Jurnal
Teknologi

Full Paper

TRIBOLOGICAL ANALYSIS ON PALM FATTY ACID DISTILLATE AS ALTERNATIVE TRANSMISSION FLUID FOR CLUTCH APPLICATION

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Article history
Received
13 November 2017
Received in revised form
27 November 2017
Accepted
1 December 2017

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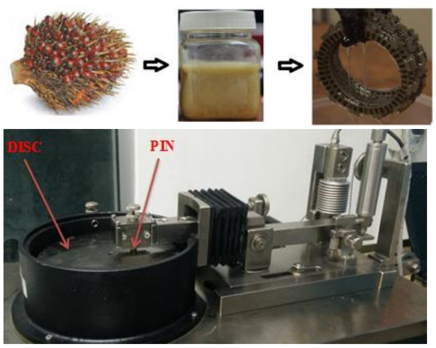
Graphical abstract



Abstract

Typically, a mineral based oil from petroleum refining has been widely used as automatic transmission fluid (ATF) in the wet clutch application. However, it has two major disadvantages: (1) It causes pollution to the environment and (2) It is a non-renewable source. Thus, Palm Fatty Acid Distillate (PFAD) is explored as an alternative lubricant for the wet clutch application. In present study, tribological behaviour of PFAD is first sought using a pin on disk tribo-tester and then its behavior will be compared with the behavior obtained in the commercial ATF. It is found in the friction analysis that PFAD has good anti friction ability at low speeds. In addition, PFAD generates almost identical dynamic friction coefficients obtained in the commercial ATF at velocity of 0.4m/s to 0.9 m/s. A slight positive slope in the friction coefficient–velocity graph indicates that PFAD has tendency to have anti-shudder properties, which can improve engaging quality of the wet clutch. However, PFAD has two weaknesses; low viscosity index and less anti wear ability. Some additives should be added into PFAD so that it can give better friction level and less wear rate.

Keywords: Wet clutch, ATF, PFAD viscosity, coefficient of friction, wear

1.0 INTRODUCTION

The lubricant of wet clutch also known as automatic transmission fluid (ATF) is used and it has a high frictional performance to efficiently transmit the torque and giving smooth engagement. Many vegetable oils have been investigated to be the alternative lubricant replacing mineral oil [1-4]. Palm Fatty Acid Distillate (PFAD) is one of the by products produced from refined crude palm oil which is extensively tested to become alternative lubricant for the petroleum basestock [5-8]. Vegetable oil has many advantages such as it is environmental friendly product which give no harm to human, animal, and environment [9, 10]. Petroleum-derived oils also have been identified to be toxic and significant contributors to eco-pollution, and to have poor biodegradability besides being from a non-renewable source [10]. This necessitates alternative biodegradable and eco-friendly fluids from renewable sources such as vegetable oils. Vegetable oil also is cheap and easily manufactured compared to mineral oil. PFAD has been proven that it has good anti-friction and anti-wear ability compared to engine oil and hydraulic oil [5, 8] in which this ability can be utilized as alternative lubricant for wet clutch.

This work involves the study of the tribological behaviour of alternative lubricant in term of friction force, coefficient of friction and wear analysis for the clutch friction materials and its separator plate application. The lubricants for wet clutch that will be compared is the commercial automatic transmission fluid (ATF) with one of vegetable oils which is Palm Fatty Acid Distillate (PFAD). In wet clutch system, during the lock up stage, coefficient of friction should be high enough so that no slippage occur between friction plate and separator plate and also torque can be transmitted efficiently [11]. If PFAD can maintain high coefficient of friction and reduce the wear rate of clutch plate as low as possible, then it could be a good lubricant to replace ATF.

2.0 METHODOLOGY

2.1 Pin on Disc Friction Test

Pin on Disc Friction test was done to measure the friction and wear of the sliding contact between pin and rotating disc. The parameters such as normal load, wear track distance, and sliding speed were to follow the operating condition of the real clutch system. Wet clutch test was operated by increasing the velocity value of 0.1 to 0.9 m/s and running for five minutes per test. The apparent contact pressure was 2.3 MPa, which was the average contact pressure in actual wet clutches for an automatic power shift.

