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Friction Analysis Of Waste Palm Methyl Ester (WPME) Under Stribeck Lubrication Regimes

Siti Hartini Hamdan[1], Noorannisa Irdina Nasaruddin[1], Nor Qayrawani Redzuan[1] ,William Chong Woei Fong[2,3] and Norulakmal Nor Hadi[4]

[1] Bioengineering Cluster, Section of Technical Foundation, Universiti Kuala Lumpur MICET, 78000 Alor Gajah, Melaka, Malaysia
[2]School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia UTM, 81310 Johor Bahru, Johor, Malaysia,
[3]Automotive Development Centre (ADC), Universiti Teknologi Malaysia UTM, 81310 Johor Bahru, Johor, Malaysia
[4]Section of Process Engineering Technology, Universiti Kuala Lumpur MICET, 78000 Alor Gajah, Melaka, Malaysia

*Corresponding author's e-mail: sitihartini@unikl.edu.my

Abstract. This paper aims to investigate the tribological friction using the Stribeck curve lubrication regime using an alternative source of biodiesel. Replacement of current usage of fossil fuels is essential, therefore, it is important to develop a proper recycling, renewable and sustainable product that reduces global warming. Biodiesel also known as Fatty Acid Methyl Ester (FAME), is biodegradable, produced from a renewable source, non-toxic, and produces a minimum greenhouse gas emissions. To reduce raw material cost, waste cooking oil is one of the most suitable replacements of vegetable oil for biodiesel synthesis. Rheological behavior of Waste Palm Methyl Ester (WPME), such as kinematic viscosity, density, and acid value, was measured based on EN14214 and compared with Palm Methyl Ester (PME). The friction performance of WPME was evaluated using a pin on the disc tribometer machine. The influence of different operating conditions such as loads at 1kg, 2kg, 3kg and 4kg and sliding velocity range from 0.00625 m/s to 4 m/s were optimized in this study. The preliminary result shows significant changes on the Stribeck curve concerning the sliding speed and also loads. It is found that as for the same entrainment velocity and surface roughness, a higher load will initiate a higher temperature, thus lead to decreasing the viscosity and coefficient of friction. In summary, WPME is highly considered as a potential waste that can replace the current energy source.

1. Introduction

Energy demand has been tremendously increased for hundreds of years as industrialization dominates the source of income and urban growth worldwide. As mentioned by Arshad et al. (2018) and Sahar et al. (2018), energy resources such as petroleum, natural gas, coal, and non-renewable nature have been declining day by day. Due to high demand as the primary fuel source for electricity generation and transportation, petroleum prices have marked a record in history (Sahar et al., 2018). On the other hand, it is well known that diesel engine vehicles are one of the most significant contributors to air pollution due to the exhaust emissions, which produce routine hazardous emissions in the cities and urban areas (Harreh et al., 2018). Thus, it is vital to explore a renewable energy source to replace fossil fuels, thus reducing toxic emissions (Harreh et al., 2018).

In Malaysia, around 5000 tons of waste cooking oil (WCO) were disposed of without proper treatment (Nurdin et al., 2016). The untreated WCO will not only solidify and accumulates inside the sewage system, but it will also contribute to water pollution, soil contamination, and aquatic life destruction (Khdour & Nawaj, 2016; Nurdin et al., 2016). A large quantity of WCO released into the environment will cause an increase in water and management costs (Khdour & Nawaj, 2016; Nurdin et al., 2016). As mentioned by Kabir et al. (2014) and Alias et al. (2018), the appearance of WCO in the water system that covers the water's surface has caused difficulties for oxygen to dissolve into the water, hence destroying aquatic life. Therefore, WCO needs to be treated and appropriately managed not to be harmful to human health and the environment (Kabir et al., 2014; Nurdin et al., 2016). Any source of fatty acid, either animal or plant lipid, can be used to produce biodiesel through the esterification process (Yaakob et al., 2013; Alias et al., 2018). As mentioned earlier, fossil fuels consumption is more than its production. Therefore WCO is an excellent alternative for fuel, biodiesel, and diesel engine (Nurdin et al., 2016).

