ICMIEE20-122

Tribological Investigation of Bio-lubricants Derived from Vegetable Oil Sources

Nazmus Sakib, Anzaman Hossen, Sobahan Mia*
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT
The utilization of petroleum based lubricating oils is expanding day by day and individuals are getting reliant on petroleum based oils to run them. Large use of crude oils may result shortage with future demand as the natural fields are gradually being empty. Petroleum based lubricants also have harmful effects on human life. Tremendous utilization of petroleum based oils additionally made many negative impacts on environment. So considering all the facts petroleum based lubricants should be replaced by some suitable oils. Among them Vegetable oils are mostly like to replace this place. Because vegetable oil is environment friendly, non-toxic, biodegradable, cheap and it can be cultivated according to the demand.
In this paper, five different bio-lubricants derived from vegetable oil sources have been investigated to study and analyze its lubricating properties. Furthermore, an experimental comparison of viscosity and viscosity index has also been shown after mixing an additive with base oils. PMA (poly methyl acrylate) is a conventional commercially available viscosity modifier that enhances the tribological performance of lubricating oils. In order to ascertain the efficiency of PMA as additive, the tribological performance of PMA blended base oils have been compared with mineral based oils used in different industrial application. The comparative study of experimental result demonstrated that some vegetable oils have good lubricating properties like viscosity to be replaced with petroleum based oils and viscosity index of base oils were increased by adding additive in different concentration. So vegetable oils can be a better future recommendation for replacing a large portion of petroleum based lubricants in near future.

Keywords: Tribology, Bio-lubricant, Vegetable oil, Additives, Petroleum based oils

1. Introduction

A lubricant is a substance acquaints with diminish grinding between moving surfaces. It might likewise have the capacity of shipping remote particles and of appropriating heat. Lubricant goes about as lifeguards of any tribo-system for wide scope of utilities and applications. All in all oils are the multifaceted operators required for smoother tribo-pair activities. Contingent on the properties required, accessibility, innovation based to customary mineral based through the ages [1]. Reports show that almost 38 million metric huge amounts of lubricants were utilized all inclusive in 2005, with an anticipated increment of 1.2% throughout the following decade [2]. Approximately 85% of lubricants being used around the world are petroleum-based oils [3]. Reducing wear and friction is a key element to decrease energy losses, particularly in engines and drive trains. Mineral oils have been utilized as a lubricant in IC motors for quite a while. Be that as it may, as a result of the refining of unrefined petroleum, mineral oils must be utilized as long as raw petroleum is accessible. Also, discarding mineral oils prompts contamination in both sea-going and earthbound biological systems [4]. Moreover, the ignition of mineral oils as an ointment has been demonstrated to discharge hints of metals, for example, calcium, phosphorous, zinc, magnesium, and iron nanoparticles [5]. Besides, petroleum based oils or crude oils are being drilled rapidly from the oil field. Large use of crude oils may result shortage with future demand as the natural fields are gradually being empty. Mineral based lubricants additionally effectually affect human life. Worldwide population growth has forced the excessive extraction of limited crude reserves in variety of applications. Traditional lubricant produced using the mineral oils and added substance bundle are possibly harmful to water and soil because of their heavier arrangement and lower biodegradability. Heightening crude oil costs, inappropriate removal strategies, nonattendance of grease utilization standards overall compromising condition has unequivocally drew its consideration towards the regular partners [6, 7].

The expanding oil costs, the consumption of the unrefined petroleum save on the planet, and the interest to ensure nature against contamination brought about by greasing up oils and their uncontrolled spillage have restored enthusiasm for creating and utilizing elective oils. Bio-ointment oils are seen as options in contrast to mineral oils since they have certain normal specialized properties and they are biodegradable. Contrasted and mineral oils, vegetable oil-based bio-lubricants for the most part show high lubricity, high consistency file (VI), high glimmer point, and low evaporative misfortunes [8]. Vegetable oils profess to be the better options in contrast to the customary partners. Vegetable oils are artificially triglycerides containing long chain unsaturated free unsaturated fats joined at hydroxyl bunches by means of ester linkage. Varieties in physical and synthetic properties and the conduct relies upon these essential squares [9]. They are favored over poisonous partners essentially because of their serious specialized properties like higher slickness, viscosities and lists, higher glimmer focuses, lower evaporative misfortunes and lower full bookkeeping cost including the activity cost and nature renewal cost. Despite the fact that they do have certain second rate attributes like diminished oxidation and warm strong qualities, helpless virus stream properties,

