Applied Science and Engineering Journal for Advanced Research
ISSN (Online): 2583-2468
Volume-1 Issue-6 || November 2022 || PP. 17-20 DOI: 10.54741/asejar.1.6.4

Tribological Investigation of Bitter Almond Oil Containing TiO_2 Nanoparticles as Additive

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Received: 11-10-2022	Revised: 27-10-2022	Accepted: 20-11-2022

ABSTRACT
In the recent years, the environment friendly lubricants have been using worldwide. Vegetable oils-based lubricants are the best substitute of the mineral and synthetic lubricant. In view of this present study concerns on tribological investigation of bitter almonds oil containing TiO_2 nanoparticles and Triton X-100 as surfactant. Four different volume fractions of nanoparticles (0.01, 0.02, 0.03, and 0.04) used for nano lubricant formulation and the ratio of TiO_2 nanoparticles and Triton X-100 is 2:1. The tribological investigation of formulated Bitte almond oil-based nano lubricant on Four ball tribotester using ASTM 4172B. Bitter almonds oils containing 0.02 vol. fraction nanoparticles showed minimum average wear scar diameter and coefficient of friction.

Keywords: *bitter almonds oil, four ball tester, nanoparticles, nano lubricant*

I. INTRODUCTION

A lubricant is a substance solid, liquid, or semi-solid that facilitates sliding motion between contact surfaces by reducing friction. Lubricants can be categorized into mineral oil, synthetic and bio-lubricants based on the base oil used [1]. Though Mineral oil and synthetic lubricants are cheap and have high oxidation stability, they rank very low in the biodegradability index(BI) while bio-lubricants apart from showing high viscosity index are biodegradable [2]. Mineral oils and synthetic oils as a lubricant are serious concerns to the environment. These have far been used as a lubricant, predominantly in the auto and manufacturing industry, which disturbs the ecology due to harmful hydrocarbon emissions rich in sulfur and nitrogen. The worldwide demand for lubricants rose from 37.1 million tons per year in 2003 to 38 million tons in 2014 and is expected to cross the 40 million mark by 2023 [3]. Vegetable oils derived from plants show characteristics of a bio-lubricant. Investigation shows that vegetable oils when taken as lubricant basestock shows poor oxidative stability and pour point but their properties can be improved by additives that make them suitable for industries [4]. Among additives, studies of nanoparticles like CuO, ZnDP, ZnDTP, graphenes, fullerenes, and Al_2O_3 in lubricant base stock have suggested a significant effect on the thermal properties of a lubricant. The addition of nanoparticles in neem oil, rapeseed oil, and other bio-based lubricants generally improves the friction and wear characteristics of the lubricant. As the induction of nanoparticles in lubricant base-stock enhances its tribological characteristics and thermo-physical significance, it becomes of utmost importance to explore bio-nano lubricants as an alternative to mineral oil. Ettefaghi et al. investigated the effect of MWCNT in engine oil which used the ball mill method for uniform dispersion of nano lubricant. The findings of the experiment were increments of 13.2%, 18%, and 22.7% in thermal conductivity at 0.1,0.2 and 0.5wt% concentration respectively. They concluded that viscosity, pour point, flash point didn't show appreciable at lower concentrations but they improved as the concentration increased and were better than the base oil [5]. Asrul et al. studied the tribological characteristics of CuO nanoparticles in paraffin. Their study indicated that the viscosity decrease as temperature increases from 40 deg. to 100 deg. Celsius. The lowest coefficient friction of modified CuO was at 0.3wt% concentration in sharp contrast to unmodified CuO which indicated the same at 0.1wt% concentration [6].

