SEMARAK ILMU PUBLISHING
Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Feasibility Studies of Treated Used Cooking Palm Oil as Precursor for Bio-Lubricant

Muhamad Azwar Azhari[1], Nor Hasrul Akhmal Ngadiman[1,*], Noordin Mohd Yusof[1], Ani Idris[2], Norazlianie Sazali[3]

[1] Department of Material, Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2] Department of Bioprocess Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[3] Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, Malaysia

ARTICLE INFO

Article history:
Received 7 July 2023
Received in revised form 9 September 2023
Accepted 25 September 2023
Available online 3 November 2023

Keywords:
Cooking oil; treated used cooking oil; bio-lubricant

ABSTRACT

The non-renewability and and non-biodegradability of petroleum-based lubricants as well as the environmental impacts their waste contributes to the environment has caused the search for a substitute for precursor of lubricant formulation. The food security issue has caused major concerns on how vegetable oil could replace petroleum-based product lubricants. This paper reports the feasibility studies of kinematic viscosity, friction and wear properties of treated used cooking palm oil as precursor for development of new bio-lubricant. The treated used cooking palm oil displayed a comparable value of kinematic viscosity of 43.6cSt, coefficient of friction of 0.126 and 122µm which is almost similar to the value of fresh cooking palm oil. Treated used cooking palm oil is seen to be a suitable candidate for precursor of bio-lubricant formulation, However, some additives may need to be added as to increase the tribological properties for treated used cooking oil to be used as a bio-lubricant.

1. Introduction

To date, there has been an increasing awareness in the environmental effect caused by use of petroleum-based products [1]. Mahipal *et al.*, declared that petroleum based lubricant may contribute to environmental pollution when disposal is done in an improper way [2]. The toxicity that it imposes as well as being a non-biodegradable element has put petroleum-based lubricant in the limelight for a substitution. It is reported that petroleum-based lubricant contaminates the environment through spills and leakages causing water and soil pollution [3]. In addition to that, most of the lubricants developed throughout the years are based on petroleum products which are non-renewable materials [1]. Being a product of petroleum distillate, commercially available lubricant is susceptible to depletion as it is produced from a non-renewable resource [4]. While addressing the

[*] *Corresponding author.*
E-mail address: norhasrul@utm.my

https://doi.org/10.37934/aram.111.1.3037

environmental and depletion issues of non-renewable materials, vegetable oil is seen to be a suitable candidate to replace petroleum-based products as lubricant precursor.

The studies for development of new biodegradable and renewable lubricant using vegetable oil has been in the limelight as vegetable oils are renewable, biodegradable and imposes less impact towards the environment. Apart from that, vegetable oil displayed superior properties of lubricity, high viscosity index, high thermal stability and higher flash point compared to petroleum-based lubricant [1]. Vegetable oil also exhibits a high solubilizing power for polar additives molecules [5]. This will ensure higher solubility of polar additive molecules added into vegetable-based lubricants. Many researchers have added different type of additives into different type of vegetable oil as to formulate a new bio-lubricant. Mahipal *et al.,* added Zinc Dialkyldithiophosphate into karanja oil as a new bio-lubricant [2]. Liu *et al.,* added ethanol into castor oil[6] while Shafi and Charoo added Zinc Dialkyldithiophosphate into hazelnut oil to formulate a new bio-lubricant [7]. The success achieved by these researchers showed that vegetable oil is indeed a very competitive candidate to replace petroleum-based lubricant.

However, there has been many concerns on the availability of food source as most vegetable oil are needed as food supply. The shortages of food and food security issues has now been the biggest obstacle for bio-lubricant formulation which utilizes food-based oil as primary precursor. It was reported by Mohd Yusof *et al*., in their studies that food shortages caused a food crisis in 2007 and 2008 when the world has failed to manage the source of food [8]. As such, to prevent such crisis from happening they propose an option of utilising non-food based oil. Malaysia is known to be one of the major producers of palm oil in the world. On top of that, Kabir *et al.,* stated that in their studies that apart from being a major palm oil producer, Malaysia also uses a large number of palm oil for frying where it accumulates to yield up to 50,000 tons of waste cooking oil annually [9]. This may be one of the solutions where used cooking oil may be utilized as a primary precursor for bio-lubricant formulation. However, the impurities produced as byproducts during frying process shall be removed prior to be used as a precursor for bio-lubricant formulation [10, 11]. Free fatty acids and excess free water content in the used cooking palm oil shall be removed as it may contribute to the oxidation of oil [12]. This paper examines the kinematic viscosity, friction and wear properties of treated used cooking palm oil in determining feasibility of making it as a precursor for a development of bio-lubricant.

