The Effects of Palm Oil with Nanoclay Additive in Hydrodynamic Journal Bearing Lubrication

Izatul Hamimi Abdul Razak, Mohamad Ali Ahmad, Nadia Nurul Nabihah Ahmad Fuad

Abstract*: In the present study, palm oil has been tested to study its capability as a lubricant to replace commercial mineral oil. To enrich the performance, nanoparticles additives were added. Previous studies proved that by adding the small size of additives into lubricating oil can lessen the friction and improve anti-wear properties. In this research, the size of the nanoparticle used was below 20nm. Four ball tester following ASTM D4072-94 was conducted to determine the optimum concentration of palm oil bio-lubricant with Nano-clay additive ranged from 0.02% to 0.08%wt. The results discovered that 0.04wt% of Nano-clay additive added into palm oil was the optimum concentration of the lubricant with the coefficient of friction 0.081, which recorded 16% reduction as compared to mineral oil (20W-40) – the reference lubricant. It also shows good anti-wear ability which the wear scar diameter was improved by 32%. The oil was then tested in journal bearing to characterize the hydrodynamic lubrication properties. The properties that have been observed were the coefficient of friction, pressure profile and temperature profile. The results showed that modified palm oil with Nano-clay provided better performance with low coefficient of friction (reduced more than 50% as compared to mineral oil) and also temperature profile (reduced up to 20% compared to mineral oil). As for the pressure profile, even slightly higher pressure recorded for palm oil due to lower viscosity, yet the pressure was improved with the presence of Nano-clay additive. In overall, it had been proven that palm oil with Nano-clay additive shows massive potential as an alternative lubricant to the same range with the current industrial mineral oil.

***Keywords* : Coefficient of friction, journal bearing test rig oil, pressure profile, temperature profile.**

I. INTRODUCTION

Lubricant is a substance used to facilitate the relative motion of solid bodies by minimizing friction and wear between interacting surfaces. In addition to the primary purposes of reducing friction and wear, lubricating oils are also required to carry out a range of other functions, including the removal of heat, corrosion prevention, and the transfer of power [1]. Commonly used lubricants in the global market are formulated from mineral oil added with different types of additives which usually not environmentally friendly [2] and the production process produces some environmentally hazardous chemical components. The toxicity, difficult-to-dispose and recycle issues makes the condition even worse. With the rise of environmentally concern nowadays, the scientific world is currently looking for alternative lubricants that are safer to the environment. This also to overcome the fluctuations and uncertainty in the crude oil market as well as depletion of the crude oil reserves. It was reported in 2016 that the global lubricants market is projected to increase to about 2.4% by 2011 from 36.36 million tons in 2014. Thus, vegetable-based bio-lubricant is expected to help in fulfilling the growth of needs.

At present, bio-lubricants that derived mainly from vegetable oils have attracted attention due to the good friction and wear characteristics. Not only offers significant environmental benefits in terms of its non-toxicity, renewability, and biodegradability, the bio-based oils also have excellent lubricating properties such as high viscosity index, high lubricity, low volatility and excellent solvents for fluid additives [3 – 5]. There has been an enormous amount of research carried out to explore the potential of vegetable oils to perform as effective as petroleum-based lubricants, including jatropha oil [5 – 7], sunflower oil [3], [4], rapeseed oil [8], [9], soybean oil [10], [11], castor oil [4], canola oil [12] and palm oil [13], [14].

Palm oil is one of the promising candidates for biodegradable lubricants. It contains major fatty acid of palmitic acid (C16:0), oleic acid (C18:1) and stearic acid (C18:0), which generate strong interaction with the lubricated surfaces [15]. This thus giving advantage to palm oil to act as anti-wear protector and friction modifier. Masjuki et al. [16] carried out a comparative study between palm oil and commercial mineral-based lubricating oil and found that palm oil exhibit better performance in terms of wear whereas mineral oils was better in friction. Palm oil also was more effective in reducing CO and hydrocarbon emission levels.

