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INFLUENCE OF VOLTAGE ON FRICTION COEFFICIENT DISPLAYED BY OIL ADDITIVES

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ABSTRACT
The present work investigates the influence of direct current (D. C.) voltage, applied on the sliding surfaces lubricated by different oil additives dispersed in paraffin oil, on the friction coefficient. The additives are graphite, molybdenum disulfide (MoS_2), detergent additive (calcium sulphonate), zinc dialkyldithiophosphates (ZDDP), metalloid fusion lubricant as an anti-wear additive of nanospheres less than 0.1 µm in diameter and heteropolar organic base additive (CMOC). The concentration of the additives in the lubricant was 5.0 wt. %. Experiments were performed with and without voltage applied to the sliding surfaces using cross pin wear tester. The values of voltage used were 0, 3, 6 and 9 volts.

Based on the experimental results, it was found that friction coefficient displayed by the sliding surfaces lubricated by oil free and oil dispersed by the tested additives increased with increasing applied voltage. The response of the additives to the applied voltage depended on the polarity of their molecules. Besides, friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by MoS_2 and graphite additives showed relatively higher friction than that observed for oil free of additives and oil dispersed by ZDDP. The effect of voltage was more pronounced in the presence of graphite, where the friction decreased with voltage increasing. Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by detergent additive (calcium sulphonate) and the nanospheres particles (< 0.1 µm) of the metalloid fusion additive displayed the minimum friction values (0.035). The effect of voltage was highly pronounced.

KEYWORDS
Lubricant additives, friction, direct current voltage, detergent, anti-wear additives.

INTRODUCTION
Engine oils contain numerous chemical additives in order to improve, their thermal, physical and tribological properties. Recently, significant progress has been made in developing nanolubricants, [1 - 10], like Ag, Cu, Ni, MoS_2, WS_2. It was found that the nanoparticles of these materials can offer various benefits like friction reduction, wear resistance, high fuel efficiency, energy savings, and low harmful emissions. Copper, silver, MoS_2 and WS_2 nanoparticles showed significant friction reduction and wear

resistance under different tribological regimes such as hydrodynamics, mixed, and boundary lubrication.

There is an increasing demand to save the frictional losses in various mechanical and electronic devices, where magnetic field are applied. It is important to consider the friction and wear of their components and to understand the influence of magnetic field on their performance in order to prevent premature failure and to achieve higher energy efficiency. The effect of magnetic field on friction and wear processes has been studied by a number of researchers. The influence of magnetic field on the friction coefficient displayed by sliding of steel pin on steel disc lubricated by paraffin oil and dispersed by different lubricant additives such as zinc dialkyldithiophosphates (ZDDP), molybdenum disulphide (MoS_2), heteropolar organic based additive (CMOC), graphite (C), detergent additive (calcium sulphonate) (DA), polytetrafluroethylene (PTFE) and polymethyl methacrylate (PMMA) was discussed, [11, 12]. It was observed a significant transformation in tool wear tests with the magnetic field, [13 - 18]. Abrasive wear without magnetic fields was transformed, in the presence of magnetic field, to fracture due to the shift of shear stress to the subsurface region. Also, a decrease in wear, a lower friction coefficient, increase in hardness of magnetised steel surface and a rise in temperature of rubbing surfaces were observed. In magnetic fields, strongly oxidised wear particles will pose a serious problem for the contact due to the paramagnetism of oxygen. Accelerated oxidation does affect not only wear particles but also contacting surfaces. More specifically, highly oxidised wear particles, affected by magnetic force operating between contacting surfaces, act both as abrasive and as lubricating agents depending on their conditions.

It was observed that, for sliding of steel pin against oil lubricated brass discs, magnetic field decreased friction coefficient for all the tested oils, [19]. Dispersing oil by polyethylene (PE) particles significantly increased friction coefficient. A drastic reduction of friction coefficient was observed for olive, castor and almonds oils, when dispersing the tested oils by polyamide (PA) particles. Sliding of steel pin on oil lubricated aluminium disc caused significant friction increase for all the tested oils. Drastic friction reduction was observed for castor, almonds, jasmine and camomile oils when dispersed by PE particles. Dispersing vegetables oils by PA particles showed relatively lower friction coefficient for olive and castor oils, while corn, almonds, camomile and jasmine oils showed relatively higher friction values. Sliding of steel pin on oil lubricated steel disc showed the highest values of friction coefficient. Dispersing the tested oils by PE particles did not decrease friction coefficient. Jasmine oil displayed relatively lower friction than the other tested oils.

