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Review on Tribological Properties of Vegetable Oil and It's Use as Lubricant

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ABSTRACT: Commercial lubricants used currently are mainly based on mineral oil (MO) due to its availability, performance and cost. However, these factors could not be maintained in the future as the base stock of petroleum is non-renewable and concerns over environmental pollution of mineral oil have increased. The pollution of the environment caused by mineral oil is one of the concerns and could not be taking too lightly. The oil spillage into the land and water may happen mainly due mineral oil. This concern has promoted research into biodegradable lubricants such as vegetable oils, since vegetable oils do not contaminate or pollute the environment. Furthermore, vegetable oils have properties such as good lubrication, high flash point, high biodegradability, and low volatility with adding additives. In this paper various vegetable oil tribological behaviour review are taken.

KEYWORDS: Mineral oil, vegetable oil, Tribological, lubrication, biodegradability, additives.

I. INTRODUCTION

Friction develops during relative motion of contacting surfaces. It is a force that resists the motion which then leads to heat and increases surface temperature. In machinery applications, friction is needed in the case of vehicle braking systems, clutches, belts and pulleys. However, in other situations like bearing support systems and the piston ring interface, friction is undesirable and needs to be reduced as much as possible. An increase of friction in an engine causes mechanical energy loss and consequently more fuel to be used in order to perform the same work. In addition, the engine quickly overheats and its working parts may wear or seize due to excessive friction. Wear is associated with the interaction between two surfaces and more specifically the removal and deformation of the surface due to the rubbing action of the surfaces. In most cases wear occurs through surface interaction at asperities. Components in an automotive engine may experience failure and need to be substituted after relatively little material has been removed or if the surface is roughened due to excessive wear. A lubricant is normally applied to the contacting surfaces in order to minimize the friction and wear. In an automotive engine, the piston ring and the cylinder liner are lubricated by oil to ensure optimum engine performance and wear protection. Lubricants smooth the movement and facilitate the transfer of heat and thus, cool the engine parts. It also cleans the internal engine components by flushing out the small particles of metal and dirt. Proper design of lubricant systems may contribute to quieter engine operation and an increase in engine life. Commercial lubricants used currently in automotive engines are mainly based on mineral oil (MO) due to its availability, performance and cost. However, these factors could not be maintained in the future as the base stock of petroleum is non-renewable and concerns over environmental pollution of mineral oil have increased [23,12]. The oil spillage into the land and water may happen mainly due to human negligence which may be caused by the spillage of used engine oil or petroleum crude oil. In the ocean, the oil spill may come from the oil tankers and offshore oil platforms. It was reported that the total volume of oil lost to the environment from 2010 until 2015 was about 33,000 tons in which the total number of spillages involving oil more than 700 tones was 11 cases [16]. An oil spill can cause problems for plant, animal and human life. Floating oil on water prevents sunlight from passing through it making it difficult for plants and sea animals to survive.

Vegetable oil as Lube:

Vegetable oils are being investigated as a potential source of environmentally favorable lubricants, due to a combination of biodegradability, renewability and excellent lubrication performance. Low oxidation and thermal stability, poor low-temperature properties and narrow range of available viscosities, however, limit their potential application as industrial lubricants. This review addresses oxidation as a limitation of vegetable oil-based lubricants.



The basic mechanism of vegetable oil autoxidation is presented, along with methods used to monitor and analyze the products of oxidation. Recently, due to environmental issues, there has been a growing concern regarding the use of mineral oils as lubricants. This concern has promoted research into biodegradable lubricants such as vegetable oils, since vegetable oils do not contaminate or pollute. Furthermore, vegetable oils possess many properties such as good lubrication in contact area, high flash point, high biodegradability, and low volatility. The high polarity of vegetable oils allows them to be useful boundary lubricants. Therefore, at higher loads, there is a performance drop in the lubricants. Additives have been used as friction modifiers due to their extremely small size, which allows them to slide into the two metals' contact area. This allows the particles to act as a rolling bearing in the interface. The addition of additives helps with the wear and friction properties. Early this century, environmental concerns have stimulated increased interest in biodegradable lubricants. Since, vegetable oils and most esters are more biodegradable than mineral oils, worldwide attention on the biodegradability of lubricants has prompted many lubricant manufacturers to reconsider vegetable oils as base stocks. Many studies have explored the possibility of replacing mineral oils with vegetable oils. When vegetable oils are used as base stocks for lubricants, they exhibit good lubricity and high viscosity index. However, their oxidative stability and low temperature properties are inferior to those of petroleum-based lubricants. Vegetable oil-based lubricants are currently used in many countries. Lubricant oil is very important component in modern technology that can be used as an intervening, friction and wear reducing films between two sliding surfaces.

