# The Evaluation of Molybdenum Disulphide ($MoS_2$) as an Additive in Vegetable Oils

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**ABSTRACT** This paper explores the use of Molybdenum disulphide ($MoS_2$) as potential additive be added to the vegetable oils. The purpose of adding $MoS_2$ into the vegetable oil is to enhance the lubricant properties in terms of providing lower coefficient of friction and wear. This study aims to measure the coefficient of friction at different loads with different concentration of $MoS_2$ between the coconut oil, castor oil and Empty Fruit Bunch Bio-Oil (EFB Bio-oil). The wear scars are also observed at the optimum concentration of each vegetable oils based on the weight loss on the ball bearing after the friction test. The test was conducted by using the four-ball test machine at 75°C under constant speed of 600 RPM for 60 minutes at four different normal loads 100N, 200N, 300N and 400N. The addition of $MoS_2$ of 1.5, 3.0, 4.5 and 6.0wt% concentration in coconut oil, castor oil and EFB bio-oil is able to improve the performance of vegetable oil in reducing the coefficient of friction and wear rather than by using pure vegetable oils with 0wt% of $MoS_2$ as increase in load. EFB bio-oils shows that increase in load at 200N the sliding time starts to reduce, results in increase the coefficient of friction at the optimum concentration of 1.5wt% of $MoS_2$. However, coconut oil has ability to operate for 60 minutes at optimum concentrations of 4.5wt% of $MoS_2$. Due to the limitation of castor oil properties and EFB bio-oil, addition of $MoS_2$ was able to provide lubricant film at a short sliding time as the load was increased. Hence, coconut oil shows better tribological performance and sliding time as increase in load at optimum concentrations of 4.5wt% of $MoS_2$ compared to castor oil and EFB bio-oil.

**KEYWORDS:** Molybdenum Disulphide; Coconut Oil; Castor Oil; Empty Fruit Bunch oil, Four-Ball Tester
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## INTRODUCTION

Environmentally friendly lubricants can be produced from vegetable oils and mainly used in industrial application. Vegetable oils are renewable resources and environmentally friendly lubricants. Vegetable oil-based lubricants have high lubricity, low volatility, high biodegradability and low toxicity which makes it a potential alternative to mineral oil (Syahrullail *et al.*, 2013). An attempt to improve the lubricant formulation was conducted due to the physiochemical properties' limitation of vegetable oils. Without the presence of additives, vegetable oils do not act as anti-wear and friction. This is because vegetable oil has low coefficient of friction and poor thermal and oxidation stability.

Molybdenum disulphide ($MoS_2$) has been used as a solid lubricant or liquid additives in most of the common industrial formulations that protect the equipment from wear and seizure under high contact loads, low speeds, and high temperature (Bowden *et al.*, 2001). $MoS_2$ possess a low coefficient of friction as the lamellar structure of $MoS_2$ imparts flexible layers that is slide to each other repeatedly without results in any damage. Apart from reducing friction, presence of $MoS_2$ in lubricants are also helping to reduce the wear and increase the scuffing load capacity and the extreme pressure property of lubricant (Deacon & Goodman, 1958).

The major problem in using vegetable oil as an industrial lubricant is its low coefficient of friction, poor thermal and oxidation stability. Hence, modification of the vegetable oils lubricant formulation with additives has been conducted to improve the physiochemical properties of vegetable oils. It was found that $MoS_2$ as an additive in vegetable oil shows that the ability of higher friction reduction, high pour point and wear resistance. Although there was extensive research carried out on the tribological performance of $MoS_2$ as additive in vegetable oils, they were limited to a particular types of vegetable oil and at the same load on the four-ball testers. This study was conducted to determine the optimum value of $MoS_2$ used in different types of vegetable oils with the increase in load.

## BACKGROUND THEORY

The coefficient of friction and anti-wear properties of the vegetable oils were examined on a four-ball friction and wear tester. The schematic diagram of four-ball tribotester are seen in Figure 1. Among the four balls, the lower three were held in fixed position in a steel cup and the rest ball into the upper chuck was rotating one.

