Investigating the Tribological Behavior of Diesel-Biodiesel Blends with Nanoparticle Additives under Short-Term Tests

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Abstract: The addition of nanoparticles to lubricant is effective for the reduction of wear and friction in the mechanical system. In this research, the effects of additions of copper oxide nanoparticle nanoparticles on the lubrication behavior of biodiesel-diesel fuel blends were investigated by using a four-ball tester. Three fuel blends with the addition of 0, 25, 50 and 75 ppm nanoparticle were tested in steady-state conditions at four different rotational speed of 600, 1200 and 1500 rev/min. the results showed that the friction coefficient decreases with the increase in nanoparticles up to 50 ppm because of filling the friction surface with the nanoparticles and replacement of sliding friction with the rolling effect in the contact zone. On the other hand, the FC was enhanced significantly with 75 ppm nanoparticle addition in fuel blends B10 and B20. However, the results showed that the lubrication of fuel blend B50 with the 75 ppm nanoparticle is better than that of other fuel blends in the same situation. Moreover, it was found that with an increase in biodiesel concentration the friction coefficient was reduced due to free fatty acids, monoglycerides, and diglycerides as the components of biodiesel.

Keywords: Biodiesel, Four-ball Tester, Friction, Nanoparticle

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1 INTRODUCTION

Nanotechnology is regarded as the most revolutionary technology of the recent century. It can be used in many fields and ushers material science into a new era [1]. Recent research papers have reported that the addition of nanoparticles to lubricant is effective for the reduction of wear and friction in mechanical systems [2]. Numerous nanoparticles have recently been investigated for use as oil additives. Nano-powders of some metals and their compounds exert an especially effective influence on the characteristics of lubricants. The use of nanoparticles that include Cu, CuO, Fe, Ni, TiO_2 and other metallic nanoparticle additives in lubricating oils provides good friction reduction and anti-wear behavior [2].

On the other hand, the fuel injectors and pump of the diesel engines are lubricated by the fuel which is flowed in these components. So it is needed to consider using some fuels with high lubrication properties. Moreover, the use of alternative fuels can lead to reduce BSFC as a result of reduction in wear and enhancing the lubricity of moving components [3]. Biodiesel as an alternative biofuel and renewable energy can enhance the lubricity property of the fuel [4-8].

Although it was shown by some researchers [9] that neat biodiesel has better tribology properties compared to No.2 diesel fuel but some problems such as auto-oxidation [10], carbon deposits [11], corrosion [12-13], unsaturated hydrocarbon chains [13]. There are many types of research about using nano-particles in lubricant and engine oil to investigate tribology properties of the oil. Chinas-Castillo and Spikes [14] investigated the mechanism of action of colloidal solid nanoparticles in lubricating oils. Their study has shown that in rolling contacts at slow speeds, colloids formed a boundary film of at least one or two times of the particle size.

Liu and co-workers [15-16] have carried out studies on a wide range of different colloid solid nanoparticles using a four-ball tribometer. Their results showed that the deposition of tribochemical reaction products produced by nanoparticles during the friction process can result in an anti-wear boundary film, and decrease of the shearing stress. Rapoport et al. [17] also found that the impregnation of IF nanoparticles provided the regime of quasi-hydrodynamic lubrication over the widest range of loads in comparison with the reference sample.

Tao et al. [18] investigated diamond nanoparticles as an oil additive and found that under boundary lubricating conditions, the ball-bearing effect of diamond nanoparticles existed between the rubbing surfaces, the surface polishing and the increase in surface hardness effects of the diamond nanoparticles were the main reasons for the reduction in wear and friction. Choi et al. [19] investigated the tribological efficiency of copper nanoparticles at different lubrication regimes. It was evident that the Cu nanoparticles were more effective in mixed lubrication than in full-film lubrication.