2. Methodology

2.1 Preparation of Samples

Used cooking palm oil were collected from local food chain restaurants. Solid particles were removed and no prior treatment were conducted upon used cooking palm oil samples. For treated used cooking palm oil, the collected oil was neutralized using 2ml of 18wt% Sodium Hydroxide (NaOH) solution. Upon addition of NaOH into the waste cooking oil, the mixture was heated at 60℃ for 30 minutes. The prepared samples were centrifuged at a speed of 1200 rpm for 10 minutes and then filtered for soap and solid particles removal. To remove water which will be formed through saponification process, physical dehydration using Zeolite 4A were conducted. This is to ensure total removal of water from the treated cooking oil. Fresh cooking palm oil and SAE40 mineral lubricant oil were purchased from a local supplier without any further treatment.

2.2 Determination of Kinematic Viscosity

Kinematic viscosity at 40℃ were investigated using a portable handheld Parker Kittiwake Heated Viscometer FGK1200PA to examine the resistance of fluid to flow.

2.3 Friction and Wear

The coefficient of friction of the prepared samples were investigated using a DUCOM K93190-M-CE Four Ball Tester in accordance to ASTM D4172. Four 12.7mm diameter steel balls of HRC63 were used to evaluate the anti-friction properties added into the bio-lubricants. A load of 392N were applied and the steel ball was rotated at a speed of 1200rpm for 60 minutes. The temperature is maintained at 75°C.

Investigation of wear scar diameter was done using Axio Lab A1 upright light microscope. The scar on the steel ball is magnified at 50x. The digital image of wear scar of the samples was captured by camera and shown in the screen.

3. Results

3.1 Kinematic Viscosity

Kinematic viscosity of various samples was investigated at 40℃ to determine the feasibility of different type of oil being a precursor for a bio-lubricant formulation. The data collected were tabulated and depicted in Figure 1. From the data used cooking palm oil showed a kinematic viscosity of 45.13cSt while the fresh cooking palm oil displayed a kinematic viscosity of 43.5cSt. The difference of kinematic viscosity between used and fresh oil is affected by the presence of free fatty acid and free water content from frying processes [11, 12]. This may increase in the kinematic viscosity of the used cooking oil. After being treated with Sodium Hydroxide the kinematic viscosity of treated used cooking oil was seen to be 43.6cSt. This value is close to the kinematic viscosity of fresh cooking palm oil. This could explain that the treatment process has successfully bring the kinematic viscosity of used cooking palm oil to equal the value of fresh cooking palm oil. The kinematic viscosity of SAE40 mineral oil however is far superior at 105.1cSt. This is because the precursor for production of an SAE40 mineral oil lubricant is a long chain petroleum product comparing to short chain palm oil [13]. The commercially available lubricants are usually made of long chain hydrocarbons which usually consist of 30 to 40 Carbon atoms in a molecule compared to 16 Carbon atoms in palmitic acid which builds the foundation of palm oil. The difference in Carbon atom number per molecule causes the kinematic viscosity between cooking palm oil and SAE40 mineral based lubricant [14]. As such different type of application may be employed for this different type of lubricant formulated using treated used cooking palm oil as primary precursor.