The effect of magnetic field on the friction coefficient displayed by sliding of steel pin against steel disc lubricated by paraffin oil and dispersed by different lubricants additives was investigated, [20]. The experiments showed that, friction coefficient increased as the magnetic field increased due to the increase of the normal load caused by the magnetic force. The performance of ZDDP and Mo S_2 additives was not affected by the application of magnetic field. Besides, it was observed that magnetic field much affected the performance of oil dispersed by additives of electrical properties such as CMOC, DA and PTFE particles. The same trend of friction decrease was observed for PMMA particles dispersed in oil.

The friction and wear of polyethylene sliding against steel in the presence of magnetic field was investigated, [21]. It was found that, application of magnetic field decreases friction coefficient at dry sliding due to its influence to decrease the adherence of polyethylene worn particles into the steel counterface. Besides, the magnetic field favors the formation of oxide film on the contact surface, where it plays a protective role in dry friction, modifies the friction and changes wear from severe wear to mild. Lubricating the steel surface by oils caused significant reduction in friction coefficient, where the maximum reduction was displayed by paraffin followed by glycerine, almond, jasmine, corn, castor, olive and sun flower oils. Besides, wear of polyethylene test specimens shows relative decrease in the presence of magnetic field.

The effect of the magnetic field on the friction and wear of steel and brass sheets scratched by a steel insert at dry, lubricated by vegetable oils and dispersed by polymeric particles such as high density polyethylene (HDPE), polyamide (PA6) and polymethyl methacrylate (PMMA) was investigated, [22, 23]. Based on the experimental observations, it was found that olive oil displayed the lowest values of friction coefficient followed by castor oil, almonds, corn, chamomile and jasmine oils, where their polar molecules could significantly improve the wear resistance developed by their strong adsorption on the sliding surfaces. Application of magnetic field on the sliding surface caused significant friction reduction at dry sliding due to the enhanced ability of the oil molecules to orient themselves in relatively long chain adhered to the sliding surface and thus decreased the friction and wear.

The effect of applying external voltage on the sliding of copper, aluminium and polyethylene against steel surface lubricated by paraffin oil dispersed by polymeric particles such as polyethylene, polyamide and PMMA was tested, [24]. It was noticed that the friction coefficient and wear were significantly influenced by the generation of electric static charge on the contact surfaces which caused an attractive force imposed to the normal load. It was found that wear was more influenced by the electric static charge than friction coefficient.

It was shown that the magnetic field had no effect on friction coefficient observed for lithium grease without additives, [25]. Grease dispersed by high density polyethylene showed friction decrease. The lowest friction reduction was observed for polymethyl methacrylate. The strong adhesion of PTFE particles into the sliding surfaces significantly increased friction coefficient. It seems that PTFE particles were adhered to surfaces of inner and outer races as well as the balls. Changing the terminal of the voltage applied to the rotating shaft showed significant friction decrease for PMMA. Viscosity of the grease decreased with increasing the voltage. Friction coefficient decreased for HDPE and PTFE. The lowest friction values were observed at 6 volts which indicated that increasing voltage across the sliding surface could significantly decrease friction coefficient.

