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Formulation and physico-chemical characteristics of biolubricant

D.I Ahmed[a], S. Kasolang[a,b,*], R.S. Dwyer-Joyce[c], K.I. Sainan[a], N.R. Nik Roselina[a,b]

[a] *Faculty of Mechanical Engineering, Universiti Teknologi MARA, UiTM Shah Alam, Malaysia.*
[b] *Centre for Tribology, Universiti Teknologi MARA, UiTM Shah Alam, Malaysia.*
[c] *Department of Mechanical Engineering, University of Sheffield, United Kingdom.*
[*]Corresponding author: salmiahk@salam.uitm.edu.my

HIGHLIGHTS

- *Newly developed biolubricants from soya bean oil has been produced and compared against a commercial ISO 68 lubricant.*
- *The newly developed blend having a mixture of 52.70 % (wt) soybean oil, 40.55 % (wt) mineral oil, and 6.75 (%) additives, produced the best results for the viscosity fitting.*
- *The blend was also tested for physico-chemical characteristics and show promising results.*

ABSTRACT

The interest in bio lubricant has grown over the past years due to its promising benefits such as environment-friendly, renewable, less toxic and readily biodegradable. In recent years, many studies explored the potential of bio lubricants for industrial applications. This study was dedicated to develop a new formulated bio lubricant having viscosity fitted to a commercialized industrial lubricant. From nine different samples, the blend having a mixture of 52.70 % (wt) soybean oil, 40.55 % (wt) mineral oil, and 6.75 (%) additives produced the best results for the viscosity fitting. The selected blend was also tested for physico-chemical characteristics. The results on viscosity index, pour point, and flash point indicate positive characteristics for application in wider temperature change, cold weather, and safer transportation. Outcome of degradation test was also promising.

Keywords:
| Bio-tribology | Biolubricants | Soya bean oil | Viscosity | Boundary lubrication |

1.0 INTRODUCTION

The term green lubricant is generally used for lubricants manufactured from vegetable or other natural sources. Lately, demand of lubricants in industrial countries is extremely huge. From the economic point of view, the production of lubricants in large quantities is of the greatest concern in the lubrication industry because these base stocks present a potential danger to cause depletion of natural resources (Vauk, 1984). The Hubbert peak theory (Kenneth and Deffeyes, 2009) predicts that oil depletion will result in oil production dropping off in the not too distant future. With the notion that we live on a planet with finite resources, there is a limited amount of fossil fuel inside the earth. Since the current world energy resources and consumption is mainly fossil fuels, we have to think about the coming generations and work for sustainable development in the field of Tribology (Nosonovsky and Bhushan, 2012). Thus, the economic concerns and price stability edge the potential use of renewable sources based lubricants over petroleum lubricants (Jun et al., 2013b). Thus, vegetable oil is being considered as potential replacement for synthetic oil base stocks in certain lubricant applications (Jun et al., 2013a). The use of vegetable oils as based lubricants will be significant in the reduction of depletion of natural resources. Moreover, vegetable oils have a capability to contribute towards the goal of energy independence and security since they are nontoxic and biodegradable which will cause less danger to environment in case of accidental spillage or during disposal of the material (Nosonovsky and Bhushan, 2012).

2.0 EXPERIMENTAL

2.1 Specimen Preparation

The formulation of the bio-lubricant was done after the determination of the chemical make-up of the vegetable oil and mineral oil respectively. In the base stocks, there are mineral oil and Soybean oil. Before any chemical and physical property tests were carried out, different kinds of mineral and soybean oil base stocks were prepared. In order to improve lubricant characteristics, a mixture of various multifunctional component additives was used. These additives had a proportionate range between 0 and 8.5% of the base stock.

Next, a mix of the mineral oil, soybean oil and additives were added together into a 500-ml flask that was equipped with a magnetic stirrer at constant speed (160 rpm) to authenticate that homogenous blends could be gained. The mixing process is rudimentary in nature and was achieved at various temperatures until homogenous structure was attained. For all blends, not more than 6.75% wt of the additives be used as normative requirements. Through the use of standard testing methods as determined by the

American Society for Testing Materials (ASTM), the author determined the selected blend's properties. The results are tabulated and presented below. The experiments and their measurements were repeated at least three times with the results being calculated by averaging out the triplicate results.

