Evaluation of tribological characteristics of natural garlic oil as an additive in rubber seed oil

K S Jesbin and D Mahipal

Department of Mechanical Engineering, Government Engineering College Thrissur, Kerala, India

1E-mail: ksjesbin@gmail.com

Abstract. Industrial oils have the essential elements of a lubricant, but their environmental feasibility and economic effect are insufficient. Vegetable oils are emerging as an alternative to industrial lubricants. The production of oil from energy resources, such as vegetable seed oils, is important. Rubber seed oil has been shown to be of greater value among the base stock of bio lubricants, since it contains large concentrations of unsaturated fatty acids. The effectiveness of natural garlic oil as an additive in rubber seed oil in enhancing the tribological characteristics of steel/steel contact is conducted in this research. The findings are compared with SAE20W40 oil data. Friction and wear experiments were carried out using a four-ball tribotesting machine. Additive added rubber seed oil offered low friction values compared to mineral oil. The newly produced oil was tested by a kinematic viscometer. Improvement in the viscosity index was demonstrated by additive added rubber seed oil.

1. Introduction

Global energy demand is likely to increase by 56% from 2010 to 2040, as per the Energy Information Administration (EIA) [1]. Many other factors, such as raising population, social support systems, and growing urbanization, are driving ever-increasing pressure on energy supplies. According to Chevron Corporation, the world population is projected to grow by 25 percent in the coming 20 years [2]. The reserves of oil are expected to expire in much less than 5 decades. At the same time, the greenhouse gases released by petroleum-based fuels adversely affect the environment and human health [3]. The need for green and biodegradable lubricants would further be pushed by increasing environmental concern [4]. The majority of the petroleum-based lubricants in the market have become popular because of their excellent quality at low prices and legislation to minimize contamination and emissions [5]. Broad usage of petro-based lubricants is because they have the longest drain period i.e. a lubricant's working life, which reduces the machine's breakdown frequency since it requires a substantial amount of time to fully change the lubricant.

While mineral oil-based lubricants have many helpful physical properties, they also are non-renewable and environmentally hazardous [6]. Improper disposal of used lubricants based on petroleum contaminates water bodies, causes diseases, and vitally impacts marine ecosystem sustainability. Industrial groups should use bio-based lubricants rather than petroleum-based lubricants [7]. Vegetable oils are naturally biodegradable, minimal ecotoxicity and low human toxicity based on renewable resources, and non-volatile organic compounds have excellent environmental characteristics [8]. Many countries, such as India, Sri Lanka, Bangladesh, Nepal, and so on have great potential of producing tree-borne edible and non-edible oils that remain untapped and can be used as a
possible vegetable oil source lubricant. Increased markets for rare seeds of this type and oil might increase farmers' revenues and optimize the use of products for agriculture [9].

Because of its economic significance, the rubber tree (Hevea brasiliensis) is used primarily for latex. Research has shown that the seeds of the rubber tree are a rich source of oil comparable to dry oils. There are currently no major applications for rubber seed, and thus even the natural development of seeds itself remains underutilized. In the dried kernel, the oil content ranges from 35 to 45 percent. Rubber seed oil (RSO) consists of 18-22% saturated fatty acids and 28-80% unsaturated fatty acids. This oil is widely used in surface coating [10]. These non-edible crops can be grown in rural, ineffective or deteriorated forests because they are well suitable to moderately arid and arid conditions. Hevea Muellbrasiensiis Arg, widely known as the rubber tree, belongs to the family of Euphorbiaceae and is the main source of 99 percent of natural rubber in the world. A good tree yields around 500 g of seed with an average annual oil content of 50–60 wt per cent. [11].

RSO should not be ingested because of its intrinsic toxicity, although it is rich in essential fatty acids [12]. The economic significance of the latex from the rubber tree is high. RSO has recently discovered many applications in areas such as biodiesel processing. These base stocks may be seen as potential for use in bio-lubricant formulations. Additional improvements to the efficiency of VO-based lubricants are possible through additives. Additives can improve the physical properties of the lubricant by providing extra features, like anti-corrosion, metal scavenging and anti-wear to the base stock [18].