In the presence of magnetic field around the tribocontact and in ambient air, the contact track was covered with very fine ferromagnetic particles, [26]. Friction and wear are influenced by the presence of oxide. The increase of oxide layer on the surface, the retention of passivated particles in the contact and their refinement by grinding modify

the contact rheology which transits from metal/metal contact to oxide/oxide contact. It was noticed that magnetic field acts on the ferromagnetic contact surface by modifying their electrical and electronic behaviour. It increases the electronic speed in their orbits, [27], and creates the electrical fields and the electrical currents. Those electrical currents enhance the oxidation. Moreover, dislocations in subsurface of the materials in contact are influenced by contact shear stress field [28]. The stress field presents a decreasing gradient from the Hertzian point. The dislocations displace from the region of strong stress gradient to the region of weak gradient. The existence of magnetic field around the contact facilitates the movement of dislocations due to mechanical stress, decreasing the obstacles through the rearrangement of magnetic domains. This accumulation of dislocations leads to the increase of surface hardness.

It is known that, during friction on metals or dielectric couples, part of the energy consumed turns into electrical energy. In the second part of the study, electrical phenomena induced by friction will be examined in situ. Hence, the appearance of the potential difference generated by lubricated friction will be studied. This electrical effect leads to an embrittlement of friction surfaces and also involves a greater reactivity of surfaces with the lubricant. Because of triboelectrification, the charged surfaces can interact with each other due to the direct electrostatic forces, [29]. Since these forces are strong and effective, they contribute a major part of the adhesion force.

By applying an electric field between the rubbing surfaces, the oxidation of the rubbing surface at anode side is enhanced, and suppressed on the cathode side surface. The oxide film formed on the anode surface being harder than the bulk steel, the rubbing surface at the anode side was little worn, but it at cathode side was abrasively worn considerably. The application of an electric field, however, is considered to promote the breakdown of EHL film formed. Therefore, the effect of the application of an electric condition tested, [30]. The influence of applying electric field on the tribological behaviour of steel in a vertical magnetic field produced by an AC or DC electric current was investigated. The effect of a magnetic field on both oxidation and concentrations of dislocations on the surface is presented, [31]. Experiments show that a magnetic field applied through the sliding contact leads to decrease the wear rate.

The present work investigates the effect of D. C. voltage on the friction coefficient displayed by steel surfaces lubricated by different types of lubricant additives.

EXPERIMENTAL

Experiments were carried out using a cross pin tester, Fig. 1. It consists, mainly, of rotating and stationary pins of 18 mm diameter and 150 mm long. The rotating pin (hardened steel, H_v = 3100 N/mm^2) was attached to a chuck mounted on the main shaft of the test rig. The stationary pin (carbon steel, H_v = 1100 N/mm^2) was fixed to the loading block where the load was applied. The main shaft of the test machine is driven by DC motor (300 watt, 250 volt) through gear reduction unit. Moreover, the motor speed is adjustable and can be controlled by varying the input voltage using an autotransformer. The friction force was measured through load cell fastened in the loading lever. Experiments were carried out at 0.80 m/s sliding velocity and 16, 32, 48,

64, 80 and 96 N load. The running time of each experiment was 300 seconds. The lubricant used in the experiment was paraffin oil, (S. A. E. 30).

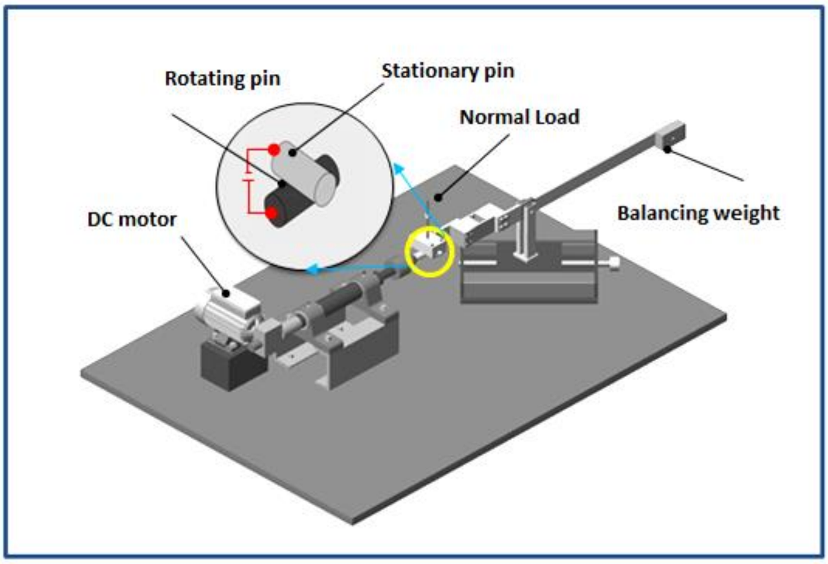

Fig. 1 Arrangement of the test rig.