Mineral oils are the main lubricant fluid consumed worldwide. Yet, the depletion of world fossil fuel resources, stronger environment concern and strict environment regulations have boosted the demand on developing eco-friendly and cost-effective lubricants. Hence, replacing mineral oil-based lubricants with sustainable plant-derived resources is highly desired. Vegetable oils are considered as an alternative with great potential to replace toxic, non-renewable petroleum-based lubricants. Unlike mineral oils, vegetable oils provide benefits such as economic feasibility, low toxicity, renewability, biocompatibility and satisfactory lubricating performance. Vegetable oil-based lubricants are currently used in many countries. Lubricant oil is very important component in modern technology that can be used as an intervening, friction and wear reducing films between two sliding surfaces. Mineral oils are the main lubricant fluid consumed worldwide. Yet, the depletion of world fossil fuel resources, stronger environment concern and strict environment regulations have boosted the demand on developing eco-friendly and cost-effective lubricants. Hence, replacing mineral oil-based lubricants with sustainable plant-derived resources is highly desired. Vegetable oils are considered as an alternative with great potential to replace toxic, non-renewable petroleum-based lubricants. Unlike mineral oils, vegetable oils provide benefits such as economic feasibility, low toxicity, renewability, biocompatibility and satisfactory lubricating performance. Furthermore, their superior anti-wear and friction properties allow them to be better lubricating oil than the mineral ones [27].

- The following **Table** provides the important Physicochemical properties of oils [15]

Vegetable oils non-edible	Density (Kg/m ³)	Kinematic viscosity at 40 °C (mm ² /s)	Oxidation stability 110°C, h	Cloud point °C	Flash point °C
Jatropha	878	4.82	2.3	2.75	136
Karanja	918	4.80	6.0	9.0	150
Mahua	850	3.40	-	-	210
Neem	885	5.20	7.2	14.5	44
Castor	898	15.25	1.2	-13.5	260
Tobacco	887	4.25	0.8	-	166

Vegetable oils edible	Density (Kg/m ³)	Kinematic viscosity at 40 °C (mm ² /s)	Oxidation stability 110 °C, h	Cloud point °C	Flash point °C
Palm	875	5.72	4.0	13.0	165
Sunflower	878	4.45	0.9	3.42	185
Coconut	805	2.75	35.4	0	112
Soybean	885	4.05	2.1	1.0	176
Linseed	890	3.74	0.2	-3.8	178
Olive	892	4.52	3.4	-	179
Peanut	882	4.92	2.1	5.0	177
Rape seed	880	4.45	7.5	-3.3	62
Rice bran	886	4.95	0.5	0.3	-

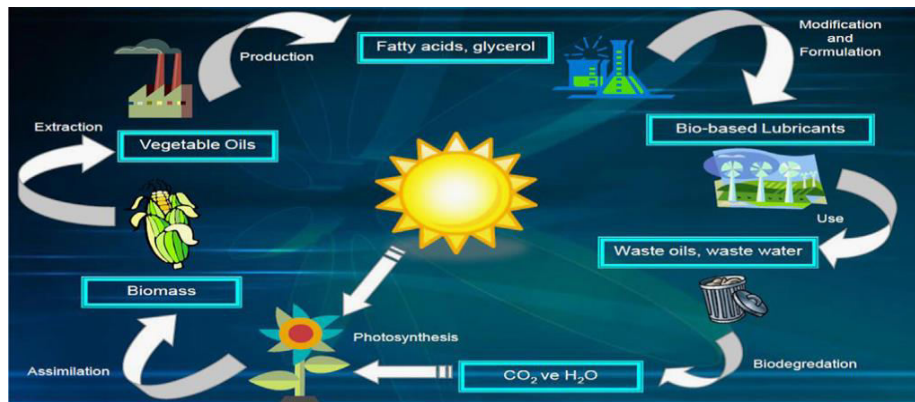


Fig. 1. Life cycle of bio-based lubricants [15]