S. Arumgam and G. Sriram used a combination of rapeseed oil, nano CuO, and 7% diesel to study friction and wear characteristics on piston ring and cylinder liner friction pair. The optimum concentration for least friction and wear was determined as chemically modified rapeseed oil (CMRO) with 0.5wt% nano CuO. Also, the oxidative stability increased two times concerning raw rapeseed oil and its pour point further decreased [7]. Dinesh et al. performed an experiment taking mineral oil as a base oil with 0.005 wt% of MWCNT and 0.02wt% of ZnO nanoparticles. They observed that friction and wear characteristics have enhanced showing a reduction of 15 times in wear when compared to the base oil. Also, thermal conductivity, viscosity, and flash point showed an increment of 2.2%, 20.07% at 307 K, 6.612% respectively [8]. Cortes and Ortega studied the tribological characteristics of coconut oil with SiO_2 and CuO nanoparticle additives using a custom-made tribotester. They were able to reduce friction force by adding nanoparticles to the bio-lubricant. At a concentration of 1.25wt% SiO_2 and 0.5wt% of CuO, the coefficient of friction declined significantly. It was also observed that volumetric wear was reduced to a great extent by using SiO_2 and CuO as nano additives in coconut oil. Similar results were obtained when the bio lubricant was changed to sunflower oil [9]. Cortes et al. found that on varying the concentration of nanoparticles from 0.25wt% to 1.25wt%, minimum coefficient of friction was observed at 1.25wt% for SiO_2 and 0.75%wt for TiO2. As for the volumetric wear it was minimum at 1.25wt% for SiO_2 and 1.0wt% for TiO_2 [10]. Opia et al. investigated the effect of organic carbon nanotubes in rapeseed oil and compared it with mineral oil on the apparatus high-frequency reciprocating test rig. The coefficient of friction for carbon nanotubes in rapeseed oil was lower compared to a combination of mineral oil but the converse is true in the case of wear rate. It led them to conclude that rapeseed oil performed better at lower working conditions (load and frequency) [11]. Along with the friction tests dispersion of nanoparticles are also important. In his paper, Rio et al. used graphene oxide nanoparticles with ionic liquid as a dispersant in a bio lubricant. The nano dispersion was stable for four weeks and a test was conducted on the ball on disc arrangement. They concluded that mixing a bio lubricant BIOE with 1wt% IL and 0.05wt% graphene oxide decreased the coefficient of friction by 34% compared to the base oil. They also found that the surface roughness of nano lubricant was less than that of BIOE base oil [12]. Many studies in literature are related to emergence of nanoparticle as an additive in vegetable oils due to their multifunctional advantages such as corrosion resistant, anti-wear and extreme pressure properties. Extensive research has been published regarding tribological performance of chemically modified vegetable oil due to their environmental benefits and compatibility. Despite various research contributions there is a lack of implementation of optimization techniques in nano bio lubricants that is effective in reducing cost, time and money. To the best of author's knowledge there has been no experimental investigation on TiO_2 nanoparticle as an additive in bio lubricant using response surface methodology.

II. METHODOLOGY

The Pure bitter almonds oil has been purchased from local market. The titanium oxide nanoparticles have been purchased from HPLC Pvt. Ltd. The Triton X-100 was used as surfactant and purchased from Loba Chemie Pvt. Ltd. Four different volume fractions of nanoparticles (0.01, 0.02, 0.03, and 0.04) used for nano lubricant formulation and the ratio of TiO_2 nanoparticles and Triton X-100 is 2:1. The calculated amount of each additive is mixed in bitter almonds oil by using magnetic stirring for 40 minutes. After that this mixture is ultrasonic bath sonicated for 30 minutes.

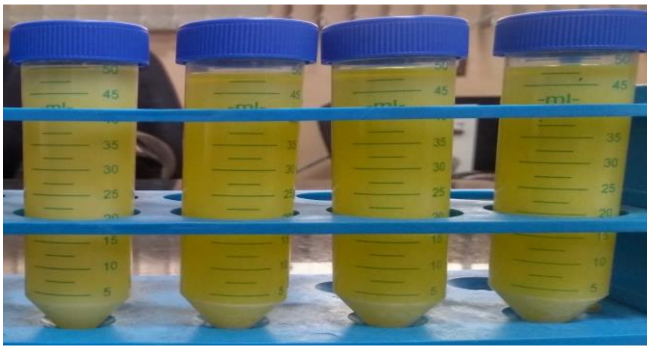

Figure 1: Bitter almond oil-based nano-lubricant (PBA1, PBA2, PBA3, PBA4 L to R)

The tribological properties of formulated bitter almond oil-based nano lubricant was investigated using four ball tribotester at ASTM 4172B. The operating conditions are Load:392N, Speed: 1200, temperature 75°C, and time 01 hour.

IIII. RESULTS AND DISCUSSION

The TiO_2 nanoparticles were characterized by using FESEM at 1,00,000 magnifications and showed in figure 2. TiO_2 nanoparticles are spherical in shape and the particles size was 10-15 nm.