The lubricant used in these experiments is paraffin oil. Fine powders of graphite (C), molybdenum disulphide ($Mo\ S_2$) and heteropolar additive (CMOC) of particle sizes less than 1.0 µm were dispersed into the paraffin oil at 5.0 wt. %o concentration. Also, zinc dialkyldithiophosphate additive (ZDDP), detergent additive (calcium sulphonate) and a metalloid fusion additive of nanospheres less than 0.1 pm in diameter were tested. The voltage was applied to the rotating pin through rolling bearing supporting the rotating shaft after the total insulation of the stationary pin.

RESULTS AND DISCUSSION

The relationship between friction coefficient and Stribeck number (viscosity of the lubricating fluid [η], load [F], and velocity [U]) is illustrated in Figs. 2 - 8. The curve illustrates the characteristics of various lubrication regimes, including boundary lubrication, elastohydrodynamic lubrication (EHL), and mixed lubrication, [32]. In hydrodynamic lubrication, the fluid completely isolates the friction surfaces, where the fluid friction alone determines tribological characteristics. In elastohydrodynamic lubrication, fluid viscosity and the elastic coefficient of the solid surface are the most dominant factors. In contrast, the boundary lubrication regime is mainly characterized by the facts that friction surfaces are in contact at microasperities, where hydrodynamic effects of lubricating fluid insignificantly influence tribological characteristics and the interactions in the contact between friction surfaces and between friction surfaces and the lubricant dominate tribological characteristics.

Friction coefficient displayed by the sliding surfaces lubricated by oil is shown in Fig. 2. The relationship shows increased friction at low Stribeck number, a well developed minimum at intermediate Stribeck number and an increased friction at high Stribeck number. As the voltage increased, friction coefficient decreased. The minimum friction

value (0.028) was observed at 9.0 Volts. The conventional lubrication mechanisms are based on physical and chemical adsorption, where the polar molecules play a key role in interactions with the sliding surfaces. The best tribological performance is expected for polar oils. Efficiency of the lubricant depends on the strength of the fluid film and consequently on the adsorption on the sliding surfaces. Increasing the polar functionality in oil structure has a positive impact on friction reduction resulting from stronger adsorption potential on metal surface. It seems that applying D. V. voltage on the sliding surfaces forces the polar molecules to orient themselves with the polar end directed towards the metal surface making a close packed monomolecular or multimolecular layered structure resulting in a surface film believed to inhibit metal-to-metal contact and progression of pits and asperities on the sliding surfaces.

