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TRIBOELECTRIFICATION OF METALLIC SURFACES LUBRICATED BY USED OILS

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ABSTRACT

The present work investigates the tribological properties of used oils such as friction coefficient and wear. Besides, the voltage generated from the triboelectrification of the sliding surfaces lubricated by the used oils was measured. It was found that, friction coefficient displayed by used oil I significantly decreased with increasing the load, while friction slightly increased with increasing the running distance. For used oil II, friction coefficient increased up to maximum at 6000 km then decreased with increasing running distance. Blending the used oil III by fresh one slightly increased friction coefficient up to maximum then decreased with increasing running distance. The sliding velocity showed insignificant effect on friction coefficient displayed by used oil I.

Wear displayed by the used oil I increased as the running distance increased. As the load increased wear significantly increased indicating the loss of the lubricating properties of the used oil. In contradiction to the friction wear showed significant decrease with increasing running distance for used oil II. At lower load, wear slightly increased with increasing fresh oil content blending used oil, while at higher load wear decreased with increasing fresh oil content. The relatively higher velocity displayed wear higher than that shown for the lower velocity. As the sliding velocity increased the voltage increased.

Voltage generated by the triboelectrification of the sliding materials, lubricated by used oil I, decreased with increasing running distance. The voltage generated showed drastic decrease with increasing running distance for used oil II. Voltage significantly increased with increasing the fresh oil content blending the used oil. It seems that generation of carbon soots was responsible for the voltage decrease, where the oil conductivity increased. This behaviour can be used to test the validity of the used oil and to determine its life time.

KEYWORDS

Friction coefficient, wear, triboelectrification, voltage, electrical properties, used oil.

INTRODUCTION

The tribocharging of selected engine oil and the effect of an auxiliary external DC electric field on the work of machines which contain rotating shafts and crankshafts is discussed, [1]. DC voltage was applied between the stiffening ring of four different lip seals under test and a rotating, earthed shaft in a metal shaft-oil film-lip seal system. The relationships of the torque to the voltage of positive and negative polarities were established on the basis of measurements of the torque under steady-state conditions for a constant oil temperature and given different angular shaft velocities. In general, it was found that positive and negative DC electric fields produce adverse effects on the torque depending on the type of oils and on the material of which the lip seals were made.

It was found that, [2 - 4], the tribocharging in the oil film between a rotating shaft and a lip seal displayed a significant increase in the torque. The natural tribocharging had the adverse effect on the operation of the system especially that the torque increased with the increasing level of electrification and temperature of the oils tested. When the shaft rotates, in the interfaces: shaft/oil film and oil film/lip seal and in the inside of the oil film some various types of charging occur. The tribocharging depends on the type and qualityof oils used, [5], the oil temperature, the material and surface roughness, [6, 7], of a shaft, the material of the seal, and the intensity and the type of contacts between the bodies.

The influence of magnetic field on the friction and wear of engineering materials was discussed, [7]. Tests were carried out at oil lubricated surfaces. Paraffin, Fenugreek, Camphor, Cress, Olive, Almonds, Sesame, Aniseed and Habet El-Baraka oils were used as lubricants. The friction coefficient and wear of the tested composites were investigated using a tribometer designed and manufactured for that purpose. It was found that, at no magnetic field, friction coefficient increased with increasing applied load. The maximum value of friction coefficient was displayed in the presence of paraffinic oil, while the minimum values were displayed by olive and Habet El Baraka oils. As the magnetic field of 0.2 mG flux intensity was applied on the sliding surface significant friction decrease was observed. The rank of the tested oils as friction reducer was Olive, Camphor, Aniseed, Habet El Baraka, Fenugreek, Cress, Sesame, Almond and Paraffin. Camphor oil was much influenced by the application of the magnetic field. Increasing the flux intensity of magnetic field to 0.3 mG was accompanied by further decrease of friction coefficient. Wear of the polyethylene lubricated by the tested oil increased with increasing applied load. In the presence of Almonds oil on the sliding surfaces wear displayed the lowest values, while Olive oil displayed the highest wear. Application of the magnetic field significantly decreased wear. The best wear resistance was displayed by Aniseed and Fenugreek oils, while Paraffin and Almonds oils displayed the highest wear values.

The influence of magnetic field on the friction coefficient displayed by the sliding of steel pin on aluminium 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 investigated, [8, 9]. Aluminium was used as friction counterface to reduce the magnetic force acting on the contact surfaces when the magnetic field was applying. It was found that, for surfaces lubricated by paraffin oils free of additives friction coefficient increased with increasing applied load. As the magnetic field increased friction coefficient increased. In condition of application of magnetic field it was found that when the paraffin oil was dispersed by ZDDP, MoS_2, DA and PTFE friction coefficient increased, while COMC, C and PMMA showed significant decrease in friction coefficient. Besides, the lowest values of friction coefficient were observed for PTFE particles dispersed in the oil.

The effect of magnetic field on the friction and wear of steel scratched by TiC insert is discussed, [10 – 14]. The steel was lubricated by oil and dispersed by iron, copper and aluminium powders as well as polymeric powders such as high density polyethylene (PE), polymethyl methacrylate (PMMA) and polyamide (PA6). Molybdenum disulphide (MoS_2) and graphite (C) were added to the oil as dispersant. Paraffin oil was used as lubricant. Friction coefficient and wear of the tested composites were investigated using a tribometer designed and manufactured for that purpose. It was found that application of induction magnetic field decreased friction coefficient. The decrease was significant for oil lubricated steel and oil dispersed by aluminium, copper, PMMA and PA6 + 10 wt. % C, while addition of iron, PE and MoS_2 particles showed slight friction decrease. At no magnetic field friction coefficient for oil dispersed by aluminium and copper particles showed values lower than that observed for oil dispersed by iron particles. The lowest values of friction coefficient were displayed by oil dispersed by PE particles. Magnetic field caused significant wear increase for oil lubricated steel, where aluminium, copper and PA6 + C particles displayed relatively higher wear, while addition of iron, PE, PMMA and MoS_2 particles showed slight wear increase. At no magnetic field wear decreased due to the action of aluminium particles which formed a continuous layer on the steel surface and consequently decreased wear. Wear of oil lubricated steel dispersed by PE particles displayed relatively low values. Magnetic field showed no significant change on wear of the steel surface.

In the present work the friction coefficient and wear of the used oil were investigated. Besides, the electric voltage generated from the triboelectrification of the sliding surfaces lubricated by the used oil.