Despite the advantages, there is still constraint is commercializing the vegetable oils including palm oil due to the weaknesses in terms of the properties and performance. The low oxidative as well as thermal stability properties [17] cause the oil to oxidize rapidly and becomes cloudy and solidify at cold temperature. These thus limiting the potential of vegetable oils as a commercial lubricant. Few attempts have been carried out in past studies to improve the deficiencies, especially via chemical modifications such as transesterification, hydrogenation, and epoxidation [18].

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A study conducted by Heikal et al. [14] showed the good potential of palm oil-based trimethylolpropane (TMP) ester as a base stock in the biodegradable lubricant. The palm oil-based TMP was obtained from the transesterification process and the authors claimed that the viscosity, viscosity index, and flash point are comparable to commercial industrial oil ISO VG46. In another study, Gulzar et al. [13] added CuO and MoS_2 nanoparticles additive to chemically modified palm oil as an effort to improve the anti-wear (AW) and extreme pressure (EP) properties and prove the effectiveness when the AW/EP properties were enhanced by 1.5 times.

Utilization of additives into lubrication oils is basically with the purpose to boost the certain desired performance. Different types of additive giving different specific functions, for instance as friction and wear improver, contaminations and cleanliness improver such as anti-oxidant, dispersant and detergent, as well as to maintain fluid properties. Zulkifli et al. [19] added TiO2 nanoparticles into palm oil-based TMP for automobile lubrication and demonstrated a good friction reduction when the coefficient of friction was reduced by 15% with minimum wear scar diameter. Using another type of nanoparticle, Kiu et al. [20] added a different concentration of graphene nanoparticle into palm oil through hydrodynamic and acoustic cavitation as a homogenizing mechanism. The tribological properties of the palm oil were improved which reduced the friction coefficient and wear scar diameter were obtained with 50 ppm was an optimum concentration.

In the present work, nanoclay has been used as an additive for palm oil bio-lubricant. Nanoclay is nanoparticles of layered mineral silicates that belong to a wider group of clay minerals. Having nonmetric thickness and diameter of 50–200 nm, the clay minerals may simply be described as fine-grained with sheet-like structure stacked over one another [21]. Previous studies have found that Nano-clay offers improved properties in tensile modulus and strength, thermal properties and heat distortion temperature, resistance to flammability, and reduced permeability to liquids or gases [22]. Besides, the availability and environmentally friendly properties causing Nano-clay to be adopted in numerous applications. Yet only a few efforts been placed to study the potential as a lubricant performance enhancer. Hence, in this study, Nano-clay has been used as an additive in palm oil bio-lubricant. The tribological properties of palm oil bio-lubricant with different compositions of Nano-clay additive were tested using four-ball wear tester. The optimum composition of Nano-clay was then being applied in a hydrodynamic journal bearing test rig to observe the pressure and temperature profiles.

II. EXPERIMENTAL METHOD

A. Preparation of Lubricant Sample

Commercialized cooking palm oil was purchased from a local store with properties as listed in Table- I and used as the base oil. The Nano-clay surface-modified contains 0.5-5 wt% Amino Propyl Triethoxy Silane 15-35 wt% with the size and true density was provided by the supplier. The nanoparticles were mixed using an ultrasonic vibrator to ensure homogeneous dispersion of mixture without agglomeration. Seven oil samples were prepared, which are palm oils mixed with Nano-clay at 0.02% (NC2), 0.03% (NC3), 0.04% (NC4), 0.05% (NC5), 0.06% (NC6), 0.07% (NC7) and 0.08% (NC8) of weight percentages. Mineral oil CRB Diesel 20W-40 from Castrol Lubricants Malaysia with properties as in Table- I was also used as reference lubricant.