The thermal stability, oxidation stability, physiochemical properties and tribological properties of RSO base stock are evaluated and compared with SAE20W40. Major constituents of RSO is as follows: Palmitic acid – 12.75%, Stearic acid – 6%, Oleic acid – 45.66%, Linoleic acid – 25.45%, Linolenic acid – 15.32%. [19]. Earlier studies indicate that vegetable oils with high oleic acid content are promising replacements for mineral oil-based lubricants [20]. The goal of each new formulation is to achieve improved performance, increased energy efficiency and better machine life, as well as longer cycles to replace lubricating oil [13]. Many additives are extremely reactive and will be more prone to happen water or soil pollution.

There is also a need for environmentally friendly additives to be produced that are compliant with environmental regulations. Commercially available additives that are alkyl and aryl disulphides and polysulphides, sulphurized hydrocarbons, fats, oils, fatty carboxylic acids, dithiocarbamates, chlorinated, etc [14]. Unfortunately, these additives are eco-toxic and not environmentally acceptable. This paper discusses the effectiveness of natural garlic oil (NGO) as an additive in RSO in enhancing the tribological characteristics of RSO and high efficiency of NGO which is an environmentally friendly and extreme pressure/antiwear additive for oils.

2. Material and methods

2.1 Materials

The RSO was collected from M/S Index International, Virughnagar, Tamil Nadu. Gulf Master Engine oil SAE20W40 and NGO were obtained from local dealers. RSO was extracted from the seed and NGO cold-pressed from Garlic.

2.2 Rheological property

Dynamic viscosities were measured in a temperature range between 40°C and 100°C. The viscosity index (VI) was computed in accordance with ASTM D 2270. The equipment used for the experiments was BROOKFIELD DV2T extra viscometer, USA.

2.3 Tribological properties

A four-ball tester machine was used to determine the coefficient of friction (CoF) and anti-wear properties of RSO. The process consists of a mechanism by which three fixed balls, which remain submerged in the sample, rotate in contact with the ball. The equipment used for the experiments was the Four-Ball tester TR-30L-PNU-IAS DUCOM, Germany. The CoF, Wear Scar Diameter (WSD),
and viscosity tests were conducted for RSO with NGO as an additive by the weight concentrations of 1%, 2%, and 3%. The test conditions were 392N load, 750°C, 1200 RPM, and 3600 seconds. Four balls of chromium alloy steel ball (ASTM D 2783, 2596, IP 239) made of ANSI standard steel ball, E5100, 12.7 mm in diameter, 64 HN (hardness number), EP grade (extra polish) were used in this test. In a ball port, the three balls were fixed and one ball was fixed on the motor spindle.

2.4 Flash temperature parameter (FTP)
A flash temperature parameter expresses the critical flash temperature and at which, the fluid thin film begins to collapse. Alternatively, it expresses the lesser possibility of the thin oil layer to fail [17]. This parameter is very important because it helps to set the necessary working conditions for the fluid in which the oil will function successfully; this means that the high value of this parameter implies better fluid efficiency. The value of the flash temperature parameter is calculated by using the mathematical equation described below:

\[ FTP = \frac{W}{D^{1.4}} \]

Where, \( W \) indicates the load value applied in unit kg; \( D \) indicates the value of the diameter of the scar, which is measured in unit mm.

2.5 Frictional torque and coefficient of friction
The friction parameter (frictional torque and friction coefficient) is an important factor in assessing the performance characteristics of fluids. The values of the friction torque are obtained directly from the four-ball unit, but the values are adopted after around 5 to 10 minutes from the start of the test, as this time is given for the stability of the friction values [15]. The friction torque values are essential because they are used to compute the coefficient of friction (\( \mu \)) according to IP-239 using Equation:

\[ \mu = \frac{T\sqrt{\delta}}{3Wr} \]

where \( T \) is frictional torque (kg.mm), \( W \) is Applied load (kg), and \( r \) is the rotation radius (3.67 mm).