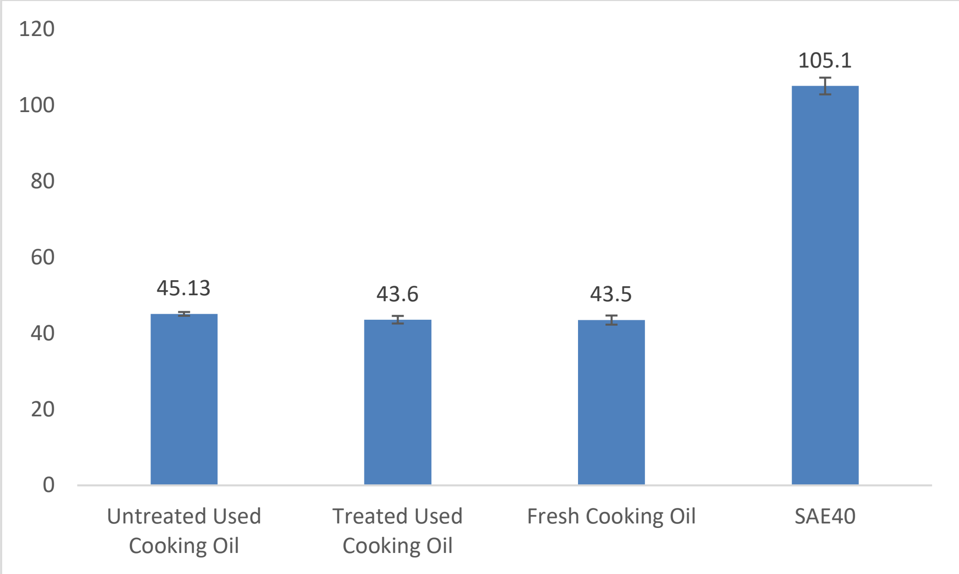

Fig.1. Kinematic viscosity at 40℃ of untreated used cooking palm oil, treated used cooking palm oil, fresh cooking palm oil and SAE40 mineral oil

3.2 Friction and Wear

The coefficient of friction observed during the four ball test were recorded as in Figure 2. From the test, it can be seen that fresh cooking palm oil exhibited a coefficient of friction of 0.125. Comparing to SAE40 mineral oil lubricant, this coefficient of friction is relatively high. This is due to the fact that fresh cooking palm oil was not equipped with any lubrication additive such as anti-friction, anti-oxidation or anti-wear agent to reduce the value of coefficient of friction. This is extensively studied by prior researchers namely Mahipal *et al.,* [2], Shafi and Charoo [7], Azhari *et al.,* [15], and Farhanah *et al.,* [16], The untreated used cooking palm oil on the other hand exhibited a coefficient of friction of 0.151. This is relatively a very high coefficient of friction as it is mainly contributed by the free water content in the used cooking oil. The high content of free fatty acids in the untreated used cooking palm oil caused the untreated used cooking oil to be prone to premature oxidation. According to Azhari *et al.,* the presence of acids in vegetable oil may trigger the initiation process of oxidation [17]. With the increase of free fatty acid concentration in the untreated used cooking oil, the oxidation of vegetable oil is accelerated and this resulting in the increase of viscosity due to oxidation process. This may cause the coefficient of friction exhibited by untreated used cooking oil to be high.

Upon treatment of the used cooking palm oil, the coefficient of friction was reduced to 0.126. This coefficient of friction value is close to the coefficient of friction exhibited by fresh cooking palm oil which is 0.125. It can be deduced that the treatment process has successfully removed the impurities that affected the high friction of untreated used cooking oil. The removal of free fatty acid through saponification process and removal of water through physical separation has clearly reduced the possibility of premature oxidation in the treated used cooking oil. This coefficient of friction however is still far from the ones displayed by SAE40 mineral based lubricant. In a typical commercial mineral based SAE40 lubricant, several additives were added to increase the tribological properties of lubricity. Zinc, Sulfur and Molybdenum are commonly added into mineral based oil to increase their anti-friction and friction modification properties [4, 18, 19]. This is the main reason why the coefficient of friction of SAE40 mineral base lubricant is much lower compared to treated used cooking palm oil and fresh cooking palm oil.