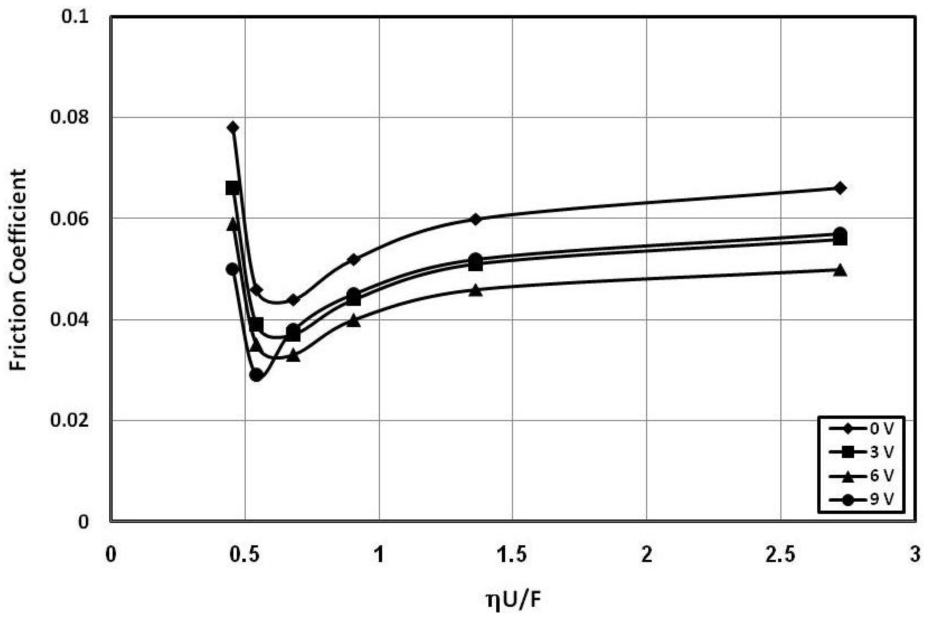

Fig. 2 Friction coefficient displayed by the sliding surfaces lubricated by oil.

Application of voltage on sliding surfaces lubricated by oil dispersed by ZDDP additive showed significant friction decrease in friction, Fig. 3. As the voltage increased, friction decreased, where the minimum friction value (0.055) was displayed at 6 and 9 volts. The friction decrease might be from the formation of soluble organic sulphides, organo thiophosphates and organo phosphate which under tribological conditions of high pressure and temperature form oil insoluble components such as zinc polyphosphates on surfaces as tribological films. It seems that voltage facilitates the formation of this films and causes the decrease in the friction coefficient.

Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by MoS_2 additive, Fig. 4, shows relatively higher friction than that observed for oil free of additives and oil dispersed by ZDDP. Slight decrease of friction coefficient was displayed as a result of the effect of voltage, where the minimum value was 0.06. It seems that the good surface adherence of MoS_2 attributed to strong metal-sulfur bonds, while the compound shears easily to give low friction because of the weakness of the sulfur-to-sulfur bond.

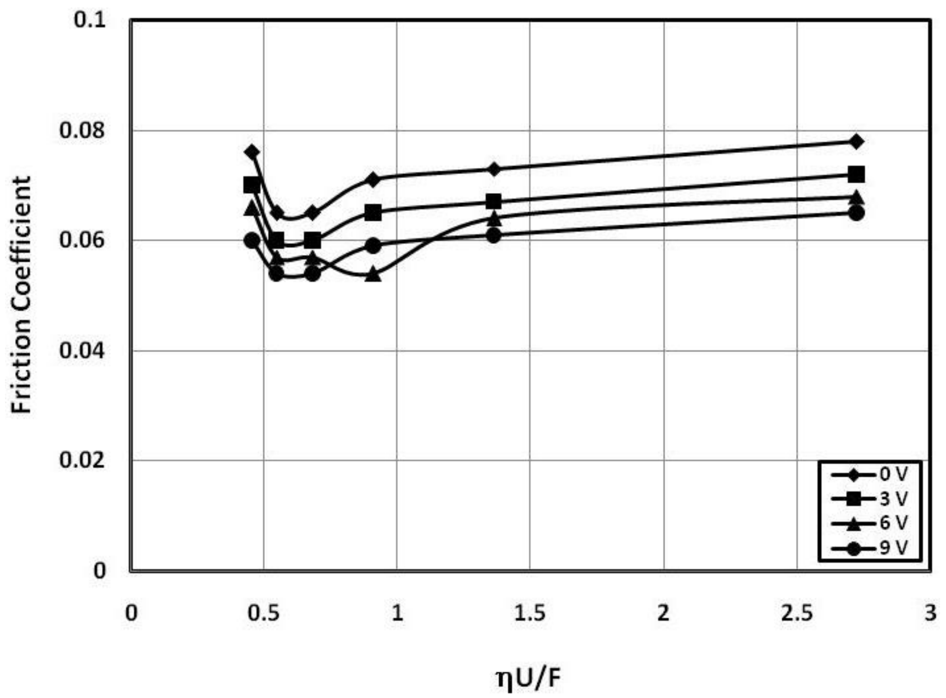

Fig. 3 Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by ZDDP additive.