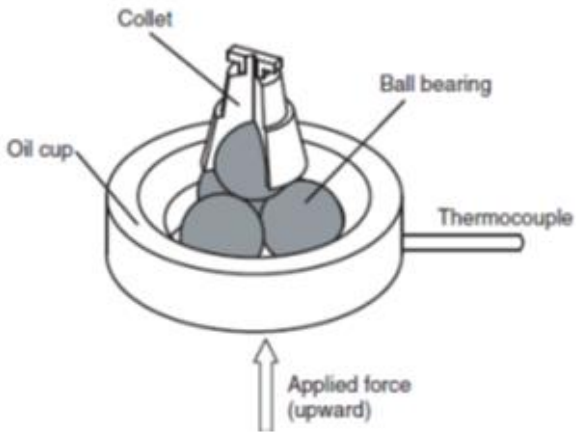


**Figure 1.** The schematic diagram of four-ball tribotester

The four-ball wear testing machine was connected to a computer in order to record the friction torque. The coefficient of friction is calculated based the resultant of forces on normal and tangential surface of the balls by the following equation.

$$\mu=(T\sqrt{6})/3Wr \quad (1)$$

$T$ is friction torque (kg mm), $W$ is applied load (kg), $r$ is the distance from the centre of the contact surfaces on the lower balls to the axis of the rotation (which is 3.67 mm).

## METHODOLOGY

*Apparatus*

Machine used to measure the tribological performance of the vegetable oils is the Ducom TR-30L Four-Ball Tribotester. The test was conduct according to ASTM D5183 standard. According to the standard the rotating speed, run time and the temperature for the test are 600rev/min, 60 minutes and 75°C respectively. The material required for the test is ball bearing with diameter of 12.7 mm. The test ball bearing used composed of chrome alloy steel which made from AISI E52100 and have a Rockwell hardness of 64-66.

*Lubrication Preparation*

Three types of vegetable oils were used as test lubricants coconut oil (pure), castor oil and EFB bio-oil. The type of coconut oil used in this study is unrefined coconut oil and the castor oil used is unrefined castor oil under the cold pressure. The EFB bio-oil was undergone a process through thermochemical processing of biomass which is known as pyrolysis or gasification. The test lubricant is made up of 50 ml of coconut oil, castor oil and EFB bio-oil added with the $MoS_2$. The lubricant tests are prepared with different concentrations of $MoS_2$ for every 50 ml which is 0, 1.5, 3.0, 4.5 and 6wt% Weight percentage of $MoS_2$ is determine by measure the weight of 50ml of vegetable oils using the electronic weighing scale. The properties of the lubricants are listed in Table 1

**Table 1.** Properties of lubricants

| | Coconut Oil | Castor Oil | EFB Bio-Oil |
|---|---|---|---|
| Viscosity at 40°C (mm²/s) | 24 | 220.6 | 2.2 |
| Acidity (pH) | 5.4 | 5.5 | 4.93 |
| Density at 20°C (kg/l) | 0.919 | 0.95 | 1.043 |
| Flash Point (°C) | 325 | 250 | 48 |
| Pour Point (°C) | 21 | -27 | <-9 |

*Experiment Settings*

The friction and wear test were conduct at various loads such as 100 N, 200N, 300 N and 400 N at constant rotating speed, temperature, and run time as in the ASTM 5183 standard. The mixture of each vegetable oils and different concentrations of $MoS_2$ is fill into the ball pot at sufficient amount (approximately 10 ml) to ensure that the three lower balls are cover with the test lubricant. The four-ball machine is connected to the computer that is integrated with instrumentation and controller to obtain the friction torque on certain sliding time (s). The friction torque is used to determine the performance of the vegetable oils with $MoS_2$ based on the coefficient of friction.

The wear analysis is based on weight loss method using electronic weighing scale OHAUS PX163/E (China) maximum 160g (0.001) and optical microscope to observe the surface of ball bearings after the friction test. Weight loss for three lower ball bearings was recorded by weighting the ball bearings before and after tests. The accuracy of weighting scale used was to three decimal places in grams. Then, the average weight of three lower ball bearings before and after test was determined to measure the weight loss. Optical microscope at different magnification was used to observe the wear scar produced on the surface of ball bearings. The images of wear scar in coconut oil, castor oil and EFB bio-oil was taken at the optimum concentrations of $MoS_2$ as increase in load.

## RESULTS AND DISCUSSION

The effect of using the different concentration of $MoS_2$ in the coconut oil, castor oil and EFB oil has been observed and discuss. The comparison on the effectiveness of the coconut oil, castor oil and EFB oil was observe and discuss based on the coefficient of friction and wear that was produced.

