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Evaluation of Friction Co-efficient and Wear Performance of Jatropha Oil Using Standard Steel Ball on Aluminium Disc Tribometer

T. Y. Woma[1, 2], T. D. Ipilakyaa[3], A. A. Abdullahi[1], U. G. Okoro[1], A. Bello[1], J. Abutu[4], S. A. Lawal[1,5,*], A. S. Abdulrahman[6], M. A. Olutoye[7]

[1]*Department of Mechanical Engineering, Federal University of Technology Minna - Nigeria.*
[2]*Department of Physics, Federal University Wukari- Nigeria.*
[3]*Department of Mechanical Engineering, Joseph Sarwuan Tarka University Makurdi - Nigeria*
[4]*Department of Mechanical Engineering, Taraba State University Jalingo- Nigeria.*
[5]*Department of Mechanical Engineering, University of Mines and Technology, Essikado Campus, Tarkwa, Ghana.*
[6]*Department of Metallurgical and Materials Engineering, Federal University of Technology, Minna, Nigeria.*
[7]*Department of Chemical Engineering, Federal University of Technology Minna, Nigeria.*
**Corresponding author, Email address: lawalsunday@futminna.edu.ng*

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Abstract: Friction and wear cause energy dissipation and material wastage in industrial machines and therefore need to be controlled. Lubrication is one of the most effective means of reducing friction and wear. The global concern about the negative impact of using mineral oil-based lubricants is driving the growth in bio-lubricant research. The friction and wear performance of jatropha oil as compared to that of mineral oil lubricant SAE 20W50 has been evaluated using Anton Par standard steel ball on aluminium disc tribometer TRN version 6.1.19. The friction coefficient of the steel upon aluminium tribo-pair under dry (no lubrication) conditions was 0.420 while the wear rate was 0.01513 $mm^3N\text{-}1m^{-1}$. The mineral oil-based lubricant SAE 20W50 reduced the friction coefficient to 0.115 corresponding to 72.6 % reduction and the wear rate to 0.0067 mm3N-1m-1 corresponding to 55.7 % reduction. The jatropha oil reduced friction coefficient by 96.7 % (friction coefficient of 0.014) and the wear by 58.9 % (0.0062 mm3N-1m-1). From the results of this research, it is obvious that the jatropha oil is a very effective lubricant that is superior to mineral oil based lubricant SAE 20W50 in friction and wear reduction, and therefore is recommended as an environmentally-friendly and sustainable alternative to mineral oil-based lubricant SAE 20W50.

1. Introduction

Machines are used in virtually all industries. These machines have to move contacting parts. When mechanical components that are in relative motion come in contact, friction is generated. Friction causes energy dissipation in mechanical devices leading to lower efficiency. It is estimated that one-third of the world's energy resources in present use are needed to overcome friction in one form or the other (Bhushan, 2013a). Friction is also the major cause of wear in mechanical devices. Wear is the continual removal of material from the surface in sliding, rotating or rolling contact against a counter surface. Wear is the main cause of material wastage and loss of mechanical performance therefore; any reduction in wear can give rise to considerable savings (Stachowiak and

Batchelor, 2000). Considerable savings can be made through improved friction control and lubrication is an effective means of controlling wear and reducing friction (Bhushan, 2013b). Lubrication is the process or technique of using a lubricant to reduce friction and/or wear in a contact between two surfaces. Thin low shear strength layers of gas, liquid and solid are interposed between two surfaces in order to improve the smoothness of movement of one surface over another and to prevent damage. Menezes *et al.*, (2013) defined lubricant as substance introduced between two moving surfaces to reduce friction and minimize wear, distribute heat, remove contaminants and improve efficiency.

There are over ten American Society for Testing and Materials (ASTM) standards for evaluating wear. The selection of which laboratory test method to adopt has always been a challenge because wear tests are not designed to replicate field working conditions (Jimbert *et al*; 2015). The first comparison between wear tests was made by A. W. Ruff (Ruff, 1989). Where block on ring, crossed cylinder on cylinder and pin on disk tests were compared. It was concluded that the laboratory tests are not sufficiently well controlled in terms of certain critical factors that determine wear rates. Laboratory tests can provide a good measure of the relative wear behaviour of a material, only if the laboratory and field wear tests exhibit similar wear mechanisms (Sare and Constantine, 1997; Ferreiro *et al.*, 2010 and Tylczak *et al.*, 1999). In a wear evaluation research involving the comparison of pin-on-disk (POD) and ball-on-disk (BOD) tests for cryogenic-treated metal shears, it was discovered that the BOD was a better method (Jimbert *et al.*, 2015). In the present research, the ball on disc (BOD) method was used to evaluate the performance of jatropha oil and mineral oil-based lubricant SAE 20W50.

