Chapter 69
Friction and Wear Performance of Jatropha Oil Added with Molybdenum Disulphide Nanoparticles

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Abstract Nano-materials offer potential scope for an increasing numerous novel applications when engineered to deliver availably functional properties. The nano-sized additives when added to biodegradable oils improve their tribological performance and contribute to energy saving and sustainability. In the present study, the MoS_2 nanoparticles with different mass ratios were employed as lubricant additives in the base jatropha oil, and their tribological properties were evaluated using a reciprocating ball-on-disc tribometer for steel-steel contacts. The results demonstrate that the MoS_2 nanoparticles exhibit superior lubrication performance. The optimal concentration of MoS_2 nanoparticles in the base oil was found to be 0.5% for minimum friction and wear rate. Addition of load decreased friction and increased wear rate. The coefficient of friction and wear rate was reduced by 63% and 35%, respectively. The excellent lubrication properties of the MoS_2 nanoparticles are attributed to the physical synergistic lubricating actions of nano-MoS_2 during the rubbing process.

69.1 Introduction

The demand for energy is growing with time which is leading to the swift depletion of fossils [1]. The researchers are extensively searching for renewable sources in order to curtail environmental pollution and mitigate the dependence on fossils [2]. Tribology and sustainability when used together can be useful in increasing the sustainability of the environment. Sustainable tribology can save energy by reducing the losses due to friction and wear by introducing the lubricants [3]. The demand for ecofriendly lubricants is predicted to see a considerable spike in the coming years [4]. Biolubricants are the ones to replace petroleum-based lubricants due to their highly favourable lubricating properties. These properties can further be improved by

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mixing of desirable additives [5]. The lubricating properties of vegetable oils can be vehemently improved by the addition of nanoparticles [6]. Using nanolubricants can reduce the consumption of energy and maintenance costs, thereby increasing the life span of the machines and tools [7]. Jatropha oil has excellent lubricating properties as compared to mineral oils [8]. Biolubricant can be prepared by adding some proper additives to the jatropha oil which can be a good substitute to use in place of mineral oils [9, 10]. Micro-sized MoS_2 has been proved to improve the tribological properties of jatropha oil [11]. The tribological performance of jatropha oil was ameliorated by addition of graphite nanoparticles [12] and hexagonal boron nitride particles [13]. MoS_2 nanoparticles are very effective in enhancing the tribological properties of vegetable oil [14] and polyalphaolefin (PAO4) [15].

This research analyses the friction and wear characteristics of jatropha oil with and without MoS_2 nanoparticles. The nanoparticles were added with three different mass ratios and tribological testing was undertaken for steel-steel tribo-pair. The variation of friction and wear with load was also figured out.

69.2 Materials and Experimental Procedure

69.2.1 Lubricant and Sample Preparation

The jatropha oil was used as base oil whose properties are presented in Table 69.1. The nanoparticles of MoS_2 were acquired from a reliable supplier and its properties are given in Table 69.2. They were added to the base Jatropha oil in mass ratios of 0.25, 0.5, and 0.75%. The mixtures were stirred in a test tube and ultrasonicated for 4–6 h to allow uniform dispersion of particles. EN-8 steel disc and 52,100 steel balls (12.7 mm diameter) were used as a friction pair. Sandpapers of size ranging from 280 to 2000 were used in sequence to give proper finish to the surface of the disc. The average roughness of the surface was 0.3231 μm which was calculated using surface profilometer by taking multiple readings at different points.

Table 69.1 Properties of jatropha oil

S. No.	Property	Jatropha oil
1	Kinematic viscosity @ 40 °C	48–52 Cst
	Kinematic viscosity @ 100 °C	10 Cst
2	Viscosity index	182
3	Density	0.92×10^3 kg/m^3
4	Pour point	6 °C
5	Flash point	180 °C

Table 69.2 Properties of MoS_2 nanoparticles

S. No.	Property	MoS_2
1	Appearance	Black powder
2	Purity	99.9%
3	Size	80–100 nm
4	Density	5.05 g/cm^3
5	Melting point	1182 °C
6	Molecular weight	160 g/mole

69.2.2 Friction and Wear Tests

The tests were undertaken on a reciprocating tribometer. EN-8 disc was held fixed in a clamp and the steel ball was slided against it. Different lubricant mixtures of base jatropha oil with and without additives were used to lubricate the friction pair. The tests were conducted for 30 min each, at ambient temperature and loads of 15, 30, 45, and 60 N. The stroke and speed of each test were 2 mm and 500 Rpm, respectively. The tribo-pair was washed by acetone before and after each test to remove the unwanted dirt and contaminants. The coefficient of friction was calculated with the help of a software system installed in computer attached to the tribometer. The wear volume (mm^3) of each scar was calculated with the help of 3D profilometer and Eq. (69.1) was used to calculate the specific wear rate (mm^3/Nm).