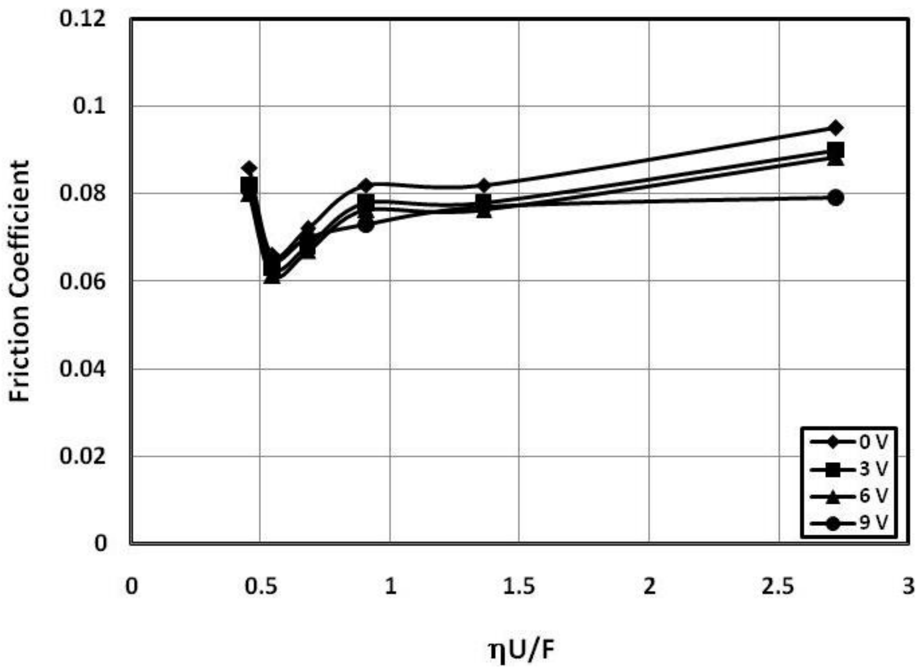

Fig. 4 Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by MoS_2 additive.

Slight friction increased was observed for surfaces lubricated by oil dispersed by graphite, Fig. 5, compared to those lubricated by oil dispersed by ZDDP and MoS_2. In

this condition, the effect of voltage was more pronounced, where the friction decreased with increasing the voltage.

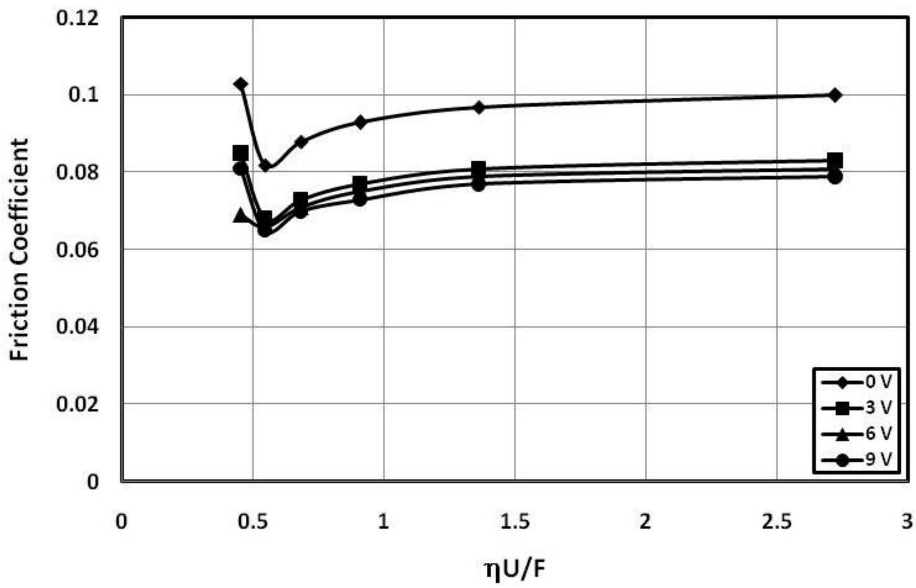

Fig. 5 Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by graphite.