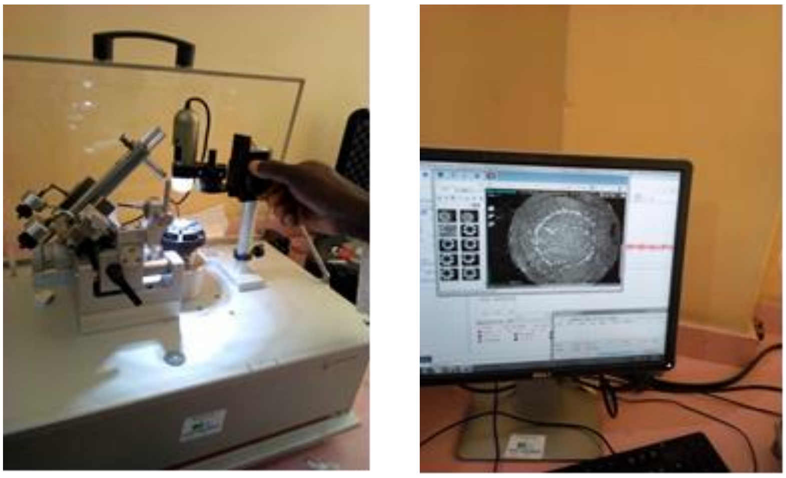
The base oil used for the formulation of most lubricants is the environmentally hostile mineral (petroleum) oil (Bartz, 2006, Ajithkumar, 2009, Woma *et al.*, 2021). The fluctuation in petroleum oil prices and the depleting global mineral oil reserves has given rise to research into the development of more sustainable base stocks for lubricant production. Besides, the negative impact of mineral oil-based lubricants on the soil, aquatic life, plants and the health of operators is another driver for biolubricant research (Woma *et al.*, 2019a). Currently, vegetable oils are considered to be alternatives to mineral oils for lubricant base oils due to certain inherent technical properties and their ability to be biodegradable (Garba *et al.*, 2013, Syaima *et al.*, 2014, Menkiti *et al.*, 2015, Kania *et al.*, 2015, Kania *et al.*, 2017, Onuh *et al.*, 2017 and Woma *et al.*, 2023). Compared to mineral oils, vegetable oils in general possess high flash point, high viscosity index, high lubricity, high biodegradability and low evaporative loss (Erhan and Asadauskas, 2000; Ratoi *et al.*, 2000, Adhvaryu and Erhan, 2002; Mercurio, *et al.*, 2004, Awoyale *et al.*, 2011, Woma *et al.*, 2019a, and Abubakar *et al.*, 2020,). Jatropha oil, a non-edible vegetable oil produced from the seeds of jatropha curcas seed plant is one of the largely investigated oils for industrial and automotive lubrication (Silva *et al.*, 2013, Mamuda *et al.*, 2016, Arbian and Salimon, 2010). The bio-lubricant produced from Jatropha curcas oil have a more preferable cooling characteristics than that from palm oil, better viscosity than that from castor oil and higher oxidative stability and lower acidity than that from soybean oil (Arbian and Salimon, 2010). The world production of jatropha plant is around 1.5Mt. Africa, including Nigeria, has a contribution of around 1.08Mt. Jatropha plant is very productive in most parts within Nigeria. The yield of jatropha curcas seed in Nigeria is rated at between 9901,700 kg/ha (Mamuda *et al.*, 2016), and virtually every part of the country is suitable for jatropha plantation. Woma *et al.*, (2019b) made detail analysis of the physicochemical, thermo-oxidative stability, corrosion inhibition and rheological properties of jatropha oil produced in Nigeria.