* Corresponding author. Tel.: +88-01677631379
E-mail addresses: nazmuss18@gmail.com

lower timeframe of realistic usability; yet by thorough adjustment strategies and methodical examination they can be improved [10, 11].

Expanding consideration towardsmanageability and ecological issues has driven subbing mineral oils with bio-lubricants. Innovative work is being done on bio-lubricants for powerful oil with unrivaled tribological execution under wide scope of working conditions and contact geometries. Surveys on the accessible writing to investigate the capability of bio-oils have been distributed. A basic audit has been made on vegetable - based oil added substances with explicit properties, producing procedures, favorable circumstances and applications. An examination on the source, properties, favorable circumstances, and impediments, capability of vegetable oil-based bio-lubricants as elective oils for vehicle applications, the world bio-oil market and its future possibilities are talked about [8]. As the future seems optimistic for vegetable oils as a viable replacement for petroleum based lubricants, many countries and scientists are interested to research in vegetable oils.

An examination was done on Coconut oil as a base oil for modern ointments assessment and adjustment of warm, oxidative and low temperature properties. In that review it has been indicated that coconut oil demonstrated nearly less weight increase under oxidative condition among the vegetable oils. Coconut oil has high pour point as a result of the transcendently soaked nature of its unsaturated fat establishes blocking its utilization as a base oil for lubricant in mild and cold atmosphere condition. The examination introduced in this investigation show that pour purpose of coconut oil can be brought down somewhat utilizing appropriate pour point depressants and additionally oppressing coconut oil to substance adjustment forms [12].

Another research was on high pressure tribological conduct of vegetables oils as oils. In this examination, high weight thickness, high weight thickness, pressure consistency coefficient, cementing point and eliminate conduct were pointed by comparing tests. Vegetable oils are acceptable in limit oil and earth desirable over mineral oil. Vegetable oils indicated high thickness list and consistency is acceptable contrasted with mineral oil at air pressure and furthermore moderate high weight. Weight consistency coefficients of vegetable oils indicated lower esteems contrasted with mineral oil and due with low pressure-consistency coefficient these can be utilized in EHL at moderate high weight, and so forth. [13].

Another examination was done on tribological conduct of anti-wear added substances in vegetable oils. Here it has been indicated that the recently orchestrated added substance, DBP has demonstrated the fantastic enemy of wear execution contrasted and the customary added substance, TCP, under rapid and temperature conditions. It has additionally seen that the new added substance has indicated the double capacity of hydrogen rummaging and defensive film arrangement, and was to be a compelling enemy of wear added substance in different oil frameworks [14].

In any case, just a couple of these papers have broken down and investigated bio-oils. The primary target of the current investigation is to give data to engineers, strategy creators, industrialists, and analysts, who are keen on bio-lubricants. It presents a thorough survey of the possibilities of utilizing bio-lubricants as elective lubricants in car applications, including subtleties of vegetable oil properties and their potential as oils. In this paper, five diverse bio-lubricants got from vegetable oil source have been researched to contemplate and break down its greasing up properties. Besides, an exploratory examination has additionally been appeared subsequent to blending an added substance in with base oils. PMA (poly methyl acrylate) is a customary industrially accessible thickness modifier that upgrades the tribological execution of greasing up oils.

2. Experimentation

2.1 Lubricant Collection

Mustard oil: The term mustard oil is utilized for three distinct oils that are produced using mustard seeds. A greasy vegetable oil coming about because of squeezing the seeds, a fundamental oil coming about because of granulating the seeds, blending them in with water, and separating the subsequent unpredictable oil by refining. An oil made by mixing mustard seed extricate into another vegetable oil, for example, soybean oil.

