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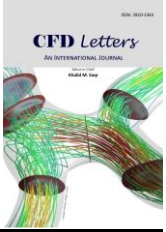

Potential of RBD Palm Oil as a Lubricant in Textured Journal Bearing using CFD with Consideration of Cavitation and Conjugate Heat Transfer

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ABSTRACT

The revolution of tribology technology involved lubricant has driven researchers recently due to strict environmental policy. RBD palm oil has remarkable properties that can improve the performance of plain or textured journal bearings. At the same time, surface texture modification can improve journal bearing performance. The potential of RBD palm oil as an environmentally friendly lubricant in textured journal-bearing applications was investigated in this case study. ANSYS FLUENT was chosen as a method of analysis. The validation study was compared with experimental data to validate the correct approach with actual journal bearing. In addition, the cavitation model and conjugate heat transfer were considered in this case study. Results revealed that RBD Palm oil performed well when the surface texture was introduced at the divergent area as compared to convergent area and plain journal bearing. The suitable condition of textured journal bearing needs to be chosen correctly to optimize the maximum film pressure of journal bearing load and load-carrying capacity of journal bearing. The optimum condition of a textured journal bearing is when the rotational speed of the journal bearing is above 800 rpm, and the eccentricity ratio is above 0.3. In conclusion, combining the correct location of surface texture and the suitable parameter condition of journal bearing will make RBD palm oil perform well as a renewable source of lubricant in textured journal bearing applications.

1. Introduction

As mentioned in ancient Egyptian frescoes, various vegetable oils, animal products, and even water were used as lubricants as early as 4000 years ago. Due to environmental concerns, vegetable oil is still regarded as the best substitute for hydrocarbon-based synthetic lubricants. The poor oxidation stability of vegetable oil makes it unsuitable for use as a bio lubricant [1]. Afifah and her friends [2] stated that the global awareness of declining environmental health, climate change,

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increasing energy demand, and crude petroleum reserve depletion has increased motivation and the need for sustainable resources. According to Azman and Samion [3], the introduction of nanotechnology has resulted in a significant number of experimental studies into the use of nanoparticles as lubricant additives over the last few decades. Despite their excellent tribological performance, the poor long-term stability of nano lubricants limits their use in practical uses. In addition, Rosenkranz *et al.,* [4] mentioned that artificial intelligence and machine learning methods have recently gained significant attention in the tribological community due to their ability to predict tribologically relevant parameters such as the coefficient of friction of the oil film thickness.

Palm oil is a triglyceride, which is a fatty acid ester of glycerol [5]. Rasep *et al.,* [6] proposed that palm oil is the best vegetable oil because it has a lower coefficient of friction than other vegetable oils such as rapeseed, soybean, and sunflower oil. As a result, palm oil has high potential for substitution of mineral oil. Due to its high viscosity, the palm oil-based lubricant has similar properties to the recommended mineral oil in terms of lower extrusion load [7]. However, according to Yahaya *et al.,* [8], vegetable oil faces several issues and challenges in the industry, including oxidation stability and poor low-temperature behavior. Even so, much more research is needed to improve the quality of vegetable oil. Palm oil is widely used in a variety of scientific fields. Bahar [5] investigated the performance of crude fatty acids from palm oil as a lubricant in 2020 by running a cold forward extrusion experiment and discovered that this crude fatty acid gives a low load in the process and that fatty acids are good in reducing friction contact between billet and die. In the same year, Yahaya *et al.,* [9] demonstrated that palm kernel oil provides better surface protection to the material. It indicates that the workpiece roughness is lower than the Commercial metal forming oil (CMFO); additionally, the wear scar observation demonstrates that the CMFO has a lot of wear on the workpiece surface. Afifah and her friends [2] developed innovative technology in 2019 to create a new bio lubricant from a by-product of palm oil by using a catalyst for the transesterification reaction of palm stearin with methanol. Later, Kiu *et al.,* [10] confirmed that adding graphene to vegetable oil improved tribological properties by lowering friction coefficient and wear scar diameter. Sapawe *et al.,* [11] proposed that combining palm oil with an antioxidant can decrease the development of wear scarring. The addition of Tertiary-butyl hydroquinone (TBHQ) improves protection at metal-contacting surfaces by increasing lubricity and smoothness of motion. TBHQ can reduce oxidation by protecting the thin layer of lubricant film from breakdown. Syahrullail *et al.,* [12] then investigated the performance of RBD palm olein using a pin-on-disk tester. Refined bleached and deodorized (RBD) palm olein outperformed hydraulic mineral oil in terms of anti-friction and anti-wear performance under American Society for Testing and Materials (ASTM) experimental conditions. In the same year, Syahrullail *et al.,* [13] reported that mixing Palm fatty acid distillate (PFAD) into CMFO reduced the friction coefficient from 0.08 to 0.054 (20 percent PFAD). This demonstrates that the PFAD can function as a lubricant performance enhancer (additive). Later in 2011, Syahrullail *et al.,* [14] confirmed that the lubrication performance of RBD palm stearin is comparable to that of paraffinic mineral oil in terms of reducing frictional constraint in a cold work extrusion.