Jatropha oil in its crude form has several limitations and several researches are being carried out to overcome these challenges (Erhan and Asadauskas, 2000; Adhvaryu and Erhan, 2002; Mercurio, *et al*., 2004; Musa *et al*., 2016). Most of the research being carried out on the tribological properties of jatropha oil is done using the four-ball tribometer, which is steel upon steel tribo-pair. Four ball tribometer is expensive, not readily available locally and consumes a lot of materials and time however; in this paper steel upon aluminium tribo-pair were used. This research focuses on the friction and wear performance of jatropha oil. The friction and wear of steel and aluminium was measured in dry (no lubricant) condition, and then the performance of jatropha oil as a lubricant was evaluated and compared with the performance of a commercially available mineral oil lubricant SAE 20W50. This present study will increase the knowledge available on the development of vegetable oil-based lubricants to replace the environmentally damaging mineral oil-based lubricants currently being used in transport, agricultural and metalworking industries.

2. Materials and methods

2.1 Materials and Equipment

The major materials used in this research were cold-pressed and mechanically extracted Jatropha oil sourced from Agrienergy Kano, Nigeria, and a mineral oil-based multigrade commercially available lubricant SAE 20/W50 obtained from Amasco Kano, Nigeria that was used as a control sample. The Anton Paar standard tribometer TRN version 6.1.19 shown in **Figure 1** was used for the tribological evaluation of the oil and lubricant (SAE 20W50). The TRN model standard tribometer is an Austrian design which can be used as a pin-on-disc or ball-on-disc tribometer and has an electronic microscope fitted for wear measurements and has several sensors connected to a computer for data acquisition and processing. The TRN model standard tribometer comes with standard test balls that are either 10 mm or 6 mm in diameter. The 6mm diameter steel (100 CR6) ball was selected to minimize material wastage. Circular 10 mm diameter aluminium (SAE 332) disc were also used. The disc has tensile strength of 248 MPa, yield strength of 193 MPa and 1% elongation at 240 C. The composition of the circular disc is shown in **Table 1**. A steel ball and an aluminium disc were selected to replicate the type of service materials in the industries where the lubricants are used.



(a) (b)

Figure 1. The Anton Paar standard Tribometer TRN model (a) tribometer (b) computer screen showing image of disc being measured for wear.

Table 1. Chemical Composition of the Aluminium circular disc.

Element	Si	Cu	Mg	Al
% composition	9.5	3.0	1.0	86.5

2.2 Methods

The aluminium disc was mounted on the rotating plate holder of the tribometer as shown in **Figure 2** and the tribo test parameters shown in **Table 2** were entered into the system. The parameters are the manufacturer's recommended parameters for the 6mm steel (100 CR6) ball selected. Then the steel ball was inserted into the ball holder, The tribometer was powered on for data acquisition for the dry (no lubricant) test condition. At the end of the test, the aluminium disc and steel ball were unmounted. Then new aluminium discs and steel balls were mounted and 2 mls of the jatropha oil was added on to the disc and ball contacting surface and the tribometer was turned on for data acquisition. The same procedure was repeated using the commercially available mineral oil-based lubricant SAE 20W50 as a lubricant. At the end of each run, the acquired data was saved for further processing before the next sample was mounted for subsequent testing. The tribometer and the tests carried out complied with the ASTM G133 standard (ASTM G133, 2010).

3. Results and Discussion

3.1 Friction and Wear of Steel upon Aluminium Tribo-pair under Dry Condition

The friction – time graph of the steel upon aluminium tribo-pair with no lubricant is shown in **Figure 3.** The coefficient of friction for the aluminium-steel tribo-pair was 0.420, the minimum coefficient of friction during the period of the test was 0.136 while the maximum was 0.603. The coefficient of friction was erratic at the start of the test and only stabilised after 450 seconds of running the test.