EXPERIMENTAL

Experiments were carried out using wear tester, Fig. 1. It consisted of specimen holder attached to the loading lever through load cell to facilitate the measurement of friction force. Stainless steel cylinder {403 S17 (12 % Cr, o.5 Ni %, 1.0 %, Mn, 0.8 % Si)} of 40 mm diameter and 11 mm width of surface roughness of 0.4 μm (R_a), was fastened to the rotating shaft of the tester and slid against a block, in form of cube, (20 × 20 × 20 mm), of cast bronze {G – Bz 10 (90 % Cu and 10 % Sn, DIN 1705) of 600 N/mm^2 hardness}. The friction surface of the test specimens was ground by an emery paper of 500 grades

before test. Load was applied by weights. Experiments were carried out using loads of 30, 60, 90, 120, 150 N and sliding velocity of 0.4, 1.2 m/s. Wear of test specimens was determined by the wear scar width measured by optical microscope of ± 1.0 μm accuracy.

The holder of the test specimens was insulated from the loading lever to facilitate the measurement of the electric voltage generated on the sliding surfaces from the friction. The voltage was measured by voltmeter, where the first terminal was connected to metallic pin and the other to bearing block of the rotating shaft. Three types of used oils were tested. The first oil (I) was used in an engine for 44.000 km, where every 8000 km an oil sample was taken for the tests. The second oil (II) was used for 15000 km, where oil sample was taken every 5000 km. The third oil (III) was used for 38000 km and blended by fresh oil of 20, 50, 75 and 100 wt. % content.

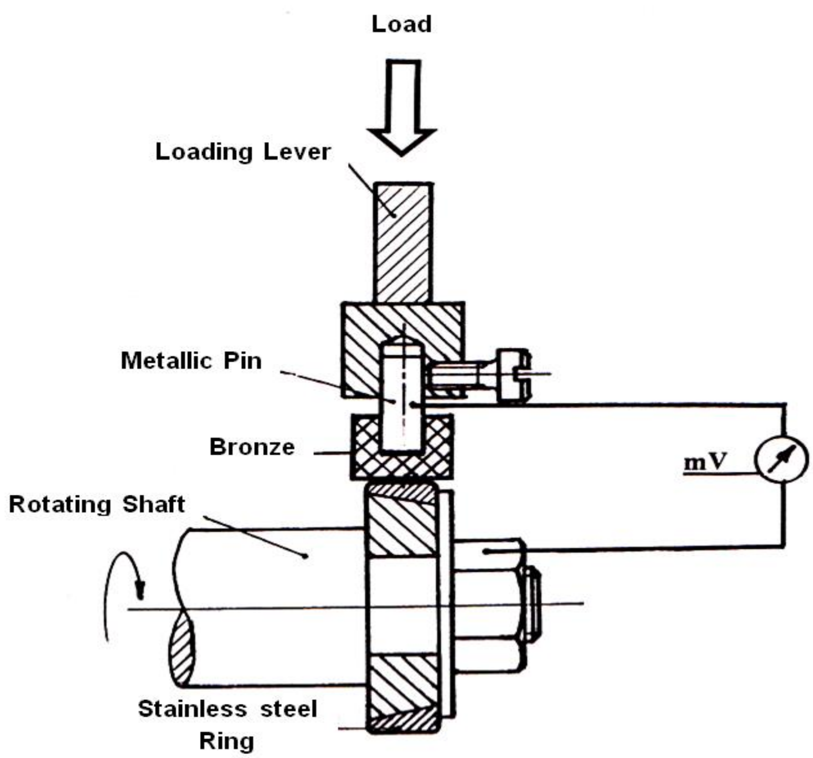

Fig. 1 Arrangement of the test rig.

RESULTS AND DISCUSSION

The deterioration of lubricating properties of used oil was caused by the decomposition of the organic components into soot particles. It was shown that, [14 - 16], soot is not abrasive but adsorbs anti-wear additives, thus diminishing anti-wear properties. It was concluded that, [17, 18], soot particles are abrasive because they generate grooves and breakouts in metal surfaces. Dispersed carbon black rapidly abraded zinc dialkyldithiophosphate (ZDDP) reaction films, [19, 20]. It was reported that the

presence of soot particles reduces the thickness of anti-wear films and they are abrasive, [21 – 23]. The chemical activity of soot particles and their reaction with ZDDP prevents the formation of liquid boundary layers on metal surfaces, [24]. There are two factors are influencing the performance of the used oil. The first is the abrasive contaminants, which accelerates wear rate. The second is the lubricant additives which reduce wear and friction as they decompose in the oil. The oil contains Zink dialkyl dithiophosphate (ZnDTP) which is one of the most effective additives influencing the lubricating properties of engine oil. It was found that, [26 - 28], the lubricating properties of engine oil containing ZnDTP increases with increasing the running distance due to the decomposition of ZnDTP in oil solution to Zink polyphosphate and a mixture of alkyl sulphides which provide the antiwear action of ZnDTP.

Friction coefficient displayed by the used oil I is shown in Fig. 2. Friction coefficient significantly decreased with increasing the load. Slight friction increase was observed with increasing the running distance. The increase might be attributed to the increase of carbon soots, solid and liquid contaminants in the used oil. The microscopic inspection was used to check the cleanliness of fresh and used oil samples, [28 - 31]. It was surprising that the fresh oil samples contained a lot of abrasive particles up to 150 µm while in used oil samples the abrasive contaminant concentration was relatively high.

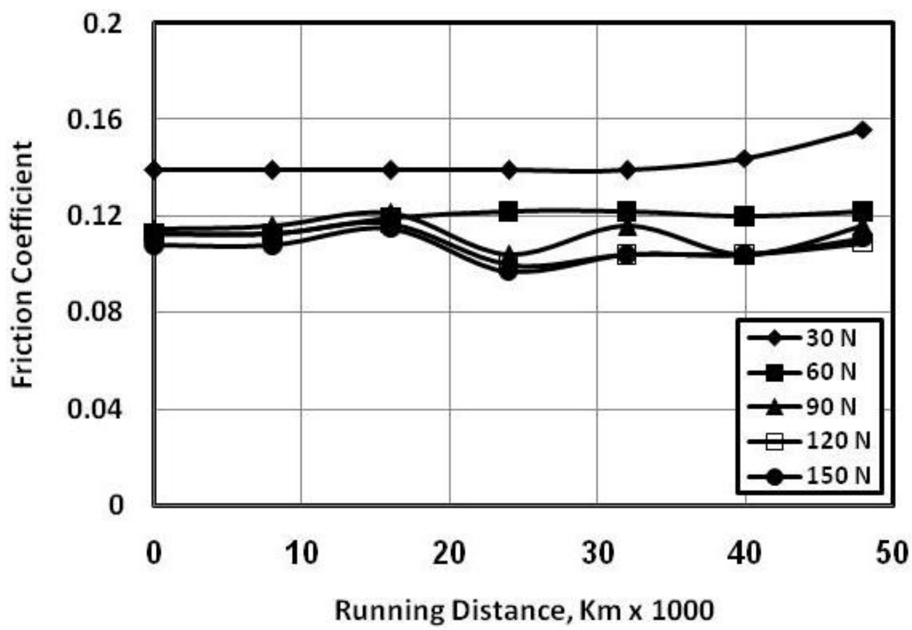

Fig. 2 Friction coefficient displayed by used oil I.