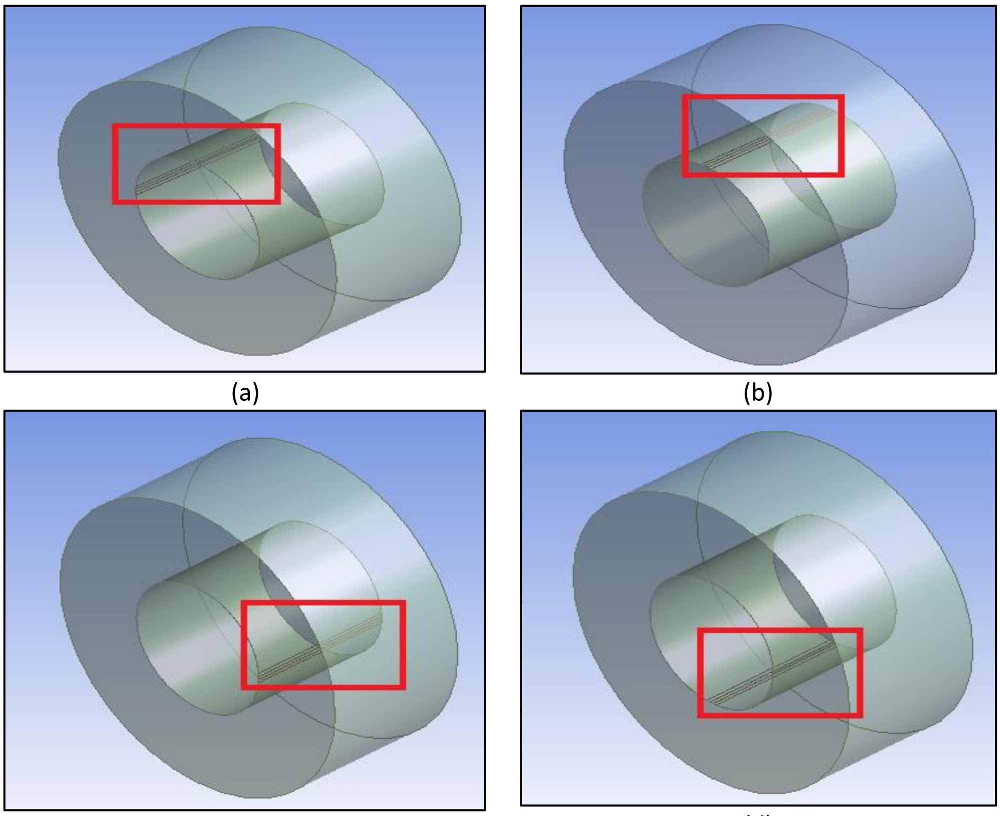
Journal bearings have been developed in various geometrical designs to meet load capacity, operational speed, stable operation, and cost-effective manufacturing [1]. Surface texturing is a more cost-effective method of die modification than tool change and hot work. Adding dimples to extrusion die designs to keep lubricant in place during the metal forming process is becoming more common. As a result, this study was carried out by embedding dimples in a tapered die sliding contact surface to investigate its effectiveness in a cold extrusion process [7]. In addition, by employing a non-edible palm oil-based lubricant as a test, this study hopes to uncover mineral-based lubricant alternatives for metal formation. Apart from cooking oil, palm oil has a wide range of possible applications [7]. The combination of vegetable oil as a future replacement for mineral oil and modification of journal bearing surface texture, as proposed by Rasep *et al.,* [6] in their review paper, will be a significant finding because it will improve journal bearing performance while also promoting the use of environmentally friendly lubricants. Tauviqirrahman *et al.,* [15] later stated that partial texturing of journal bearing surfaces has proven to be very beneficial in friction coefficient. Simulation results for conventional smooth parameters, including hydrodynamic pressure and load support, are obtained, and compared. A reference is proposed for determining optimal groove depths and the best artificial slippage placement of textured bearings under various loading conditions.

Computational fluid dynamic (CFD) techniques evolved because of trial and error and numerous validations. The Imperial College CFD group began an ambitious and appealing program to predict simple shear flows, free and confined jet flows in early 1973 [16]. Many papers highlighted thermal effects and cavitation on the hydrodynamics analysis should be considered when designing journal bearings. CFD ANSYS FLUENT software studied the impact of different blending ratios on density and viscosity [17]. It was discovered that density and viscosity have a proportional relationship with biodiesel blend composition. The potential of RBD palm oil was investigated in this study at various eccentricity ratios and speeds of the textured journal bearing. Eccentricity is defined as moving the journal away from the center distance bearing when a steady-state condition is reached. The eccentricity ratio is an essential factor in the performance and efficiency of a hydrodynamic plain journal bearing. Regarding the eccentricity ratio effect on journal bearing, Chen *et al.,* [18] found that as the eccentricity ratio increases, so does the maximum pressure and load-carrying capacity. Furthermore, as the eccentricity ratio increases, so does the range of positive pressure. This is due to rapid changes in oil-film thickness as the journal bearing radius increases. According to the case study of Dhande *et al.,* [19], peak pressure increases with both shaft speed and eccentricity ratio increase but is more sensitive to eccentricity ratio change, making the situation tightly coupled. Later, Tauviqirrahman *et al.,* [15] and Susilowati *et al.,* [20] published a study that included two recommendations. First, Tauviqirrahman *et al.,* [15] show that the higher the eccentricity ratio, the less positive the effect of texture introduction is. Susilowati *et al.,* [20], on the other hand, found that increasing the eccentricity ratio improves hydrodynamic pressure and load support. In terms of friction force, however, the opposite is true. The friction force is unaffected by a high eccentricity ratio. The influence of groove shape on journal bearing pressure distributions is substantial—maximum pressure and load-carrying capacity increase with eccentricity ratio, especially at higher eccentricity ratios [18]. According to Kalbande *et al.,* [21], as the speed of the journal increases, so does the maximum pressure in the bearing. It should also be noted that the negative pressure is minor in comparison to the positive pressure. Furthermore, as the journal speed increases, the positive pressure increases significantly. Following that, Dhande *et al.,* [19] concluded that its peak pressure rises as the shaft's rotational speed increases. Still, when compared to the peak pressure range in the eccentricity ratio, the peak pressure range gradually decreases.