The industrial gear oil was investigated by Lee et al. [20] to find the physical and tribological properties of nano lubricants. The friction coefficients and temperatures were measured by a disk-on-disk tribometer. The surfaces of the fixed plates were observed by a scanning electron microscope and an atomic force microscope to analyze the characteristics of the friction surfaces. The results showed that when comparing fixed plates coated with raw and nano lubricants, the plate coated with a nano lubricant containing graphite nanoparticles had a lower friction coefficient and less wear. These results indicate that graphite nanoparticle additives improve the lubrication properties of regular lubricants.

Ku et al. [21] studied the tribological behaviors of fullerene nanoparticles-added mineral oil a function of various viscosities. Tribological properties were evaluated using a four-ball tester. The lubrication tests were performed with a disk-on-disk tester for different normal loads. The results showed that the wear scar diameters of the raw and nano-oil decreased as the oil viscosity increased and wear scar diameters for all nano-oil were less than those of raw oil. Also, it was found that the difference of friction coefficient between raw oil and nano-oil was outstanding when the viscosity of raw oil was low and the normal load is high. Liu et al. [22] presented research on the mending effect of copper nano-particles added to lubricant oil. Pin-on-disk experiments and Scanning Electron Microscopy (SEM) observations showed that copper nano-particles do display an excellent mending effect.

The observation by Scanning Tunnelling Microscopy (STM) reveals that the mending effect results from the deposition of copper nano-particles onto the wear scar. It has also been disclosed by heating simulation that, due to nano-scale effects, which bring a decrease in the diffusion temperature of copper nano-particles, the heat generated by friction leads to the diffusion of copper nano-particles and their subsequent deposition, which finally results in the so-called mending effect.

Wu et al. [1] examined the tribological properties of API-SF engine oil and a Base oil, with CuO, TiO_2, and Nano-Diamond nanoparticles used as additives. The friction and wear experiments were performed using a reciprocating sliding tribometer. The experimental results showed that nanoparticles, especially CuO, added to standard oils exhibit good friction-reduction and anti-wear properties. The addition of CuO nanoparticles in the API-SF engine oil and the Base oil decreased the friction coefficient by 20 and 6%, respectively, and reduced the worn scar depth by 17 and 80%, respectively, as compared to the standard oils without CuO nanoparticles. Padgurskas et al. [2] performed tribological investigations on mineral oil containing Fe, Cu and Co nanoparticles. The tribological tests showed that each set of nanoparticles significantly reduced the friction coefficient and wear of friction pairs. The use of Cu nanoparticles provided the most effective reduction of friction and wear in each combination of nanoparticles. Surface analysis shows that the constituent elements of nanoparticles precipitated on the contact surface during the use of the oils with nano-additives. Moreover, the SEM micrographs and EDX chemical analysis confirm the formation of a tribo-layer composed of the elements from the nanoparticles.

According to that the nanoparticle additives have a positive effect of the tribological behavior of the lubricant oils and these additives can be used in the diesel-biodiesel blends to improve tribological properties of the mixture and there is not any research study related to this issue, the novelty of this research is investigation the effects of copper oxide nanoparticles additives on tribological behavior of various biodiesel-diesel fuel mixture in terms of friction by using a four-ball tester.

2 MATERIALS AND METHODS

The conversion of biodiesel from waste cooking oil was performed under the alkaline catalyzed transesterification method with the presence of potassium hydroxide and methanol as catalyst and alcohol respectively [23]. In this research, the copper oxide nanoparticle with an average size of less than 100 nm was supplied. In order to improve the stability of nanoparticles, a surfactant was used and it makes a cloak on the surface of the nanoparticles [23].

An ultrasonic emulsifier (400 W, 24 kHz) was used to agitate the nanoparticles in fuel blends at 0.7 s duty cycle for 30 min to obtain well-suspended nanoparticles dispersion in fuel blends [24]. The test fuels are indicated as B10 (10% biodiesel and 90% diesel), B20 and B50 with the addition of 0, 25, 50 and 75 ppm CuO nanoparticles.

Fig. 1 The test balls and prepared fuel blend.