2.2 Viscosity Fitting

The viscosity of the formulated oil was determined according to the International Standards Organization (ISO) specifications, creating a biodegradable environment-friendly lubricant at an ISO 68 viscosity grade for sliding bearings. However, the required viscosity is 68 cSt and the corresponding kinematic viscosity at 40 ºC for an ISO VG 68 is between 61.2 to 74.8 cSt (ASTM D 445). In addition, after storing the blends of soybean oil, mineral oil and other additives for at least three months no sedimentation and separation phase has been observed.

2.3 Pour Point Test

Pour point is a major characteristic of low-temperature properties. It is an indicator of the fluid's ability to flow at colder operating temperature. It is the lowest temperature at which the fluid will flow when cooled under prescribed conditions. For this study, the pour point test was conducted according to the method described in ASTM D97-12 with an accuracy of ±2 ºC with the pour point tester. The apparatus has a minimum temperature of -68 ºC using methanol as cooling liquid. Approximately 45 ml of oil sample was poured into a test jar until it reached the level mark. Then, the pour point apparatus is cooled down until the temperature reached to -37ºC. While waiting for the pour point apparatus to cool down, the test jar that contained the sample was heated to 45 ºC by using a water bath that was kept at a constant 45 ºC and then cooled down to 27 ºC in another water bath and maintained at 27 ºC. Whilst the pour point tester reached -36 ºC, the test jar was placed in the hole (in a horizontal position) at the top of the pour point tester until the oil shows no movement. The pour point temperature is taken when the oil shows no movement when the test jar is held in a horizontal position for 5 seconds. All iterations of the test were repeated for at least three times.

2.4 Flash Point Test

Flash point is the lowest temperature at which a liquid will form an explosive vapour under normal atmospheric conditions. The flash point of a lubricant was tested using a Cleaveland open cup tester conforming to ASTM D92-12b. For this test, four samples were tested: newly developed lubricant (Lubricant A), ISO 68 lubricant (Lubricant B), mineral base oil, and original soybean oil.

2.4 Degradation Test

Lubricant degrading is a common problem both in lubrication and hydraulic systems. Lubricants in sliding bearings will degrade over time, depending on the operating conditions, type of the oil and the environment. When the oil deteriorates, it changes its composition and functional properties. The main cause of this is thermal degradation due to the high temperature produced during the bearings operating. However, as a result of 10 hours of bench test by means of an ISL viscometer, the degradation of viscosity and viscosity index (VI) of lubricants A and B has been accomplished.

3.0 RESULTS AND DISCUSSION

3.1 Viscosity Fitting

The selected composition of the kinematic viscosity of soybean oil, mineral oil and additives at 40 ºC (cSt) is presented in Table 1. However, in blend No. 1, in order to forecast the viscosity of the mixture of 44 % soybean oil and 56 % mineral oil with no additive, but the desired viscosity has not been attained. In blends No. 2 and 3, the additive package was introduced but the desired viscosity has not been attained. In blends No. 4 and 5, the compositions of the vegetable oil and mineral oil are adjusted by keeping the additive dosage at 6.61 % wt and thus it brings the decline in the viscosity of the blends (Blend No.5) and an increase in the content of soybean oil and a decrease in the content of the mineral oil was observed. However, in blends No. 6 through 9, a different trend was observed because the mineral oil viscosity is higher than vegetable oil viscosity which is 503.40 cSt and 144.72 cSt at 40 ºC, respectively. Moreover, the outcomes of the viscosity of all the blends are shown in Figure 1.