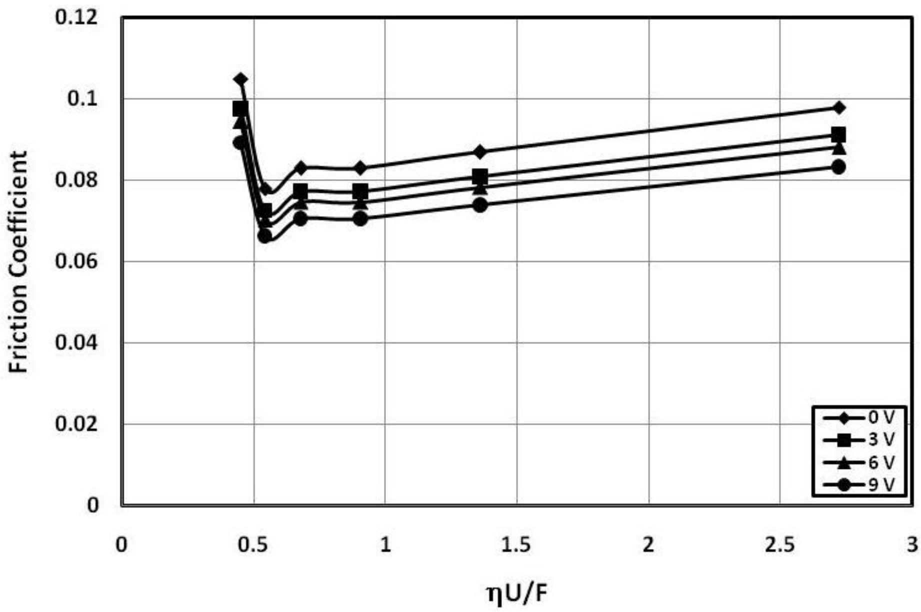

Fig. 6 Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by CMOC.

Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by copper quinolinolate (Cu C_{18} H_{12} O_2 N_2), which will be referred in text as CMOC, is shown in Fig. 6. The effect of the voltage on decreasing friction coefficient is clearly noted. The reduction in friction may be attributed to the ability of CMOC particles (<

1.0 µm) to be adhered to the surface of the sliding surfaces, due to their polarity, forming relatively thick layer protecting the sliding surfaces from excessive friction. The polarity of the additive particles strengthened the effect of the electric current.

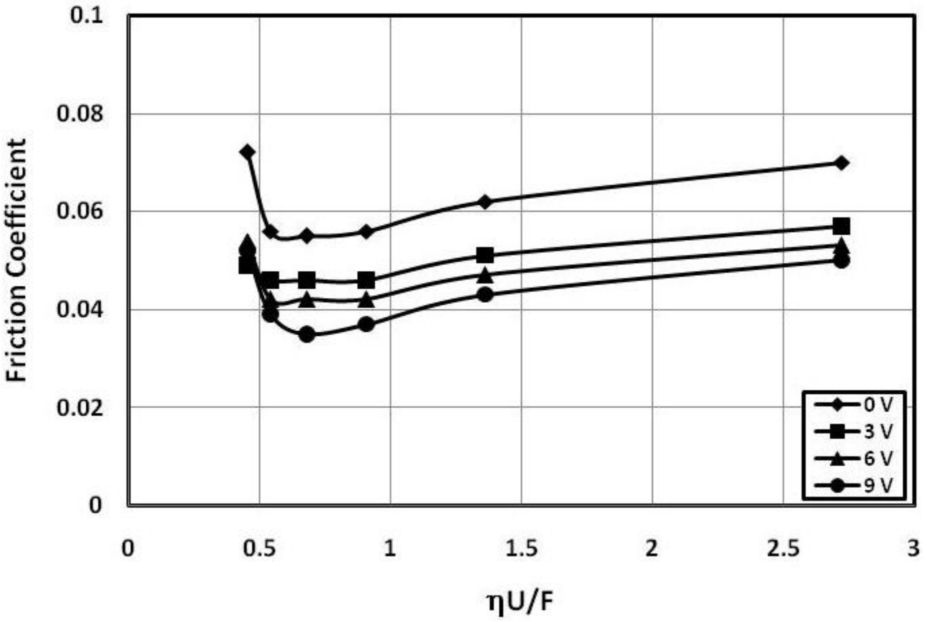

Fig. 7 Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by detergent additive.