Oil content, physical properties, chemical composition and suitability, are parameters used as guidelines to choose the feedstock (Ambat et al., 2018). The different feedstock used will have other properties due to various fatty acid compositions. The most critical specification in biodiesel standard is viscosity; for this reason, viscosity has been extensively studied (Alicke et al., 2015). The rheological method has been introduced to measure the viscosity for different types of biodiesel and diesel blends (Santos et al., 2011; Alicke et al., 2015). Rheological properties are one of the major concerns for biodiesel's end product concerning the liquids' viscosity and density. Giwa et al. (2014) mentioned that the rheological properties of biodiesel depend on a few significant factors such as the shear rate, temperature, concentration of biodiesel, time, pressure, chemical properties, and catalyst used in the production.

Therefore, this study aims to measure and understand the rheological properties and tribological study of two different types of biodiesel, Waste Palm Methyl Ester (WPME), and compared with a standard Palm Methyl Ester (PME).

2. Materials and methods

Transesterification is a common standard to derive biodiesel and a well-known procedure for its low costs and simplicity (Atabani et al., 2012; Ambat et al., 2018). This process involves the presence of a catalyst to transform the fat oil using alcohol. In the transesterification reaction, with the help of an appropriate catalyst, the triglyceride components of oils reacted with the alcohol (methanol or ethanol) and converted into fatty acid methyl ester and glycerol, as shown in Figure 1 (Yaakob et al., 2013; Mohammed & Bhargavi, 2015; Ambat et al., 2018).

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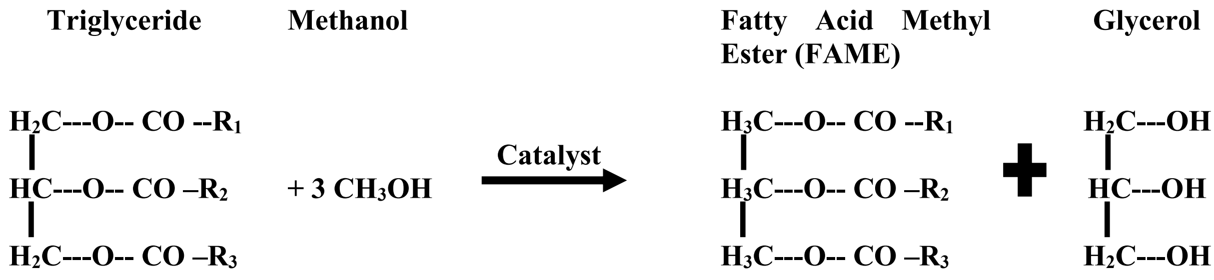


Figure 1. Equation of Transesterification Process

The friction analysis is conducted by using a pin-on-disc tribometer, as shown in Figure 2. It consists of a pin-on-disc test to measure the friction under boundary conditions of lubrication using a pin against a plate disc. For each test, a new pair of pin and wear disks were used.

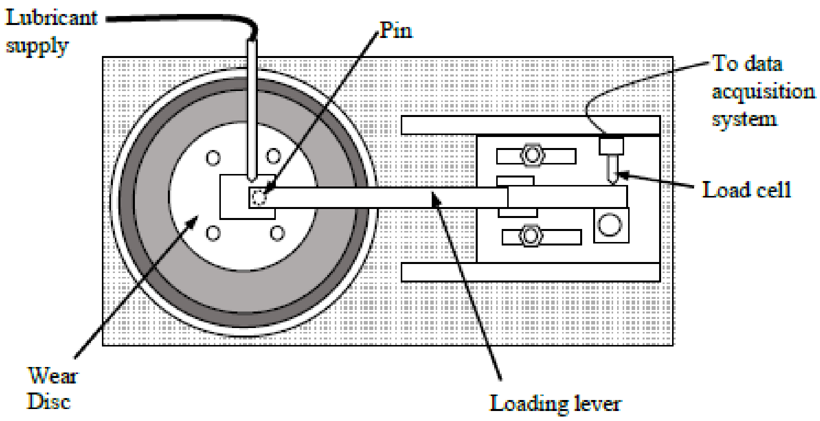


Figure 2. Pin-on-disc friction tester (Hamdan et al., 2018)