Friction characteristics of fuel mixtures were studied under steady-state condition and short-term tests by using the four-ball wear testing machine according to ASTM D4172 standard. The test balls and prepared fuel blend are shown in "Fig. 1". The HMI controller records the friction torque and calculated the friction coefficient by following the "Eq. (1)" [25]. The test conditions in the present study are described in "Table 1".

$$\text{Coefficient of friction}(\mu) = \frac{T\sqrt{6}}{3Wr} \quad (1)$$

Table 1 Transitions selected for thermometry

Applied load (N)	392
Rotation (rpm)	900, 1200, 1500
Test duration (s)	1500
Fuel blends	B10, B20, B50
CuO nanoparticles(ppm)	0, 25, 50, 75

3 RESULTS AND DISCUSSION

3.1. Effect of Nanoparticle Addition for Fuel Blend B10 at Various Speeds

The results of the effect of steady-state conditions on friction coefficient (FC) for fuel blend B10 rpm are shown in "Fig. 2".

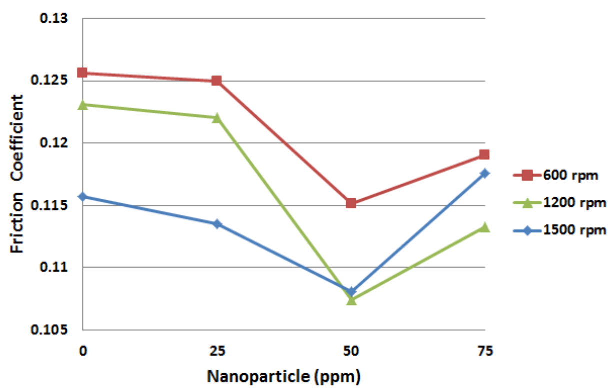

Fig. 2 Effect of nanoparticle addition on friction coefficient for B10.

According to the result, the maximum value of friction coefficient (0.1256) happens at 600 rpm for fuel blend without nanoparticle and the minimum value of friction coefficient (0.1074) belongs to fuel blend with 50 ppm nanoparticle at 1200 rpm. According to results, the friction coefficient decreases with increase in nanoparticles amounts from 0 to 50 ppm that indicates that copper oxide nanoparticles improve the lubrication properties of fuel blend; this is due to that the constituent elements of nanoparticles precipitated on the contact surface during the use of the biodiesel-diesel mixture with Nano additives [2]. On the other hand, the FC was enhanced significantly with 75 ppm nanoparticle addition in the fuel blend. This could be related to the oxygen content of copper oxide nanoparticle that causes oxidation and degradation of the fuel [19], [25]; therefore it may result in reduced lubricity. Moreover, the friction coefficient was reduced for all fuel blends when the RPM increased. This may be due to high-temperature condition at higher speeds that causes a protective film of fuel-copper with friction surface as a result of an electrochemical reaction and electrostatic adhesion of Cu nanoparticles and plasticity of copper [2].

3.2. Effect of Nanoparticle Addition for Fuel Blend B20 at Various Speeds

Figure 3 shows the variation of the friction coefficient for fuel blend B20 at various rotational speeds. According to the results, the maximum value of friction coefficient (0.1235) happens at 1200 rpm for fuel blend with 75 ppm copper oxide nanoparticle and the minimum value of friction coefficient (0.0966) belongs to fuel blend with 50 ppm nanoparticle at 1500 rpm. As in the previous case, the FC decreases with increase in nanoparticles amount from 0 to 50 ppm indicating that copper oxide nanoparticles have a positive effect on tribology properties of the fuel blend. The reason is filling with the micro asperities of the friction surface with the nanoparticles and replacement of sliding friction with the rolling effect in the contact zone [1-2]. The FC was enhanced significantly with 75 ppm nanoparticle addition in the fuel blend. Although, like the previous trend, FC was enhanced significantly with 75 ppm nanoparticle addition in fuel blend related to causes of oxidation that helps to expose the fuel blends to air [26]. Moreover, the friction coefficient was reduced for all fuel blends when the speed increased.