Sesame oil: It (otherwise called Gingelly oil or Til oil) is an eatable vegetable oil got from Sesame seeds. The oil is famous in Asia and is additionally one of the most punctual known yield based oils, yet overall mass present day creation keeps on being restricted even today because of the wasteful manual gathering process required to extricate the oil.

Benna oil: The oil is extracted from Aphanamixis polystachya, the Pithraj tree, is a types of tree in the family Meliaceae. Locally it is known as Benna.

Kalojira oil: Black seed oil, squeezed from Nigella sativa seeds, has a long history of therapeutic use, remembering for antiquated Greek, Asian, and Islamic medication, just as being a subject of momentum clinical exploration. It very well may be tested for its potential in grease division.

Neem oil: Neem oil is a vegetable oil extracted from the leafy foods of the neem (Azadirachta indica), an evergreen tree which is endemic to the Indian subcontinent and has been acquainted with numerous different zones in the tropics. It is the most significant of the industrially accessible results of Neem for natural cultivating and medications.

Mobil 1 5w-50: It is suggested for a wide range of stature obligation vehicles, reasonable for use in superior turbo charged, too changed gas and diesel, multi esteem fuel infused motors found in travelers vehicle, light vans and tracksides.

Mobil Super 2T: Mobil super 2T is a superior, two - stroke motor oil for use snowmobiles and lean oil/fuel proportion cutting apparatuses Mobil super 2T is pre-weakened to guarantee fast blending when added to fuel.

Mobil GX 80W-90, 140: These are elite hard core gear greases defined from great base oils and a propelled added substance framework.

All the vegetable oils were purchased from local market of Khulna, Bangladesh. By ensuring the quality of extraction from seeds, they were collected and selected for experimental analysis after initial purification process.

2.2 Test Procedure

2.2.1 Density:

The density was controlled by electrical exactness balance. Scientifically, thickness is characterized as mass partitioned by volume:

$$\rho = \frac{m}{v} \tag{1}$$

The following density was calculated under room temperature which was 29°C. Electronic precision balance was used to complete the density test.

2.2.2 Kinematic Viscosity:

The ratio of the dynamic viscosity and the mass density is known as kinematic viscosity and is denoted by the v. The approximate relationship between kinematic viscosity and time t for a Saybolt universal viscometer is expressed by:

$$\nu = (0.0022t) - (1.8/t) \tag{2}$$

Where, υ is in stokes and t is in seconds. Now, the absolute viscosity is given by

$$\mu = \nu * \rho \tag{3}$$

Kinematic viscosity was measured by using Saybolt viscometer. In this test, time in seconds is noted for 60 ml of the following oils at 40°C and 100°C to flow through an orifice.

2.2.3 Viscosity Index:

The viscosity index was calculated using the following formula:

$$V = 100\,\frac{(L-U)}{(L-H)} \tag{4}$$

Where V indicates the viscosity index, U the kinematic viscosity at 40 degrees Centigrade, and L & H are various values based on the kinematic viscosity at 100 degrees Centigrade available in ASTM D2270.

2.2.4 Acid Value:

Acid value (or "neutralization number" or "acid number" or "acidity") is the mass of potassium hydroxide (KOH) in milligrams that is required to neutralize one gram of compound substance.

$$AN = (V_{eq} - b_{eq})\, N\, \frac{56.1}{Woil} \tag{5}$$

V_{eq} is the volume of titrant (ml) consumed by the crude oil sample and 1 ml of spiking solution at the equivalent point, b_{eq} is the volume of titrant (ml) consumed by 1 ml of spiking solution at the equivalent point, and 56.l is the molecular weight of KOH. W_{oil} is the mass of the sample in grams.

The molar concentration of titrant (N) is calculated as such:

$$N = \frac{1000M}{204.23Veq} \tag{6}$$

In which M is the mass (g) of KHP in 50 ml of KHP standard solution, V_{eq} is the volume of titrant (ml) consumed by 50 ml KHP standard solution at the equivalent point, and 204.23 is the molecular weight of KHP.