*Coconut Oil*

Figure 2 shows the average coefficient of friction against load for coconut oil blends with different concentrations of $MoS_2$. It can be seen that the optimum concentration of $MoS_2$ is increasing in normal load from 100N to 400N which can be due to the ability of $MoS_2$ to resist high temperature in oxidizing environment. Jayadas & Nair (2006) showed that under oxidative environment, among vegetable oils that were studied, coconut oil has lower weight gain and highest pour point that indicate of oxidative stability. Therefore, the presence of additive reduces the limitation of coconut oil which has poor temperature properties on its own. The lubricant test with concentrations of 1.5wt% and 3.0wt% of $MoS_2$ shows that increasing in normal load result in increasing the coefficient of friction. However, the concentrations of $MoS_2$ at 4.5wt% and 6.0wt% shows a sudden drop of coefficient of friction as load was increased from 300 to 400N. According to Chowdhury *et al.*, (2013), which indicated that reduction in the coefficient of friction as the applied load increase was related to the higher amount of wear debris between the rubbing surfaces. Another reason was due to the formation of low shear strength tribofilm between two moving surfaces resulting from an increase in the surface temperature of interfaces.

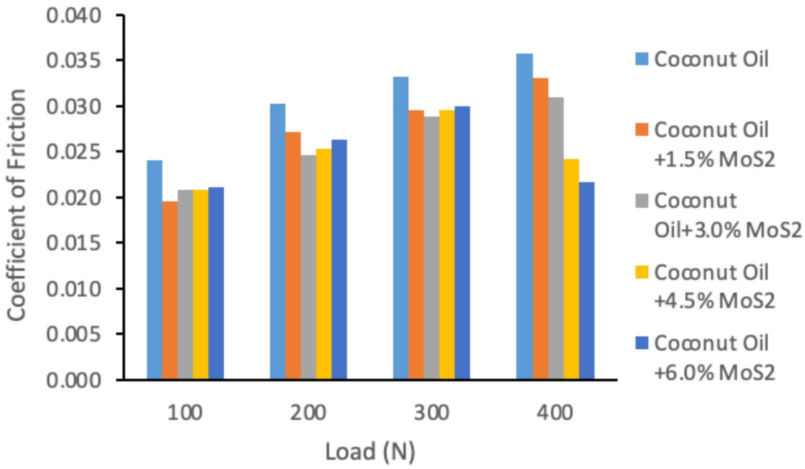


**Figure 2.** The average coefficient of friction against load for coconut oil blends with different concentration of $MoS_2$.

The optimum concentration of $MoS_2$ for coconut oil is 4.5wt%. This is clearly shown in Figure 2 where at 300N of load the average coefficient of friction is 0.0296 and at 400N the coefficient of friction is drop to 0.0242. Even though the concentration of $MoS_2$ at 6.0wt% shows the same trend as 3.0wt%, it will result in increasing the price of lubricant due to greater amount of additives is required. Hence, minimum amount of $MoS_2$ with greater lubricant performance was chosen as optimum concentration for coconut oil.

*Castor Oil*

Figure 3 shows the average coefficient of friction against load for castor oil blends with different concentrations of $MoS_2$. The graph was plotted to determine the optimum concentration required as increase in load to minimize the use of additive in castor oil. It was noticed that the coefficient of friction value increased from 0.01 to 0.02 for pure castor oil as load was increased from 100N to 400N. The mixtures of castor oil with $MoS_2$ with concentrations of 1.5, 3.0, 4.5 and 6.0wt% showed an improved tribological performance of the test lubricant, as the value of coefficient of friction was reduced compared to pure castor oil even at increasing loads. Interestingly, a different trend was at applied loads of 300N and 400N, where there was slightly increase in the coefficient of friction when the $MoS_2$ additive concentrations was at 1.5wt% and a decrease in coefficient of friction with increasing the concentration of $MoS_2$ to 3.0wt%.

It is commonly known that the polarity of vegetable oil may influence its affinity towards the contacting surface. According to Suarez *et al.* (2010), a lubricant that has high polarity of molecules will have a high affinity towards the steel surface and vice versa. It was concluded that the additives molecules and the high affinity of polar- based oil molecules might compete to each other to attach on the surface to form a protective layer. This means that when the concentration of additive is low, there will be competitive adsorption between the additives and the vegetable oil. However, as the concentration of additives was increase, the additive becomes dominant and attach to the surface to form a protective layer, therefore improving the friction-reducing performance.