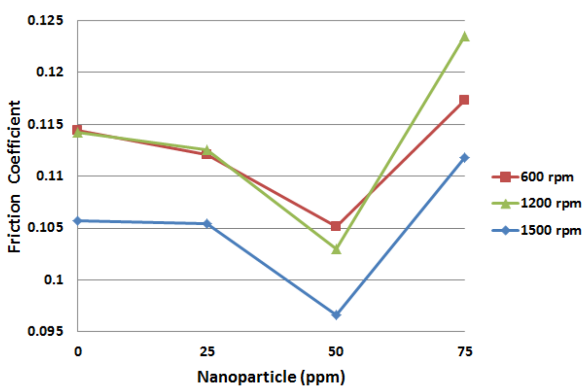

Fig. 3 Effect of nanoparticle addition on friction coefficient for B20.

3.3. Effect of Nanoparticle Addition for Fuel Blend B50 at Various Speeds

The variation of friction coefficient for the diesel-biodiesel blend (B50) at various speeds is presented in “Fig. 4”. According to the results, the maximum value of friction coefficient (0.1256) happens at 600 rpm for fuel blend without nanoparticle and the minimum value of friction coefficient (0.0775) belongs to fuel blend with 50 ppm nanoparticle at 1500 rpm. It is seen in the figure that the friction coefficient decreases in all cases when the rpm increases.

The reason is related to the formation of the ultrathin protective film of fuel-copper and electrostatic adhesion of Cu nanoparticles with friction surface at higher temperature condition [2], [27]. Also, it can found that the addition of nanoparticles up to 50 ppm improves the tribological properties of the diesel-biodiesel blend because of that the sphere-like nanoparticles may result in rolling effect between the rubbing surfaces, and the situation of friction is changed from sliding to rolling [1]. Although the friction coefficient of fuel blend with 75 ppm nanoparticle is higher compared to fuel blend with 50 ppm; but the results imply that the lubrication of fuel blend B50 with the highest amount of nanoparticle is better than that of other fuel blends in the same situation.

Moreover, the results showed that the friction coefficient reduces significantly as the biodiesel content of the mixture increases because of that the thin layer of the neat biodiesel helps to reduce the friction more than that of other blends [25], [28], [29]. Another reason is related to free fatty acids, monoglycerides, and diglycerides which are in trace components of biodiesel. These organic carbon compounds improve the lubrication properties of biodiesel [30-31].

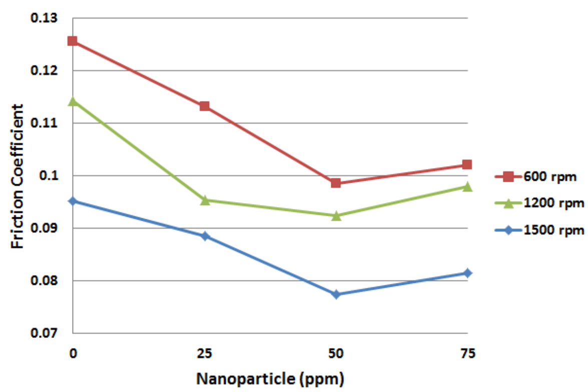

Fig. 4 Effect of nanoparticle addition on friction coefficient for B50.

4 CONCLUSION

According to the results, it can be concluded:

Friction coefficient decreases with increase in nanoparticles amount from 0 to 50 ppm indicating that copper oxide nanoparticles have a positive effect on tribology properties of the fuel blend. The reason is filling with the micro asperities of the friction surface with the nanoparticles. Also, the sphere-like nanoparticles may result in rolling effect between the rubbing surfaces, and the situation of friction is changed from sliding to rolling, therefore the FC decreases. On the other hand, the FC was enhanced significantly with 75 ppm nanoparticle addition in fuel blends B10 and B20.

This could be related to the oxygen content of copper oxide nanoparticle that causes oxidation and degradation of the fuel. However, the results showed that the lubrication of fuel blend B50 with the 75 ppm nanoparticle is better than that of other fuel blends in the same situation. Also, the friction coefficient decreases in all cases when the rpm increases due to the formation of ultrathin protective film of fuel-copper and electrostatic adhesion of Cu nanoparticles with friction surface at higher temperature condition. Among all cases, the best tribological behavior belongs to fuel blend B50 with 50 ppm nanoparticle.

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