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Vegetable Oil as Bio-Lubricant and Natural Additive in Lubrication: A Review

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ABSTRACT

Due to the decreasing petroleum reserves and environmental issues, the approach of using vegetable oil as lubricant has drawn the researchers' attention. In comparison to mineral-based lubricant, the vegetable based-oil bio-based lubricant has better physical properties, high lubricity, renewable, and biodegradable. The source of bio-based lubricant can be virgin natural oil, or processed fruit waste. This review discusses the vegetable oils as bio-lubricant and natural additive in lubrication according to the current findings. A brief discussion of physicochemical and tribological properties findings completes the review.

KEYWORDS*:* Vegetable Oils, Physicochemical Properties, Tribological Properties.

1. INTRODUCTION

Various types of lubricants are available all over the world including mineral oils, synthetic oils, re-refined oils, and vegetable oils. Most of the lubricants available in the market are mineral oil derived from petroleum oil which not adaptable with the environment due to toxicity and non-biodegradability [1,2]. Lubrication is important to sustain the performance of a machine, engine or any contacting metal surfaces by reducing the friction and wear. The use of additive can improve the performance of lubricant [3]. The problem faced by conventional lubricant mineral-based is decreasing petroleum reserve and environmental issues. Thus, the development of lubricant from bio-based materials has been initiated since years ago. In addition, the source of bio-based lubricant production can be obtained from virgin vegetable oils, fruit wastes and animal fat. Nowadays, the insecurity of raw materials such as vegetable oil and animal fat are the main obstacle for the development of new technologies in the production of bio-based oils. The available raw materials will deplete over time and also depends on the number of the population [4].

As the petroleum reserves are decreasing, there is a need to find an alternative that renewable, and suitable for future demand. Therefore, using fruit peel waste, natural oil or vegetable oil as a bio-based lubricant could significantly reduce the dependencies on petroleum-based lubricant due to its abundance, low material cost, good performance and environmental friendly [5]. Plant-based oils are a potential and highly attractive candidate to replace the conventional mineral oils for the lubricant production because they are structurally similar to long chains hydrocarbons in mineral oils. Moreover, the plant-based oils are also renewable, non-toxic, economic and environmentally friendly [6,7].

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A good example of fruit waste that has been used for bio-lubricant production is banana peels that have a smooth and slippery surface, and have the lowest coefficient of friction among other fruit waste [8]. Generally, a banana peel has an outer surface and inner surface called epicarp. Al-Nasrawi [9] has prepared the banana peels as a bio-based lubricant by removing the epicarp from the banana skin. After that, the epicarp was blended with paraffin oil using an ultrasonic homogenizer [9].

On the other hands, castor oil is one example of bio-lubricant obtained from the seeds of the castor plant and it is non-edible vegetable oil. The botanical name of castor plant is *Ricinus-communis*. Castor plant available worldwide and famous for its medicinal usage as a laxative. Castor oil has high lubricity compared to other non-edible vegetable oils and it also has high oxidative stability, therefore, it will be used as base oil [10].

In summary, the study on vegetable oils as a lubricant and natural additive is still ongoing. This review covers the physicochemical and tribological properties of current studies.

2. AN OVERVIEW LUBRICATION AND LUBRICANTS

The purpose of lubricants is to reduce wear and heat loss that occurs from the contact surface in motion. Lubricant reduces the coefficient of friction between two contacting surfaces. Besides that, it also prevents rust and reduces the oxidation. Moreover, lubricant act as an insulator in transformer application and as a seal against dirt, dust and water. A lubricant is a substance that reduces friction and wears by providing a protective film between two moving surfaces. Two surfaces separated by a lubricating film is known as lubrication. Lubricants available in liquid, solid, and gaseous forms. High viscosity index, high boiling point, thermal stability, low freezing point, corrosion prevention capability, and high resistance to oxidation are the characteristics of a good lubricant [11-13].

The conventional lubricants faced issues related to environmental and toxicity as well as their rising cost due to global shortage and their poor biodegradability leading to renewed interest in the development of environmentally friendly lubricants. There has been an increasing demand for green lubricants and lubricant additives in recent years. Vegetable oils are viable and appropriate alternative resources because they are environmentally friendly, non-toxic and biodegradable [14]. Majority of bio-lubricants come from esters. There are natural esters which are triglycerides of vegetable oils. Triglycerides of vegetable oils are more polar than petroleum-based oils, thus they have a higher affinity to metal [15]. Compared to mineral oils, vegetable oil-based generally exhibit high lubricity, high viscosity index, high flash point and low evaporative losses. Bio-lubricant oils are great alternatives to mineral oils because they possess certain natural technical properties and biodegradable [15,16].

3. PHYSICOCHEMICAL PROPERTIES OF VEGETABLE OILS

Vegetable oil has many valuable and useful physicochemical properties. They offer technical advantages, unlike the typical petroleum-based lubricants. It has high lubricity, high viscosity index, high flash point, and low evaporative losses [17,18]. Overall, the vegetable oil-based shows several excellent properties compared to mineral oils. Table 1 shows the result of the comparative analysis of vegetable oils properties.