2.2 Material and Lubricant Selection

Materials for rotating disc and the pin were selected using the same material as real wet clutch mechanism. The friction material investigated was a dispersion sintered brass lining applied to a hardened carbon steel disc [11]. Sintered brass was the pin specimen and carbon steel was the rotating disc. Diameter measurements for pin and disc were 8 mm and 165 mm respectively. The standard automotive transmission fluid (ATF) lubricant for wet clutch system which is type of SP III [12] was used together with PFAD as the tested lubricant oils. Viscometer was used to determine and compare the viscosity of the two lubricants which are ATF and PFAD. Viscosity test was run on four different temperatures which are at 40°C, 50°C, 80°C, and 100°C. Viscosity test at 40°C, and 100°C are a standard temperature used to estimate the viscosity of lubricant while viscosity test was done at 50°C due to the initial temperature of wet clutch as the engine warms up [11] and at temperature of 80°C due to standard operating temperature in wet clutch [13]. Surface roughness test was conducted to measure the surface roughness of rotating disc which represents separator plate of wet clutch. This test also was conducted on the disc that have been run on pin on disc test by using both lubricant that was heated at 80°C that represent standard operating temperature in wet clutch.

3.0 RESULTS AND DISCUSSION

3.1 Viscosity Test

Viscosity test was done to determine viscosity index and compare the viscosity of both ATF and PFAD. The viscosity test was operated at four different temperatures which are 40°C, 50°C, 80°C, and 100°C. The result of the viscosity test is shown in Figure 1.

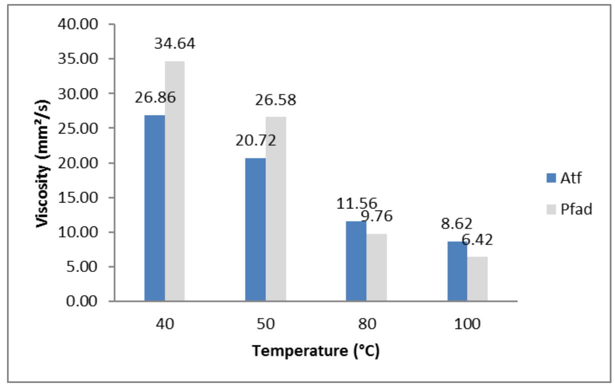


Figure 1 Viscosity for ATF and PFAD at four different temperatures

From Figure 1, the ATF shows trend of mild downfall over the temperature whilst PFAD shows dramatic fall between 50°C to 80°C. It shows that PFAD cannot maintain the oil viscosity as good as ATF. This is also proven by the calculated value of viscosity index which gives viscosity index for ATF and PFAD as 330 and 140 respectively. Higher viscosity index indicates that lubricant has higher percentage to sustain oil stability (viscosity) with the change of temperature [12]. From the viscosity result also, it shows that the viscosity at 80°C and 100°C for both lubricants produced values that are closed to each other. This increases the possibility for PFAD to be used in the wet clutch due to its similar viscosity value to the ATF at the operating temperature of 80°C.

3.2 Coefficient of Friction Analysis

Figures 2 and 3 show the graph of CoF versus velocity at 50°C (initial temperature of automatic transmission as engine warms up) and 80°C (standard operating condition of automatic transmission) respectively.