Table- I: Properties of oil samples

Properties	Palm oil	Mineral oil
Density (g/ml)	0.914	0.883
Kinematic viscosity at 40°C (mm^2/s)	47.57	134.1
Kinematic viscosity at 100°C (mm^2/s)	10.2	14.7
Viscosity index	209.68	109.95

B. Tribology Testing

A four-ball wear tester (Koehler) was utilized to study the tribological properties of Nano-clay additive for palm oil following ASTM D4127. In this test, friction and wear during sliding action between three stationary balls and one rotating ball (as shown in Fig. 1) with applied load were estimated by determination of coefficient of friction and wear scar produced. The balls used in this study were AISI 52100 steel balls with 14.7 mm ball mean diameter and hardness range between 61 and 63 HRC. A new set of four balls was used for each set of experiment. The balls were thoroughly cleaned with n-Heptane and dried before the test set up. Palm oil with different concentration of Nano-clay additive ranges from 0.02 to 0.08 wt% with an approximate volume of 10 ml was poured into the ball pot assembly. The test conditions applied were depicted in Table- II, with the main purpose to determine the optimum concentration of Nano-clay additive in palm oil to be applied in a journal bearing test rig.

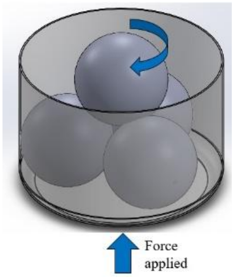


Fig. 1. The four-ball assembly

Table- II: Four-ball tester parameters according to ASTM D4172

Parameter	
Rotating Speed (rpm)	1200
Load (kgf)	40
Duration (hour)	1
Temperature (°C)	75
Based Oil	Palm Oil
Additives	Nano-clay
Additive concentration (%wt)	0.02 to 0.08

C. Journal Bearing Test

The Journal Bearing test rig in Fig. 2 was utilized in this experiment. The bearing used was modified to place 12 units of pressure sensors (transducer) and temperature sensors (thermocouple). The bearing was cleaned by n-heptane before the testing to remove any dust and rusty parts on it and prevents any clogged so that the lubricant can be passed through all the tiny holes where the transducers and thermocouples were located. For pressure readings, the loading arm was mounted to the bearing with the frictional force sensor attached on the spindle housing. When the loading arm presses the loading pin, the force sensor will record the friction values. The tests were conducted at two different loads; 10 and 20 kN applied by pneumatic while the oil inlet pressure was maintained at 0.2 MPa throughout the experiment. The journal speed applied were 300, 400 and 500rpm. Details of test bearing dimensions, lubricant properties, and operating parameters are given in Table- III.

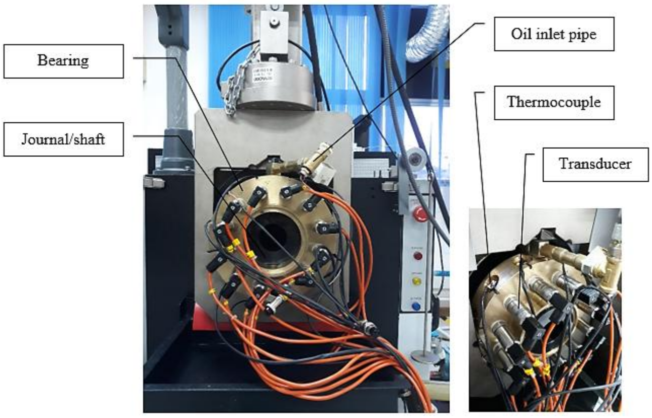


Fig. 2. Bearing fitted to the journal and attached with transducers and thermocouples

Table- III: Test specifications

Parameter	Value
Bearing diameter, *D* (mm)	100
Bearing length, *L* (mm)	50
Radial clearance, *c* (μm)	52
Applied load, *W* (kN)	10 and 20
Journal speed (rpm)	300, 400, 500
Journal material	Brass
Bearing material	Hard carbon steel
Duration (min)	40
Pressure inlet oil (MPa)	Control below 0.2
Pressure sensor:	
Model	Sensortronic MEAS (M5156)
Range (MPa)	10
Accuracy (MPa)	0.001± 1%
Temperature sensor:	
Model	PT 100
Range (°C)	0-100
Accuracy	± 1% measured temperature
Room temperature (°C)	23-26

III. RESULTS AND DISCUSSIONS

A. Tribology Test

Tribological properties of palm oil samples with different concentration of Nano-clay additive were evaluated using the four-ball tester. Tests with mineral oil (MO) and palm oil (PO) without additive were also prepared as a reference to analyze the influence of the vegetable oil and Nano-clay additive on the friction and wear of metallic surface.