Wear resistance of the used oil as a function of wear scar width is shown in Fig. 3. Wear increased as the running distance increased. As the load increased wear significantly increased indicating the loss of the lubricating properties of the used oil. The asperities of bronze have negative electric static charge as a result of their friction against steel, while steel gains positive charge. Lubricating oil is considered as insulating material. If

the two sliding surfaces are well insulated the voltage difference across the oil film can be measured. When the oil contains solid contaminants the value of the voltage can be influenced by the electrical properties of the contaminants. Voltage generated by used oil I as a function of the running distance is shown in Fig. 4. Generally, voltage decreased with increasing running distance. It seems that generation of carbon soots was responsible for the voltage decrease, where the oil conductivity increased. This behaviour can be used to test the validity of the used oil and to determine its life time.

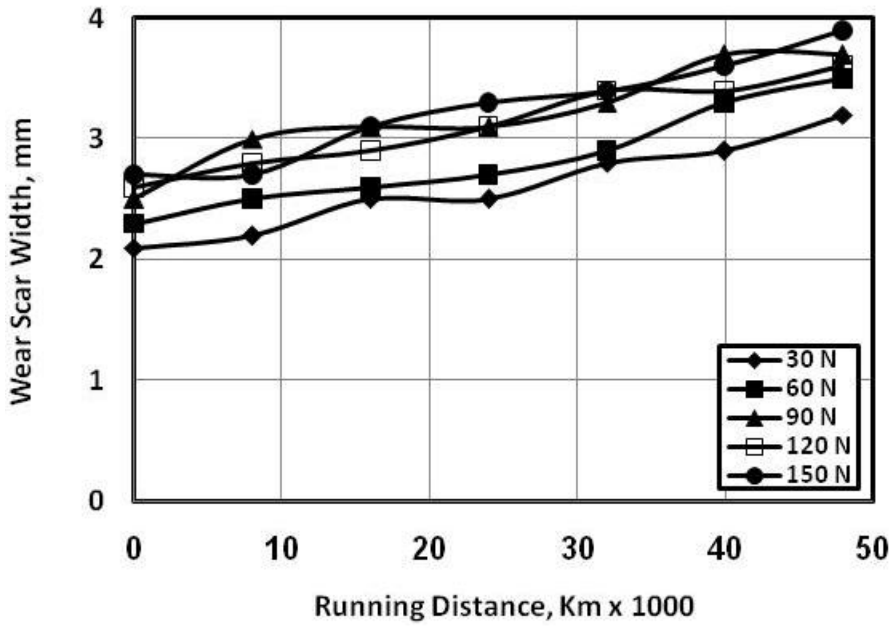

Fig. 3 Wear displayed by used oil I.

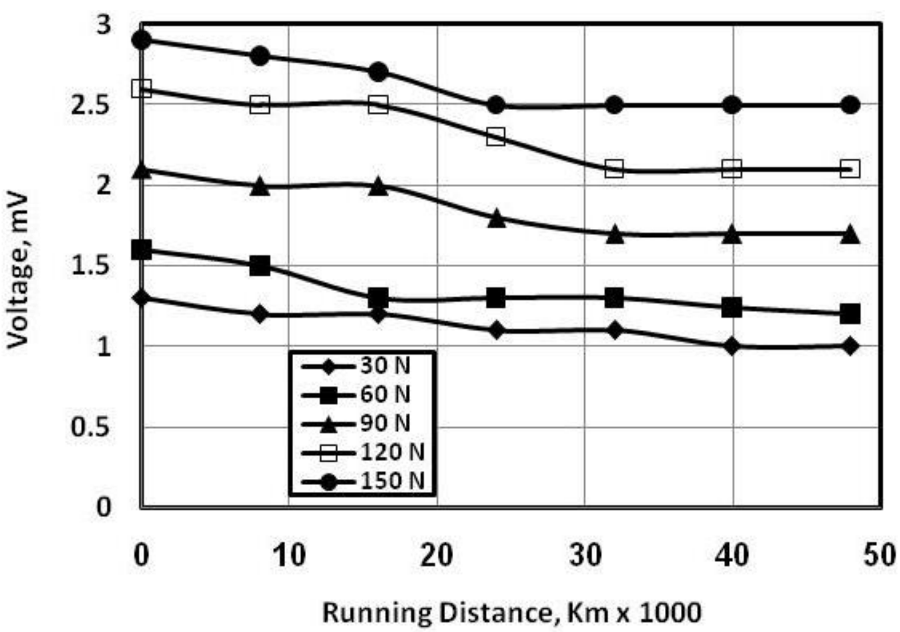

Fig. 4 Voltage generated by used oil I.

The followings are the results of friction coefficient, wear and voltage of the used oil II, Figs. 5, 6 and 7 respectively. Friction coefficient increased up to maximum at 6000 km then decreased with increasing running distance, Fig. 5. This type of oil showed relatively higher friction than oil I.

In contradiction to the friction, wear showed significant decrease with increasing running distance. It seems that the anti-wear additive began to be active after working inside the engine. This behaviour was discussed in several works. It was shown that, used oils possess relatively better lubricating properties than the fresh oils, [32, 33]. As for oils exposed for oxidation, wear increased due to the negative effect of oxidation on the reduction of the effect of antiwear additives. The decomposition products of the antiwear additives are responsible for the wear reduction.

