. 4. It was seen that; all vegetable oils have a better thermal stability property than mineral based oils. The decomposition temperature of MOO, COO, RBO and SAE20W40 are 379.77°C, 369.63°C, 384.78°C and 249.20°C respectively.

The mass degradation of *M.oleifera* oil was quickly compared to RBO. Therefore, *M.oleifera* oil and rice brain oil showed almost similar thermal stability properties compared to coconut oil. The presence of higher amount of unsaturated fatty acid composition is the main reason for increasing the thermal stability of the oil [13]. Thermal stability of the oil is mainly depends on the chain length of fatty acid, branching and degree of unsaturation [15]. Hence, MOO showed a thermal stability property compared to other oils due to the presences of higher amount of oleic acid in *M.oleifera* oil.

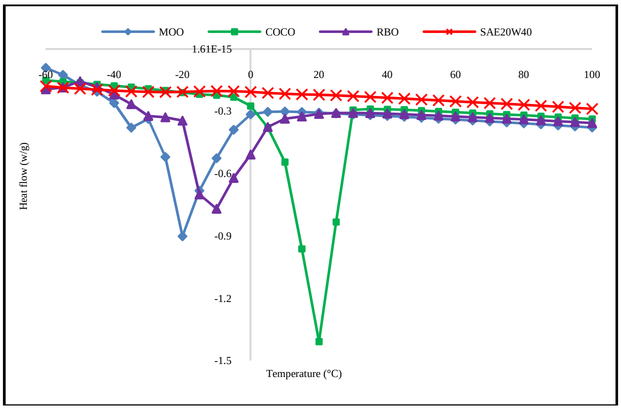


**Fig. 3 DSC analysis.**

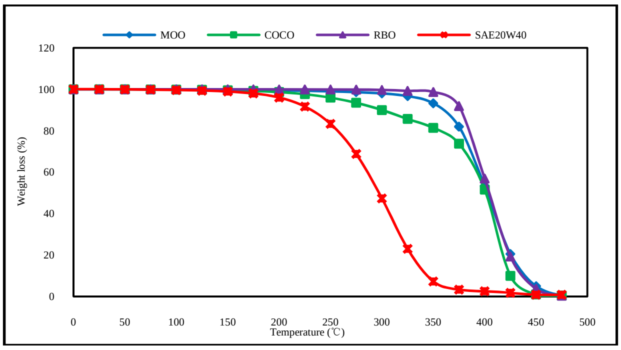


**Fig. 4 TGA analysis.**

*3.4 Friction Characteristics*

A lubricant oil can creates and maintains a stable lubricating film at the metal contact zone, it is the main ability for all of the lubricating oils. Vegetables oil provides an excellent lubricating performance due to their ester functionality [16]. Fig. 5 shows the variation of coefficient of friction (COF) with time for different types of vegetable oil under 40 kg load and 75°C temperature condition. COF of vegetable oils reaches at steady state condition after 30 seconds for each oil. It was clear that, MOO showed a lower amount of COF than COCO, RBO and SAE20W40. Because MOO contained a higher amount of unsaturated and lower amount of saturated fatty acid compositions, this may cause the lower COF compared to other vegetable oils.

Vegetable oils showed the lowest amount of COF compared to commercial lubricant oil. Vegetable oils contained a higher amount of fatty acid composition which enable to reduce the friction from the metal contact surface. MOO has been reduced more friction from sliding surfaces due to the presences of free fatty acid composition [17]. MOO contains higher amount of oleic acid which could be reduced the friction. However, MOO showed low frictional characteristics compared to SAE20W40, this results can be attributed on the basis of free fatty acid.

*3.5 Wear Scar Diameter*

The variation of wear scar diameter (WSD) for different types of vegetable oils are shown in Fig. 6. The average WSD of MOO was 19.07%, 3.26%, and 24.52% lower than COCO, RBO and SAE20W40 respectively. The minimum amount of WSD was found by MOO and it has a maximum ability to protect the metal to metal contact surface area. WSD of MOO is less compared to other vegetable oils and commercial lube oil. This result can be attributed by the presence of natural anti-oxidants compounds (gamma oryzanol and tocopherols) in the vegetable oils.

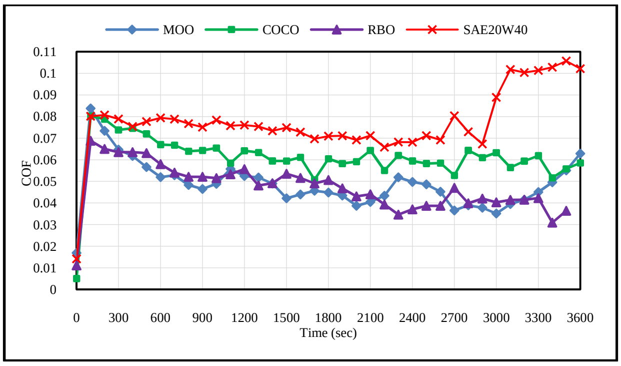


**Fig. 5 COF for vegetable oils.**

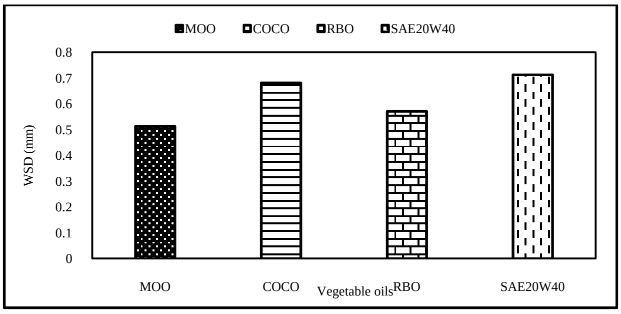


**Fig. 6 WSD for vegetable oils.**

The fatty acid chain length has a tendency to increase the absorbed of film thickness and if the length of fatty acid increasing it has been increased the protective area of the metal contact surfaces [18]. However, MOO has a maximum ability to retain the lubricating film and suspend the particles of wear by reducing the specific wear between the contact areas to avoid the metal surface interactions. Therefore, MOO has a lowest WSD compared to other oils, demonstrating the potential of *M.olefiera* as a possible lubricant ingredient.

## 4. Conclusion

The lubricant and tribological properties of some vegetable oils such as; *M. oleifera*, coconut and rice brain oil were compared to commercial lubricating oil. In general, all oils have a unique lubrication property that make a suitable lubricating oil for lubricant applications.MOO contained almost 73% of oleic acid and its oxidation stability is better than other vegetables and commercial oils. MOO showed a higher amount of viscosity compared to other vegetable.

RBO was more thermally stable compared to MOO, COCO, and SAE20W40. The lower pour point and cloud point found by RBO due to the presence of higher amount of polyunsaturation fatty acid composition. Average co-efficient of friction of MOO is less compared to other vegetable oils and commercial oil because MOO contains higher amount of unsaturation fatty acid composition which can enable to reduce friction from metal contact surfaces. MOO showed a lower amount of WSD than other oils.

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