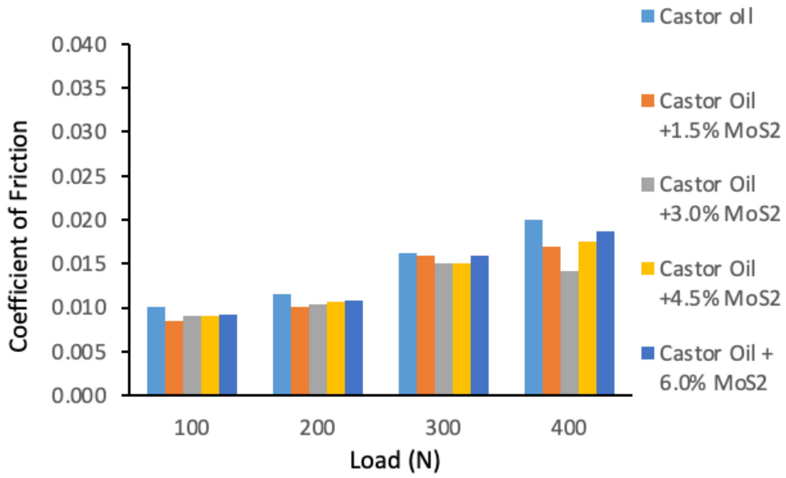


**Figure 3.** The average coefficient of friction against load for castor oil blends with different concentration of $MoS_2$.

*Empty Fruit Bunch Bio-Oil (EFB Bio-Oil)*

Figure 4 shows the average coefficient of friction against load for EFB oil blends with different concentrations of $MoS_2$. Lubricant tested with pure EFB bio-oil shows increasing in the average of coefficient of friction as increase in load. EFB bio-oil is relatively low viscosity and thus result in increase in coefficient of friction. This is described in Stribeck curve which shows the formation of thin fluid film between the two contacting surfaces (Bahari, 2017). It was noticed there was a slight reduction in coefficient of friction at 100N to 200N load. This is due to the reducing in sliding time of EFB oil as increase in load. The blending of EFB bio-oil with 1.5, 3.0, 4.5 and 6.0wt% of $MoS_2$ resulted in a general reduction in coefficient of friction from pure EFB bio-oil for all loads. For all samples there is a general increase in the coefficient of as the load was increased.

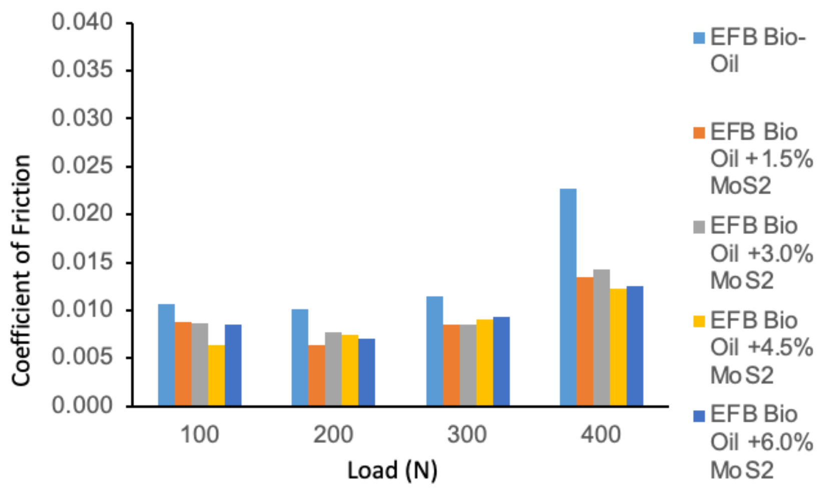


**Figure 4.** The average coefficient of friction against load for EFB Bio-Oil blends with different concentration of $MoS_2$.

There were slight differences in the average coefficient of friction for all blends. This shows that increasing the blend higher than 1.5% would not improve the performance of the blend. Hence it may be concluded that addition of 1.5% of $MoS_2$ is sufficient to reduce the coefficient of friction and increasing additive percentage would not be giving an improved lubricant performance.

*Comparison of Optimum Concentration of $MoS_2$ between Different Types of Oil.*

It was observed that the addition of $MoS_2$ as additive helps to improve the tribological performance of coconut oil, castor oil and EFB bio-oil. However, different types of oil will act differently based on the properties of the vegetable oils. It was observed that the EFB bio-oil has the lowest coefficient of friction followed by castor oil. This is due to decrease in sliding time as increase in normal load. However, the coconut oil shows the highest coefficient of friction which result in longer of sliding time up to 3600 seconds as increase in normal load. As shown in Table 1, castor oil the highest viscosity. According to Silva *et al.*, (2013), its high viscosity is due to the dominant ricinoleic acids which is around 90%. High viscosity of castor oil requires large amount of energy to move, thus it result in increasing the rubbing and friction between the contacting surfaces (Tajuddin *et al*., 2014). The efficiency of vegetable oil in reducing friction and wear is greatly influenced by its viscosity, as the viscosity determines the lubricant's film strength and efficiency in preventing friction between moving parts. EFB bio-oil has the lowest viscosity and it is not enough to keep a good oil film between the moving parts thus result in increase of friction and rapid wear on the parts. Moreover, EFB bio-oil has higher acidity value and the combination with $MoS_2$ which is an acidic additive does not show improvement in tribological performance of the EFB bio-oil. This indicates that the $MoS_2$ fail to function as anti-friction and wear agents in acidic base oils.