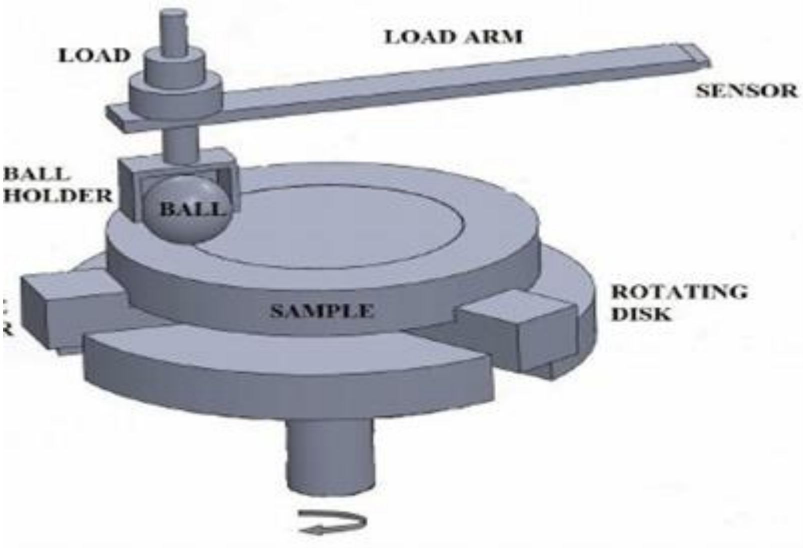


Figure 2. Schematic diagram of the ball on disc tribometer

Table 2. Tribotester parameter for tribological evaluation

S/N	Parameter	Unit	Value
1	Dimension of ball	mm	6.0
2	Diameter of disc	mm	20.0
3	Test radius	mm	5.0
4	Linear speed	cm/s	10.0

5	Normal load	N	8.0
6	Run time	s	1500.0
7	Linear distance	m	150
8	Acquisition rate	Hz	10

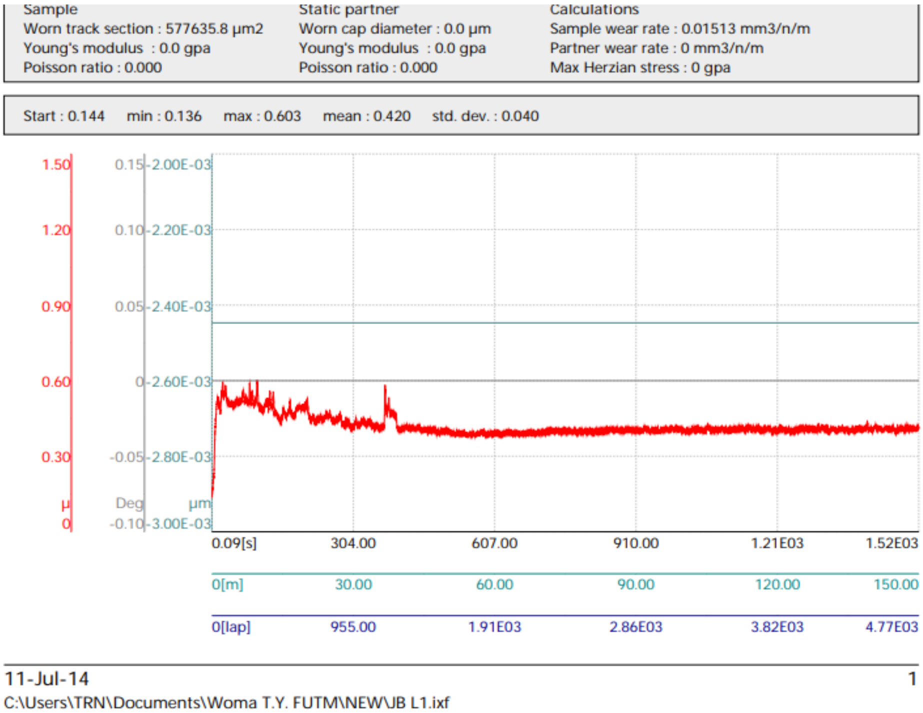


Figure 3. Friction-time graph of steel upon aluminium under (no lubrication) dry condition

The high coefficient of friction recorded for the dry (no lubricant) condition of the steel on aluminium is consistent with rhe findings of other researchers and shows that it is possible to do friction stir welding (FSW) of the two metals (Meyghani and Awang, 2022; Meyghani and Wu,2020; and Meyghani, 2021). The aluminium-steel tribo-pair had a wear rate of 0.01513 $mm^3N^{-1}m^{-1}$. This wear rate is very high therefore it is necessary to lubricate any machine part that has these two materials contacting each other to avoid material waste and save cost that will arise from frequent replacement of worn-out machine parts. Interestingly, it shows that the steel can be used as a cutting tool for machining this aluminium material. For machining, lubrication would still be necessary to be able to get good surface finish.