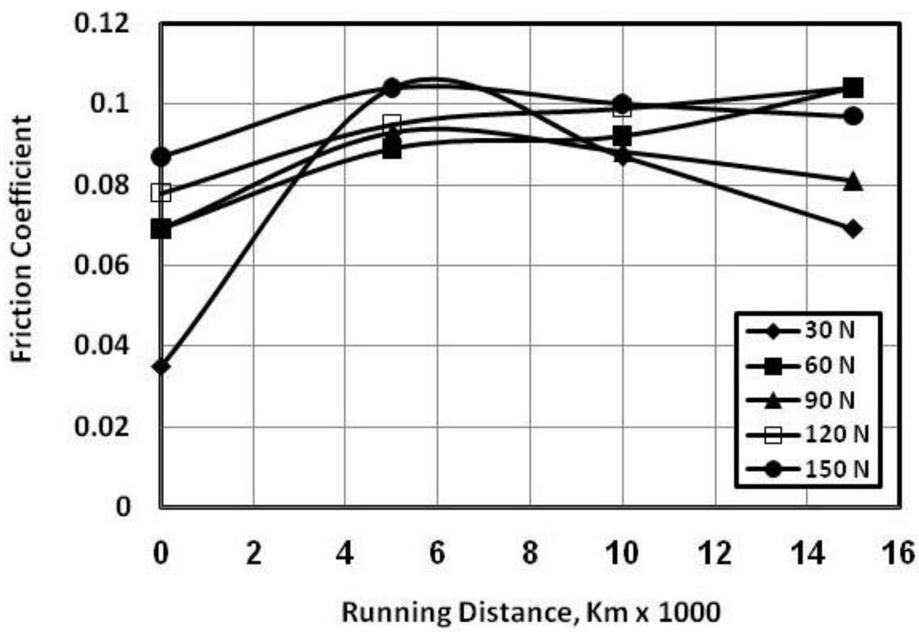

Fig. 5 Friction coefficient displayed by used oil II.

The effect of preheating oil and additives on their lubricating properties was discussed, [34]. The experiments showed that addition of zinc dialkyl dithiophosphate to as received oil up to 0.5 wt. % zinc content caused significant wear decrease. It was found that the best wear resistance can be obtained by preheating both the oil and zinc dialkyl dithiophosphates together for 150 hours at 150 ºC. It was observed that the addition of sulphur to as received oil up to 8 wt. % can reduce wear, [35]. Further increase of sulphur causes wear increase. Zinc dialkyl dithiophosphates can significantly improve the lubricating properties of as received oil containing sulphur additive. The main antiwear agent used in engine oils is zinc dialkyl dithiophosphate (ZDDP) that

decomposes thermally resulting in the formation of various compounds that include 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, [36]. The thickness and coverage of these films on the surface is important in determining the wear resistance under boundary lubrication. When the protective film breaks down there is a steep rise in the friction coefficient. This rise in friction results in the further breakdown of the ZDDP and the establishment of the protective antiwear film. The formation of this protective film results in the decrease in the friction coefficient. Wear decrease may be due to the balance between the formation of the stable antiwear film and the abrasive action of the debris present in the wear track.

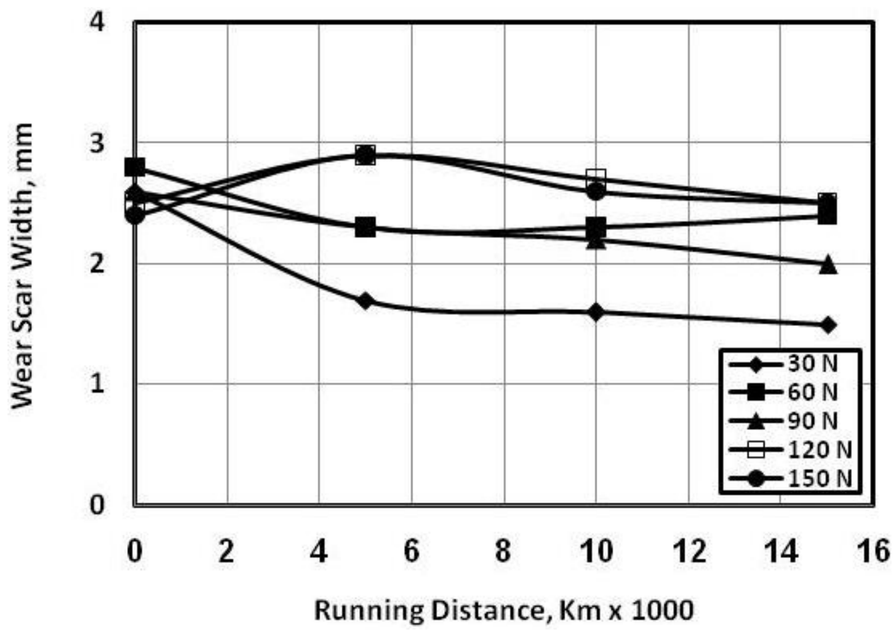

Fig. 6 Wear displayed by used oil II.

The voltage generated showed drastic decrease with increasing running distance, Fig. 7. The decrease might be from the decomposition of the oil molecules into carbon soots. This type of oil showed early response to the drop of the generated voltage. Fresh oil showed higher voltage and as the load increased voltage decreased. Testing the used oil at higher load displayed insignificant voltage decrease, where at lower load the change of voltage with running distance was quite high.

The effect of blending the used oil III by fresh one on the friction, wear and voltage is illustrated in Figs. 8, 9 and 10 respectively. Friction coefficient slightly increased with increasing running distance up to maximum then decreased, Fig. 8. As the load increased friction coefficient increased.

At lower load, wear slightly increased with increasing fresh oil content, Fig. 9, while at higher load wear decreased with increasing fresh oil content. Effect of adding fresh oil into used oil III on the generated voltage is shown in Fig. 10. At all values of load, voltage significantly increased. This behaviour can be attributed to the fact that the concentration of soot particles decreased with increasing fresh oil content. The effect of the sliding velocity on the friction coefficient displayed by used oil I is shown in Fig. 11. The lubrication regime prevailed during the experiments was mixed lubrication, where the fluid viscosity and the elastic coefficient of the solid surface are the most dominant factors. Generally, friction coefficient showed slight decrease with increasing running distance. The sliding velocity showed insignificant effect.