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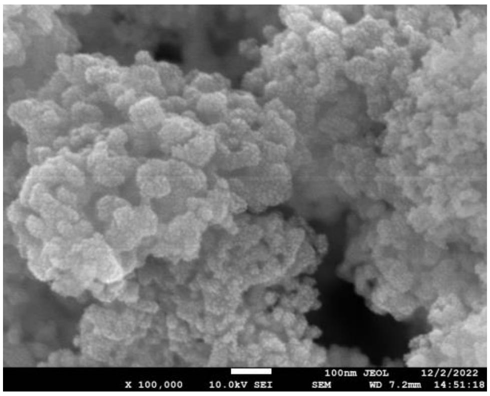

Figure 2: FESEM image of TiO_2 nanoparticles

The anti-wear properties of formulated bitter almond oil-based nano lubricant was investigated using four ball testers under ASTM 4172B. The operating condition are as 392N Load, 1200 rpm, 3600 sec. after the experimentation the wear scar diameter of balls were investigated using optical microscope. Average wear scar diameter and coefficient of friction was recorded in table 1. Bitter almond oil showed the maximum average wear scar diameter and CoF.

Table 1: Average wear scar diameter and CoF

Sr. No	Nano lubricant	Conc. (%)	AWSD (µm)	CoF (µ)
1.	PBA	-	620	0.08
2.	PBA 1	0.01	559	0.06
3.	PBA 2	0.02	519	0.05
4.	PBA 3	0.03	610	0.07
5.	PBA 4	0.04	600	0.06

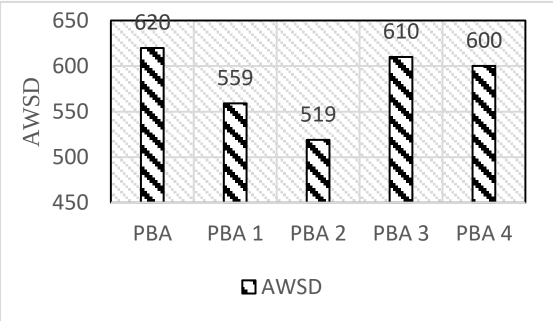

Figure 3: AWSD of formulated nano lubricant

By the addition of TiO_2 nanoparticles in bitter almond oil the antiwear properties are increased.

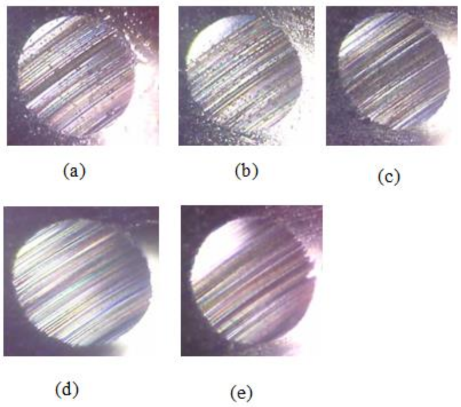

Figure 4 Optical microscopic images of worn-out surfaces of balls under formulated nano lubricant (a) PBA (b) PBA1 (c) PBA2 (d) PBA3 (e) PBA4

The minimum AWSD and CoF was recorded for bitter almond oil containing 0.02 vol. fraction of TiO_2 nanoparticles. Figure 3. showed the average wear scar diameter (AWSD) of steel balls after the experimentation under different nano lubricant. Optical microscopic images of ball after experimentation were presented in figure 4. Figure 4(a)-(e) showed the optical images of balls under lubrication of bitter almond oil and oil containing 0.01, 0.02, 0.03 and 0.04 vol. fraction of nanoparticles, respectively. The AWSD was measured after taking the optical microscopic images. The optimum concentration was 0.02 vol fraction of nanoparticles.

IV. CONCLUSION

Bitter almonds oil-based nano lubricant containing TiO_2 nanoparticles and Triton X-100 was successfully formulated. Four different volume fractions of nanoparticles (0.01, 0.02, 0.03, and 0.04) used for nano lubricant formulation and the ratio of TiO_2 nanoparticles and Triton X-100 is 2:1. The tribological investigation of formulated Bitte almond oil-based nano lubricant on Four ball tribotester using ASTM 4172B. Bitter almonds oils containing 0.02 vol. fraction nanoparticles showed minimum average wear scar diameter of 519 μm and 0.02 coefficient of friction. Bitter almond oil is a non-edible oil and it can be recommended for the lubricant formulation with TiO_2 nanoparticles.

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