Before executing the friction test analysis, the pin and wear disc were cleaned using an ultrasonic bath and left dry in the desiccator. The purpose of this method is to remove tooling fluid residuals from the machining processes. The pin-on-disc is subjected to a disc rotational speed between 20 rpm to 2000 rpm corresponding to linear disk velocity ranges between 0.04 m/s to 4 m/s. A clean wear disc is placed on a rotating table and clamped with screws. The temperature is controlled at 25 °C throughout the process. The load applied on the pin and wear disc ranges from 10 N, 20 N, 30 N, and 40 N for each feedstock sample. The wear track sets at 20mm, which measures the distance of the pin from the center wear disc

3. The Results and Discussion

The rheological properties of WPME and PME are measured through experimental validation. Both types of biodiesel were produced using the same methanol/oil molar ratio, but WPME has a lower yield than PME yield and the yield stated in Table 1. This is because the source of WPME biodiesel was WPCO, which has high FFA content compared to Raw PCO. The presence of high FFA content in WPCO resulted in soap formation instead of biodiesel during alkali catalyzed transesterification reaction (Kayode & Hart, 2017).

Therefore, it can be concluded that the higher the FFA content in palm cooking oil, the lower the biodiesel yield will be. Table 2 shows the rheological properties of Waste Palm Cooking Oil (WPCO) and Palm Methyl Ester (PME). The kinematic viscosity of both biodiesels is found to be in the standard range stated by EN 14214).

Table 1. Biodiesel Yield

Type of Biodiesel	Percentage Yield, %
WPME	82.5
PME	96.4

Table 2. Rheological properties of Waste Palm Cooking Oil (WPCO) and Palm Methyl Ester (PME)

Chemical properties	Standard Biodiesel (EN 14214)	WPME	PME
Density @ 40°C (kg/m^3)	860-900	865	867
Kinematic Viscosity @ 40°C (mm^2/s)	3.5-5.0	3.479	5.800
Acid Value (mg KOH/g max)	0.5	0.957	0.776

Meanwhile, the friction analysis conducted using a pin-on-disc tribometer shows the coefficient of friction of WPME derived from WPCO measured at varying sliding velocities with four different loads applied, which are 1kg, 2kg, 3kg and 4kg, and has been converted to 10N, 20N, 30N and 40N respectively. It is clear that as the sliding velocity increases, Figure 3 shows the transition of regimes from BL to EHL regime when the different load is applied. The transitions of WPME from BL to ML regimes for 10N, 20N, 30N and 40N occur at 0.5m/s, 1.55m/s, 1.90m/s and 1.10m/s respectively. The increased sliding velocity affects the lubricant entrainment, which elongates the separation gap between opposing sliding surfaces. Hamdan et al. (2017) mentioned that the separation gap would prevail in fluid film lubrication, thus minimizing the surface asperity interaction.