$$\text{Specific Wear Rate} = \text{Wear Volume/Load} \times \text{Distance} \tag{69.1}$$

69.3 Results and Discussion

69.3.1 Analysis of Friction

Figure 69.1 displays the variation of average coefficient of friction (COF) at different loads and MoS_2 mass ratios. The COF between the friction pair was high when lubricated with base jatropha oil. As the addition of nanoparticles was initiated, the COF values began to drop as shown in Fig. 69.1. The nanoparticles intrude between the surfaces of friction pair, cover the asperities and limit their direct contact. The nanoparticles react with the base oil and the ambient atmosphere to form a protective layer on the surface. This layer acts as a shield and prevents the direct rubbing between the surfaces thereby decreasing the COF. [16, 17].

As shown in Fig. 69.1, the COF increased with the increments in load from 15 to 60 N when it was lubricated with pure base oil. This increment can be due to more rigid engagement between asperities at higher loads in absence of protective tribo-layer. But when base oil mixed with nanoparticles was used as lubricant, the

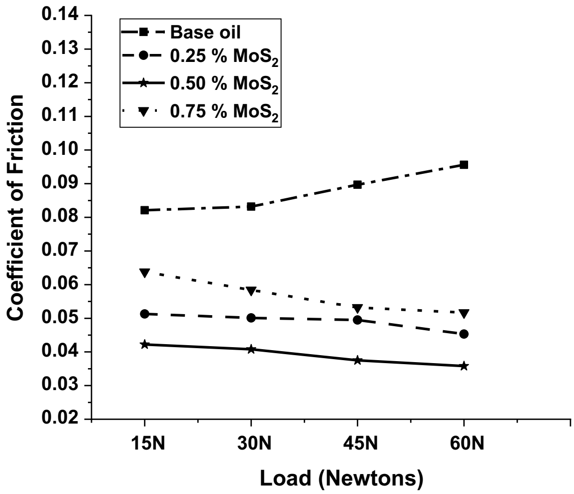

Fig. 69.1 Average coefficient of friction values recorded at various testing conditions

COF reduced with increase in load. However, the decrement due to increasing load was marginal as compared to the decrement caused by addition of nanoparticles. The reason for this decrease in COF with increasing load may be that the nanoparticles are better dispersed on the surface at higher loads. Also, there is more heat dissipation at higher loads which makes the reaction of nanoparticles with base oil and surroundings fast and expedites the development of the tribo-layer [18, 19]. Generally, the COF was reduced by up to 63% as compared to base oil. The highest COF (0.0956) was recorded for base oil as lubricant at 60 N, while as the lowest COF (0.0358) was recorded at 0.5% concentration of nanoparticles at 60 N. As the weight ratio of nanoparticles was increased to 0.75%, the COF began to rise marginally due to superfluous concentration of nanoparticles. Hence, 0.5% weight ratio was the optimum concentration of nanoparticles in the base jatropha oil for minimum COF.

69.3.2 Analysis of Wear

The wear volume (mm^3) was calculated by using 3D profilometer by analysing all the wear scars. The specific wear rates as calculated from the Eq. (69.1) are plotted in Fig. 69.2. It was observed that the specific wear rates for scars lubricated with pure base oil were high and started decreasing with the addition of nanoparticles. The specific wear rates at 0.5% nanoparticles addition were found to be the lowest, hence, resembling the results of friction analysis. With increasing load, the specific wear rate exhibited a marginal increment is shown in Fig. 69.2. This can be attributed to the reduction in inter-molecular bonding between lubricant particles due to higher pressures [20]. The highest wear rate (15.566×10^{-6} mm^3/N m) was recorded at 60 N when the scar was lubricated with base oil without nanoparticles. While as the

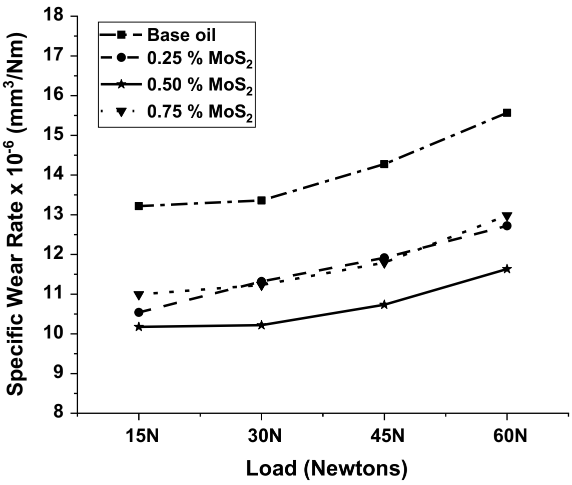

Fig. 69.2 Specific wear rate values recorded at various testing conditions

lowest wear rate (10.176×10^{-6} mm^3/N m) was observed at 0.5% of nanoparticles concentration at 15 N. The wear rate was reduced by up to 35% due to addition of nanoparticles as compared to base oil. The results received in the wear analysis were observed to be in close agreement with the results from frictional analysis.