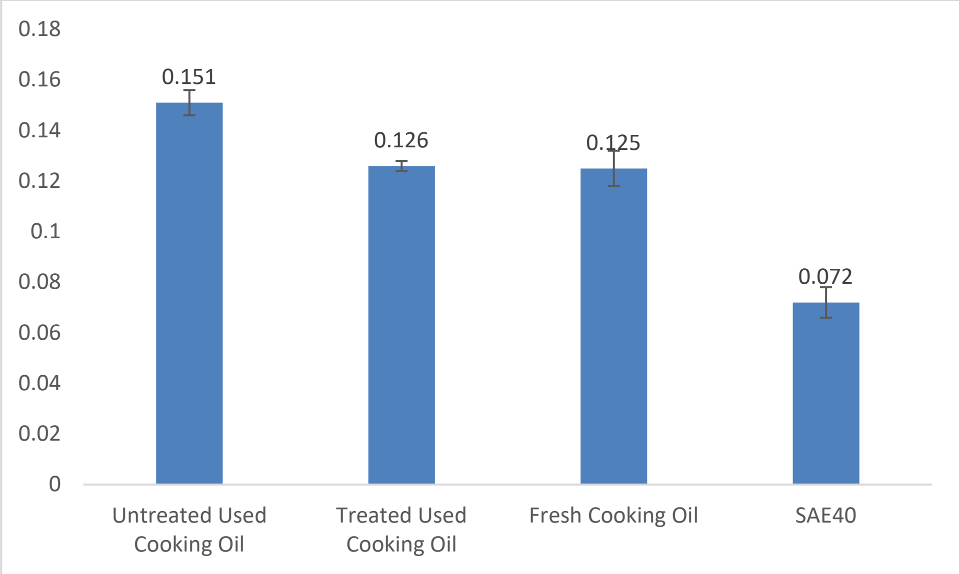

Fig. 2. Coeficient of friction for untreated used cooking palm oil, treated used cooking palm oil, fresh cooking palm oil and SAE40 mineral oil

The wear scar diameter of four ball test were measured to investigate the feasibility of treated used cooking palm oil as precursor for biolubricant formulation and displayed as in Figure 3. Untreated used cooking palm oil showed a diameter of 185µm while fresh cooking palm oil displayed a wear scar diameter of 119µm. Treated used cooking palm oil on the other hand displayed a value of 126µm. The high value of wear scar diameter for untreated used cooking palm oil is mainly caused by the impurities produced during frying processes [11, 12]. This may induce the oxidation process of untreated used cooking palm oil and resulted in increasing the kinematic viscosity of the oil. This will further increase the resistant of flow of the oil as lubricant which resulted in increase of wear scar diameter altogether. The treated used cooking palm oil however displayed a wear scar diameter value that is again to proximate the value of fresh cooking palm oil. This is another evidence that the treatment process has removed the unnecessary impurities produced during frying process. The treatment has been a success resulting the wear scar diameter of treated used cooking palm oil to be close to the value of wear scar diameter of fresh cooking palm oil.

Commercially available SAE40 mineral based lubricant is usually added with additives to improve their tribological properties. In order to increase the wear performance, zinc and phosphorous were always added as to act as a protective sacrificial layer to reduce wear of contacting surfaces [20]–[22]. In fact, many bio-lubricant formulated by previous researchers incorporated organo zinc and organo phosphorous compound into various type of vegetable oil as to increase their wear performance. Mahipal *et al.,* added zinc into karanja oil [2], Azhari *et al.,* added into canola oil [15] while Shafi and Charoo added zinc and phosphorous into hazelnut oil [7]. This is the main reason to the lower value of wear scar diameter exhibited by SAE40 mineral based lubricant at 84µm. The images of wear scar for each type of oil are depicted as in Figure 4.