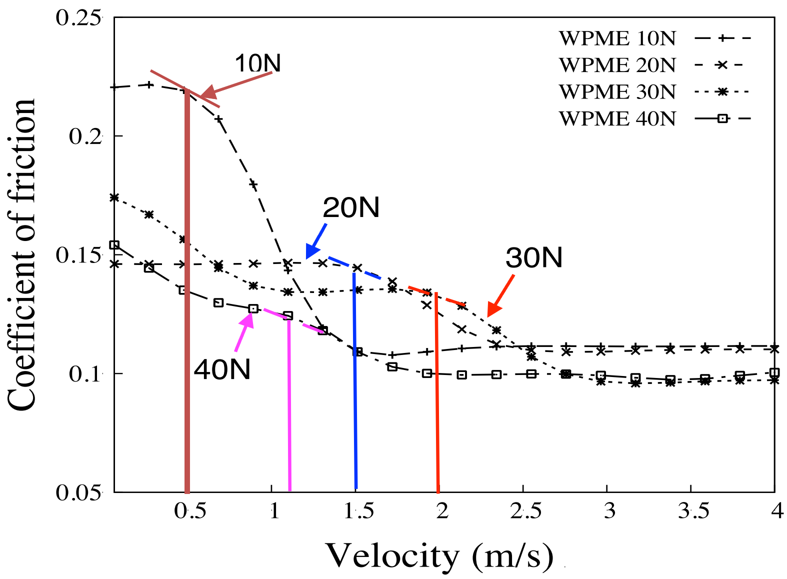


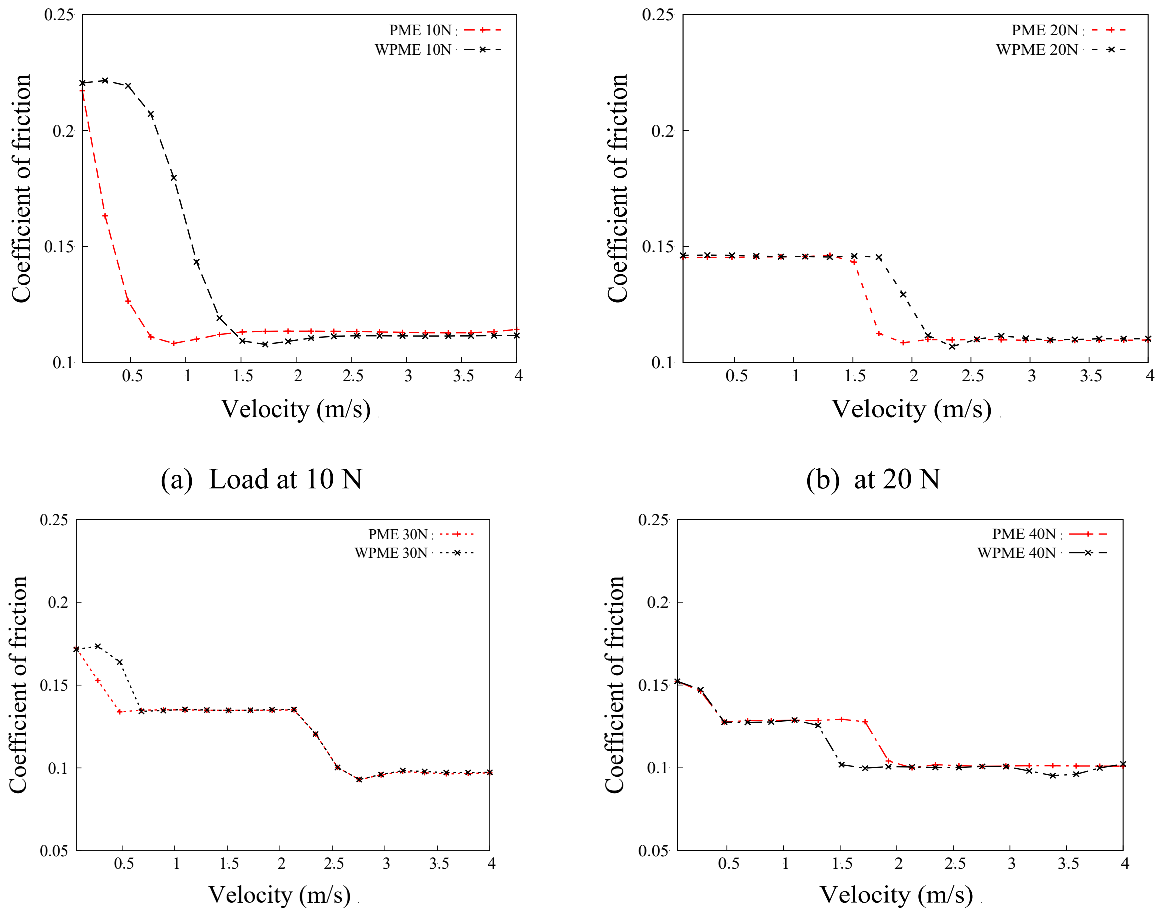
Figure 3. Coefficient of Friction (CoF) measured for WPME at varying velocities with different loads for tested lubricants