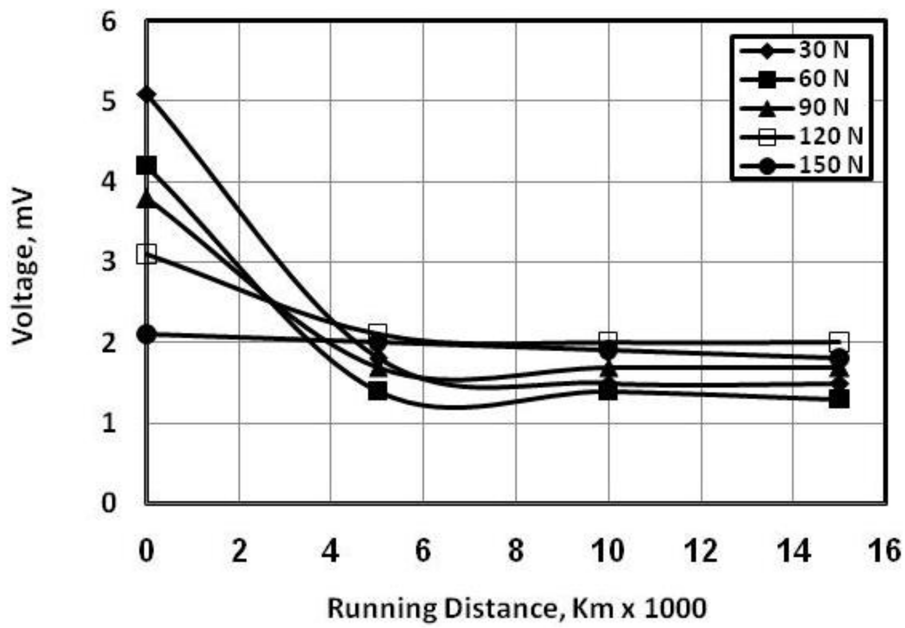

Fig. 7 Voltage generated by used oil II.

Several additives in engine oils are necessary to improve the efficiency of engines by reducing friction and wear as well as by protecting the oil from oxidation [37 - 44]. As both an antiwear and an antioxidant additive, ZDDP has been used in engine oil for several decades. However, in spite of its outstanding properties, ZDDP is the primary source of P, S and heavy metal Zn in the exhaust. Development of metal free additives is a part of a new trend in engine oils.

The effect of sliding velocity on wear caused by the sliding of surfaces lubricated by used oil is shown in Fig. 12. The relatively higher velocity displayed wear higher than that shown for the lower velocity. The difference slightly increased with increasing running distance.

The voltage generated from the lubricated sliding by used oil is shown in Fig. 13. At the higher velocity (1.2 m/s), voltage displayed higher values than that observed for the

lower velocity (0.4 m/s). It seems that as the oil film increased the electrical resistance of the oil increased so that the measured voltage increased. At 1.2 m/s voltage slightly decreased, while it increased at 0.4 m/s with increasing running distance.**

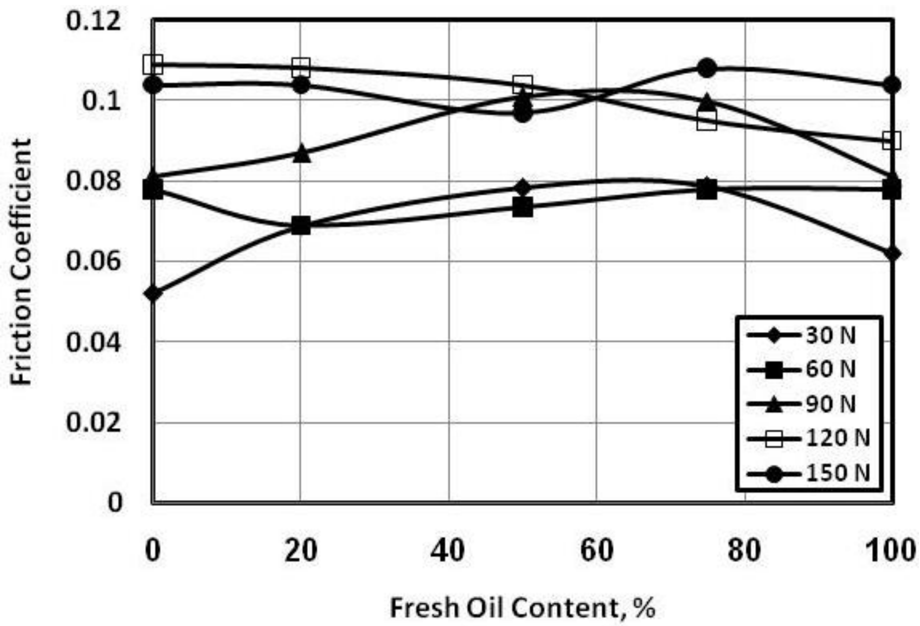

Fig. 8 Effect of adding fresh oil into used oil III on friction coefficient.

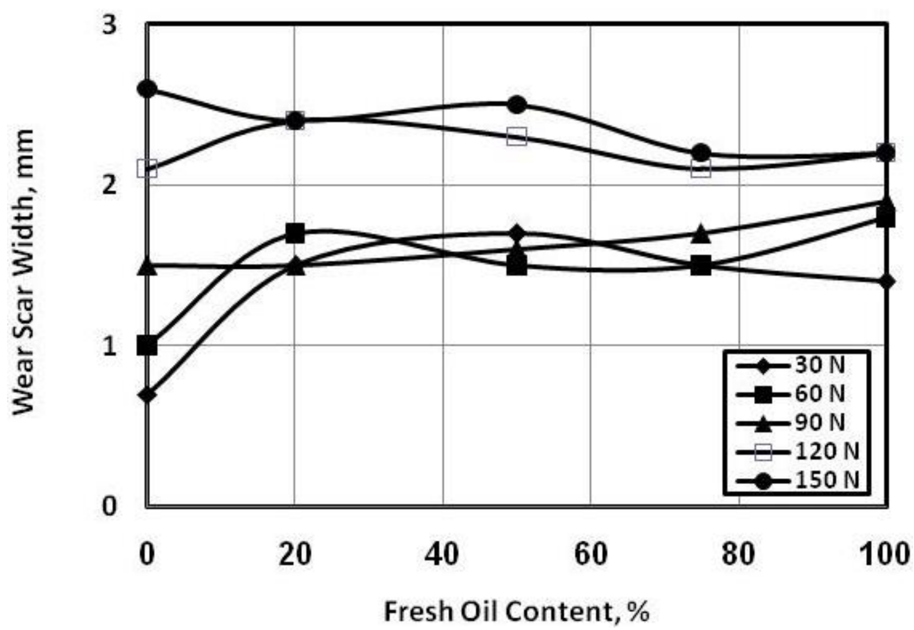

Fig. 9 Effect of adding fresh oil into used oil III on wear.