2.2.5 Surface tension:

Surface tension of vegetable oils were measured by the capillary rise method. When a liquid rises in a capillary tube, the weight of the column of the liquid of density ρ inside the tube is supported by the upward force of surface tension acting around the circumference of the points of contact. Thus, surface tension:

$$T = \frac{r(h+\frac{r}{3})\rho g}{2cos\theta} \tag{7}$$

Where, h is the height of the liquid column above the liquid meniscus, ρ is the Density of the liquid, r is the inner radius of the capillary tube and θ is the angle of contact.

2.2.6 Pour Point:

ASTM D5853, Standard Test Method for pour point of crude oils. The specimen was cooled inside a cooling bath. At about 9°C above the expected pour point, and for every subsequent 3°C, the test jar was removed and tilted to check for surface movement. When the specimen did not flow when tilted, the jar was held horizontally for 5 sec. If it did not flow, 3°C was added to the corresponding temperature and the result was the pour point temperature.

2.2.7 Flash Point:

The outer container of the flash point measuring apparatus was filled with water and inner container with oil through the port. Then the apparatus was switched on. After 4-5 minutes the flame port was opened by pressing the switch and a flame was brought to the flame point. If the flame was flashing the thermometer reading was noted. If not, the waiting time was extended to another 4-5 minutes.

After the following experimentation, base oils were mixed with poly methyl acrylate (pma) which is an additive. A stir bar with a combined hot plate magnetic-stirrer device was used for mixing additive with base oil samples. Around 100°C heat was adjusted for all the samples and stirring for an hour which allows the homogenization of mixable liquids and stir-up of solid additive particles in liquids. Then the kinematic viscosity test was repeated for different percentage of additive mixture with base oil samples.

3. Result and Discussion

Table 1 Experimental data of different tribological properties of vegetable oil samples

Samples	Density (gm/cm^3)	Kinematic Viscosity (cSt)		Viscosity Index
		40°C	100°C	
Mustard Oil	0.875	48.9	8.88	163
Sesame Oil	0.889	38.18	6.79	136
Benna Oil	0.898	130.89	22.04	197
Kalojira Oil	0.872	39.07	7.4	158
Neem Oil	0.811	51.33	11.64	230
Mobil 1 5W50	0.859	125	18	161
Mobil Super 2T	0.878	63	8.7	111
Mobilube GX Gear oils 80W-90	0.89	135	14.5	107

According to the Table 1, it is shown that, the test of kinematic viscosity had been conducted basically for two distinctive temperature. For 40° temperature, it is clear from the gap that Sesame oil has the lowest value of kinematic viscosity while Benna oil has the highest. The result is same for 100°C temperature also. This variation depends on the saturation of the fatty acid distribution in the oil. For standardized application, Sesame and Kalojira oil is most preferable for this aspect only.

Then, it turns out that Neem oil has the highest value of viscosity index followed by Benna and Mustard Oil. The VI has direct impact on low temperature viscosity. According to this, among these oils in terms of VI Sesame and Kalojira oil performs quite satisfactorily.

From the above statistics, it is observable that, all the tested oils excluding Neem oil have almost the same values of density which is in .88 gm/cm^3 range. The Neem oil performed poor having a value of .811 gm/cm^3. The range that these vegetable oil have is quite remarkable in comparison with other crude oils. Density was measured in 27°C.

Flash point is an alarming parameter. If an oil ignites at an ambient temperature, then the end result can be not so good for the operator near it. For that, every oil used as a lubricant must have a high flash point as they always expose to very high temperature.

Table 2 Experimental data of different tribological properties of vegetable oil samples.

Samples	Acid Value	Surface Tension (dyne/cm)	Flash Point (°C)	Pour Point (°C)
Mustard Oil	0.74	19.32	250	-28.9
Sesame Oil	3.31	25.78	200	-6
Benna Oil	4.17	24.82	222	2
Kalojira Oil	2.63	29.53	284	-17
Neem Oil	3.44	9.02	165	10
Mobil 1 5W50	-	-	236	-51
Mobil Super 2T	-	-	132	-12
Mobilube GX Gear oils 80W-90	-	-	240	-33

From the Table 2, it is clear that Mustard oil has the lowest acidic value among all other oils. The gap is not negligible though. Benna oil having an acidic value of 4.17 making it less feasible to use in engine.