Fig. 3 presents the comparison of the average coefficient of friction (cof) of the lubricant samples without and with Nano-clay additive concentration of 0.02 to 0.08 wt% (NC2 to NC8). The friction coefficient value clearly shows high for mineral oil, which is 0.096. There was about 10.4% reduction of friction coefficient for palm oil, showing the significant advantage of the vegetable oil utilization as an effective lubricant alternative. Even at lower kinematic viscosity yet having high viscosity index, the palm oil shows a good role in reducing friction between surfaces. This was aligned with findings by Ing et al. [23] who's found a lower coefficient of friction for the studied RBD palm olein as compared to paraffinic mineral oil. The authors claimed that the lower friction was contributed from the fatty acid contained in the RBD palm olein which the lubricant molecules can stick on the lubricated surfaces and maintain the lubricant layer.

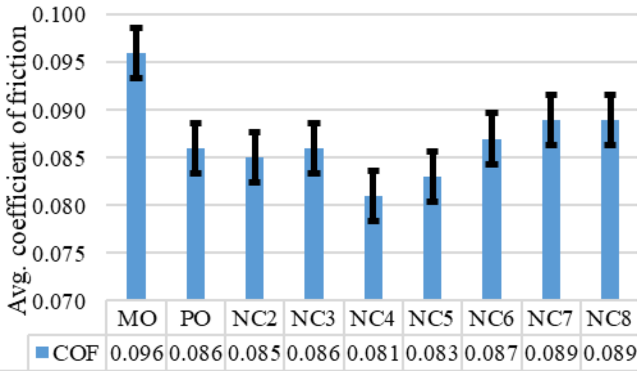


Fig. 3. The average coefficient of friction for different lubricant samples

The addition of Nano-clay into the palm oil had improved the friction coefficient even more. The minimum coefficient of friction recorded for the addition of 0.04 wt% (NC4) of Nano-clay in palm oil, which is 0.081. It contributes to 16% friction reduction as compared to mineral oil lubricant. This was due to the thin layer developed by the nanoparticles additive on the contact surfaces which minimizes adhesion and contributes to lower friction torque [24]. The higher concentration of the Nano-clay, however, increases the friction coefficient gradually up to 0.089 at 0.07 wt% of the additive. At this condition, the high concentration of Nano-clay particles causes rough rubbing action between the contact surfaces. This finding was in agreement with Talib et al. [5] and Razak et al. [25], which the high nanoparticles concentration leads to stress concentration due to the stacking and agglomerates of the particles and contributing to higher friction and wear.

The wear scar produced on the steel balls due to the material removal during sliding contact was observed by optical microscopy with 200x magnification. Fig. 4 and 5 illustrate the optical micrograph of wear scars for mineral oil and palm oils with different concentration of Nano-clay additive. The average wear scar diameters are tabulated in Fig.6. It was presented that palm oil base lubricant giving significant improvement to wear generation. Results show that the optimum concentration of the palm oil mixed with 0.04 wt% of Nano-clay (NC4) produce the lowest wear scar diameter; 0.692mm. This was contributed to about 32% reduction of the scar as compared to lubrication with mineral oil. The results obtained agree with the coefficient of friction value obtained in Fig. 3 which the higher coefficient of friction producing the larger wear scar.