II. RELATED WORK

According to Balulescu, Lee, Anand and Lawal Metal working fluids are used in machining operations to increase the quality of manufacturing operations. The composition of metal working fluids is highly complex due to the variety of machining operations and demanding machining quality requirements. The major issue with the MWFs is pollution caused by them as are either lost into the environment or disposed of in an unregulated manner. Most of the occupational diseases of operators in machine shop were due to the skin contact with metal working fluids. Metal working fluids cause irritation/allergy to skin and respiratory tracts. In order to be environment friendly, cutting fluids should be readily biodegradable after disposal without being toxic to the ecosystem. Use of vegetable oils for making cutting fluid, brings combined benefit of high performance in machining with good environment compatibility [3, 25,19]. In earlier studies of Shashidhara and Bartz it was observed that with the use of Vegetable oils it was possible to increase production volume by 10 %, and also reducing tool cost by 50 % in machining titanium and stainless steel medical implants. The study also showed that by using Vegetable oil as cutting fluid, tool life increased by a 15-fold, while tapping steel parts for an automobile application, [32,4]. Xavior and others have studied the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel with carbide tool using Coconut oil emulsion and compared it with a neat cutting oil. They have observed that the relative performance of the effectiveness of the cutting fluids in reducing the tool wear and improving the surface finish was better when Coconut oil was used compared to conventional mineral oil [37]. De Chiffre and Bellucoevaluated the performance of cutting fluids for turning, drilling, reaming and tapping operation for austenitic stainless steel and other four materials. Two different groups of cutting fluids water based and straight oils, with mineral, synthetic and vegetable based formulations were tested. Various parameters such as cutting thrust, tool life and product quality were considered for the evaluation as per ASTM D5619-94 standards. The results, on austenitic steel, showed that the cutting force under vegetable oils and esters modes were low and the tool life was also escalated with vegetable oils/ester based formulations. In another study they evaluated the new vegetable oil based cutting fluid efficiency with respect to part accuracy, surface roughness and micro hardness in reaming and micro hardness in tapping. The vegetable oil based cutting fluids showed better performance than mineral oils in reaming and tapping. They have noticed that cutting fluid have a significant effect on surface integrity and on thickness of the strain hardened layer in the subsurface [6,7]. Peter Raynor et al. developed five metal working fluid formulations from soybean oil. The study showed that, under impactation mechanism, both the tested fluids and commercial fluids generated similar amount of mist. However, under centrifugal mechanism, soya based fluid produced more mist compared to petroleum based fluid. The study concluded that the air-oxidizedsoybean oil formulation was most promising candidate among the tested samples [26]. Singh and others used metal working fluids from non-edible oils and studied their performance as per ASTM standards. They reported that new emulsions developed were stable at room temperature and passed the copper strip corrosion test. Lubricity test revealed that all the formulations had reduced wear scar diameter substantially and the formulation was nontoxic to bacteria [33]. The results, on austenitic steel, revealed that the cutting force under Vegetable oils and esters were low compared to reference mineral oil based formulations and the tool life was escalated [34]. Abdulla et al. studied the development and application of metal removal fluid using commercial and natural vegetable oils. Vegetable based oils such as coconut, sunflower, rapeseed, palm olive, rapeseed were



used for this purpose. Tribological studies revealed that very low friction values were found under naturally derived cutting oil compared to commercial oil. Further, the results of micro tap test reported that the vegetable oil with naturally derived additives had low cutting force and torque while machining on stainless steel metal.