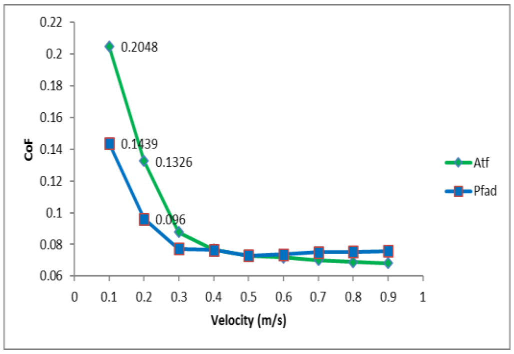


Figure 2 CoF against velocity at two different temperature 50°C for ATF and PFAD

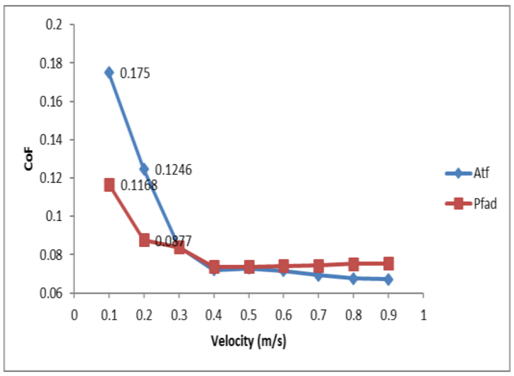


Figure 3 CoF against velocity at temperature 80°C for ATF and PFAD

From Figures 2 and 3, the CoF is higher at 80°C compared to 50°C for both lubricants. This is due to the thinning of the oil film between the contact surfaces as temperature increases. Viscosity at lower temperature is higher than viscosity at higher temperature because the lubricant oil molecules are still bonded by inter molecular forces. When the temperature increases, the molecules of the liquid started to receive the required energy to overcome inter molecular forces, thus increase the viscosity. It can also be seen that CoF is high at velocity value of 0.1 m/s. This is due to high surface contact between pin and disc at lowest speed compared to surface contact at higher velocity. At this state, the static coefficient of friction is dominating due to the specimen tend to reach the lock up stage of clutch [14].

Next, for ATF, CoF decreases as velocity increases while PFAD gives slights increase in COF from 0.4m/s to 0.9m/s for both temperatures which shows good anti-shudder properties. Shudder can be described as a self-excited vibration due to continuous slip-page of its plates (clutch plates and separator plates) in the modern automatic transmission which used lock-up clutch. Small positive slope at dynamic friction coefficient as function of velocity (velocity value of 0.4 m/s to 0.9 m/s) shown by PFAD lubricant at both temperatures indicated that PFAD has the tendency to have anti-shudder properties which can improve engaging quality of the wet clutch. Furthermore, the results also show that PFAD had good lubricity at low sliding speeds. This may be due to the concentrations of unsaturated fatty acids in the oil upon aging, which form free fatty acids to facilitate the formation of metallic soaps that react chemically on the specimen surfaces, acting as a better friction modifier than those used in the pure mineral oils [7]. This result also supports the work of Golshokouh *et al*. [5] and Abere *et al*. [6] that stated PFAD had high anti friction ability.

3.3 Wear Rate Analysis

Figures 4 and 5 show the graph of wear rate against velocity at 50°C and 80°C of ATF and PFAD respectively.

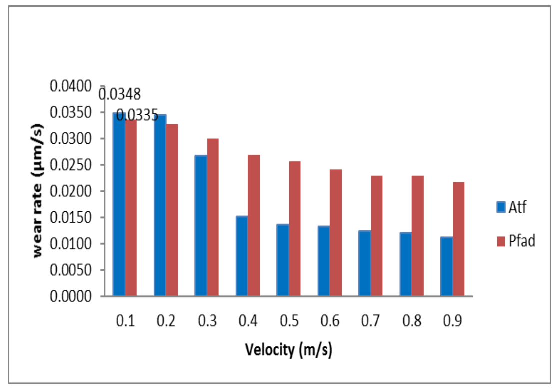


Figure 4 Wear rate against velocity at temperature 50°C of ATF and PFAD

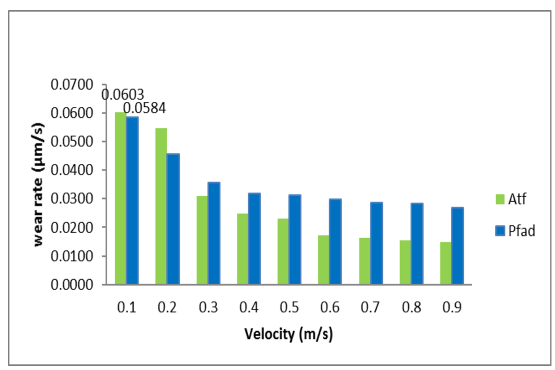


Figure 5 Wear rate against velocity at temperature 80°C of ATF and PFAD

From Figures 4 and 5, the wear rate of pin specimen is higher at 80°C compared to 50°C for both lubricant. This is due to viscosity at lower temperature is higher than viscosity at higher temperature. As viscosity decreases, the thickness of thin film between the surface contacts is decreases, thus increases the CoF at surface contact and wear rate at the specimen also increases [16]. This proves the results of Fernandes *et al*. [15] in which they found that the wear rate of clutch friction material (pin specimen) increases as temperature increases.