Fig. 4. Optical micrograph of wear scars for mineral oil (magnification 200X)

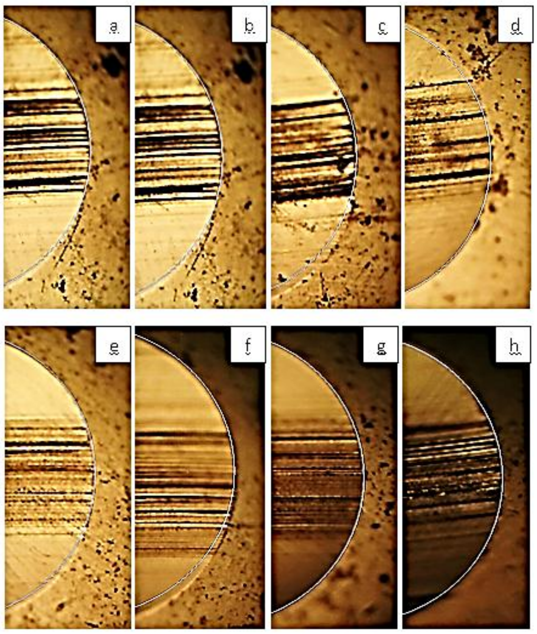


Fig. 5. Optical micrograph of wear scars for palm oils with Nano-clay concentration (magnification 200X): (a) PO, (b) NC2, (c) NC3, (d) NC4, (e) NC5, (f) NC6, (g) NC7, and (h) NC8

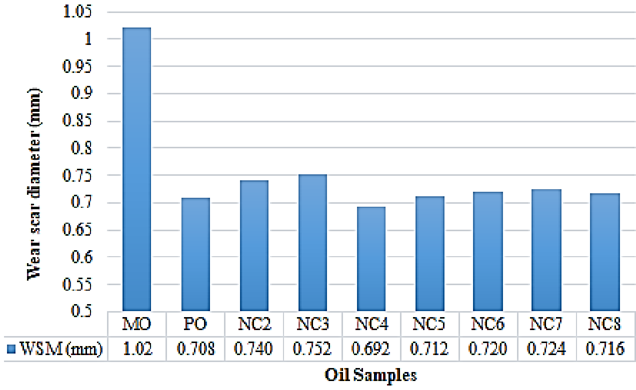


Fig. 6. Average wear scar diameter for different lubricant

According to Shaari et al. [26], when the coefficient of friction was increased, the wear scar also increased. This is due to the high friction phenomenon, also by the chemical attack on the rubbing surface [23].

B. Journal Bearing Test

Characteristics of the palm oil lubricant with the optimum concentration of Nano-clay additive; 0.04 wt% was further investigated for journal bearing application. The tests were conducted under two different loads; 10 and 20 kN with three speeds for each load; 300, 400 and 500 rpm. Results obtained were in terms of the influence of the lubricants on the coefficient of friction, pressure, and temperature at the different loads and speeds.

Fig. 7 and 8 portray the coefficient of friction obtained for the lubricants at three different speed at 10 kN and 20 kN loads respectively. Results show the valid trends which higher load and slower speed initiating higher friction coefficient. It is well known that in hydrodynamic lubrication, operation with higher speed will give better lubrication [27]. Which, in this condition, the two moving surfaces were not in contact with each other and being separated by a thin layer of lubricant. In the journal bearing application, as the shaft rotated in high speed, floating shaft phenomenon occurred and consequently, the coefficient of friction was also less.