Table 1 Comparative analysis properties of vegetable oils [12]

Properties	Vegetable Oil	Mineral Oil
Density @ 20 ˚C (kg/m^3)	940	880
Viscosity Index	100…200	100
Shear Stability	Good	Good
Pour Point, ˚C	-20…+ 10	-15
Clod flow behaviour	Pour	Good
Miscibility with mineral oils	Good	-
Solubility in water	Not miscible	Not miscible
Oxidation stability	Moderate	Good
Hydrolytic stability	Poor	Good
Sludge forming tendency	Poor	Good
Seal swelling tendency	Slight	Slight

3.1 Viscosity

The most important property of oil is viscosity. It specifies the resistance to flow and directly related to temperature, pressure, and film formation. Viscosity is the resistance of fluid (liquid or gas) changes in shape or movement of neighbouring portions relative to one another that denotes opposition to flow. Viscosity is a major factor in determining the forces that must be overcome when fluids are used in lubrication and transportation engine. Some applications of the kinematic viscosity are useful than the absolute or dynamic viscosity. Kinematic viscosity is the absolute viscosity of a fluid divided by its mass density [20].

3.2 Viscosity Index (VI)

The Viscosity Index (VI) was developed by Dean and Davis in 1929 for purpose ASTM D 2270. It is empirically derived with a non-unit number. Based on the methodology, Pennsylvania crude (paraffinic) is set as a benchmark at one extreme, representing low viscosity changeability relative to temperature. The other extreme is the Texas Gulf crudes (naphthenic). If a lubricant like the Pennsylvania crude, it assigns a VI of 100. If it like Texas Gulf crude, it assigns a VI of 0. Halfway in between is VI of 50 and so forth. The higher the VI, the more stable the viscosity across a range of temperatures, which is more desirable. The temperatures used to determine the VI are 40˚C to 100˚C [20,21]. Table 2 shows the properties of vegetable oils compared to mineral oils. Unlike most mineral oils, vegetable oils display a high viscosity index. A relative measurement in the change of base fluid viscosity between 40˚C and 100˚C indicates the change of viscosity over an extended temperature range [23].

Table 2 Properties of vegetable oils compared to mineral oil [23]

	Viscosity 40˚C (cSt)	Viscosity 100˚C (cSt)	Viscosity Index	Pour Point, ˚C	Flash Point, ˚C
Coconut Oil	27.7	6.1	175		
350 Neutral mineral oil	65.6	8.4	97	-18	252
Low erucic rapeseed oil	36.2	8.2	211	-18	346
High oleic sunflower oil	39.9	8.6	206	-12	252
Conventional soybean oil	28.9	7.6	246	-9	325
Palm oil	39.7	8.2	188	N/A	N/A

3.3 Pour Point

Pour point is an important factor. The pour point is defined as the lowest temperature at which the sample still pours from a tilted jar. Simply, pour point is the lowest temperature at which oil flows or pours. This method is routinely used to determine the low-temperature flow properties of fluids. Generally, materials with lower pour point exhibit improved fluidity at low temperatures than those with a higher pour point [24]. Vegetable oil-based bio-lubricants have lower pour points than mineral oils, thus providing excellent lubrication for cold starts. Pour point is an important low-temperature property of any oil used as a lubricant. Pour points of vegetable oils is tabulated in Table 3 where the pour point values are based on different types of oil measured by Adhvaryu *et al.* [2], Evidence-based [25], Kassfeldt and Goran [26], and ASTM D97 [27].

Table 3 Pour points of vegetable oils [2,24,25]

Oil	Pour point (˚C) ASTM D97	Temperature (˚C) after holding for 15 min	Remark
Castor	-33	-27	-
Coconut	21	24	-
Groundnut	3	5	-
Linseed	-30	-27	-
Mustard	-18	-15	-
Olive	-9	-5	-
Palm	*	5	*Poor repeatability
Sunflower	-18	-16	-

3.4 Flashpoint and fire point

Flashpoint is the lowest temperature in which lubricant must be heated before it vaporizes. Flashpoint is an indicator of safety for transportation and storage purposes. Flashpoint measurements are based on the ASTM D92 method. The flashpoints of diesters and polyol esters are above 200°C which indicates a low evaporation tendency and fulfils the basic requirement as a lubricant [28]. Table 4 shows the flashpoint test of vegetable oils using the ASTM D92 method [29].

Table 4 Flash points of vegetable oils [30][31][32][33][34]

Oils	Flash Point (˚C)
Soybean	240
Sunflower	252
Rapseed	240
Jojoba	248
Jatropha carcass	240
Corn	280

3.5 Cloud point

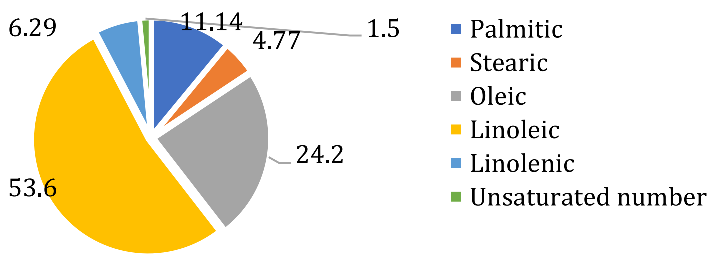
Based on Suhane *et al.* [35], the cloud point is the temperature where the mixture starts to phase separate and then two phases appear that becoming cloudy. This behaviour is the characteristic of non-ionic surfactants containing polyoxyethylene chains that exhibit reverse solubility versus temperature behaviour in water. Therefore, the cloud appears at some point as the temperature increased [35]. Table 5 shows the cloud point of various vegetable oils.