In Table 2, a comparison between the viscosity (ASTM D445-15a) and viscosity index (ASTM D2270) of some selected blends is given. In viscosity index, the viscosity of soybean oil is higher than the viscosity of mineral oil and thus the higher viscosity index of soybean oil brings the higher viscosity index of the blend. This is attributed to the fact that the molecular weight of soybean oil, which contains triglycerides, is much more stable than that of mineral oil (Chen et al., 2012; Salimon et al., 2012). The high linearity of the vegetable oil also permits the triglycerides to maintain stronger intermolecular interactions with increasing temperature than branched hydrocarbons or esters. This ensures the high viscosity index of vegetable oils (Asadauskas et al., 1997). However, the mineral oil is consisting of molecular weight hydrocarbons and thus the molecular weight of vegetable oil has resulted in a higher viscosity index of oil which can help in counter- acting the extreme thickening. Thus vegetable oil can be used as a base stock for the lubricants.

Table 1: Composition of various blends

Blends No.	Compositions (wt.%)			Viscosity at 40 ºC
	Soybean oil	Mineral Oil	Additive	
1	44.00	56.00	0	50.04
2	40,00	55.00	5	56.03
3	37.55	54.40	8.05	59.90
4	52.46	40.93	6.61	80.40
5	58.21	35.18	6.61	60.01
6	57.22	36.03	6.75	63.20
7	56.36	36.89	6.75	66.06
8	52.70	40.55	6.75	68.05
9	40.25	53	6.75	80.09

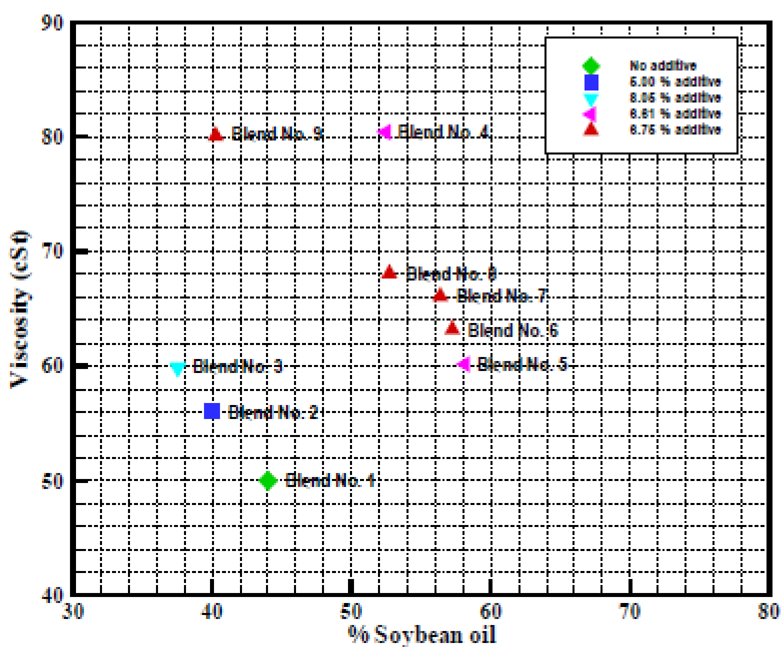

Figure 1**:** Viscosity of various blends at 40 ºC (ASTM D445-15a)

After the blends of soybean oil and mineral oil were achieved and the desired viscosity was attained, Blend No. 8 (lubricant A) was selected to be included in the property tests. The results of the tests are presented in the successive sections. However, it is difficult to determine whether the oil is sufficiently thin at low temperature or sufficiently thick to lubricate well with high temperatures during the steady state operating condition. This can be done by measuring the oil viscosity at all working temperature using a controlled-stress rheometer apparatus as shown in Figure 2, with viscosity range of 0.2-30,000 cSt and temperatures ranging from 20 to 140 ºC.