In one of the study, Carcel and others have carried out a systematic investigation using five different Vegetable oils (sunflower, soybean, corn and two variants of olive oil without additives for stamping operations on steels sheet, zinc plated sheet and Zn-Fe alloy coated sheet to analyze the tribological performance of different coating-oil combinations. Carefully degreased specimens were used and a uniform oil coating was applied by a roller system prior to testing. The test results showed that performance of all the Vegetable oils were better than the mineral oil based lubricant. The study also revealed that the Vegetable oils performed satisfactorily providing corrosion protection without forming rust patches. The study showed that the surface topography of the sheets has a great effect on the tribological behavior under boundary lubrication conditions. It was observed that sheets having low values of Rpk couldn't be lubricated effectively by any kind of the oils tested. It was also observed that with the better control of topography it was further possible to eliminate the use of mineral oil or minimize the use of additives in Vegetable oils for the metal forming operation [10]. An experimental investigation was carried out by White et.al on snowmobile engine emissions at Yellowstone National Park, USA to determine potential benefits of use of bio-based fuels and lubricants. As a part of investigation, different fuels and lubricants were evaluated using a fan-cooled 488-cc Polaris engine, and a liquid-cooled 440-cc Arctic Cat engine. A bio-based lubricant, synthetic lubricant, high polyisobutylene (PIB) lubricant and a conventional mineral oil based lubricant were evaluated. The biodegradable lubricant has showed reduction in carbon monoxide by 38 % compared to the conventional lubricant [36]. In another study by Bekal performance of Pongamia oil as an IC engine lubricant in a commercial four-stroke, single-cylinder, water-cooled, direct-injection diesel engine was carried out. The study showed that Pongamia oil provided the minimum brake specific energy consumption and the highest brake thermal efficiency at medium-and high-load conditions because of its low viscosity. This also reduced the frictional losses and completely eliminated the emission of metal traces when compared to mineral oil lubricants [5]. According to Mannekote, The performance evaluation of the Coconut and palm oils in four-stroke engines was carried out for duration of 100 hours. Results have showed that reduction in exhaust emission for both Coconut and palm oil in terms of oxides of carbon and nitrogen when compared with standard mineral oil based 4-stroke engine oil in addition to improved fuel efficiency. A different engine was used for different test oils used in the investigation. The tribological evaluation of the oil samples collected at different intervals from the engine was carried out by means of four ball tester revealed that the mineral oil based lubricant was better in terms of reducing the wear compared to Vegetable oils which was possibly due to the absence of the performance enhancing additives in the formulations, whereas Coconut and palm oil have showed lower friction compared to mineral oil based sample as shown in figure and the observed increase in frictional coefficient was attributed to the deterioration of Vegetable oils due to the oxidation during use[22]. Studies conducted by Jayadas et.al on two-stroke forced air cooled single cylinder engine (Bajaj Super FE scooter) and the operating parameters were selected to simulate a road speed of 50 km/h with 250 Kg cumulative load. The engine cylinders were removed and measured for diameter and circularity error at different depths of 5mm each up to 40mm from the top dead centre and the measurements were repeated after running the engines for the equivalent time of 1000, 2000 and 3000 km. The experiments were also carried out with additive Coconut oil to assess its influence on engine wear under the simulated operating conditions. In addition to that tests were also performed on a popular model of autorikshaw having similar engine cylinder was measured for diameters and circularity errors as in the earlier case and the test was repeated at 1000, 5000 and 10000km each measuring the circularity error after carefully cleaning the cylinder [17].

According to Masjuki tribological and emission performance of palm oil was evaluated using a universal wear and friction machine under testing conditions of 3.0MPa, sliding speed of 0.2m/s, with sliding stroke 80mm, under ambient conditions using the upper piston ring (UPR) and lower piston ring (LPR) of Yamaha generator, two-stroke ET950 engine followed by emission tests at constant speed of 2800 rpm under different loads. A standard mineral oil based lubricant was used as a reference sample. These studies showed that experiment conducted with palm oil based lubricant was effective in reducing the emissions level for CO and HC compared to conventional lubricants. The wear studies conducted on upper and lower piston rings of the same engine with palm oil based lubricant have showed better wear resistance compared to mineral oil based lubricants [20,21]. In another experimental investigation by Singh et.al on castor oil was chemically modified into Toly ethyl hexyl ester derivative and additive package having synergic effect was added to match the requirements of BIS standard 12434. Lubricity of the sample was evaluated using a High Frequency Reciprocal Rig (HFRR) showed that newly developed formulation meets all the requirements in terms of coefficient of friction, wear scar diameter, and wear