Palm mid olein (PMO), Double fractionated palm olein (SPL), and RBD palm oil have excellent physical properties as it shows good fluidity behaviors. Palm oil has a wide range of products in its upstream process [22]. Hence in this case study, RBD palm oil was chosen as a lubricant. This case study aims to investigate the potential of RBD palm oil as a potential lubricant that can be replaced by conventional mineral oil in the application of textured journal bearing. A fluid film maximum pressure was compared with plain journal bearing and textured journal bearing at different rotational speed values and eccentricity ratios.

2. Methodology

Figure 1 shows four different locations of textured journal bearing. The first location is at convergent A, the second location at divergent A, the third location at divergent B, and lastly location at convergent B. The rotation of journal bearing is anti-clockwise at 49°. Cavitation and conjugate heat transfer were considered in this case study. Table 1 shows a numerical analysis parameter that used in this case study. The comparison is made at different rotational speeds and eccentricity ratios for plain journal bearing and textured journal bearing at a different location. Surface of the water film is represented by a 'stationary wall,' while a 'moving wall' represents the inner surface. The paper's numerical analysis uses the pressure-based solver: Figures 2 (b) and 2 (c) show a shaft and bearing boundary condition.



(a) (b) (c) (d)

Fig. 1. Location of textured journal bearing (a) location surface texture at convergent A, (b) location surface texture at divergent A, (c) location surface texture at divergent B, (d) location surface texture at convergent B

Table 1
Numerical analysis parameters

Parameter	
Bearing outer radius	89.941 mm
Bearing inner radius	40.041 mm
Shaft radius	40.001 mm
Bearing length	80.21 mm
Radial clearance	0.04 mm

2.1 Simulation Model

The governing equations are solved in steady state condition, with no gravity force and operating pressure of 101325 Pa. The viscous model is developed to the laminar model and enhanced wall treatment based on the journal bearings dimensional parameters and working conditions. Figure 2 (a) depicts one of the water film clearances as an inlet and the other as an outlet. The boundary conditions at the inlet and outlet are 'pressure inlet' and 'pressure outlet,' respectively.

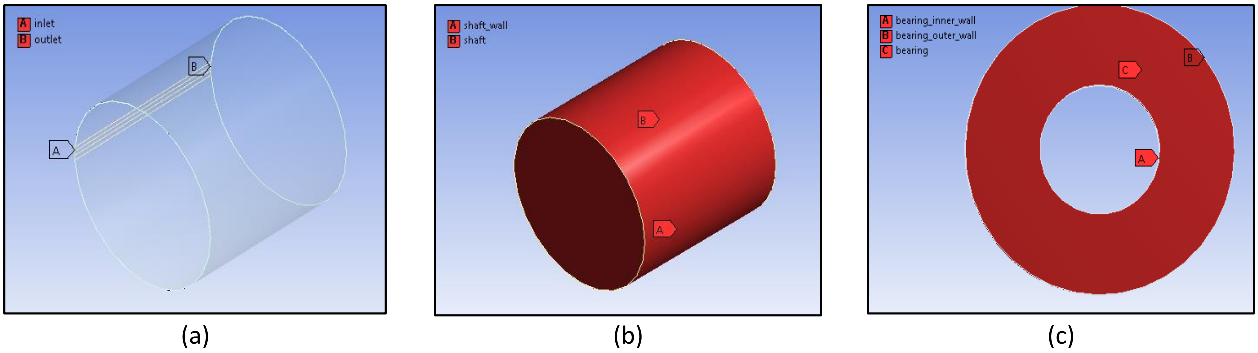


Fig. 2. The boundary condition for a) fluid area b) shaft c) bearing with consideration of conjugate heat transfer

2.2 Temperature-Dependent Viscosity

The current trend in modern industry is to use machinery that rotates at high speeds and carries heavy loads. In such cases, hydrodynamic bearings are commonly used. When a bearing operates at high speeds, the heat generated by high shear rates in the lubricant film raises its temperature, lowering the lubricant's viscosity and affecting journal bearing performance [23]. Furthermore, Dang *et al.,* [1] stated in their paper that an increase in temperature causes a decrease in lubricant viscosity, which leads to a degradation in bearing performance. As a result, obtaining the bearing performance characteristics while maintaining constant viscosity may result in an incorrect prediction about the bearing [24]. As a result, the study cavitation effect and conjugate heat transfer condition were used in this case. The CFD ANSYS FLUENT software is used to create the code for this user defined function. The following relationship has been used for the variation of viscosity as a function of pressure and temperature. This equation is based on the reference [22].

$$\mu = 47.451 * \exp(-0.021 * Temp)$$

The above equation has been appended to the ANSYS FLUENT software, and cavitation effect and conjugate heat transfer condition were applied in this case study. Chen *et al.,* [18] and Rasep *et al.,* [25] highlighted the importance of applying the cavitation model in journal bearing studies in their case study. Hence in this situation, the Zwart-Gerber-Belamri cavitation model was used.

2.3 Validation

The goal of this simulation is to solve a real-world problem involving lubrication and journal bearing application. Gao *et al.,* [26] compares the simulation results to the published experimental data. The validation was conducted using water as a lubricant and a rotational speed of 1500 rpm with an eccentricity ratio of 0.8. Figure 3 shows that the model's simulation results agree well with the experimental results, indicating that the proposed model is reasonable and precise in describing the hydrodynamic characteristics of a journal bearing.