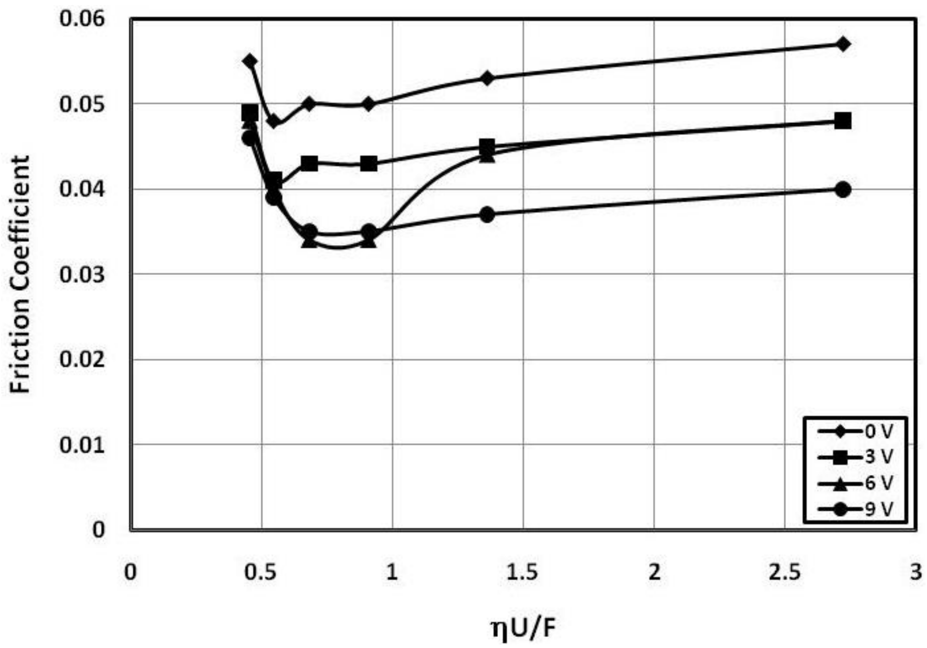

Fig. 8 Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by metalloid fusion additive.

Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by detergent additive (calcium sulphonate), Fig. 7, displayed the minimum values (0.035). The effect of voltage was highly pronounced, where the lowest values were presented by 9 volts. This behaviour might be attributed to high polarity of detergent molecules. The decrease of friction coefficient might be attributed to the ability of the polar molecules to form multilayer on the steel surface. The mixed lubrication provided by the tested oil is primarily governed by the formation of a stable oil film on the sliding surfaces. Polar molecules of the tested oil and additive can significantly improve the friction resulting from their adsorption on the sliding surfaces.

The same trend was observed for friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by a metalloid fusion additive of nanospheres particles (< 0.1 µm), Fig. 8. The response of the additive to the applied voltage was high, where friction coefficient significantly decreased with increasing voltage.

CONCLUSIONS

1. Friction coefficient displayed by the sliding surfaces lubricated by oil increased with increasing applied voltage.
2. Application of voltage on sliding surfaces lubricated by oil dispersed by ZDDP additive showed significant friction decrease.
3. Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by MoS_2 additive showed relatively higher friction than that observed for oil free of additives and oil dispersed by ZDDP. Slight decrease of friction coefficient was displayed as a result of the effect of voltage.
4. Slight friction increased was observed for surfaces lubricated by oil dispersed by graphite compared to those lubricated by oil dispersed by ZDDP and MoS_2. The effect of voltage was more pronounced, where the friction decreased with increasing the voltage.
5. The effect of voltage on decreasing friction coefficient is clearly noted for sliding surfaces lubricated by oil dispersed by CMOC.
6. Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by detergent additive (calcium sulphonate) and the nanospheres particles (< 0.1 µm) of the metalloid fusion additive displayed the minimum friction values (0.035). The effect of voltage was highly pronounced.

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