From the column of surface tension, it is shown that, Neem oil has the lowest value of surface tension of 9.02 dyne/cm. In terms of practicality, this value is below standard. In terms of standard, Mustard oil holds a good spot having a standard value of surface tension at 19.32 dyne/cm range.

The Kalojira and Mustard oil is pure winner in this category. The above 250°C range is quite good flash point territory. Neem oil showing a 165°C flash point making it a bit risky to use as a lubricating oil without proper additive mixing. Comparing to practical usage, Kalojira, Mustard and Benna oil performs satisfactorily in terms of flash point.

According to the data, Mustard oil shows the lowest pour point -28.9°C followed by Kalojira oil -17°C. These values of pour point are quite remarkable, as it is somewhat better than typical gear oil. However, Benna and Neem oil show positive pour point value which is not desirable for as a property of a lubricant.

Table 3 Experimental data of different tribological properties of vegetable oil samples mixed with additives.

Samples	Kinematic Viscosity (cSt)		Viscosity Index
	40ºC	100ºC	
Mustard Oil (3% PMA)	49.05	10.63	215
Mustard Oil (5% PMA)	50.29	11.47	231
Sesame Oil (3% PMA)	40.17	8.36	191

Sesame Oil (5% PMA)	41.02	9.14	214
Benna Oil (3% PMA)	132.36	28.4	254
Benna Oil (5% PMA)	137.85	30.60	263
Kalojira Oil (3% PMA)	41.49	9.51	224
Kalojira Oil (5% PMA)	42.88	10.61	250
Neem Oil (3% PMA)	55.06	15.19	291
Neem Oil (5% PMA)	55.59	16.28	310

This Table 3 represents the value of kinematic viscosity of various sample oils in both 40°C and 100°C temperature and the viscosity index for base oil with 3% (w/v) and 5% (w/v) poly methyl acrylate.

The Fig. 1 compares the increment of viscosity index increasing with the percentage of PMA. It is clear from the chart that percentage of PMA impacts on viscosity index. Neem oil with 5% PMA has a highest viscosity index among all the samples. Besides, the change is regular for all the samples. For 3% PMA viscosity index is increased a bit then it reaches its highest point for 5% PMA mixture with base oils.

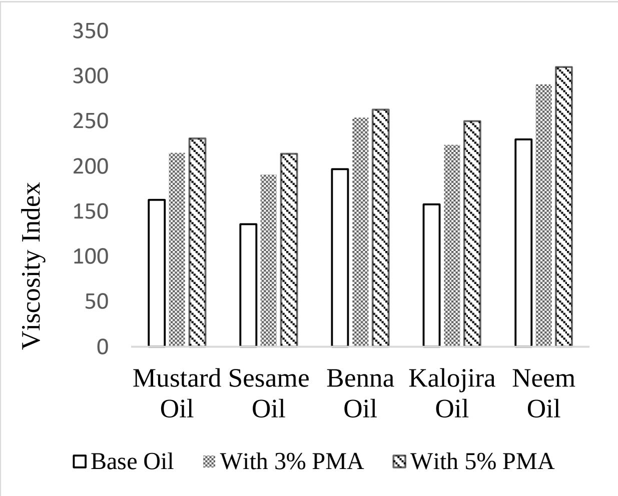

Fig. 1 Comparison of Viscosity Index of base oils and additive mixtures

Viscosity index is mostly used to characterize the viscosity-temperature behavior of lubricating oils. The lower the VI, the more the viscosity is affected by changes in temperature. The higher the VI, the more stable the viscosity remains over temperature fluctuations. So, the above results indicate that vegetable oils have higher viscosity index than petroleum based lubricants. It is an important property which can be used as alternative lubricants in engineering purposes.