*Wear Scar Analysis at Optimum Concentration of $MoS_2$*

Wear analysis represents the optimum concentration of each oils with increased in load is conducted based on the weight loss of the ball bearing as shown in Figure 5. The weight of the ball bearing was measured using analytical weighting scale. It was observed that the wear is increase as increase in load. According to Farhanah (2016), an increase in the applied load lead to an increase in the real contact area between the two rubbing surfaces, therefore causing high loss of the metal and increased in wear scar on the surface of ball bearing. However, the castor oil and EFB bio-oil shows that the ball bearings experienced catastrophic welding at 400N normal load due to increase in wear on the surface of ball bearing.

The optimum coconut oil blend was 4.5wt% of $MoS_2$ with an increase of coefficient of friction from 0.021 to a high of 0.03 as the load was increased from 100N to 300N, further increase in load reduced the coefficient of friction to 0.024. The minimum wear was 0.010g and the maximum wear was 0.137g. It interesting that the coconut oil produced greater wear while the addition of $MoS_2$ had greater effectiveness as an anti-friction agent. Based on the test conducted, the sliding time for the castor oil and EFB bio-oil was reduced as the load was increased. This is due to the greater force in contact between two surfaces that leads to increase in wear produced on the surface of ball bearing.

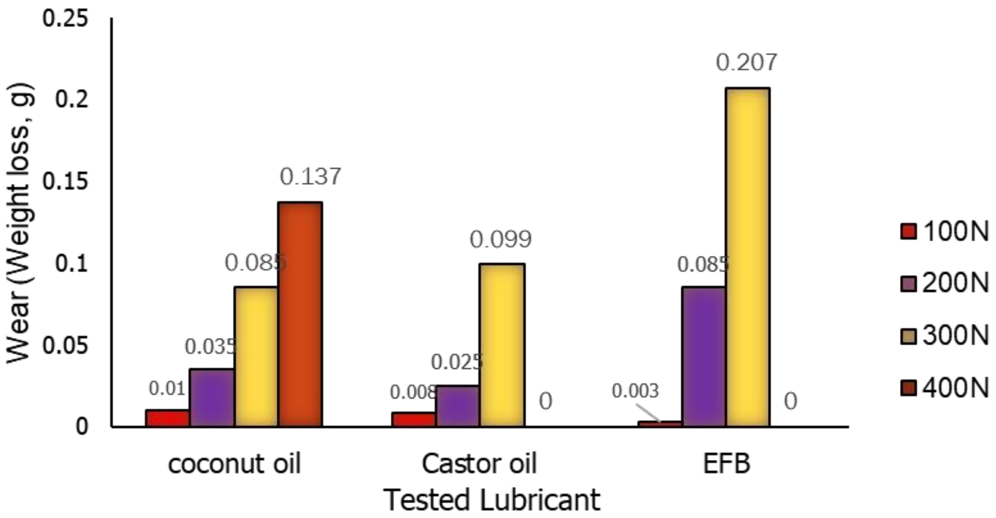


**Figure 5**. Wear reduction against load at optimum concentration of $MoS_2$.

## CONCLUSION

The experimental work presented has demonstrated the friction and wear effects of addition $MoS_2$ in vegetable oils. The addition of $MoS_2$ of 1.5%, 3.0%, 4.5% and 6.0% concentration in coconut oil, castor oil and EFB bio-oil can reduce the coefficient of friction rather than using pure vegetable oils which 0% of concentration of $MoS_2$. This work showed that the coefficient of friction was reduced with the addition of $MoS_2$ as additive blends with the vegetable oils compared to without additives when subjected to increasing loads of 100 to 400N. This is due to the prevention of metal-to-metal contact whereas, $MoS_2$ can form boundary film on sliding contact between the two-sliding surface of ball bearing. The wear analysis of each vegetable oils was measured based on the weight loss of the ball bearing. It was noticed that the formation of wear was increased as the load increased. This is due to the high contact load result in increasing the metal-to-metal contact that led to increase in wear on the surface of ball bearing. At optimum concentrations of $MoS_2$ which is 4.5% blends in coconut oil, the wear produced was increased as the normal load was increased.

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