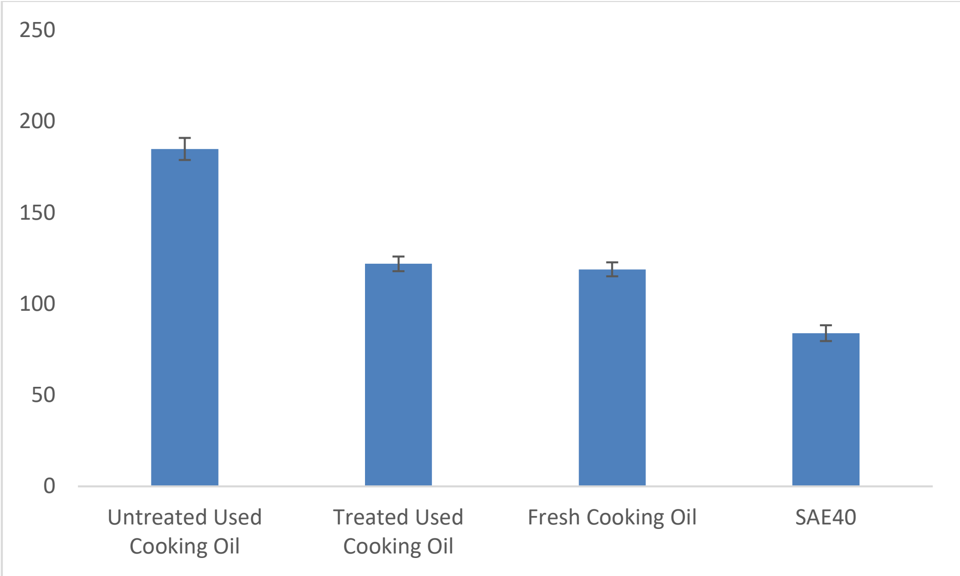

Fig. 3. Wear scar diameter for untreated used cooking palm oil, treated used cooking palm oil, fresh cooking palm oil and SAE40 mineral oil