4. Conclusion

The tribological performance of Mustard oil, Sesame oil, Benna oil, Kalojira oil, and Neem oil blended with PMA have been investigated through various tribological tests which are Density, Kinematic viscosity, Viscosity index, Acid Value, and Surface tension. The selected additive PMA has effectively improved the tribological performance of base oils. The following accomplishment can be extracted from the results presented above:

(1) PMA has a great impact on kinematic viscosity and viscosity index. 3-5% of PMA mixture with base oils increase Viscosity index compared to the viscosity of base oils.

(2) Neem and Benna oil offers better viscosity index and kinematic viscosity also. Specifically, Kalojira oil has a moderate lubricating properties among the five base bio-lubricants. Overall, above experimental results suggest that Neem, Benna and Kalojira oil has the potential to be an alternative lubricants on the basis of lubricating performance.

References

[1] M. D. Theo, "Lubricants and Lubrication," *WILEY-VCH Verlag GmbH & Co. KGaA* , vol. 2nd Ed., pp. ISBN:978-3-527-31497-3, 2007.

[2] Kline & Company, Inc. , "Competetive intelligence for the global lubricants industry," Kline & Company, Inc. , 2006.

[3] C. P. G. B. G. V. R. N. Loredana P, "Basestock oils for lubricants from mixtures of corn oil and synthetic diesters," *J Am Chemical Society,* pp. 85:71-6, 2008.

[4] C. D. Ssempebwa JC, "The generation, use and disposal of waste crankcase oil in developing countries: a case for Kampala district," Uganda. J Hazard Mater, 2009.

[5] G. A. Miller AL, "Role of lubrication oil in particulate," *Environ Sci Technol,* no. 41, p. 6828–35, 2007.

[6] I. S., "On the Future of Biodegradable Vegetable Lubricants Used for Industrial Tribo Systems," *Gal I Fascicie,* vol. VIII, pp. 1221-4590, 2002.

[7] W. Bartz, "Ecotribology: Environmentally Acceptable Tribological Practices," *Tribology International,* vol. Vol. 39, p. 728–733, 2006.

[8] H.M.Mobarak, "The prospects of biolubricants as alternatives in automotive applications," *Renewable and Sustainable Energy Reviews,* vol. Volume 33, pp. Pages 34-43, May 2014.

[9] A. Willing, "Lubricants Based on Renewable Resource – An Environmentally Compatible Alternative to Mineral Oil Products," *Chemosphere,* vol. Vol. 43, p. pp 89–98, 2001.

[10] O. A. K. O. M. O.-j. Emmanuel, "Biodegradation of Vegetable Oils: A Review," *Scientific Research and Essay*, vol. Vol.4(6), p. pp543–548, 2009.

[11] Z. E. B. K. S. J. M. P. Sevim, "Oxidation and Low Temperature Stability of Vegetable Oil-Based Lubricants," *Industrial Crops and Products,* vol. Vol.24, pp. pp. 292-299, 2006.

[12] K. P. N. H. Jayadas, "Coconut oil as a base oil for industrial lubricants-evaluation and modification of thermal, oxidative and low temperature properties," *Tribology International,* no. 39, pp. pp 873-878, 2006.

[13] S. H. N. O. Sobahan Mia, "High pressure tribological behavoiur of vegetables oils as lubricants," *International Conference on Mechanical Engineering,* 2007.

[14] B. G. A. O. K. K. Y. J. C. U. S. Choi, "Tribological behavior of some antiwear additives in vegetable oils," *Tribological International* , vol. Vol. 30, no. No. 9, pp. pp 677-683, 1997.

NOMENCLATURE

ρ : density, $kg\cdot m^{-3}$
m : mass, kg
v : volume, m^3
υ : kinematic viscosity, $m^2\cdot s^{-1}$
μ : absolute viscosity, $N\cdot s\cdot m^{-2}$
t : time, s
V : viscosity index
AN : acid number
N : molar concentration of titrant, $mol\cdot L^{-1}$
T : surface tension, $N\cdot m^{-1}$
h : height of the liquid column above the liquid meniscus, m
r : inner radius of the capillary tube, m
θ : angle of contact