Table 5 Cloud Point of vegetable oils [35]

Oils	Cloud Point (°C)
Coconut	0.0
Linseed	-3.8
Olive	-
Soybean	1.0
Sunflower	-3.4
Palm	13.0
Peanut	5.0
Rapseed	-3.3
Ricebran	0.3
Castor	-13.4
Jatropha	2.7
Karanja	9.0
Mahua	-
Neem	14.4

3.6 Oxidation stability

Oxidation stability analysis of vegetable oil lubricant has been done by Erhan *et al.* [36]. The used of Pressure Differential Scanning Calorimetry (PDSC) help obtained the oxidation properties. The oxidation properties are based on fatty acid composition. The composition of fatty acid of soybean oil, safflower oil and sunflower oil are shown in Figure 1(a), 1(b) and 1(c), respectively [36]. Unsaturated number soybean is the highest compared to safflower and sunflower. This suggests that soybean have more relative amounts of saturated, monounsaturated and polyunsaturated fatty acids in the vegetable oils compared to safflower and sunflower.



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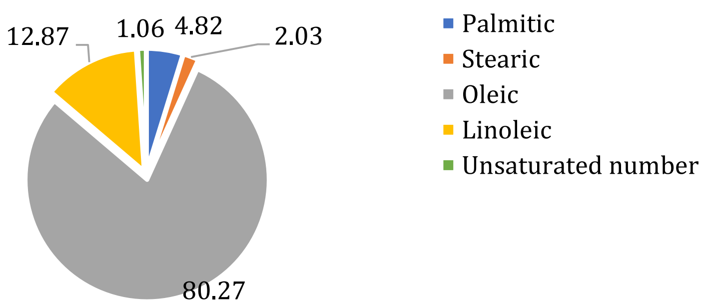

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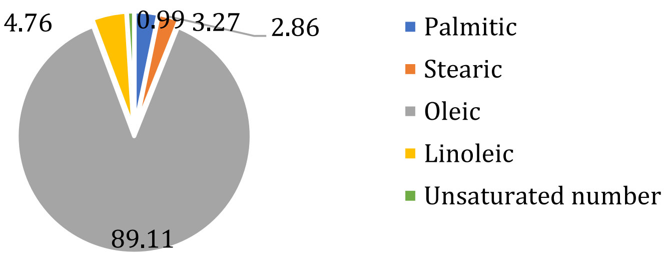


(c)

Figure 1. The fatty acid composition on three types of vegetable oils bio-based lubricant (a) Soybean, (b) Safflower, and (c) Sunflower [36].

3.7 Spectral Analysis

Infrared (IR) spectroscopy is the only analytical method which provides both ambient temperature operation and the ability to directly monitor the vibrations of the functional groups which characterize the molecular structure and govern the course of chemical reactions. Infrared spectroscopy is a technique based on the vibrations of the atoms of a molecule. An infrared spectrum is commonly obtained by passing infrared radiation through a sample and determining what fraction of the incident radiation is absorbed at a specific energy. The energy at which any peak in an absorption spectrum appears corresponds to the frequency of vibration of a part of a sample molecule [35,36]. Based on Japir *et al.* [39], FT-IR spectra of high free fatty acid crude palm oil (HFFA-CPO) and low free fatty acid crude palm oil (LFFA-CPO) are shown in Figure 2. The major peaks and their assigned functional groups are shown in Table 6. The absorption band at 1712 cm^{-1} for HFFA-CPO denotes carbonyl (C=O) carboxylic acid. The absorption band is more distinct in LFFA-CPO due to the higher percentage of FFAs. Sharp absorption bands of high intensity at 1746 cm^{-1} and 1747 cm^{-1} for HFFA-CPO and LFFA-CPO, respectively, are assigned to functional groups of esterified carbonyl C=O. The peaks at 2927 cm^{-1} and 2855 cm^{-1} indicate CH_2 and CH_3 scissoring of HFFA-CPO and LFFA-CPO, respectively. The peak at 3005 cm^{-1} indicates stretching aliphatic double C=C bond while the peaks of 3473 cm^{-1} and 3474 cm^{-1} signify -OH stretching of HFFA-CPO and LFFA-CPO, respectively [39].