3.2 Friction and Wear of Steel upon Aluminium Tribo-pair Lubricated with Jatropha oil

The friction–time graph of the steel upon aluminium tribo-pair lubricated with jatropha oil is shown in **Figure 4.** The coefficient of friction for the aluminium-steel tribo-pair lubricated with jatropha oil was 0.014, the minimum coefficient of friction during the period of the test was 0.008 while the maximum was 0.006. The coefficient of friction at the start of the test was high and reduced sharply and eventually stabilised after 305 seconds. The frictional force followed the same pattern. The aluminium-steel tribo-pair lubricated with jatropha oil had a wear rate of 0.006217 $mm^3N^{-1}m^{-1}$

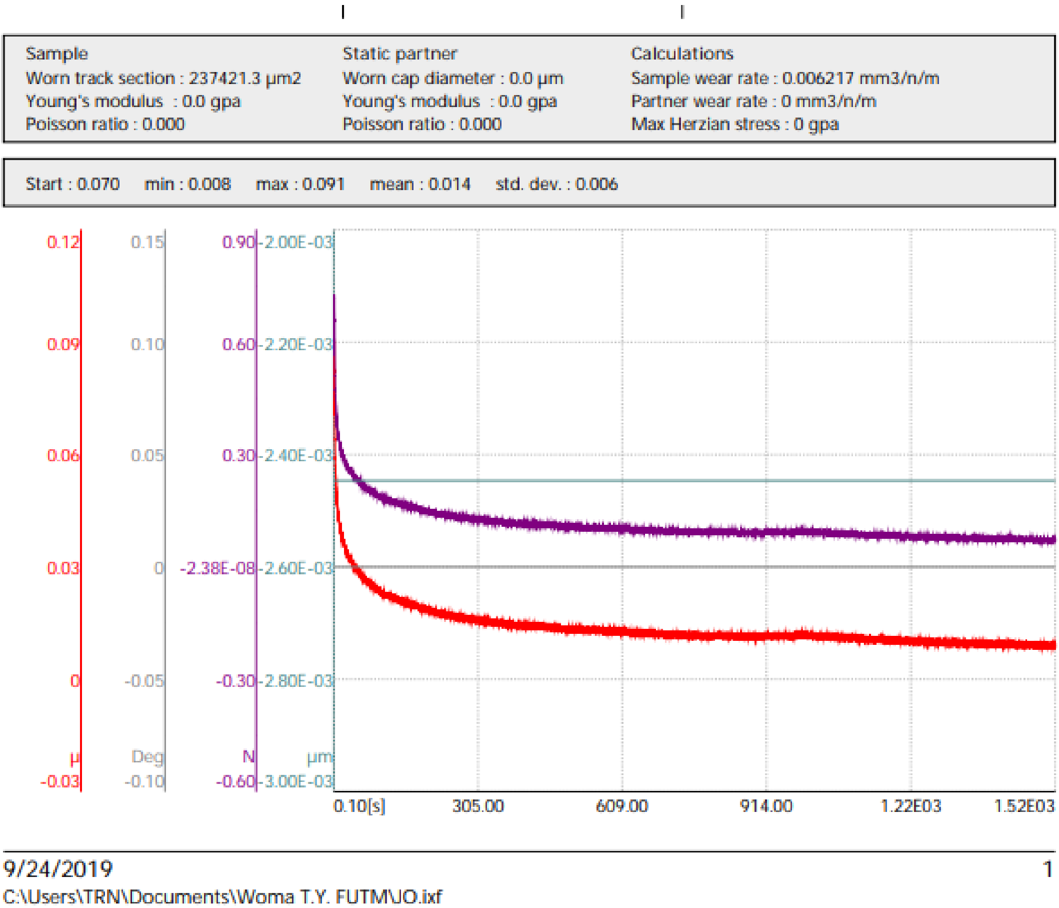


Figure 4. Friction-time graph of steel upon aluminium tribo-pair lubricated with jatropha oil

3.3 Friction and Wear of Steel upon Aluminium Tribo-pair Lubricated with Mineral Oil Lubricant SAE 20W50

The friction – time graph of the steel upon aluminium tribo-pair lubricated with mineral oil-based lubricant SAE 20W50 is shown in **Figure 5.** The coefficient of friction for the aluminium-steel tribo-pair lubricated with SAE 20W50 was 0.115, the minimum coefficient of friction during the period of the test was 0.004 while the maximum was 0.139. The coefficient of friction stabilised in less than 1 second, therefore the coefficient of friction was nearly constant all through the test period. The frictional force followed the same pattern like the coefficient of friction. The aluminium-steel tribo-pair lubricated with SAE 20W50 had a wear rate of 0.0067 $mm^3N^{-1}m^{-1}$