69.3.3 Wear Scar Analysis

Figure 69.3a, b displays optical microscopy image of wear scars on steel disc and steel ball, respectively, when lubricated with base jatropha oil. A number of deep grooves and furrows can be seen in Fig. 69.3a which clearly depict the high roughness of the surface. The sliding direction can be easily visualised and both the adhesive

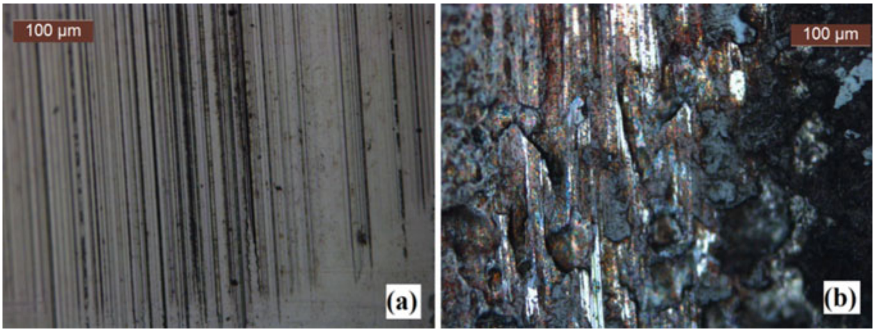

Fig. 69.3 Optical images of the wear scars of tribo-pair when lubricated with base jatropha oil: **a** steel disc, **b** 52,100 steel ball

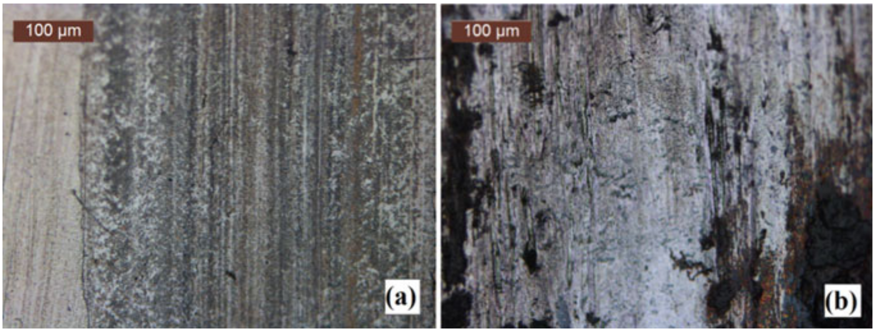

Fig. 69.4 Optical images of the wear scars of tribo-pair when lubricated with base jatropha oil + 0.5% MoS_2: **a** steel disc, **b** 52,100 steel ball

and abrasive wear mechanisms were followed. Figure 69.3b reveals the formation of heavy pits and metal removal on the surface of steel ball during sliding in presence of base oil as lubricant. Figure 69.4a, b correspond to the wear scars on steel disc and steel ball, respectively, when lubricated with base oil + 0.5% MoS_2. As evident from Fig. 69.4a, the surface is fairly smooth with minimum damage occurred as compared to Fig. 69.3a. Some small rubbing marks are present on the surface suggesting mild abrasion. As seen from Fig. 69.4b, the heavy pits are absent and less damage has occurred as compared to Fig. 69.3b. From the wear scar analysis, it can be drawn that the addition of MoS_2 nanoparticles to jatropha oil has eminently boosted its wear reducing capabilities. These results are in complete agreement with the wear analysis.

69.4 Conclusion

Ball-on-disc reciprocating tribological tests were executed. Jatropha oil with and without MoS_2 nanoparticles were used to lubricate the steel-steel tribo-pair to analyse the friction and wear. Following conclusions were compiled.

1. MoS_2 nanoparticles were found to be very effective in curtailing both friction and wear rate. This was attributed to the formation of protective layer on the surfaces of tribo-pair thereby restricting the metal-to-metal contact.
2. The optimum weight ratio of MoS_2 nanoparticles for least friction and wear rate was observed to be 0.5%. The COF and wear rate reduced by 63% and 35%, respectively.
3. After increasing the concentration of nanoparticles to 0.75%, friction and wear rate started to increase due to their presence in exorbitant quantity.
4. The COF decreased and the specific wear rate increased with respect to increase in load.

It was concluded that jatropha oil has outstanding lubricating characteristics which can be made better by addition of MoS_2 nanoparticles. It can be a good option as lubricant to substitute for mineral oils and contribute to sustainable and less polluted environment.

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