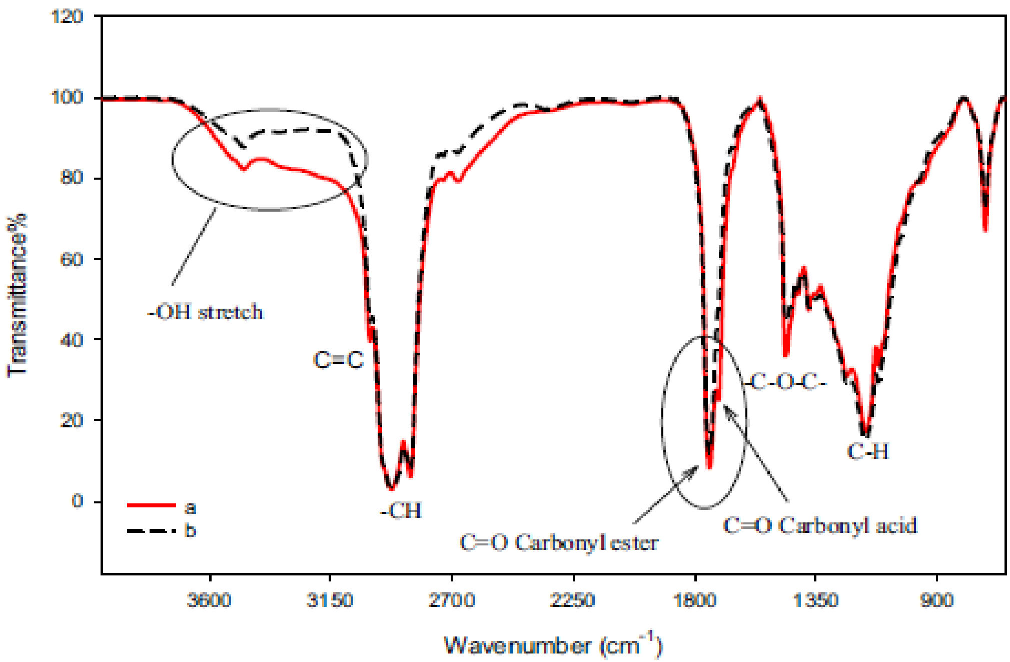


Figure 2. FTIR spectrums of (a) HFFA-CPO and (b) LFFA-CPO [39].

Table 6 FTIR Functional groups of HFFA-CPO and LFFA-CPO and their wavelengths [39]

Functional Group	Wavelength HFFA-CPO	Wavelength LFFA-CPO
-OH stretching vibration	3473	3473
C=C Bending vibration (aliphatic)	3004	3005
CH Stretching vibration (aliphatic)	2923, 2855	2927, 2855
C=O Stretching vibration (ester)	1746	1747
C=O Stretching vibration (carboxylic acid)	1712	-
C-H Scissoring and bending vibration (aliphatic)	1459	1465
C-O-C Stretching vibration (ester)	1235, 1165, 1118	1235, 1165, 1117
C-H Group vibration (aliphatic)	722	722

3.8 Stability of Mixture Vegetable Oil as an Additive in the Lubricant

The use of fruit peel waste as bio-based lubricant oil has started since years ago. There is a constraint on using petroleum-based lubricant for a long term due to non-biodegradable and toxicity characteristics. Blended paraffin oil with 20% banana peel does not experience any change in terms of colour and there is no sediment after five-days observation as shown in Figure 3 [40]. The stability of the mixtures of oils before and after the experimental procedures were observed and shown in Figure 4. Based on the criteria of lubricant, visibility and clarity of the oil are one of the parameters that should be considered.

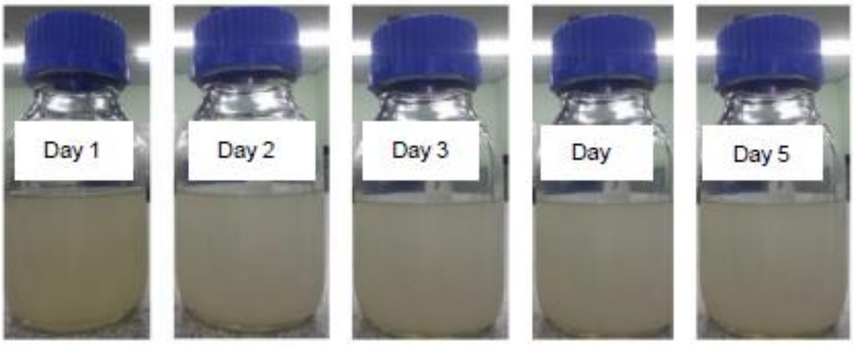


Figure 3. Observation of paraffin oil with 20% of Banana Peel in five days [40].

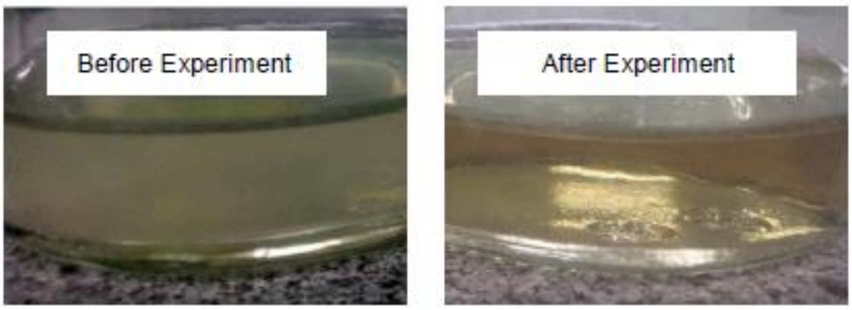


Figure 4. Paraffin oil with 20% of banana peel before and after the experimental procedure [40].

4. TRIBOLOGICAL PROPERTIES OF VEGETABLE OILS

4.1 Wear

Wear is a process of gradual removal of material from surfaces of solids subject to contact and sliding. Damages of contact surfaces are results of wear. They can have various patterns which are abrasion, fatigue, ploughing, corrugation, erosion and cavitation [41]. The study was done by

Nathe *et al.* [42] on the different rate of wear from different loads. The wear analysis of EN31 steel on the relation load to wear scar has been done by using a pin/ball on disk wear testing [42]. Based on their result, the increasing of normal load affects the increasing rate of wear scar (see Figure 5). Besides, the increasing of different loads is affecting the increase of frictional force.