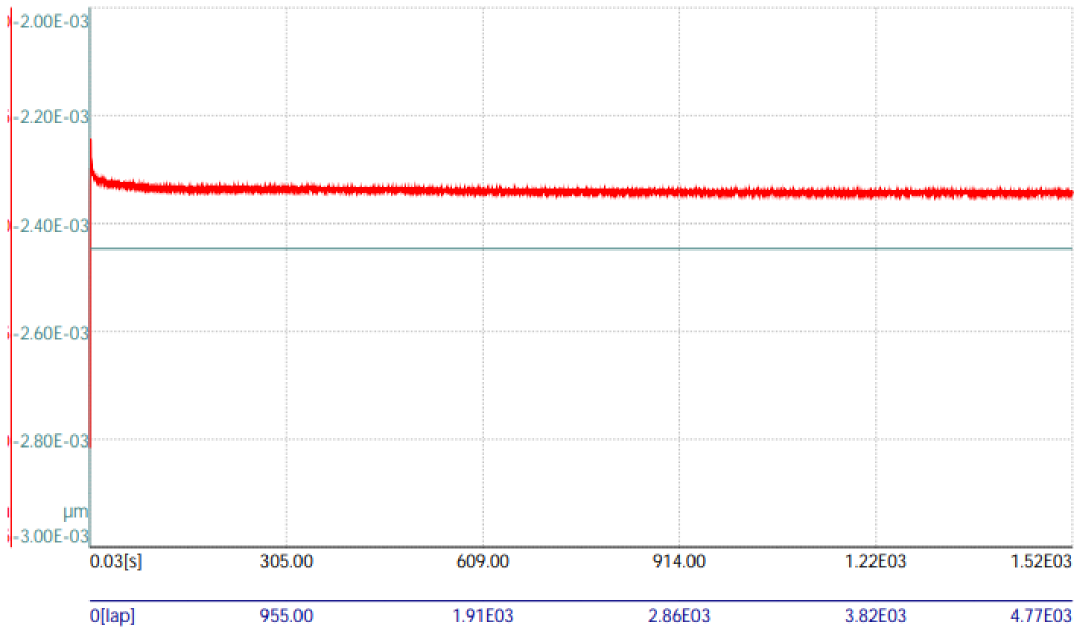


Figure 5. Friction-time graph of steel upon aluminium lubricated with mineral oil SAE 20W50

3.4 Friction Performance of Jatropha oil and Mineral oil Lubricant (SAE 20W50)

The friction reduction performance of the jatropha oil and mineral-based oil lubricant SAE 20W50 is shown in **Figure 6.** Both the jatropha oil and SAE 20W50 succeeded in reducing the coefficient of friction of the tribo-pair. The jatropha oil reduced the friction of the tribo-pair by 96.7 % while SAE 20W50 reduced the friction of the tribo-pair by 72.6 %.