Dry contact occurs at very minimum velocity for all types of lubricants, where the coefficient of friction (CoF) values is independent of the speed at low sliding velocities. This is known as the boundary lubrication (BL) regime, where interaction between surfaces, solid to solid, is the predominant mode of action. In this lubrication regime, surface asperity interactions dominate load-carrying capacity and frictional properties, separated only by thin boundary lubrication films. These BL films remain the last barrier in prohibiting direct contact between metal to metal.

Meanwhile, referring to the Stribeck curve, at intermediate speeds, the mixed lubrication (ML) regime occurs where the coefficient of friction reduces with increasing velocity. Finally, the elastohydrodynamic lubrication (EL) regime appears at the highest speed where the pressure separates the sliding surfaces. Chong et al. (2019) mentioned in this regime, where heat generation between the surface contact could reduce friction, leading to non-Newtonian behavior appearing.

A clear view of overall frictional performance between different types of oil-based on load has been plotted in Figure 4. It shows a comparison between four different loads; 10N, 20N, 30N and 40N using two different materials WPME and PME. The graphs show the CoF values for the measured experiments concerning the sliding velocity for a different load. Most of the tested lubricants exhibit increases in CoF at lower velocities. During the transition of lubrication regimes along with EHL and ML regimes, lubricant rheology-pressure relation becomes important. The contact-to-contact between pin and disc causes the contact pressure generated at EHL and ML regimes to be significantly high to affect the lubricant rheology. However, Chong and Ng (2016) discussed that BL is the most significant regime among other lubrication regimes due to increased surface interactions along opposite rough surfaces because of excessive friction generated. Therefore, the effectiveness of a lubrication system can be determined in the performance of the boundary film during sliding.

Regarding the tribological behavior of the biodiesel produced that emerges at 10N, the transition of WPME from BL to ML and EHL is the most sudden. This is apparently because, at sufficiently high load or low sliding speed, the lubricant ejected from the friction zone, causing the rubbing surface to be unlubricated. In this case, it will have resulted in severe friction (Yılmaz Özmen, 2016). The coefficient of friction basically depends on oil viscosity, sliding velocity, and load. Thus, it can be concluded that as WPME and PME perform almost similar as the load increases, usage of WPME as an alternative source in biodiesel production is much better as a replacement of raw palm.



(a) Load at 10 N

(b) at 20 N

(c) Load at 30 N

(d) Load at 40 N

Figure 4. Stribeck curve measured for (a) WPME and (b) PME with different loads analysis.

4. Conclusions

Transesterification method used managed to produce a high yield biodiesel of PME at 96.4% and 82.5% of WPME. This might due to WPME biodiesel derived from waste palm cooking oil, which has high FFA content compared to raw palm coking oil. A Stribeck curve lubrication regime have been developed to study the frictional study of WPME and compared with PME. It is proven that the properties of WPME replicates the behavior of PME at higher load, thus this is an alternative choice in biodiesel production.