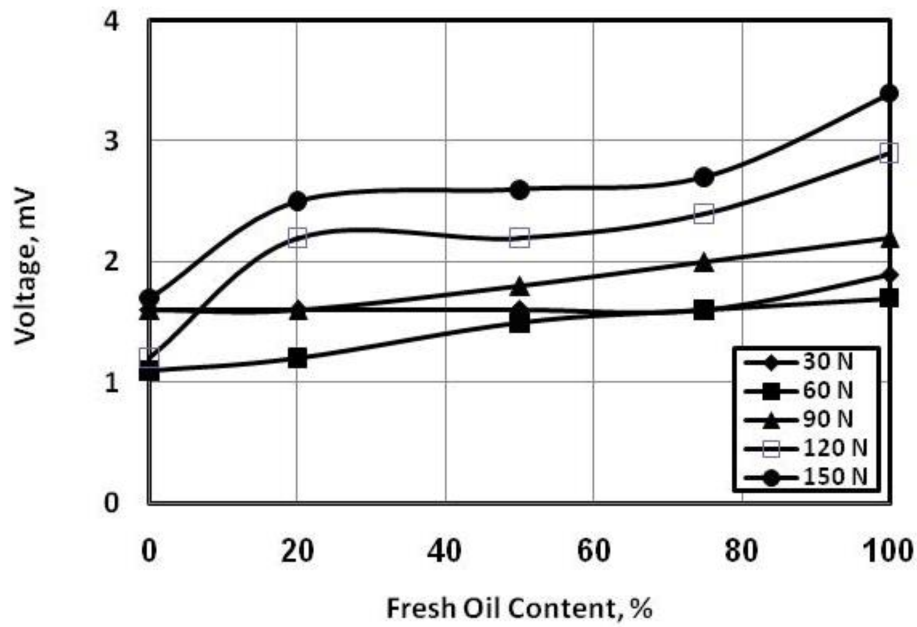

Fig. 10 Effect of adding fresh oil into used oil III on the generated voltage.

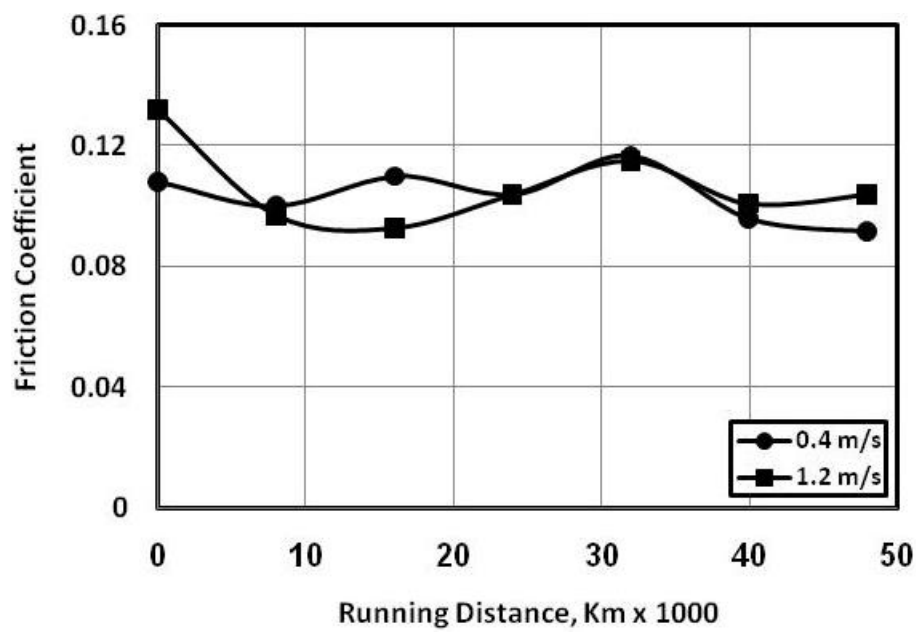

Fig. 11 Effect of sliding velocity on friction coefficient.

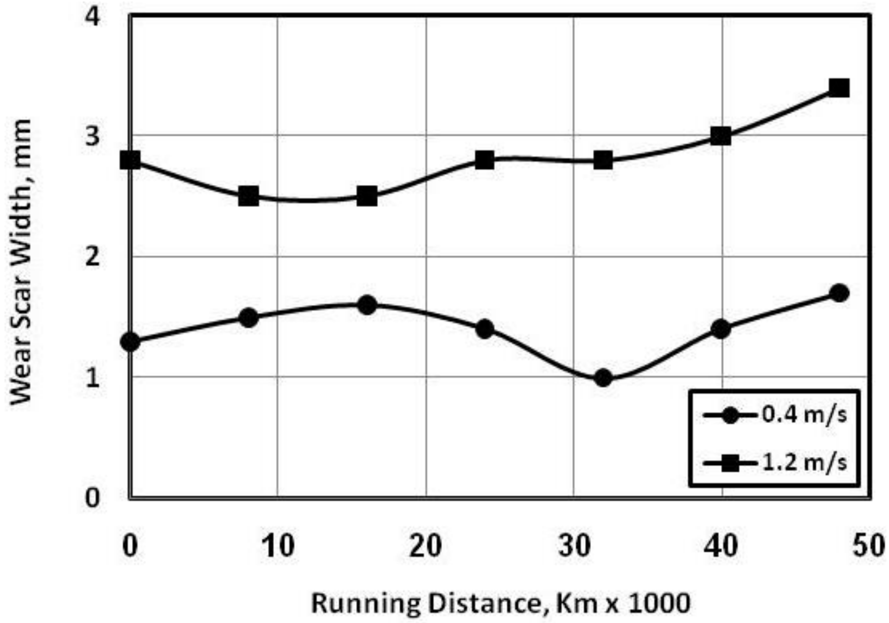

Fig. 12 Effect of sliding velocity on wear.

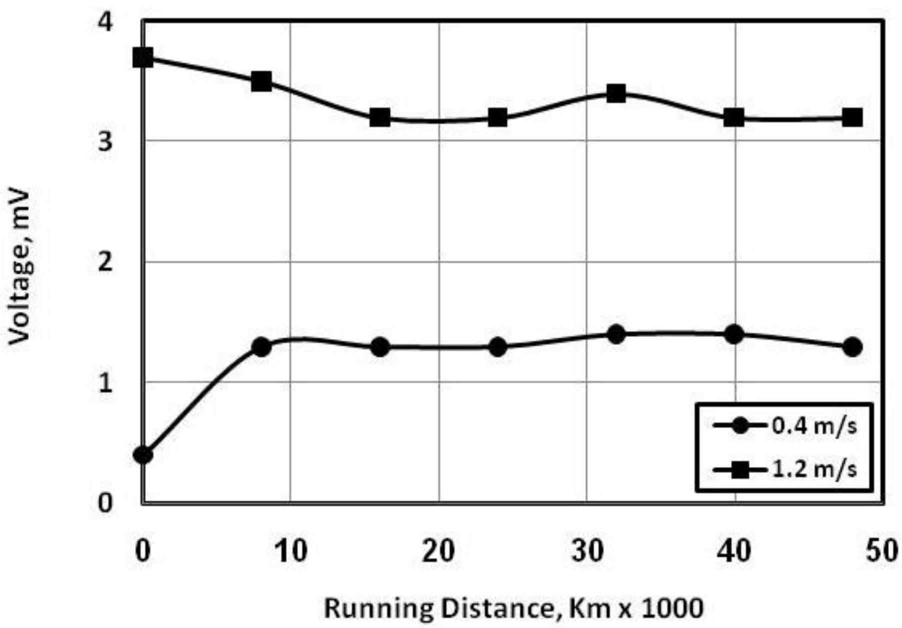

Fig. 13 Effect of sliding velocity on the generated voltage.