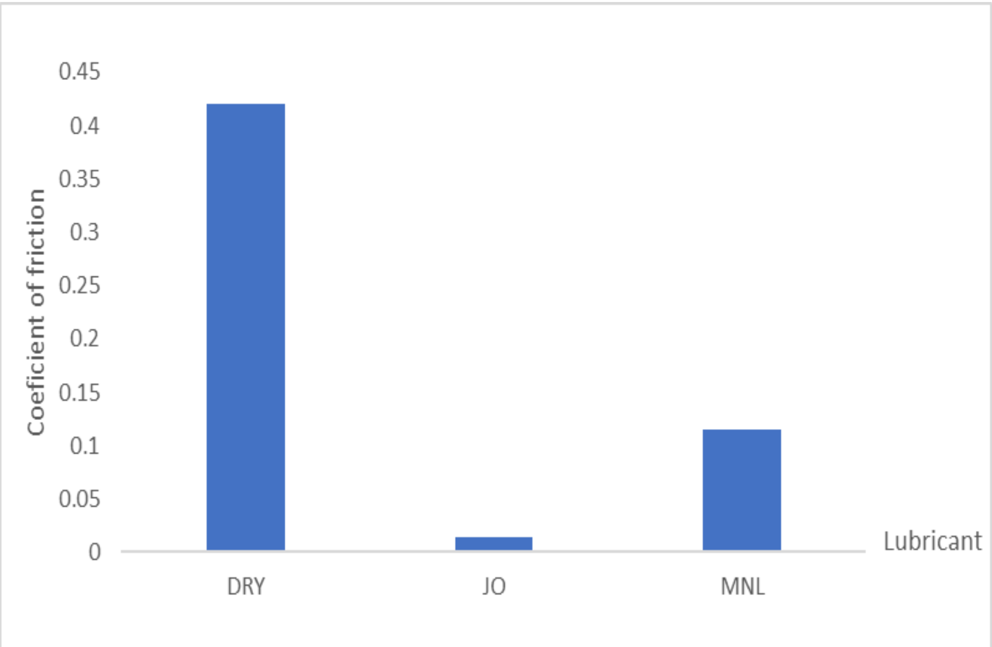


Figure 6. Steel upon aluminium tribo-pair coefficient of friction under dry condition, lubricated with jatropha oil and lubricated with mineral oil lubricant (SAE 20W50)

The jatropha oil had lower coefficient of friction (0.014) compared to the commercial mineral oil-based lubricant which had coefficient of friction of 0.115. This means that the jatropha oil had better friction reduction ability than SAE 20/W50. Thus, a machine using jatropha oil as lubricant will have less energy loss due to friction compared to the machine using SAE 20/W50.Thus, the fuel consumption of a machine lubricated with jatropha oil will be lower than that of a machine lubricated with SAE 20/W50. This result is in agreement with the findings of earlier researchers (Ratoi *et al*., 2000., Weijiu *et al*., 2003., Shahabuddin *et al*., 2013a; Shahabuddin *et al*., 2013b., Golshokouh *et al*., 2014 and Binfa *et al*., 2015). The jatropha oil performed better than the mineral oil based lubricant in friction due to its ester functionality. The polar heads of the fatty acid chains of the jatropha oil adsorbed to the metal surfaces by a chemical process that allowed a monolayer film formation; while the non-polar end of the fatty acids (hydrocarbon chains) stocked away almost perpendicularly from the metal surface as shown in **Figure 7**. This ester functionality (property) of vegetable oils is called "lubricity" (Ratoi *et al*., 2000). The fatty acid single bond (-CH2-) chain of the jatropha oil offered a sliding surface that prevented the two metal surfaces from making direct contact with each other. Additionally, the fatty acids in the jatropha oil reacted with the metals to form metallic salts that absorbed to the metal surfaces in contact to form a tribo-film. The metallic salt tribo-film had low shear which further reduced the friction. Adhvaryu and Erhan (2002), gave detail explanation of the chemical reaction taking place between vegetable oil and metals at the contact surface.

The coefficient of friction obtained while using jatropha oil as lubricant is lower than the result reported by Mushtaq and Hanief (2021), this is because of the difference in materials used to carry out the tests and the slight change in methods used. While this research used steel ball on aluminium disc, Mushtaq and Hanief (2021) used steel pin on steel disc.

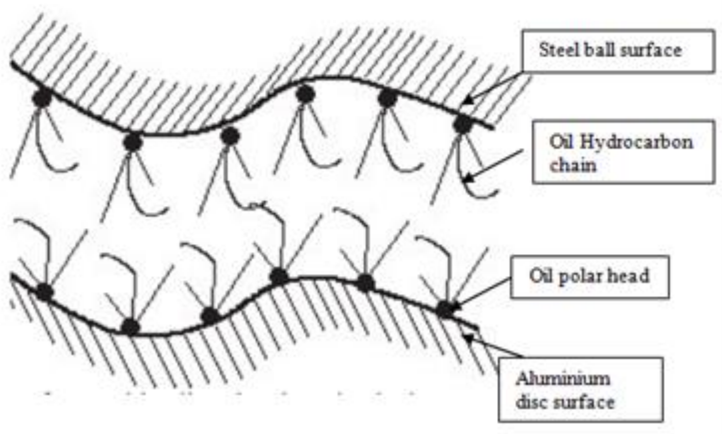


Figure 7. Schematic representation of monolayer of jatropha oil molecules adsorbed to aluminium and steel surfaces modified after (Ratoi *et al*., 2000)

3.5 Wear Performance of Jatropha oil and Mineral oil Lubricant (SAE 20W50)

The wear reduction performance of the jatropha oil and mineral based oil lubricant SAE 20W50 is shown in **Figure 8**. Both the jatropha oil and SAE 20W50 succeeded in reducing the wear rate of the tribo-pair. The jatropha oil reduced the wear rate of the tribo-pair by 58.9 % while SAE 20W50 reduced the friction of the tribo-pair by 55.7 %.