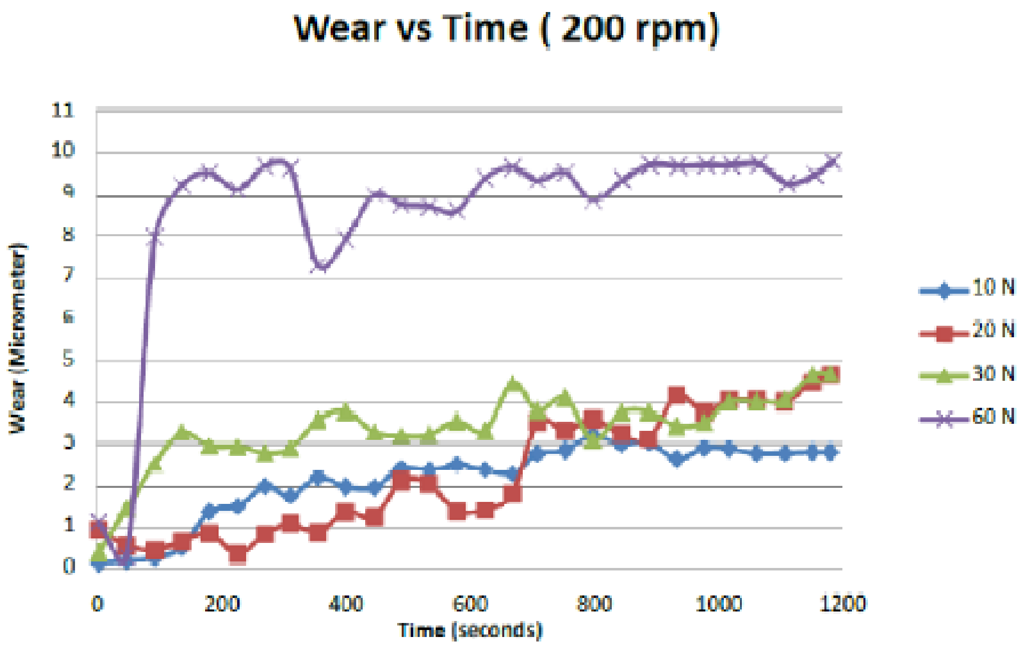
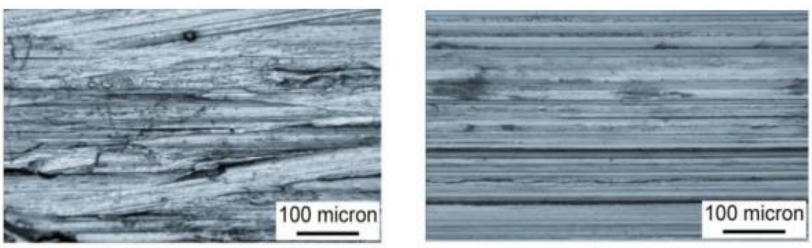


Figure 5. Wear vs Time for 200 rpm [43].

The interacting surfaces in relative motion depend on the friction between participated surfaces and caused wear on the surface. This wear can reduce the lifespan of a machine, its performance, and total production or output [44].

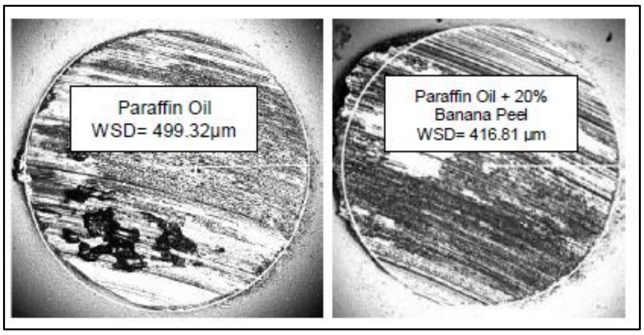
The pin-on-disk tester can be used as a comparative testing method that controls wear and measures friction in study samples. Syahrullail *et al.* [45] has investigated the performance of palm olein by using a pin-on-disk tester at different speeds: 0.4 m/s and 4.0 m/s. Their result showed that the grooves created parallel to the sliding direction. Different speed has different wear scar groove development as shown in Figure 6. At 4.0 m/s, the wear scar has fully generated on the disk, compared to at 0.4 m/s.



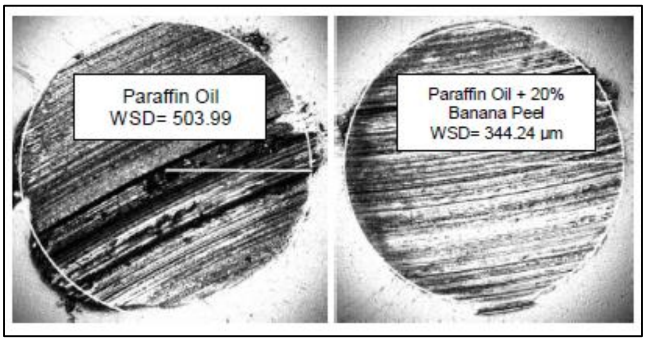
(a) (b)

Figure 6. the wear groove at different speed of disk (a) at 0.4 m/s, (b) at 4.0 m/s [45].