CONCLUSIONS

1. Friction coefficient displayed by used oil I significantly decreased with increasing the load. Slight friction increase was observed with increasing the running distance. Wear displayed by the used oil I increased as the running distance increased. As the load increased wear significantly increased indicating the loss of the lubricating properties of

the used oil. Voltage generated by the triboelectrification of the sliding materials, lubricated by used oil I, decreased with increasing running distance. It seems that generation of carbon soots was responsible for the voltage decrease, where the oil conductivity increased. This behaviour can be used to test the validity of the used oil and to determine its life time.

2. Friction coefficient increased up to maximum at 6000 km then decreased with increasing running distance for used oil II. In contradiction to the friction wear showed significant decrease with increasing running distance. The voltage generated showed drastic decrease with increasing running distance for used oil II.

3. Blending the used oil III by fresh oil slightly increased friction coefficient up to maximum then decreased with increasing running distance. At lower load, wear slightly increased with increasing fresh oil content, while at higher load wear decreased with increasing fresh oil content. Voltage significantly increased with increasing the fresh oil content.

4. The sliding velocity showed insignificant effect on friction coefficient displayed by used oil I. The relatively higher velocity displayed wear higher than that shown for the lower velocity. As the sliding velocity increased the voltage increased.

REFERENCES

1. Gajewski J. B., Glogowski M. J., “Influence of an applied electric field on the torque of rotary lip seals on metal shafts. Part I: Effects of lip seal type”, Tribology International 40, pp. 49 - 55, (2007).

2. Gajewski J. B., Glogowski M., "The reduction of braking torque under the dc electric field. In: K. Sun, G. Yu, editors. Proceedings of the fifth international conference on applied electrostatics, Shanghai, China, 2–5 November 2004; Recent developments in applied electrostatics. Oxford: Elsevier;. pp. 314 - 317, (2004).

3. Gajewski J. B., Gogowski M., "Influence of tribocharging on the work of lip seals in a model engine. In: Proceedings of the ninth international conference on electrostatics" ELECTROSTATICS, 2001, Koscielisko - Zakopane, Poland, 29 May–2 June 2001;J Electrostat; 51 - 52, pp. 366 - 373, (2001).

4. Taylor D. M., Secker P. E., "Industrial electrostatics - fundamentals and measurements", Taunton: Research Studies Press Ltd; (1994).

5. Gogowski M. J., Gajewski J. B., Gawliniski M., "The DC electric field effect on braking torque in a model engine", In: Proceedings of the fifth international EHD workshop, Poitiers, France, 30–31 August 2004, pp. 230 - 235, (2004).

6. Harvey T. J., Wood R. J. K., Denuault G., Powrie H. E. G., "Effect of oil quality on electrostatic charge generation and transport", J Electrostat; 55, pp. 1 - 23, (2002).

7. Harvey T. J., Wood R. J. K., Denuault G., Powrie H. E. G., "Investigation of electrostatic charging mechanisms in oil lubricated tribo-contacts", Tribol Int; 35, pp. 605 - 614, (2002).

8. Zaini H., Alahmadi A., Abdel-Sattar S. and Ali W. Y., "Influence of Magnetic Field on the Sliding of Steel Against Lubricated Polyamide", Journal of the Egyptian Society of Tribology Vol. 9, No. 1, January 2012, pp. 39 – 51, (2012).

9. Shoush K. A., Ali W. Y., Abdel-Sattar S. and El-Lithy F. M., "Influence of Magnetic Field on the Friction and Wear Caused by the Scratch of Oil Lubricated High Density

Polyethylene", Journal of the Egyptian Society of Tribology Vol. 9, No. 2, April 2012, pp. 1 – 14, (2012).
10. Zaini H., Alahmadi A., Ali W. Y. and Abdel-Sattar S., "Influence of Magnetic Field on the Action Mechanism of Lubricant Additives", Journal of the Egyptian Society of Tribology Vol. 9, No. 2, April 2012, pp. 15 – 28, (2012).
11. Zaini H., Alahmadi A., Ali W. Y. and Abdel-Sattar S., "Influence of Magnetic Field on Friction Coefficient Displayed by the Oil Lubricated Sliding of Steel ", Journal of the Egyptian Society of Tribology Vol. 9, No. 2, April 2012, pp. 29 – 42, (2012).
12. Mohamed M. K., Alahmadi A., Ali W. Y. and Abdel-Sattar S., "Effect of Magnetic Field on the Friction and Wear Displayed by the Scratch of Oil Lubricated Steel", Journal of the Egyptian Society of Tribology Vol. 9, No. 4, October 2012, pp. 12 – 27, (2012), International Journal of Engineering & Technology IJET-IJENS Vol:12 No:06, pp. 137 – 143, (2012).
13. Abeer A. E., Abo Ainin H. M., Khashaba M. I., Ali W. Y., "Effect of Magnetic Field on Friction and Wear of Steel", Journal of the Egyptian Society of Tribology, Vol. 8, No. 2, April 2011, pp. 1 – 15, (2011), Metall 66. Jahrgang 7 - 8/2012, pp. 267 – 273, (2012).
14. Abdel-Jaber G. T., Mohamed M. K., Al-Osaimy A. S. and Ali W. Y., "Effect of Magnetic Field on the Performance of Lubricant Additives", September 27 – 29, 2011, Tribologie Fachtagung, Göttengen, Germany, (2011), Journal of Applied and Industrial Sciences, April, 2013, 1 (1), pp. 25 – 31, (2013).
15. Rounds F.G., "Carbon: cause of diesel engine wear? SAE Technical Paper 770829, (1977).
16. Rounds F.G., "Soots from used diesel engine oils-their effects on wear as measured in four ball wear tests, SAE Technical Paper 810499, (1981).
17. Antusch S., Dienwiebel M., Nold E., Albers P., Spicher U., Scherge M., "On the tribochemical action of engine soot", Wear 269, pp. 1 - 12, (2010)
18. Ryason P.R., Chan I., Gilmore J., "Polishing wear by soot", Wear 137, pp. 15 – 24, (1990).
19. Nagai I., Endo H., Nakamura H., Yano H., "Soot and valve train wear in passenger car diesel engines", SAE Technical Paper 831757, (1983).
20. Ratoi M., Spikes H.A., "The influence of soot and dispersant on ZDDP film thickness and friction", Lubric. Sci. 17 (1), pp. 25 - 43, (2004).
21. Gautam M., Chitoor K., Durbha M., Summers J.C., "Effect of diesel contaminated oil on engine wear-investigation of novel oil formulations", Tribol. Int. 32, pp. 687 – 699, (1999).
22. Soejima M., Ejima Y., Uemori K., Kawasaki M., "Studies on friction and wear characteristics of cam and follower: influences of soot contamination in engine Oil", JSAE Rev. 33 (1), pp. 113 – 119, (2002).
23. Yamaguchi E. S., Untermann M., Roby S. H., Ryason P. R., Yeh S.W., "Soot wear in diesel engines", J. Eng. Tribol. 220, pp. 463 – 469, (2006).
24. Aldajah S., Ajayi O. O., Fenske G. R., Goldblatt I. L., "Effect of exhaust gas recirculation (EGR) contamination of diesel engine oil on wear", Wear 263, pp. 93 - 98, (2007).