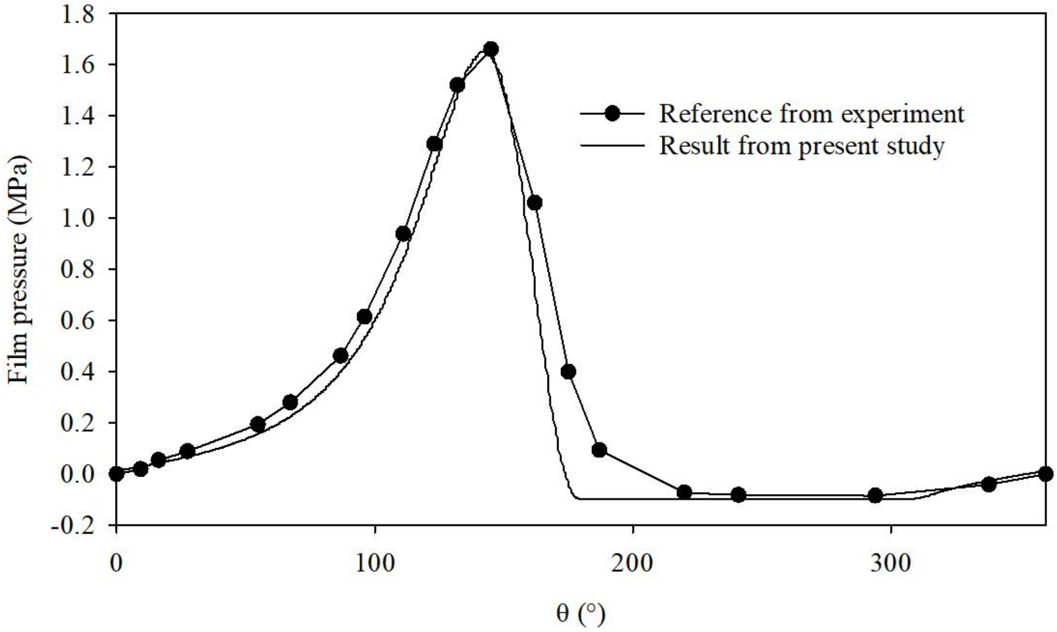


Fig. 3. Comparison between film pressure for plain journal bearing from experimental data [26] and present study at eccentricity ratio=0.8 and rotational speed at 1500 rpm

3. Results

Figure 4 shows a comparison between engine oil maximum film pressure of journal bearing and RBD palm oil. The condition was applied at 1000 rpm and eccentricity ratio of 0.7 at constant viscosity at plain journal bearing. The maximum film pressure of engine oil is 45.3MPa, while for RBD, palm oil is 27.5MPa. The comparison graph showed that RBD palm oil has a considerable potential to replace engine oil with some modification applied to the structure of RBD palm oil, whether physically or chemically. Next, the study will continue using conjugate heat transfer and textured journal bearing at different rotational speed and eccentricity ratios.

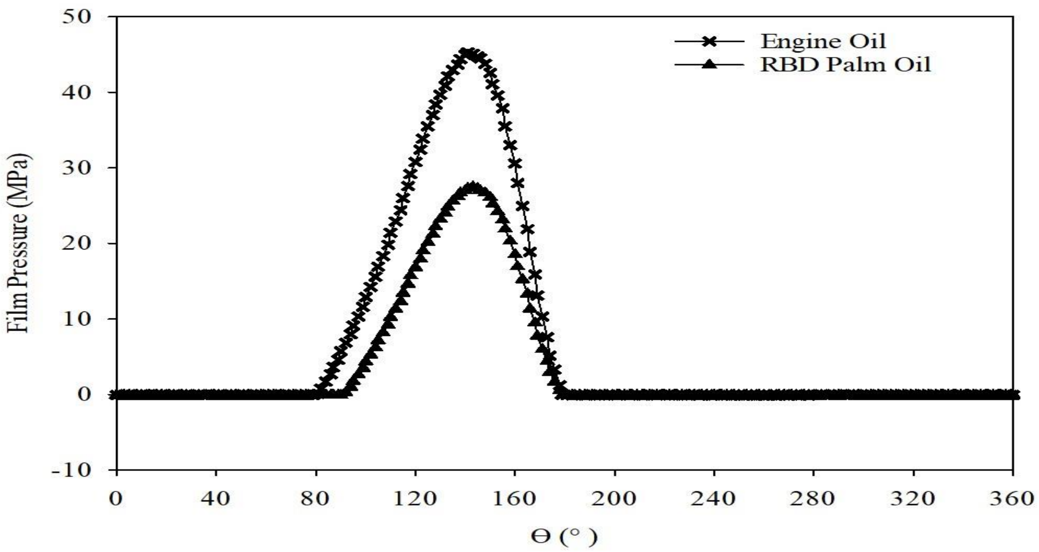


Fig. 4. Graph comparison of engine oil RBD palm oil at the condition of constant viscosity

Next, Figure 5 and Figure 6 showed a comparison of the graph and maximum pressure contour between plain bearing and four different locations of surface texture which are located at convergent A, location at divergent A, location at divergent B, and the location at convergent B. Figures 5 and Figure 6 showed that location at divergent A showed improvement in term of maximum pressure of film journal bearing as compared to the plain bearing. Other's location results showed that the maximum pressure of film journal bearing is lower compared to plain journal bearing. The maximum pressure of film journal bearing at plain bearing condition is 4.94 MPa, and location surface texture at divergent A is 4.97 MPa. Cavitation effect and conjugate heat transfer phenomena were applied in this situation, and RBD palm oil was chosen as a lubricant in textured journal bearing application. Next the study will further investigate at location of divergent A at different value of rotational speed (200, 400,600, 800 and 1000 rpm) and eccentricity ratio (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7).

Figure 7 and Figure 8 showed that maximum film pressure of textured journal bearing is higher than plain bearing at the condition of rotation speed at 800 rpm and 1000 rpm and constant eccentricity ratio at 0.7. This result showed that in a lower rate between 200 rpm until 600 rpm, the efficiency of the introduction of surface texture is not efficient as the result of maximum film pressure at lower speed is lower at the condition of surface texture at divergent A compared to the plain bearing. This result can be used as a guideline in which condition speed needs to apply to prove that introduction of surface texture will positively benefit the overall performance of journal bearing. Following that, Figures 9 and 10 demonstrated that the maximum film pressure of textured journal bearing is more significant than plain bearing at eccentricity ratios of 0.3, 0.4, 0.5, 0.6, and 0.7 at a constant speed of 1000 rpm, as stated by ref. [20] that increasing the eccentricity ratio will improve hydrodynamic pressure as well as load support.