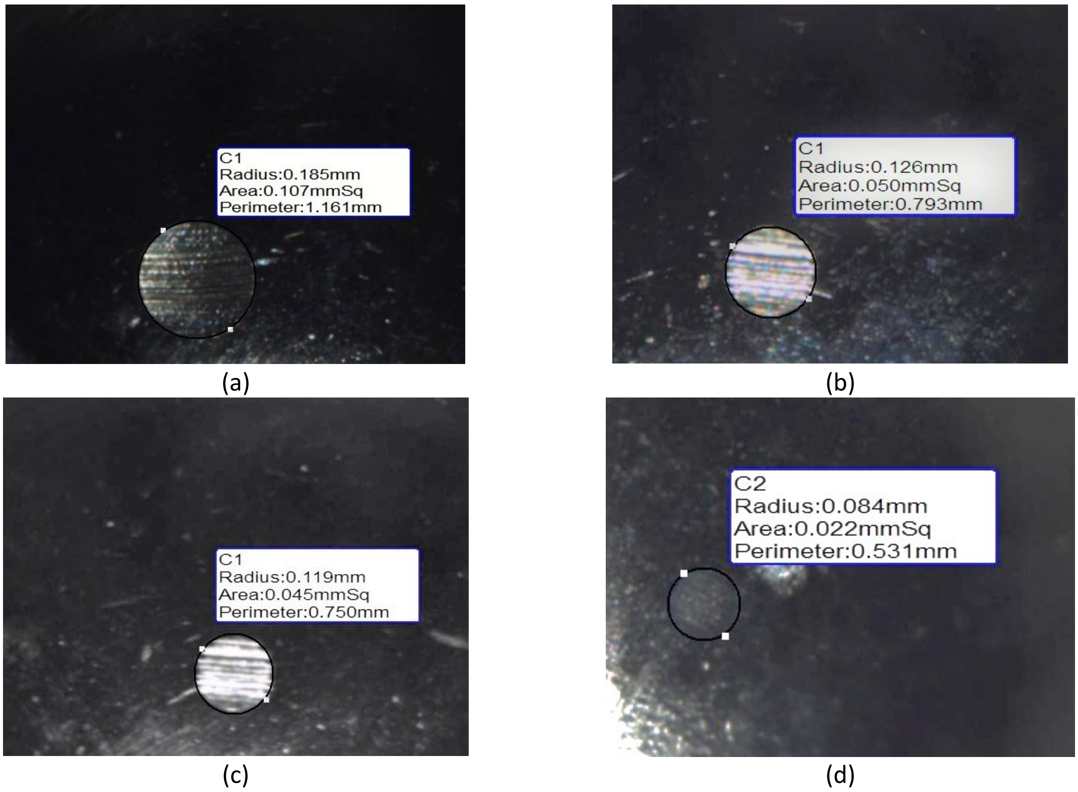

Fig.4. Images for wear scar diameter for (a)untreated used cooking palm oil (b) treated used cooking palm oil (c) fresh cooking palm oil and (d) SAE40 mineral oil

4. Conclusions

Treated used cooking palm oil exhibited a kinematic viscosity, coefficient of friction and wear properties similar to values exhibited by fresh cooking palm oil. In can be concluded that treated cooking palm oil may be suitable to be a precursor for the development of a new formulation of bio-lubricant. However, in order for the bio-lubricant to be able to compete with SAE40 mineral based lubricants, several additives may be added as to increase its physico-chemical properties as well as the tribological properties of the bio-lubricant utilizing treated used cooking oil as primary precursor.

Acknowledgement
The author would like to acknowledge the financial support from Ministry of Higher Education Malaysia and Universiti Teknologi Malaysia for the funding under UTM High Impact Research Grant (UTM HIR) (Q.J130000.2451.08G65).

References

[1] Mobarak, H. M., E. Niza Mohamad, Hassan H. Masjuki, Md Abul Kalam, K. A. H. Al Mahmud, Md Habibullah, and A. M. Ashraful. "The prospects of biolubricants as alternatives in automotive applications." *Renewable and sustainable energy reviews* 33 (2014): 34-43. https://doi.org/10.1016/j.rser.2014.01.062

[2] Mahipal, D., P. Krishnanunni, P. Mohammed Rafeekh, and N. H. Jayadas. "Analysis of lubrication properties of zinc-dialkyl-dithio-phosphate (ZDDP) additive on Karanja oil (Pongamia pinnatta) as a green lubricant." *International Journal of Engineering Research* 3, no. 8 (2014): 494-496. https://doi.org/10.17950/ijer/v3s8/804

[3] Srivastava, Anjana, and Preeti Sahai. "Vegetable oils as lube basestocks: A review." *African Journal of Biotechnology* 12, no. 9 (2013).

[4] Azhari, Tamar, Nuri, and Yusoff, “Physical property modification of vegetable oil as biolubricant using ZDDP,” *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 15 (2015)

[5] Erhan, Sevim Z., and Svajus Asadauskas. "Lubricant basestocks from vegetable oils." *Industrial crops and products* 11, no. 2-3 (2000): 277-282. https://doi.org/10.1016/S0926-6690(99)00061-8

[6] Liu, Niancong, Xing Zou, Jia Yuan, Shenghong Wu, and Yun Chen. "Performance evaluation of castor oil-ethanol blended coolant under minimum quantity lubrication turning of difficult-to-machine materials." *Journal of Manufacturing Processes* 58 (2020): 1-10. https://doi.org/10.1016/j.jmapro.2020.07.058

[7] Shafi, Wani Khalid, and M. S. Charoo. "Antiwear and extreme pressure properties of hazelnut oil blended with ZDDP." *Industrial Lubrication and Tribology* 73, no. 2 (2021): 297-307. https://doi.org/10.1108/ILT-06-2020-0217

[8] Hussein, Reda ZK, Nahed K. Attia, Mai K. Fouad, and Shakinaz T. ElSheltawy. "Experimental investigation and process simulation of biolubricant production from waste cooking oil." *Biomass and Bioenergy* 144 (2021): 105850. https://doi.org/10.1016/j.biombioe.2020.105850

[9] Kabir, Ibrahim, M. Yacob, and Alias Radam. "Households’ awareness, attitudes and practices regarding waste cooking oil recycling in Petaling, Malaysia." *IOSR Journal of Environmental Science, Toxicology and Food Technology* 8, no. 10 (2014): 45-51. https://doi.org/10.9790/2402-081034551

[10] Idun-Acquah, Nancy, George Y. Obeng, and Ebenezer Mensah. "Repetitive use of vegetable cooking oil and effects on physico-chemical properties–Case of frying with redfish (Lutjanus fulgens)." *Science and Technology* 6, no. 1 (2016): 8-14.