3. Result and discussion
The anti-wear properties of RSO have been tested and evaluated with different percentage weights of natural garlic oil as additives. Following a set of parameters such as the WSD, friction coefficient, and flash temperature parameter are provided for a better understanding of the characteristics of the natural rubber seed oil behaviour. These parameter values are then compared with the SAE20W40 oil values. In the analysis of the rubber seed oil performance features, all tests were carried out at a rotational speed 1200 rpm, and the oil temperature was also raised to 75°C, and the test time was set at 60 minutes for each experiment.

A special microscope was used to measure the WSD of the three bottom steel balls and the mean values of three were measured. Figure 1 shows the comparison of WSD between the RSO+NGO, neat RSO, and SAE20W40. It was concluded that WSD of the RSO+2%NGO lower than that of base oil. WSD measured for RSO+2%NGO were 637μm whereas base oil was 851μm and 575μm for SAEW40 oil.

With the addition of NGO, the newly developed oil has been found to create a boundary film that forms on the metal surface contacting. The film formed by the NGO act as a friction reducer showing that NGO additive in the right amount is beneficial. Complex chemisorption and tribochemical reactions were experienced by NGOs and produced a tribofilm with complex compositions containing iron oxides. Iron sulphate and iron sulphide on the lubricating surface under the combined impact of high pressure, exelectron emission and friction heat, which explains the excellent capacity of the additives to bear the load [16].
Figure 1. Variation of WSD for different weight percentage of NGO in RSO

For each sample of oils, the coefficient of friction value was calculated using the Eqn-1, then the results were scheduled, rearranged, and graphically displayed in Fig. 2. The coefficient of friction of the RSO+2% NGO sample was given a lower value than the RSO base stock, also much lower than SAE20W40 oil. The lower value for the coefficient of friction was obtained from the RSO+2%NGO at 0.028 as compared with 0.1055 under the same load for the SAE20W40 oil.

Figure 2. Variation of CoF for different weight percentage of NGO in RSO

The molecular structures of the sulfur-containing compounds in the NGO have been described by the MS spectrum. Organic sulphur compounds such as di-2-propenyl disulphide, 1-propene, 3,3-thiobis and dialyltrisulphide are the main components of natural garlic oil. [16]. The NGO's excellent anti-wear efficiency can be explained by the following two factors. First, the sulphides in NGO usually have lower molecular weight and are thus more active and easily decomposed and react with metal surfaces. Second, the presence of an unsaturated double bond in the molecule allows it more polar and sensitive to adsorb onto the newly exposed metal surface to assist in tribochemical reactions. [15].
Flash Temperature Parameter (FTP) is computed and tabulated for RSO and mineral oil under different NGO weight percentages as shown in Figure 3. The highest FTP value was 75.2 for rubber seed oil, compared to 86.8 for SAE20W40 oil under the same usual load. The explanation is that rubber seed oil caused a reduction in the probability of lubricant thin film breakdown under the lower load value and improved the quality of lubricity. Therefore, compared to the mineral engine oil, the additive added RSO lubricants have strong lubricity capabilities in terms of friction because the RSO contains fatty acids that allow the lubricant molecules to adhere well enough on the surface of the metal ball and to maintain the lubricant layer. The presence of thin lubricant films between steel ball surfaces minimized the transfer of the material and the adhesion of the two surfaces.

The higher the viscosity index, the more stable the viscosity at a higher temperature level. This will allow the oil to withstand viscosity changes during working conditions at a higher temperature. In Table-1, the viscosity indexes of the neat RSO & RSO with NGO are given. From the above findings, we can observe that additive added RSO has higher VI values compared to neat RSO, and we can presume that altered oils are ideal alternatives for mineral oils in terms of the Viscosity Index.