The study on wear scar diameter of paraffin oil and paraffin oil + 20% banana peel have been done by Hamid *et al.* [40]. The test was analyse using an inverted microscope and wear measurements were reported as volume loss in cubic millimetres. Wear scar diameter of paraffin oil and paraffin oil + 20% banana peel with loads of 500 N at 500 rpm and 100 rpm were observed using an inverted microscope and illustrated in Figure 7(a) and 7(b).



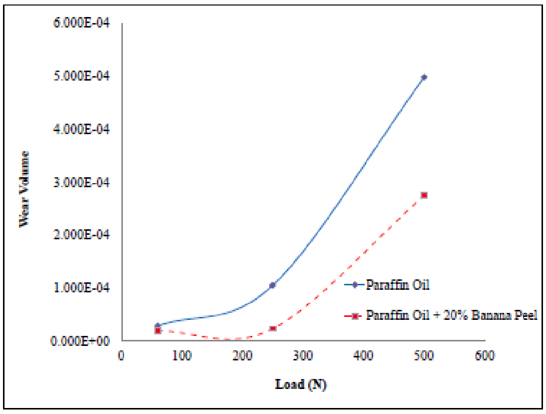
(a)



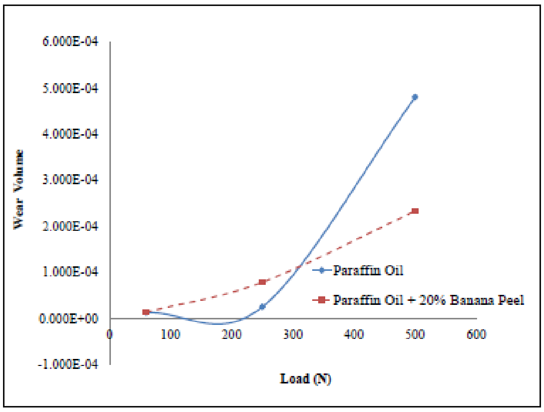
(b)

Figure 7. (a) Wear scar of paraffin oil and paraffin oil with 20% of banana peels with loads of 500 N at 500 rpm and (b) wear scar diameter of paraffin oil and paraffin oil with 20% of banana peel at 1000 rpm

Using the same parameter, the wear of paraffin oil + 20% banana peel was decreased by 16.52% at 500 rpm as shown in Figure 8(a) and (b). For 1000 rpm, the Wear Scar Diameter (WSD) was found to decrease by 31.89% as compared to paraffin oil.



(a)



(b)

Figure 8. (a) wear scar diameter of paraffin oil and paraffin oil with 20% of banana peel at 500 rpm and (b) wear scar diameter of paraffin oil and paraffin oil with 20% of banana peel at 1000 rpm.

Cottonseed encompasses kernel as well as the hull. The hull produces fibre and linters. The kernels have oil, protein, sterols etc. Cottonseed oil was detached from cottonseed kernel. Cottonseed oil is also characterized as heart oil in most used edible oils. Some polyunsaturated oils can be used for cooking purposes. Cottonseed oil is generally sliced with a light golden colour.

Cottonseed oil's light non-oily constancy and smoke point make it more desired. Cottonseed oil has the most appropriate properties for lubrication [46].

Ashwini *et al.* [46] state that the properties of cottonseed are similar to mineral oil as well as base oil. Cottonseed oil is a good alternative source of lubricant for lubrication. Figure 9 shows the result of wear scar on three steel balls, on average. The wear scar resulted from cottonseed oil is 404 μm, 38% lower compared to synthetic lubricant. This result is due to the properties of cottonseed that has high lubricity, low volatility, high viscosity index, high boiling temperatures, rapid biodegradation and better skin compatibility [46].

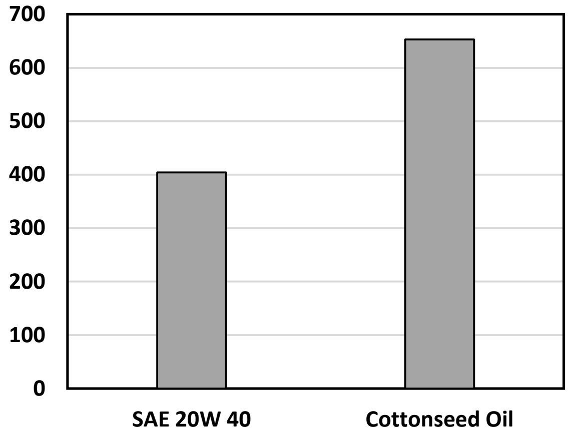


Figure 9. The wear scar comparison between SAE 20W 40 and cottonseed oil [46].

4.2 Coefficient of friction

The frictional coefficient is defined as a ratio of frictional force to vertical force and can represent the lubricating conditions. The frictional force of solid is not a characteristic of the material itself because it changes with different factors including mechanical conditions, properties of lubricant and material of opposite surface [8]. Bahari *et al.* [47] experimented on the friction and wear response of vegetable oils and their blends with mineral engine oil in a reciprocating sliding contact at severe contact conditions. Oils that have been used are palm oil (PO) and soybean oil (SBO), which is blended with mineral oil (MO). The result is shown in Figure 10, where the palm-oil-lubricated depicted lower COF (0.105) than soybean oil counterpart (COF=0.112) while the mineral engine oil demonstrated the lowest COF (0.093). The difference between the COF of PO and MO lubricated specimens is about 11%. The COFs for a blend of MO and vegetable oil generated value in between their pure oil state with only a small reduction is noted compared to their pure state. For example, a blend of MO and PO (MO:PO) gave a COF of 0.104, 1% lesser than pure PO (COF=0.105). A slight improvement of COF was also found in a blend of MO and SBO (MO:SBO), in which the COF (0.109) only reduced 3% from pure SBO (COF¼0.112) [47].