index, compared to a standard mineral oil based lubricant. In addition, deposit forming tendency, volatility, and exhaust emissions were less compared with the conventional lubricant [34]. Schneider et.al studied that Vegetable oils have become potential candidates for energy transport media in hydraulic and lubricating systems in the recent past. This will reduce the damage caused by the pollution due to accidental spillage of oils during the use and safe disposal after the use. In order to adopt these oils in various applications, it is essential to have an understanding of the rheological properties to overcome the possible failures that can occur in real operating conditions. A low compressibility results inefficient energy transfer; increased compressibility will result in loss in efficiency. Whereas certain amount of compressibility is always desirable as it dampens the pressure surges providing smoother operation [29].

A systematic study by Wan et.al on the effect of shear rate and temperature on the rheological properties of Coconut, sunflower, canola, corn, palm oil showed that viscosity of oils depends on shear rate and temperature and have showed pseudo-plastic behavior. It's important for a lubricant or for a fluid in hydraulic system where excessive reduction in viscosity is not favorable. It was also observed that shear thinning behavior becomes less significant with increasing temperature. Among the samples tested sunflower oil showed highest viscosity stability with change in temperature [35]. In another work, Krazan et.al studied that evaluation of variation of density and kinematic viscosity of high oleic sunflower oil (HOSO), three different mineral oil samples and a synthetic oil sample using automated SVM 3000 Anton Paar rotational viscometer between 278.15 and 373.15 K. Density values at high pressures were determined using an Anton Paar HPM vibrating tube densimeter. It was observed that HOSO showed better viscosity index and the isothermal compressibility values indicate that the HOSO is more efficient than the mineral oil and synthetic oil based formulations. In another study, performance of rape seed oil was evaluated for its compatibility to hydraulic system by comparing its performance under laboratory condition as well as under field working condition. The field tests have showed that the oil performed extremely well even after 2000 hours of working provided the temperature was Maintained within 800C [18]. The earlier Studies of Asadauskas have showed that the vegetable oils have reduced friction and wear when used as base stocks or as additives. Similar studies conducted by others also concluded that the lubricant formulations with rapeseed oil and high oleic sunflower oil as base oil have superior tribological performance than a mineral oil based formulation [13]. The earlier studies by Asadauskas, Bisht, Goyan, Gapinsky, Jayadas on vegetable oils are very good boundary lubricant when used as base oils or as additives due to their polar structure, which results in very low coefficient of friction [8, 13, 14, 17]. Goyan et.al. studied tribological properties of rape seed, sunflower, castor and two mono esters of oleic acids by using the four-ball tester. They observed that unsaturation of sunflower oil led to an unexpectedly higher wear, whereas the hydroxyl group branching of castor oil did not show any effect. They concluded that chain length and un-saturation of the constituent fatty acids have an effect on the friction and wear properties of vegetable oils. Since coconut oil has high content of saturated fatty acids it is expected to be less prone to deleterious interactions with additives [14]. A summary by Rudnick and Sharma et.al. of some of the important lubricant-related properties of vegetable oils has been recently published that compares these properties with those of mineral oil based lubricants and synthetic esters [28, 6]. The viscosity of lubricating oils plays an important role in the selection of oil as the chemical structure of the vegetable oil affects the flow properties of the oil. The viscometric behavior of fluids is generally characterized by viscosity, viscosity index, low temperature fluidity, and compressibility. Increase in viscosity can be achieved by changing the chain length, whereas the branching results in a viscosity decrease according to Erhan and Adhvaryu et. al..