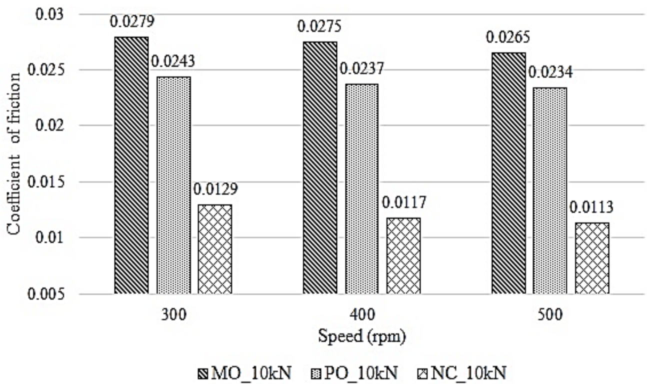


Fig. 7. Coefficient of friction for different lubricant and speed at load 10kN

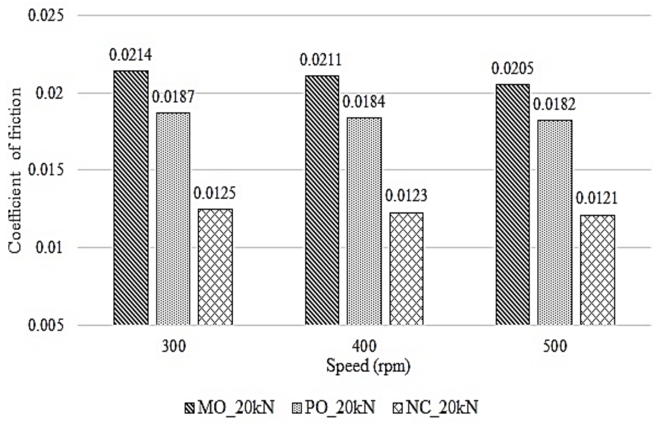


Fig. 8. Coefficient of friction for different lubricant and speed at load 20kN

The previous study shows that the coefficient of friction affected by the load and the speed apply to journal bearing. Higher hydrodynamic pressure produced at the high load tends to generate thicker oil film and resulting in a lower coefficient of friction [27]. This trend, however, was not applied to the palm oil with Nano-clay additive when very fewer changes in the coefficient of friction recorded when the different load was applied to the journal bearing. This shows the efficient performance of this type of lubricant in the system.

Furthermore, referring to Fig. 7 and 8, it was clearly shown that palm oil lubricant produced less friction in journal bearing application as compared to mineral oil usage. The friction yet further improved by more than 50% with the addition of 0.04 wt% of Nano-clay additive. This significant finding had proved the capability of palm oil with an additive as an excellent candidate for an alternative bio-lubricant.

Pressure is another important parameter in journal bearing due to the role to support the shaft load during the operation. Basically, high viscosity lubricant is required for the application that involves high pressure and temperature. Fig. 9 illustrates pressure profiles of sample lubricants when applied in journal bearing at different speeds (300, 400 and 500 rpm) and loads (10 and 20 kN). In overall, higher pressure was recorded when the load was increased from 10 to 20 kN with the same location of maximum pressure, which is at circumference angle of 210°. This represents the area of minimum film thickness which in the loaded zone or called curve wedge, lubricant was forced to flow into that region to support the shaft load. When the higher load was applied, the curve wedge region increased as the hydrodynamic pressure were increased to support the shaft load.

There was also found that the different speed and lubricant types did not affect the pressure distribution much. This might due to the slight radial clearance (52 µm) between the bearing and journal, producing an insignificant difference in the pressure changes. Yet mineral oil produces minimum pressure when compared to other lubricants, which is average of 2.03 and 4.32 MPa at circumference angle of 210° for load 10 and 20 kN respectively. This was contributed from the higher oil viscosity. Pressure for the palm oil with Nano-clay additive also was appeared lower as compared to palm oil without any additive. At the same circumference angle, the palm oil with and without Nano-clay additive recorded average of 2.06 and 2.09 MPa pressure respectively for load 10 kN, whereas for load 20 kN, the average pressure recorded was 4.54 and 4.55 MPa respectively. This result verified the good contribution of Nano-clay additive for the pressure distribution in the journal bearing system to control the oil viscosity.