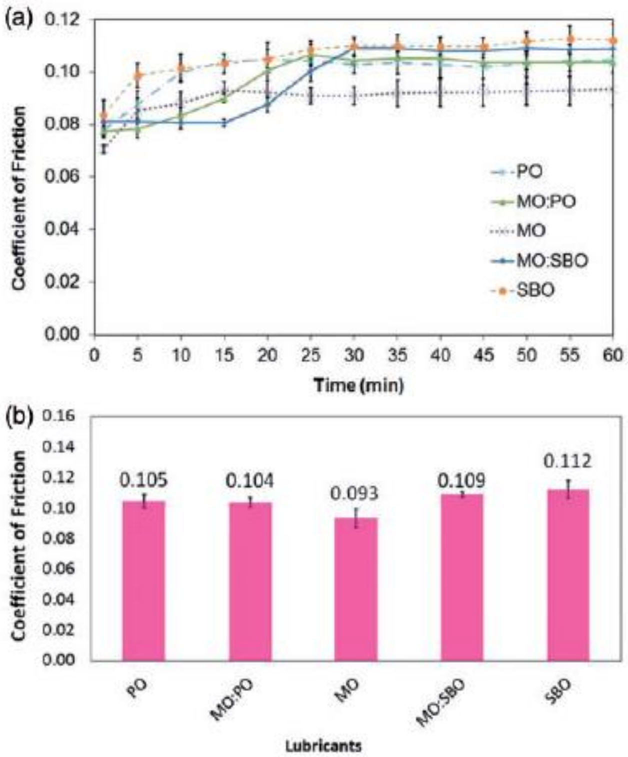


Figure 10. (a) Average coefficient of friction versus time for palm oil (PO), soybean oil (SBO), mineral oil (MO) and their oil blends, and (b) coefficient of friction value at 60 min [47].

Bongfa *et al.* [48] observed that the polar heads and consequent formation of the monolayer by vegetable oil molecules near-vertical orientation of their hydrocarbon chains to contacting metal surfaces. Generally, it has been discussed by bio-based lubricant researchers as the bases of their superiority over mineral oils of similar viscosities, as far as lubricity is concerned. Figure 11 confirmed this concept, which it can be seen that the friction reduction ability of castor oil is better than the formulated commercial mineral oil [48].

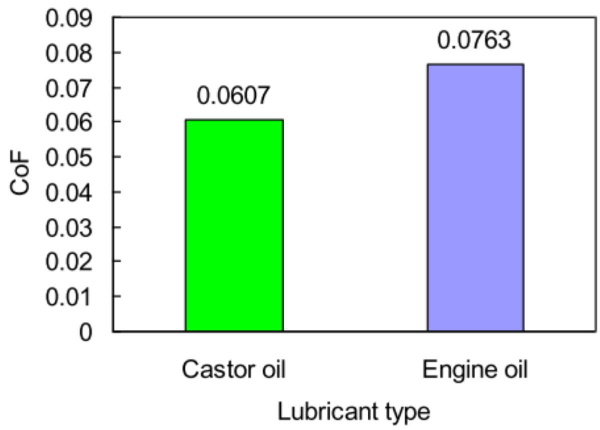


Figure 11. Coefficient of frictions of the investigated oils for wear test [48].

5. APPLICATION OF VEGETABLE OILS IN LUBRICATION

Vegetable oils as bio-lubricants provide significant advantages as alternative lubricants for industrial and maintenance applications because of their superior inherent qualities. Besides that, bio-lubricants also can be used in sensitive environments and prevent pollution because of their environmental benefits. It also can be used in various industrial and maintenance applications that require oil such as machine oils, compressor oils, metalworking fluids, and hydraulic oils. Moreover, it also can be used as automotive oils such as engine oils, transmission fluids, gearbox oils, as well as brake and hydraulic fluids [49]. Table 7 shows several types of vegetable-based lubricants developed for industrial applications.

Table 7 Several types of vegetable-based lubricants developed for industrial applications [50]

Types of oils	**Application**
Canola oil	Hydraulic oils, tractor transmission fluids, metalworking fluids, food-grade lubes,
Castor oil	Gear lubricants, greases
Coconut oil	Gas engine oils
Olive oil	Automotive lubricants
Palm oil	Rolling lubricant-steel industry, grease
Rapeseed oil	Chain saw bar lubricants, air compressor-farm equipment, biodegradable greases
Safflower oil	Light-coloured paints, diesel fuel, resins, enamels
Linseed oil	Coating, paints, lacquers, varnishes, stains
Soybean oil	Lubricants, biodiesel fuel, metal casting/working, printing inks, paints, coatings, soaps, shampoos, detergents, pesticides, disinfectants, plasticisers, hydraulic oil
Jojoba oil	Grease, cosmetic industry, lubricant applications
Crambe oil	Grease, intermediate chemicals, surfactants
Sunflower oil	Grease, diesel fuel substitutes
Cuphea oil	Cosmetics and motor oil
Tallow oil	Steam cylinder oils, soaps, cosmetics, lubricants, plastics