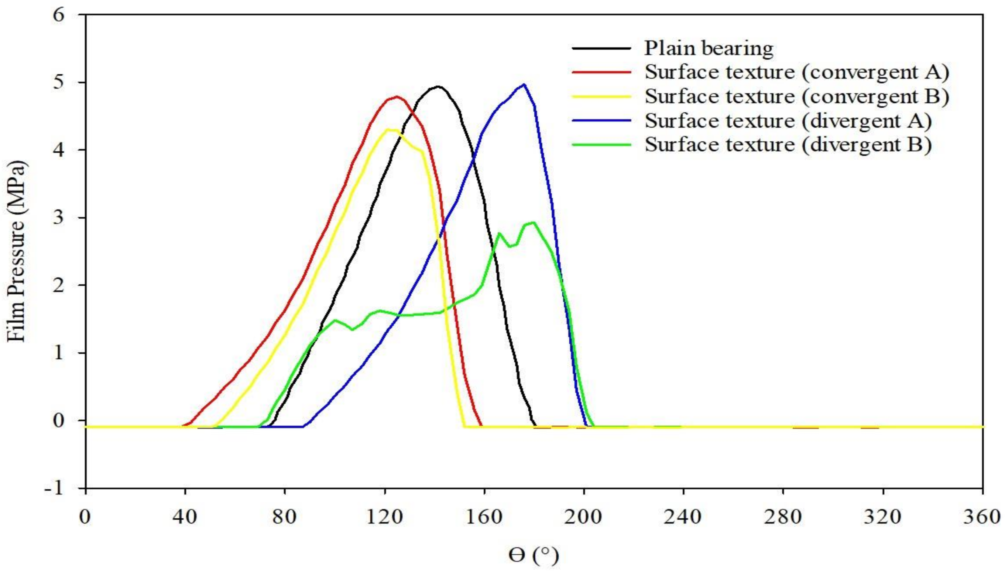


Fig. 5. Comparison for different locations of textured journal bearing with plain bearing

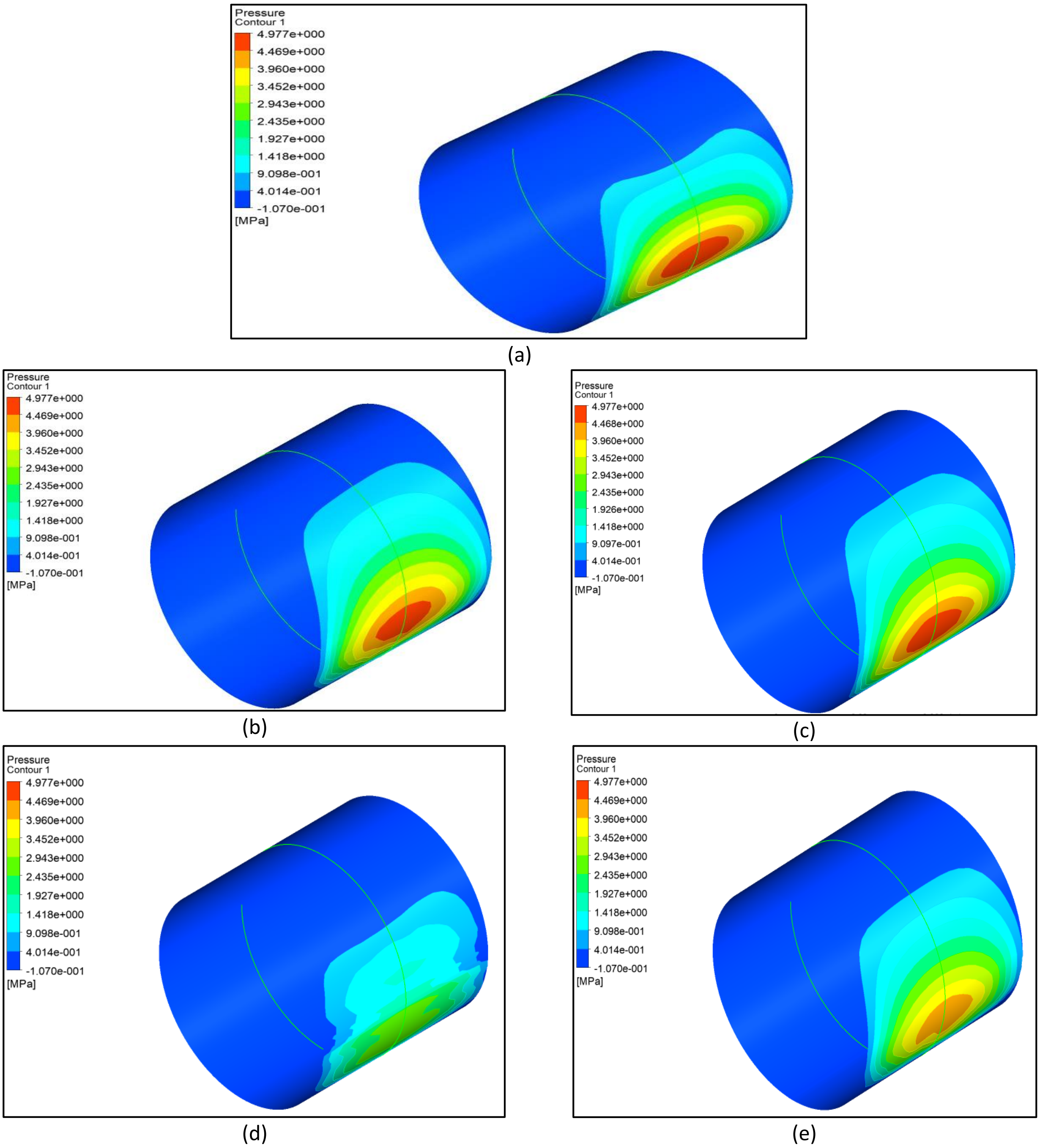


Fig. 6. Comparison of contour maximum pressure for a) plain bearing b) location surface texture at convergent A, c) location surface texture at divergent A, d) location surface texture at divergent B, e) location surface texture at convergent B