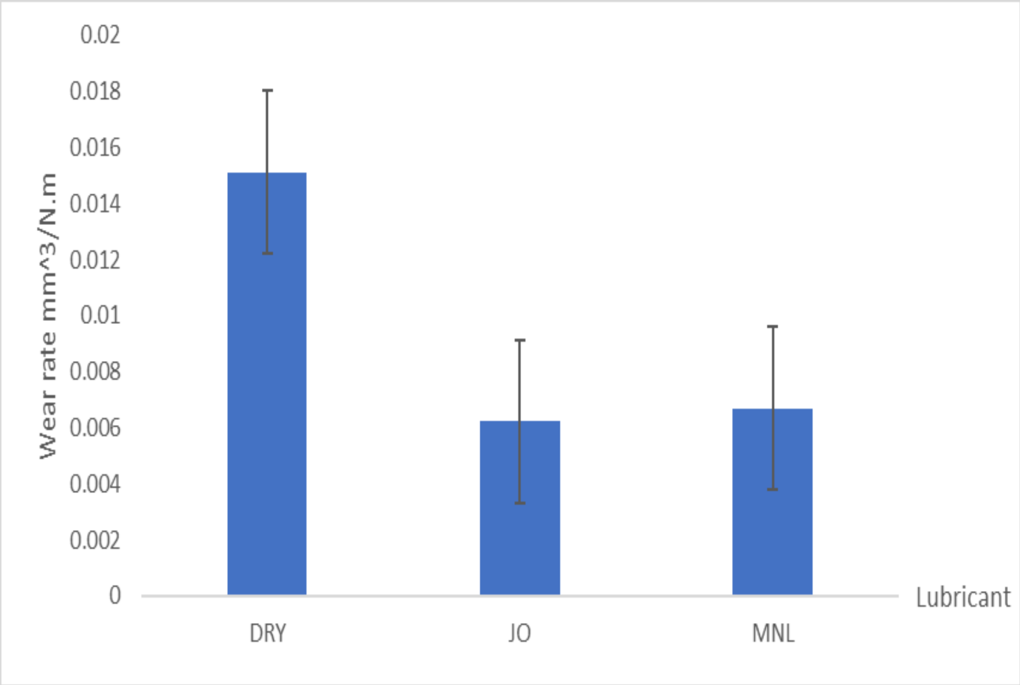


Figure 8. Wear reduction performance of jatropha oil and mineral oil lubricant (SAE 20W50)

The jatropha oil slightly exceeded SAE 20/W50 in wear protection performance. This result is similar to the findings of Asadauskas *et al*., (1996) and Stojilkovic and Kolb (2016). The jatropha oil performed better in wear protection than the SAE 20/W50 lubricant contrary to the findings of most researchers (Ajithkumar, 2009, Syahrullail *et al*., 2013 and Shahabuddin *et al*., 2013b) that vegetable oils performed less than commercial mineral oil base lubricants. The lower performance in wear protection of the SAE 20/W50 compared to the jatropha oil indicates that the additives in the SAE 20/W50 are counter- productive as they compete with each other for the surface of the metals. It is concluded that jatropha oil reduces the wear rate of steel upon aluminium components in rotating rubbing contacts and has better tribological properties than SAE 20/50.

Conclusion

The friction and wear performance of jatropha oil and commercial mineral oil-based lubricant SAE 20W50 have been evaluated successfully for a steel upon aluminium tribo-pair. Based on the obtained, the following conclusion can be drawn:

i. The friction between of a steel ball an aluminium disc under dry (no lubricant) condition is very high therefore; steel can be used as a cutting tool for machining aluminium. Both the jatropha oil and mineral oil-based lubricant SAE 20W50 succeeded in reducing the friction and wear of steel upon aluminium tribo-pair.

ii. The jatropha oil performed better than mineral oil-based lubricant SAE 20W50 in reducing the friction and wear of the steel upon aluminium tribo-pair. Therefore, Jatropha oil is an environmentally friendly and sustainable raw material for lubricant development and has the potential to replace mineral oil-based lubricants.

iii. In the future, the thermo-oxidative stability of jatropha oil should be evaluated and enhanced to increase the shelf life of lubricants developed from the oil, also, the use of additives to improve the overall tribological performance of jatropha oil can be considered.

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