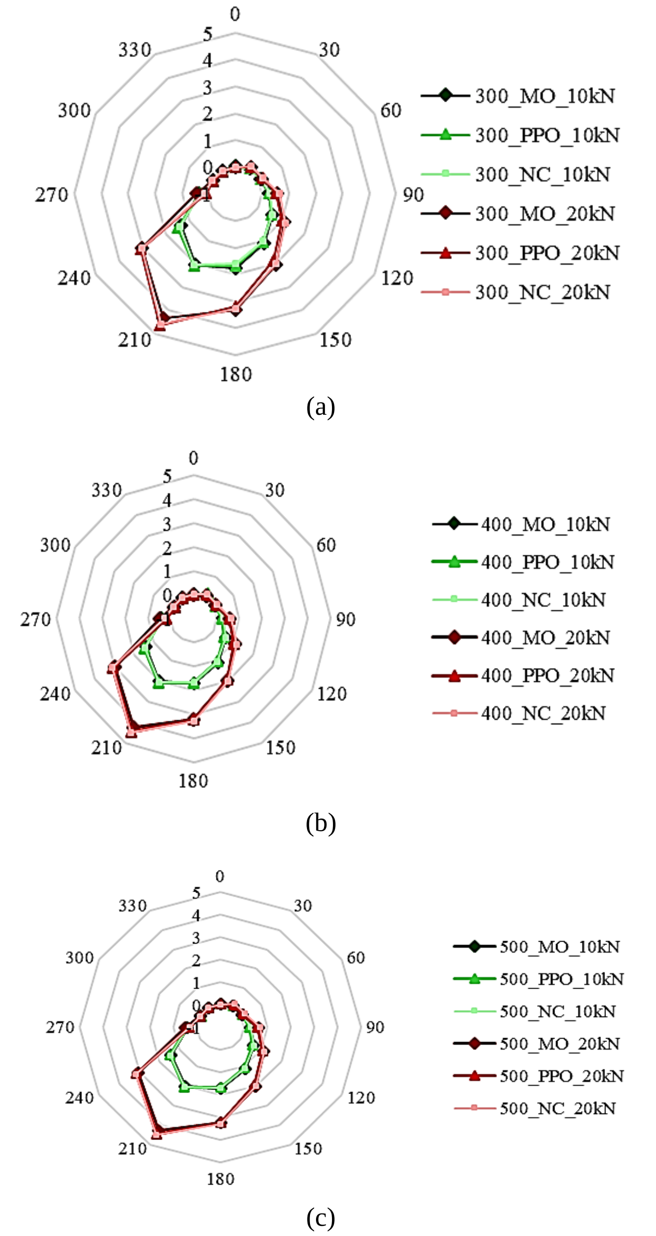
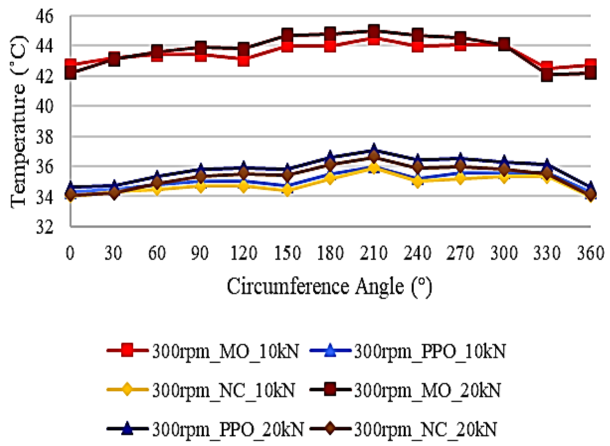


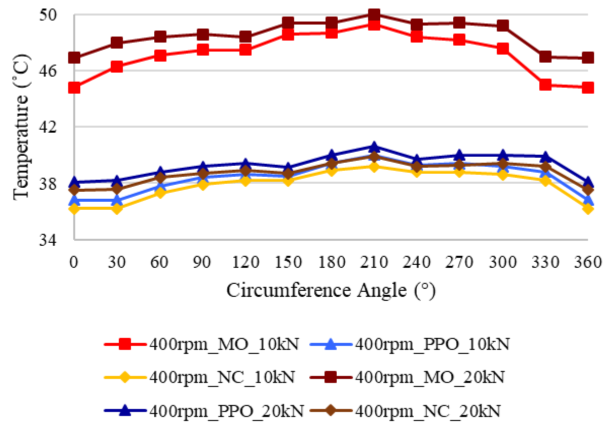
Fig. 9. Pressure profile at speed (a) 300 rpm, (b) 400 rpm, and (c) 500 rpm