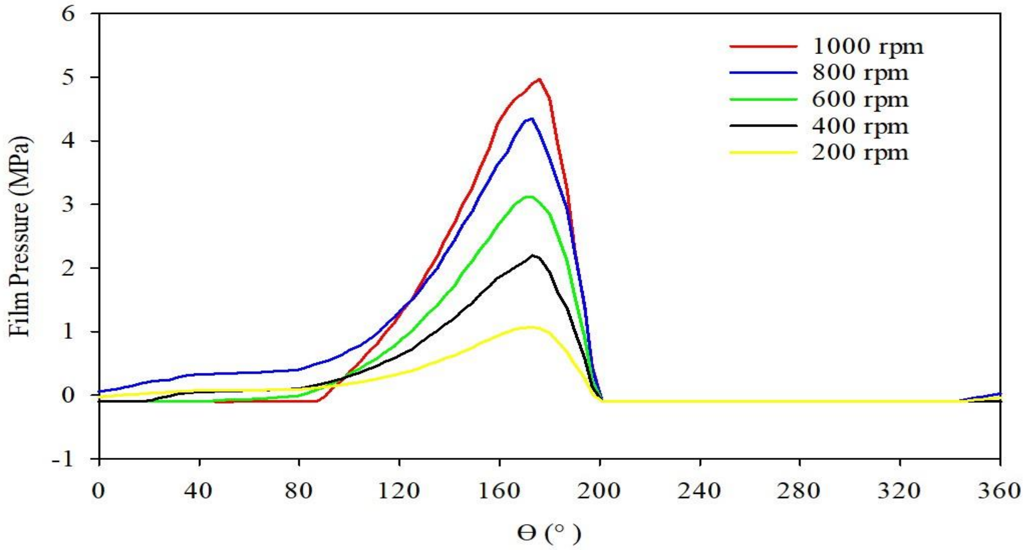
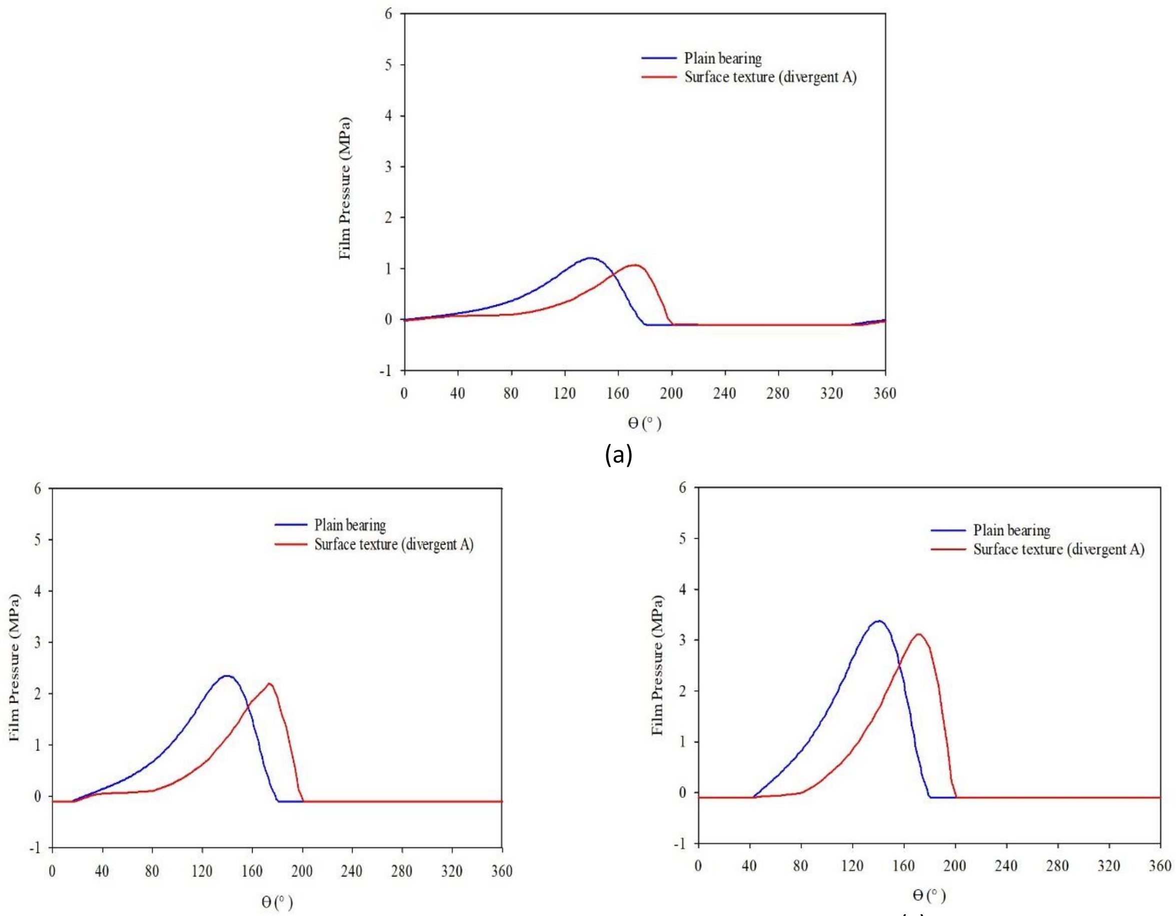