Next, it also can be seen that wear rate of specimen decreases as velocity increases. This is due to wear rate following the trend of CoF against velocity. The higher the CoF between specimens, the higher the wear rate occurs on the pin specimen. But, at the velocity 0.4 m/s to 0.9 m/s the wear rate shows a trend of downfall compared to CoF trend as function of velocity (Figures 2 & 3) that shows almost constant value of CoF. This maybe due to the existence of the anti-wear additive in the ATF lubricant that makes the wear of specimen decreases as the surface contact between pin specimen and disc is reduced as velocity increases [17, 18]. But, for PFAD which have no anti-wear additive, higher wear rate was observed compared to ATF throughout the increase in velocity.

Furthermore, at velocity of 0.1 m/s and 0.2 m/s, the wear rate of pin specimen is higher when using ATF compared to PFAD at both temperatures. This is due to ATF having very high CoF to give a sufficient friction for clutch engagement [19] which in return results in high wear rate compared to PFAD at this lock-up stage. It is also known that anti-wear additives in ATF are fully utilized at lower speed due to high surface contact occur at this state, but, significant value of CoF makes pin specimen wear more compared to PFAD. Lastly, even though PFAD has lower wear rate at lowest speed compared to ATF, but in term of usage for a long term for the engagement of clutch will results in more wear compared to ATF due to total high wear rate from 0.3 m/s to 0.9 m/s.

3.4 Surface Roughness Analysis

The surface roughness was analyzed when wet clutch was lubricated with ATF and PFAD with the lubricant temperature of 80°C. The initial average surface roughness (Ra) of disc is 0.192 µm. Figure 6 shows the graph of surface roughness against velocity.

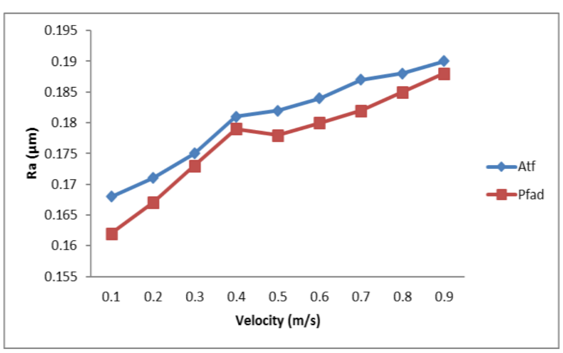


Figure 6 Surface roughness against velocity at 80°C for ATF and PFAD

Based on Figure 6, it shows that the value of Ra getting close to disc initial Ra which is 0.192µm as velocity increases. This is due to surface contact between specimens at the same spot decreases as velocity increases [20]. Another reason is pin on disc test was run for only five minutes per test, thus it may only give polishing effect to the disc which smoother the disc surface [20]. From Figure 6 also, the PFAD has lower Ra compared to ATF. This result is in line with wear results (Figures 4 & 5) in which PFAD has higher wear rate compared to ATF and thus gives lower Ra value compared to ATF.

4.0 CONCLUSIONS

From the results of viscosity test, it is found that ATF has higher viscosity index than PFAD with the value of 330 and 140 respectively. For CoF analysis, PFAD has similar CoF value to ATF for dynamic friction coefficients as function of velocity (at 0.4m/s to 0.9 m/s). From CoF analysis, it also shows that PFAD has good lubricity at low speeds (lock-up stage). Furthermore, from the wear rate analysis, it is found that ATF has good anti wear ability than PFAD. PFAD has lower wear rate at low speed (lock up stage) compared to ATF, but for long term engagement of clutch, PFAD results in more wear compared to ATF due to total high wear rate from 0.3 m/s to 0.9 m/s.

Acknowledgements

The authors would like to thank Universiti Teknologi Malaysia for the financial support of the project under the GUP vot of Q.J130000.2624.12J37.

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