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References

[1] A. M. Bano, I. Khan, N. Shahzad, M. .I Younus, M. Abbas, M. Iqbal, Electricity generation from biogas of poultry waste: An assessment of potential and feasibility in Pakistan, 2018 (Renewable and Sustainabile Energy reviews)

[2] S. Sadaf, S Iqbal, J Ullah, I Bhatti, H N Nouren, S Iqbal, Biodiesel production from waste cooking oil: An efficient technique to convert waste into biodiesel, Sustainable Cities and Society, 41 (2018) 220–226

[3] D. Harreh, A.A. Saleh, A.N.R. Reddy, S. Hamdan S, An Experimental Investigation of Karanja Biodiesel Production in Sarawak, Malaysia, Journal of Engineering United States, (2018)

[4] S. Nurdin, R.M. Yunus, A.H. Nour, J. Gimbun, N.A.N. Azman, M.V. Sivaguru, Restoration of waste cooking oil (WCO) using alkaline hydrolysis technique (ALHYT) for future bio detergent ARPN Journal of Engineering and Applied Sciences, (2016) 6405–6410.

[5] AB. Khdour, MK. Nawaj, Recycling of Waste Cooking Oil to Produce Soaps and Detergents : Technical and Economic Feasibility, Palestine Polytechnic University College of Engineering, 2016

[6] I. Kabir, M. Yacob, A. Radam, Households' Awareness, Attitudes and Practices Regarding Waste Cooking Oil Recycling in Petaling, Malaysia, IOSR Journal of Environmental Science, Toxicology and Food Technology, (2014) 45–51.

[7] I. Alias, J. Jaya Kumar, S. Md Zain, Characterization of Waste Palm Cooking Oil for Biodiesel Production, Jurnal Kejuruteraan SI, (2018) 134–137

[8] Z. Yaakob, M. Mohammad, M. Alherbawi, Z. Alam, K. Sopian, Overview of the production of biodiesel from waste cooking oil, Renewable and Sustainable Energy Reviews, (2013) 184–193

[9] I. Ambat, V. Srivastava, M. Sillanpää, Recent advancement in biodiesel production methodologies using various feedstock: A review, Renewable and Sustainable Energy Reviews, (2018) 356–369

[10] A.A. Alicke, B.C. Leopércio, F.H. Marchesini, P.R. De Souza Mendes, Guidelines for the rheological characterization of biodiesel, Fuel, (2015) 446–452.

[11] S.O. Giwa, L.A. Chuah, N.M Adam, Fuel properties and rheological behavior of biodiesel from egusi (Colocynthis citrullus L.) seed kernel oil, Fuel Processing Technology, (2014) 42–48.

[12] A.E. Atabani, A.S Silitonga, I.A. Badruddin, T.M.I. Mahlia, H.H. Masjuki, S. Mekhilef, A comprehensive review on biodiesel as an alternative energy resource and its characteristics, Renewable and Sustainable Energy Reviews, (2012) 2070–2093.

[13] A.R. Mohammed, R. Bhargavi, Biodiesel production from waste cooking oil Egyptian Journal of Chemistry, (2105) 437–452

[14] B. Kayode, A. Hart, An overview of transesterification methods for producing biodiesel from waste vegetable oils, Biofuels for sustainable development, (2017) 419-437

[15] S.H. Hamdan, W.W.F.Chong, J.H. Ng, C.T. Chong, S. Rajoo, A study of the tribological impact of biodiesel dilution on engine lubricant properties, Process Safety and Environmental Protection, (2017) 288–297

[16] W.W.F. Chong, S.H. Hamdan, K.J. Wong, S. Yusup, Modeling Transitions in Regimes of Lubrication for Rough Surface Contact, Lubricants, (2019) 77.

[17] W.W.F. Chong, J.H. Ng, An atomic-scale approach for biodiesel boundary lubricity characterization, International Biodeterioration and Biodegradation, 113 (2016) 34–43.

[18] O. Yılmaz, Si_3N_4 as a biomaterial and its tribo-characterization under water lubrication, Lubrication Science, (2016) 243–254.