**Table 1. Variation of Viscosity Index for different weight percentage of NGO in RSO**

| BASE OIL | 1% NGO | 2% NGO | 3% NGO | SAE20W40 |
|----------|--------|--------|--------|----------|
| Flash Temperature Parameter (FTP) | 50.13 | 75.2 | 72.79 | 71.11 | 86.8 |
| Viscosity (cSt) at 40°C | 23.1 | 22.85 | 23.96 | 24.58 | 105 |
| Viscosity (cSt) at 100°C | 5.05 | 5.26 | 5.26 | 5.43 | 13.9 |
| Viscosity Index | 148.3 | 159 | 151 | 153 | 132 |
4. Conclusion
The performance behaviour characteristics of the RSO were tested using a four-ball tribo tester with a different weight percentage of the NGO. The outcomes of the RSO were compared with the results of the SAE20W40 oil. The outcomes of the analyses can be presented as the following points.

- The friction coefficient obtained from the RSO +2% NGO was the lowest compared to SAE20W40 oil.
- Lubricated steel ball with additive added RSO had smaller WSD than those lubricated with neat RSO.
- Compared to the commercial mineral oil, RSO + 2% NGO recorded higher WSD.
- The overall study indicates that RSO has the potential to become a partial substitute bio-lubricant since the additives have improved the wear and lubricating efficiency.
- It can be concluded that additive added RSO displays better performance characteristics compared to mineral oil.

References
[1] International Energy Outlook 2013 Energy Information Administration Online
[2] Chevron Corporation 2014 Energy Supply and Demand Online
[3] Taufiqqurrahmi N and Bhatia S 2011 Catalytic cracking of edible and non-edible oils for the productions of biofuel Energy and Environmental Science vol4 p1087–1112
[4] Boyd S 2002 Green lubricants Environmental benefits and impacts of lubrication Green Chem 293–307
[5] Luther R 2002 Lubricants environmental aspects Ullmann'SEncycl Ind Chem
[6] Aji MM, Kyari SAZ and Oaka G 2015 Comparative studies between bio-lubricants from jatropha oil, neem oil and mineral lubricant engen super 20w/50 Res J1(4)1252–7
[7] Salimon J and Salih N 2010 Chemical modification of oleic acid oil for biolubricant industrial applications Aust J Basic Appl Sci 4 1999–2003
[8] Srivastava A and Sahai P 2013 Vegetable oils as lube base stocks: a review Afr J Biotechnol 12880–91
[9] Kumar A and Sharma S 2011 Sustain. Energy Potential non-edible oil resources as biodiesel feedstock: an Indian perspective. Renew Rev 15 1791–1800
[10] Salimon J, Abdullah B Mand Salih N 2012 Rubber (Hevea brasiliensis) seed oil toxicity effect and linamarin compound analysis Lipids Health Dis 11 1–8
[11] Sethuramiah Aand Kumar R 2016 Chapter 2 - Lubricants and their formulation. Modeling of chemical wear Oxford: Elsevier p25–39
[12] Sharma B K, Adhvaryu A and Erhan S Z 2006 Synthesis of hydroxyl thio-ether derivatives of vegetable oil J. Agric. Food Chem 54 (26) 9866–9872
[13] Thomas R , Achim F and Rudnick, L. R 2009 Sulfur Carriers. In Lubricant Additives Chemistry and Applications
[14] Weidman Li, Cheng Jiang, Mianran Chao, and Xiaobo Wang 2014 Natural Garlic Oil as a High-Performance, Environmentally Friendly, Extreme Pressure Additive in Lubricating Oils ACS Sustainable Chemistry & Engineering 2 (4) 798–803
[15] Blok H 1963 The flash temperature concept Wear Volume 6 issue 6 Pages 483-494
[16] Saha D K and Ghosh P 2018 Naturally derived green bio-additives Journal of Macromolecular Science Part A vol. 55 pp 384-392
[17] Amith Aravind, Joy M L and Prabhakaran Nair K 2015 Lubricant properties of biodegradable rubber tree seed (Hevea brasiliensis Muell. Arg) oil Industrial Crops and Products Vol 74 Pages 14-19
[18] Asadauskas S, Perez JM and Duda JL 1996 Oxidative stability and antiwear properties of high oleic vegetable oils Lubr. Eng 52 877–882