Effects of the studied lubricants on temperature profile in the journal bearing application were illustrated in Fig. 10. It was clearly shown that lubrication by palm oil without and with additive has significantly improved the temperature in journal bearing application by up to 20% as compared to mineral oil. This might due to the less friction produced with the utilization of palm oil that contributing to lower temperature, and even less with the presence of Nano-clay additives. For instance, when the journal was rotated with 500 rpm at 10 kN load, temperatures recorded at 210˚ circumference angle are 53˚C for mineral oil, 43.5 ˚C for palm oil without additive, and 42.9 ˚C for palm oil with Nano-clay.

In addition, the trend also shows temperature was slightly increased with speed and load. The temperature range recorded is between 34˚ to 45˚C for 300 rpm speed, 36.2˚C to 50˚C for 400 rpm speed and 38.7˚C to 54.2˚C for 500 rpm speed. In all cases, the temperature was increased before entering the minimum film thickness region and achieve the maximum value at the circumference angle of 210˚. This is due to the higher friction occurred between the fluid layers when entering the converging region [28].



(a)



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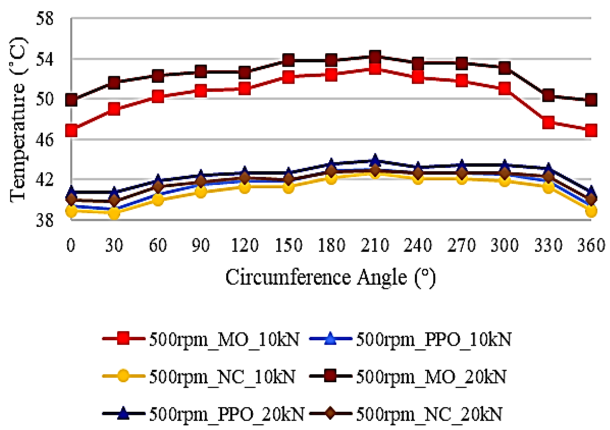

(c)

Fig. 10. Temperature profile at speed (a) 300 rpm, (b) 400 rpm, and (c) 500 rpm

Even with the slight improvement of pressure and temperature obtained for palm oil with Nano-clay additive for journal bearing application, the potential as effective alternative lubricant has been proven through the experiments conducted. Further studies need to be conducted with considering the larger clearance gap between the bearing and journal in order to extend the findings.

IV. CONCLUSION

This study focused on utilizing commercial palm oil as a lubricant and with the addition of Nano-clay additive. Experimental studies have been carried out to investigate the potential of palm oil as a lubricant as well as the effects of Nano-clay as the oil additive. Several conclusions thus can be drawn:

1. It was verified that 0.04% of Nano-clay additive into the palm oil lubricant can improve the coefficient of friction by 16%. The additive also shows good anti-wear ability which the wear scar diameter produced was improved from 1.020mm (mineral oil) to 0.692mm (palm oil with 0.04% Nano-clay) with a reduction of 32%.
2. In journal bearing operation that involving hydrodynamic lubrication, results show the better anti-friction performance of palm oil, which the coefficient of friction of palm oil with 0.04% Nano-clay was reduced by up to 50% as compared to mineral oil.
3. With the addition of Nano-clay into palm oil, pressure distribution in the journal bearing application can be improved, which the oil viscosity is increased with the presence of the additive.
4. Lubrication by palm oil without and with additive has significantly improved the temperature in journal bearing application by up to 20% as compared to mineral oil. Maintaining temperature is important due to lubricant viscosity will changes when the temperature changes.

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