Table 2: Viscosity (ASTM D445-15a) and viscosity index (ASTM D2270) of lubricating blends studied

Blends	**Viscosity at 100 ºC (cSt)**	**Viscosity at 40 ºC (cSt)**	**Viscosity Index**
100% Soybean oil	5.04	144.72	170.00
100% Mineral oil	32.51	503.40	96.15
Blend no. 8 (A)	8.65	68.05	115.00
Commercial oil (B)	8.80	68.00	98.00

Figure 2**:** Controlled-stress rheometer

Figure 3 exhibits the experimentally measured temperature dependent viscosity of the formulated oil (Blend No. 8) in comparison with the commercial lubricant ISO VG 68 at temperatures ranging from 40 to 90 ºC at 10 ºC intervals. The results indicated that the temperature dependent viscosity of the formulated oil (lubricant A) had yielded a similar trend of the commercial oil (lubricant B) with a slight discrepancy of 1% at lower temperature and 10% at higher temperature passing through all working temperatures.

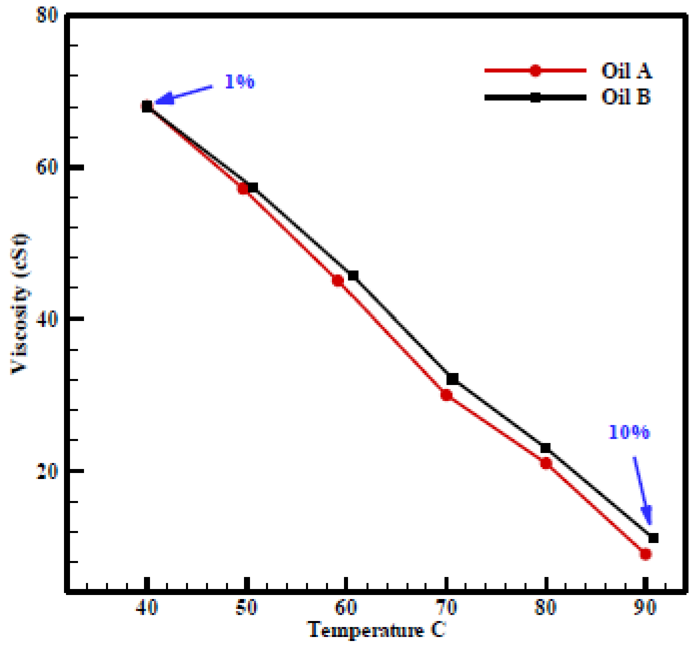

Figure 3: Temperature dependent viscosity of the formulated oil in comparison with ISO VG 68

3.2 Pour Point Test

It was noticed that the pour point of lubricant B (ASTM) D97-12 (ASTM D97-12, 2013) is -30 ºC while for lubricant A it is -20 ºC. The standard ISO VG 68 was satisfied with pour point temperature for lubricant A. The author also noted that when compared with the solidification point of an ISO VG 68, the solidification point of lubricant A is extremely lesser. As a result, one can use lubricant A both in cold and mild regions. The reason for the low pour point value obtained from lubricant A owed to the fact that the mineral oil has a higher viscosity compared to a ISO VG 68 hydraulic lubricant. In view of the fact that the pour point is the least temperature of a liquid, mainly in a lubricant when temperature is reduced it stops to flow. On the whole, the viscosity of a sample is inversely proportional to its pour point. This observation was noted as the summary of the experiments concerned.

3.2 Flash Point Test

The results for flash point test are given in Figure 4. The experimental values range for lubricant A from 250 to 262 ºC. The tests suggested that the difference between the flash points of soybean oil and mineral oil were negligible. As expected, the original soybean oil shows high flash point because of the strong interaction among molecules. Lubricant A shows unexpectedly lower flash point than that of original soybean oil and mineral base oil. This is possible due to the presence of the additive package. However, flash point of lubricant A is higher than lubricant B. It is worthy to say that the flash point of lubricant A is high, which would indicate that it would be a safer compound to transport.