[11] Liu, Ying, Jinwei Li, Yajun Cheng, and Yuanfa Liu. "Effect of frying oils’ fatty acid profile on quality, free radical and volatiles over deep-frying process: A comparative study using chemometrics." *Lwt* 101 (2019): 331-341. https://doi.org/10.1016/j.lwt.2018.11.033

[12] Nayak, Prakash Kumar, U. M. A. Dash, Kalpana Rayaguru, and Keasvan Radha Krishnan. "Physio-chemical changes during repeated frying of cooked oil: A Review." *Journal of Food Biochemistry* 40, no. 3 (2016): 371-390. https://doi.org/10.1111/jfbc.12215

[13] MD Alias, Muhammad Aizat, and Muhamad Azwar Azhari. "Preliminary feasibility studies of vegetable oil as substitution to mineral lubricant." *Journal of Mechanical Engineering (JMechE)* 1 (2017): 37-46.

[14] Owuna, F. J. "Stability of vegetable based oils used in the formulation of ecofriendly lubricants–a review." *Egyptian Journal of Petroleum* 29, no. 3 (2020): 251-256. https://doi.org/10.1016/j.ejpe.2020.09.003

[15] Azhari, Muhamad Azwar, M. F. H. M. Saroji, and M. A. Latif. "Comparison of tribological properties between canola oil-t-ZDDP and." *J Eng Appl Sci* 100 (2016): 2126-2129.

[16] Farhanah, A. N., S. Syahrullail, M. N. Musa, and M. Z. Bahak. "Modification of RBD palm kernel and RBD palm stearin oil with ZDDP additive addition." *Jurnal Teknologi* 74, no. 10 (2015): 121-126. https://doi.org/10.11113/jt.v74.4842

[17] Azhari, Muhamad Azwar, Quratul Nadia Suffian, and Nur Rashid Mat Nuri. "The effect of zinc dialkyldithiophosphate addition to corn oil in suppression of oxidation as enhancement for bio lubricants: a review." *Journal of Engineering and Applied Sciences* 9, no. 9 (2014): 1447-1449.

[18] Unnikrishnan, R., M. C. Jain, A. K. Harinarayan, and A. K. Mehta. "Additive–additive interaction: an XPS study of the effect of ZDDP on the AW/EP characteristics of molybdenum based additives." *Wear* 252, no. 3-4 (2002): 240-249. https://doi.org/10.1016/S0043-1648(01)00865-1

[19] Ilie, Filip, and Andreea-Catalina Cristescu. "A study on the tribological behavior of molybdenum disulfide particles as additives." *Coatings* 12, no. 9 (2022): 1244. https://doi.org/10.3390/coatings12091244

[20] Alias, Muhammad Aizat Md, Mohd Fadzli Bin Abdollah, and Hilmi Amiruddin. "Tribological properties of palm oil blended with zinc dioctyldithiophosphate." *Materials Research Express* 5, no. 8 (2018): 085505. https://doi.org/10.1088/2053-1591/aad36b

[21] Okubo, Hikaru, Seiya Watanabe, Chiharu Tadokoro, and Shinya Sasaki. "Effects of structure of zinc dialkyldithiophosphates on tribological properties of tetrahedral amorphous carbon f ilm under boundary lubrication." *Tribology International* 98 (2016): 26-40. https://doi.org/10.1016/j.triboint.2016.02.025

[22] Komvopoulos, K., S. A. Pernama, E. S. Yamaguchi, and P. R. Ryason. "Friction reduction and antiwear capacity of engine oil blends containing zinc dialkyl dithiophosphate and molybdenum-complex additives." *Tribology transactions* 49, no. 2 (2006): 151-165. https://doi.org/10.1080/05698190500544353