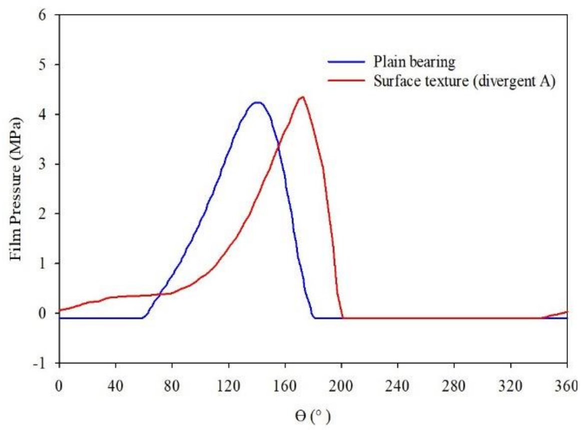
Fig. 7. Maximum film pressure of RBD palm oil at the location of surface texture at divergent A for different rotational speeds considering conjugate heat transfer phenomena



(a)

(b)

(c)



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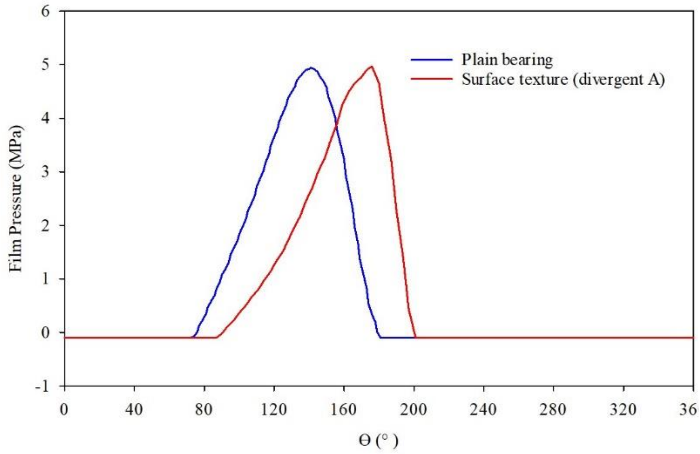


(e)

Fig. 8. Comparison of maximum film pressure for RBD palm oil between the plain bearing and textured bearing at divergent A considering conjugate heat transfer phenomena at constant eccentricity ratio 0.7 and different rotational speed a) 200rpm b) 400rpm c) 600rpm d) 800rpm and e) 1000rpm

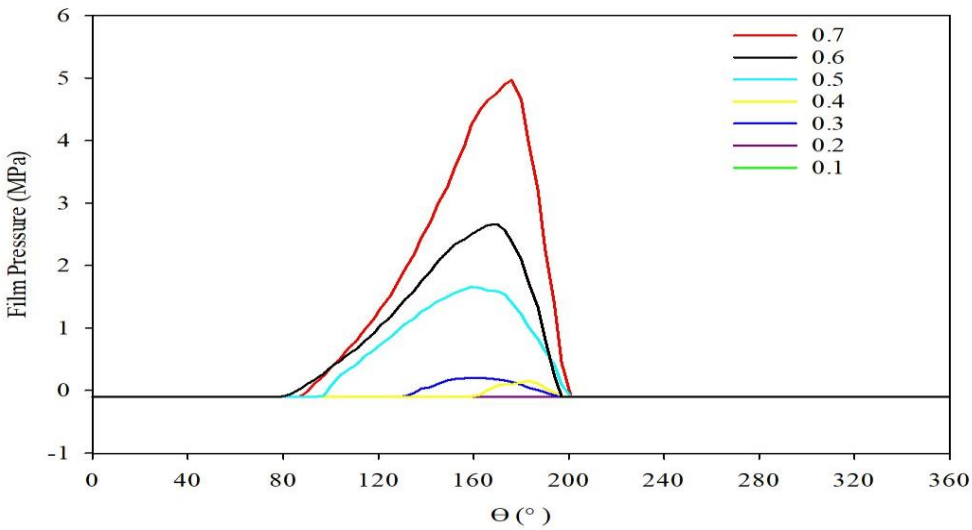
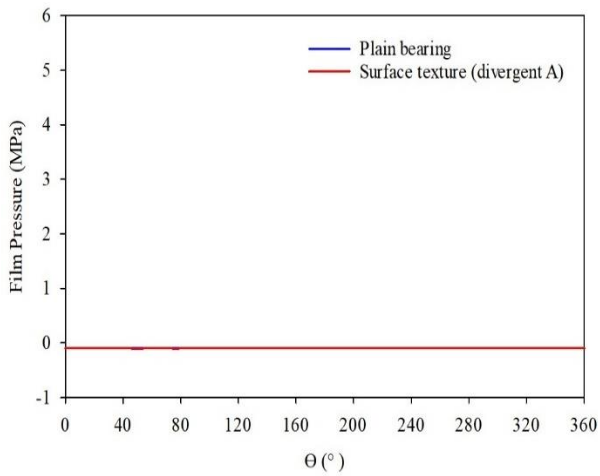
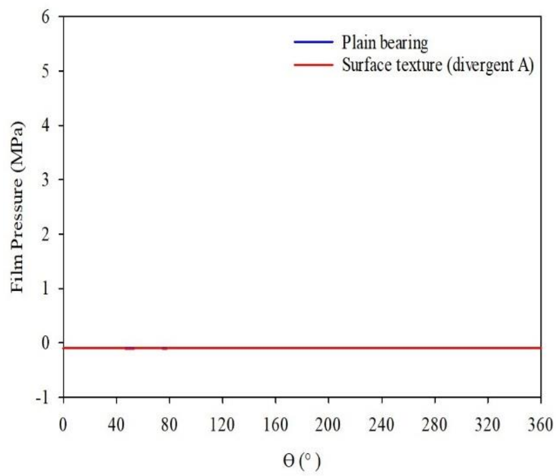