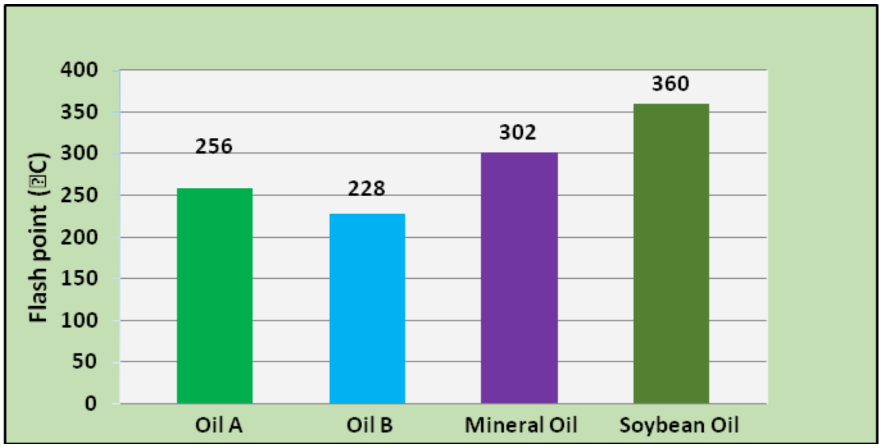

Figure 4: Flash point of selected blends (ASTM D92-12b)

3.4 Degradation Test

In Figure 5 the changes of the chemical features of the two lubricants are displayed. The kinematic viscosities of the lubricants were captured to lay at 40 ºC and 100 ºC respectively. In addition to that viscosity index is also determined. It was evident that lubricant A shows higher viscosity index than lubricant B. Lubricant A has a higher viscosity index because of the presence of triglycerides in the vegetable base oil that sustain stronger intermolecular interactions when temperature is rising (Asadauskas et al., 1997). Furthermore, it can be seen that lubricant A has a lower viscosity at 100 ºC as compared to lubricant B.

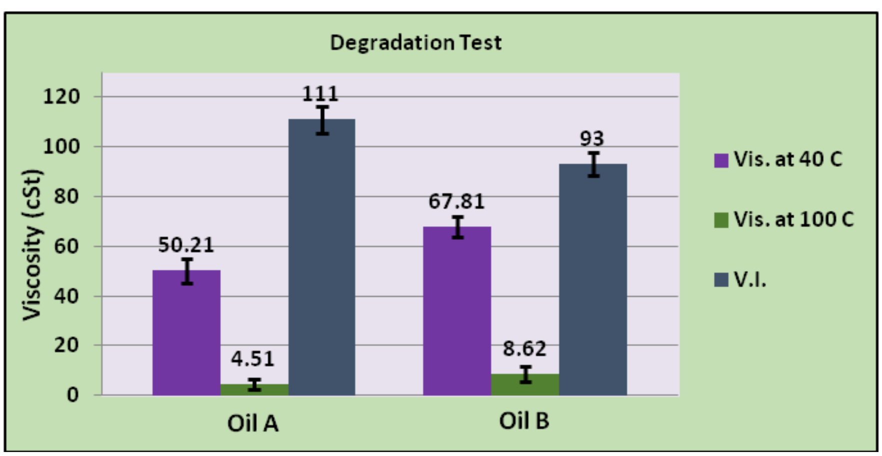

Figure 5: Changes of viscosity and viscosity index for lubricants A and B

CONCLUSIONS

The development of a new blend of bio-lubricant which is a mixture of soybean oil, mineral oil and certain additives has been described. There were 9 sets of blends prepared and initially tested for viscosity fitting based on ISO 68 lubricant for sliding bearing. The blend with the closest viscosity to that of the ISO 68 was found to have a mixture of 52.70 % (wt) soybean oil, 40.55 % (wt) mineral oil, and 6.75 (%) additives. This new formulation blend was further tested for physico-chemical properties. The pour point was found to be -20 ºC i.e. close to the pour point of industrial oil, ISO VG 68, of -30 ºC (ASTM) D5950. It was therefore concluded that this oil is suitable for use in regions with cold or mild weather. Its flash point was found to be 256 ºC indicating that the new blend could be transported safely with minimum risks of explosion. The viscosity index of the new blend reduced from 115 to 111 after the gradation test. In a further study, this newly formulated blend has been tested for friction and wear performances and reported in other papers.

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