6. VEGETABLE OILS AS ALTERNATIVE LUBRICANT

Vegetable oil-based bio-lubricants have several valuable and useful physicochemical properties by offering several technical advantages. Vegetable oils have high lubricity, high viscosity index, high flash point, and low evaporative losses [17,18]. Various vegetable oils are being used in research and development projects to improve physicochemical properties. The studies found that vegetable oil-based bio-lubricants can be efficient and inexpensive substitutes to petroleum-based oils. The summary of the research on vegetable oil-based bio-lubricants conducted by various researchers as shown in Table 8. Furthermore, researchers have reported that vegetable oil-based bio-lubricants provide better lubricity than petroleum-based oils [51]. As a result, vegetable oil-based bio-lubricants are becoming more popular because of these positive characteristics. The major characteristics include corrosive nature and the activity of unsaturated hydrocarbon chains [52][53][54]. Sulek *et al.* [55] has investigated the tribological properties of rapeseed bio-lubricants and found that they exhibit lower friction of coefficient than petroleum-based oils. The development of the lubricity of bio-lubricants was reported for each low blend levels [56].

A research found that friction and wear slightly improved with the increase in temperature [51]. Kalam *et al.* [57] experimentally investigated the friction and wear characteristics of a normal lubricant, additive added in lubricant and waste vegetable oil contaminated lubricants. The waste vegetable oil contaminated lubricants with amine phosphate as anti-wear additive reduced wear and friction coefficient and increased viscosity. Tribological performance of palm oil methyl ester blended lubricant in a steel cast iron pair was investigated by Maleque *et al.* [58]. He found that corrosive wear on the damaged surface is the most common wear modes. Mostly, mineral oils are being used as engine oil, hydraulic oil, metalworking fluid, insulating oil, and grease. Products from vegetable oils such as jatropha, neem, karanja, soybean, palm, coconut, castor, olive, mahua, and sunflower exhibit better or at least similar performances with petroleum or synthetic oil-based products, aside from being less expensive [2][35][59][60-62]. Arumugam *et al.* [63] investigated the effect of bio-lubricants and biodiesel-contaminated lubrication on the tribological behaviour of a cylinder liner piston ring combination by using a pin-on-disc. The discs and pins were prepared by white cast iron alloyed from an actual engine cylinder liner material by casting. The results show bio-lubricant reduced the coefficient of friction as well as frictional force and wear. Based on Zulkifli *et al.* [64], the wear prevention characteristics of a palm oil-based Trimethylolpropane (TMP) ester as an engine lubricant in a four-ball machine. The blended lubricants 5%, 10%, 15%, 20%, and 100% palm oil TMP esters with ordinary lubricant. The results show that the palm oil-based TMP ester-based lubricant improves wear-preventive lubrication properties in terms of the coefficient of friction and the wear-scar diameter.

Table 8 Summary of the work done by various researchers on vegetable oil

Vegetable Oils	**Reference lubricant**	**Test method and condition**	**Results**	**References**
Coconut Oil	SAE 20 W 50	Four ball tester	Less coefficient of friction Higher anti-wear properties Better lubricity properties	[51]
Palm Oil	SAE 20 W 50	High-frequency reciprocating ring	Less corrosive nature Low coefficient of friction Good oxidation and anti-corrosion properties Reactivity of unsaturated hydrocarbon chain Strong stability of lubricant film	[52][53][54] [55][56][58]
Waste palm oil	SAE 40	Four ball tester	Low coefficient of friction High viscosity	[57]
Jatropha, Neem, Karanja, Soybean, Palm coconut, Castor, Olive, Mahua, Sunflower, etc	Petroleum-based mineral oil	Different tribo-tester with a standard method	High flashpoint High viscosity index Low evaporate loss Less coefficient of friction Better lubricity properties Offer better performance Cheaper and eco-friendly	[2][35][59] [60][61][62]
Castor Oil	SAE 20 W 50	Four-Ball Tester	Greater viscosity index Low coefficient of friction High lubricity	[48]
Rapeseed oil and Palm oil	SAE 20 W 40	Pin on disc tribo-wear tribometer	Reduce the coefficient of friction and wear Excellent lubricity Renewable and biodegradable	[63][64]

7. CONCLUSIONS

Environmental factors are gaining importance in our society. Keeping in mind that the environment is continuously contaminated with various kinds of pollutants, any slight reduction is acceptable gladly. A large amount of petroleum-based lubricants polluted the environment during or after use, mostly from spills and industrial processes. Various countries are restricting the use of petroleum-based lubricants in applications where lubricants can get in contact with soil and water. Nowadays, the potential of vegetable as additive and bio-lubricant for industries is higher due to the cost and their biodegradable properties compared to other mineral oils.

Vegetable oils naturally suitable as lubricant base oils to enhance its physicochemical properties and tribological properties where vegetable oils function as good as the mineral and synthetics oils or better. The capability of vegetable oils as additive and bio-lubricants as an alternative lubricant for industrial and maintenance applications include lower toxicity, good lubricating properties, high viscosity index, high ignition temperature, increased equipment service life, high load-carrying abilities, good anti-wear character, excellent coefficient of friction, natural multi-grade properties, low evaporation rates – low emissions to the atmosphere, and rapid biodegradability. Industries can reduce tool costs and improve product quality in a safer environment by switching to bio-lubricants. Bio-lubricant reduces costs and increases competitiveness.

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