25. Truhan J. J., Qu J., Blau P. J., "The effect of lubricating oil condition on the friction and wear of piston ring and cylinder liner materials in a reciprocating bench test", Wear 259, pp. 1048 – 1055, (2005).

26. Kawamura M., Fujita K. and Ninomiya K., "The Lubricating Properties of Used Oil", Wear 77, pp. 195-202, (1982) .

27. Fujita K., Esaki Y. and Kawamura, M."The Antiwear Property of Zink Dialkyldithiophosphates in Used Engine Oils", Wear 89, pp. 323 – 331, (1983).

28. Spedding H. and Watkins R., "The Antiwear Mechanism of $Z_nDTP's$", Part 1, Tribology International, Feb. 1982, pp. 9 -13, (1982).

29. Ali W. and Mousa M., "Wear and Friction of Cylindrical Contacts by Lubricant Abrasive Contaminants." Proceedings of EGTRIB First Tribology Conference, Dec. 20 - 21, 1989, Cairo, Egypt, (1989).

30. Mousa M. and Ali W., "Particle Size Effect on Wear and Friction Caused by Abrasive Contaminated in Lubricating Oil", Proceedings of the III Int. Conference Of Mech. Eng., Ain-Shams Univ., Dec. 27 - 29, 1990, Cairo, Egypt, pp. 213 - 222, (1990).

31. Ali, W. Y. and Mousa, M. O., "Effectiveness Of Used Oil", Proceedings of EGTRIB First Tribology Conference, Dec. 20 - 21, 1989, Cairo, Egypt, (1989).

32. Ibrahim, A. A., Youssef, M. M. and Ali, W. Y., "Lubricating Properties of Used Automotive Oils", Proceedings of The 7th Yugoslav Tribology Conference, 11 – 12 OCTOBER 2001, pp. 2-65 – 2-68, (2001).

33. El-Kersh, A. M., Ezzat, F. H. Khashaba, M. I. and Ali, W. Y., "Investigation of the Lubricating Properties of Diesel Engine Used Oils", Proceedings of The International Conference of Development and Environment, Assiut University, March 26 – 28, Assiut, Egypt, pp. 363 – 371, (2002).

34. Rasha A. H., Bastaweesy A. M. and Ali W. Y, "Effect of Preheating Lubricating Oil and Zinc Dialkyl Dithiophosphates on the Wear Resistance of Steel", Journal of the Egyptian Society of Tribology, Vol. 2, No. 4, Jnuary, pp. 1 – 13, (2005).

35. Rasha A. H., Bastaweesy A. M. and Ali W. Y, "Effect of Preheating Lubricating Oil and Sulphur Containing Additives on the Wear Resistance of Steel", Journal of the Egyptian Society of Tribology, Vol. 2, No. 4, Jnuary, pp. 15 – 24, (2005).

36. Spikes H.A., The history and mechanisms of ZDDP, Tribology Letters 17 (3), pp. 469 - 489, (2004).

37. Yamaguchi E. S., Untermann M., Roby S. H., Ryason P. R., Yeh S. W., "Soot wear in diesel engines", J. Eng. Tribol. 220, pp. 463 - 469, (2006).

38. Kim B., Mourhatch R., Aswath P. B., "Properties of tribofilms formed with ashless dithiophosphate and zinc dialkyl dithiophosphate under extreme pressure conditions", Wear 268, pp. 579 – 591, (2010).

39. Nicholls M. A., Do T., Norton P R., Kasrai M., Bancroft G. M., "Review of the lubrication of metallic surfaces by zinc dialkyl dithiophosphates", Tribology International 38 pp. 15 – 39, (2005).

40. Hua W., Jing L., Hongling Y., Xiangqiong Z., Lingbo L., Tianhui R., "The tribological behavior of diester-containing polysulfides as additives in mineral oil", Tribology International 40 (8), pp. 1246 - 1252, (2007).

41. Kim Y., Chung K., Kim N., Hwang D., Cho W., "Synergistic lubricating effect of several ashless dithiocarbamates with mo-donor additives", Tribology International 40 (2), pp. 397 - 404, (2007).

42. Ribeaud M., "Volatility of phosphorus-containing anti-wear agents for motor oils", Lubrication Science 18 (3), pp. 231 - 241, (2006).

43. Mahmoud M. M., Elhabib O. A., Ayad M. A., Ali W. Y., "Determining the Operating Time of the Engine Oils", Journal of the Egyptian Society of Tribology, Vol. 7, No. 4, October 2010, pp. 40 – 51, (2010).

44. Khattab A., Mohamed M., Sulaimany A., Ali W., "Extending the Operating Time of the Used Oil by Auxiliary Filtration", Proceedings of The Second Seminar of the Environmental Contaminants and their Reduction Methods, April, 12, 13, 2009, AlMadina AlMonawwara, K. S. A., pp. 279 – 291, (2009).