The study by Masjuki revealed that with the addition of POME friction reduced and the scar surface appear to be smoother [20]. The effect of a coconut oil as diesel fuel alternatives or as direct fuel blends were investigated using a single-cylinder, direct-injection diesel engine. The spray characteristics in terms of the mean droplet diameter of these fuels were measured. The operation of the test engine with the pure coconut oil and coconut oil–diesel fuel blends for a wide range of engine operating conditions was shown to be successful even without any engine modification. Results show that neat coconut oil fuels gave lower smoke and NOx emissions. In another study epoxidized rapeseed oil was used for lubrication. The study showed that epoxidation treatment has no adverse effect on the biodegradability of the base stock. Whereas the epoxidized rapeseed oil showed superior oxidative stability compared to rapeseed oil. The tribological studies showed that epoxidized rapeseed oil has better friction reducing and extreme pressure abilities due to the formation of a tribopolymerization film is proposed as explanation of the tribological performance of epoxidized rapeseed oil [39]. A series of structural modifications of vegetable oils using anhydrides of different chain lengths was carried out and the thermo oxidation stability of new lubricant base fluids was tested. The chemically modified base fluids exhibit superior



oxidation stability in comparison with unmodified vegetable oils. The study by Sharma et.al showed that these fluids are suitable as base fluids in combination with additives [7]. In another study tribological properties of coconut oil as a lubricant was evaluated using a four-ball tester and also on a two stroke engine. The study showed that coconut oil, though a good boundary lubricant as far as the coefficient of friction is concerned, shows higher wear rate in an engine when compared to commercial lubricants [17]. Corn, canola, and castor-lauricestolide oils were prepared and the effect of chemical modifications on viscosity, viscosity index (VI), pour point (PP), cloud point (CP), oxidation stability (RPVOT), 4-ball anti-wear (AW), and extreme pressure (EP) were investigated. The sulfide modified (SM) corn and canola oils showed increased viscosity, increased thermal stability, reduced PP and reduced VI. The SM estolide displayed similar trends in VI and RPVOT but showed no change in viscosity or cold flow. The SM oils, along with commercial mono- and polysulfide additives were also investigated as additives, at 0.6% (w/w) S concentration, in corn and polyalphaolefin (PAO) base fluids. In both fluids, the additives resulted in minor changes of PP, CP, and the coefficient of friction, wear scar diameter (WSD), and weld point (WP). Only the commercial polysulfide EP additive displayed large WP increases in the fluids. The additives resulted in no change of oxidation stability of corn oil, but displayed big improvement in the oxidation stability of PAO. The difference in the effect of the additives on the oxidation stability of PAO was attributed to the difference in the reactive hydrogen content [9]

III. CONCLUSION

Vegetable oil and fat-based lubricants are promising alternative to mineral lubricants because they are renewable, non-toxic, and biodegradable, possess high flash point, low volatility, and high viscosity, etc. A thin lubricating film that reduces friction and wear, minimize metal-to-metal contacts. The use of edible and non-edible vegetable oils as an alternative to petroleum oil-based lubricants has received attention due to growing environmental pollution issues and declining petroleum supplies. The seeds of the majority of vegetable oil plants are highly oily and can be processed into bio lubricant. A bio lubricant is a naturally occurring, renewable lubricant that is nontoxic, easily biodegradable, and environmentally beneficial. In order to reduce the country's environmental impact and increase energy security, it is necessary to investigate the use of non-edible kinds and their mixes as bio-lubricants. Early this century, environmental concerns have stimulated increased interest in biodegradable lubricants. Since, vegetable oils and most esters are more biodegradable than mineral oils, worldwide attention on the biodegradability of lubricants has prompted many lubricant manufacturers to reconsider vegetable oils as base stocks. Many studies have explored the possibility of replacing mineral oils with vegetable oils. When vegetable oils are used as base stocks for lubricants, they exhibit good lubricity and high viscosity index. However, their oxidative stability and low temperature properties are inferior to those of petroleum-based lubricants.

Potential areas where environmentally friendly lubricants are useful

- Metal working and Metal forming applications
- Outboard two stroke engine oils
- Grease in total loss application
- Hydraulic applications
- Railway wheel tread and mold parting lubricants
- Food Industry applications

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