Fig. 9. Maximum film pressure of RBD palm oil at the location of surface texture at divergent A for different eccentricity ratio values considering conjugate heat transfer phenomena



(a)



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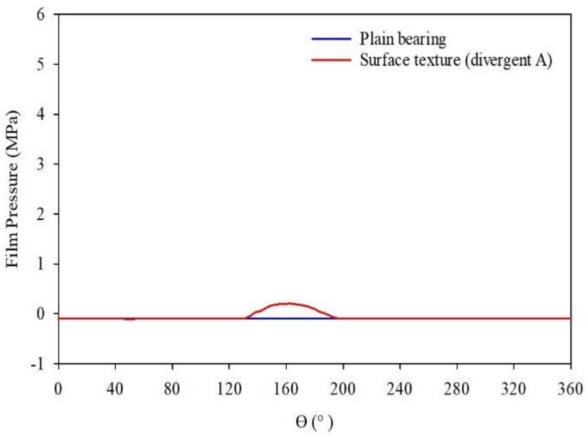

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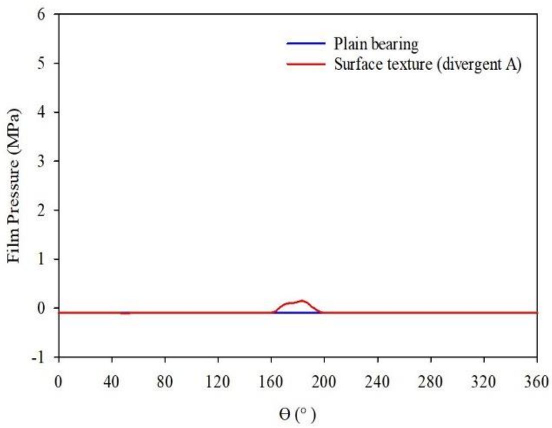

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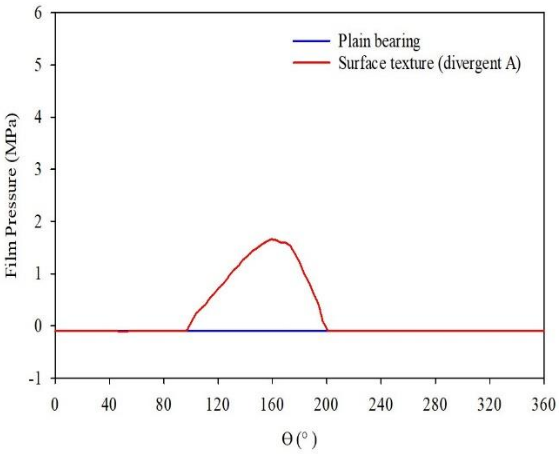

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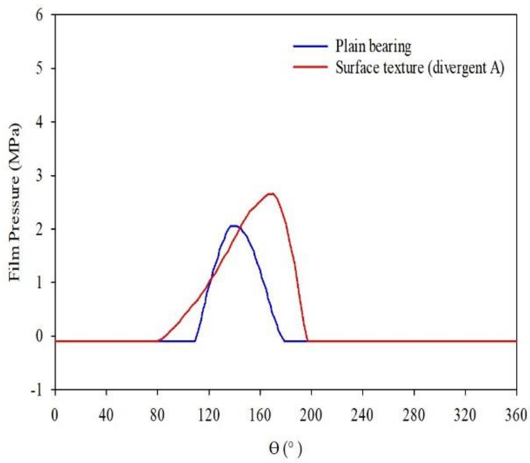
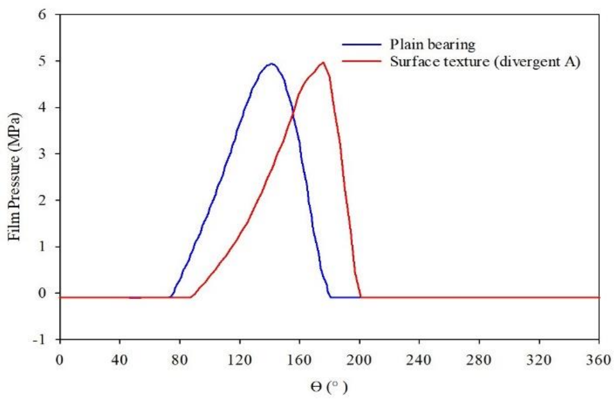


(f)



(g)

Fig. 10. Comparison of maximum film pressure for RBD palm oil between the plain bearing and textured bearing at divergent A considering conjugate heat transfer phenomena at constant rotational speed 1000rpm and different eccentricity ratio value a) 0.1 b) 0.2 c) 0.3 d) 0.4 e) 0.5, f) 0.6, and g) 0.7

4. Conclusions

RBD palm oil was tasted on the textured journal bearing application to evaluate their performance at the different conditions of textured journal bearing, considering the cavitation model and conjugate heat transfer phenomena. Later RBD palm oil was also tested at the location of surface texture at the divergent and convergent areas to study the improvement compared to plain journal bearing. The conclusions from all findings in this study were drawn below

i. In comparison to the convergent area, RBD palm oil can perform well in the divergent area. The insertion of surface texture at the proper spot will increase journal bearing performance.
ii. The suggested application of RBD palm oil is at rotational speed above 800 rpm, and the eccentricity ratio is above 0.3.
iii. RBD palm oil structure modification needs to be done to ensure these lubricants can perform as conventional mineral oil.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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