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DETERMINING THE OPERATING TIME OF THE ENGINE OILS

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ABSTRACT

The environment of Arab countries suffers from the relatively high concentration of dust in air, due to the lack of rain and the vast area of desert, which causes an increase in wear rate of engines. Consequently, the period of lubricating oil change has been reduced to get rid of the contaminated oil to avoid further wear. This solution is severely polluting the environment because some people used to get rid of the used oil by burning causing hazardous toxic fumes due to the presence of the chemical additives. Besides, used oil can leak to the water resources and pollute them. In addition to that, lubricating oil contains antiwear additives which need longer time to react and give up the required lubricating properties.

To overcome those severe environmental impacts, it was planned in the present work to investigate the change of the lubricating properties of the engine oils in use. Experiments have been carried out to investigate the lubricating properties of the used oils. Oil samples taken from three passenger cars, running in City of Al-Taif, Kingdom of Saudi Arabia, were tested using a test rig designed especially for that purpose. It was found that both the friction coefficient and wear increased with increasing running distance up to 2000 km then decreased to values lower than that displayed by fresh oils. It was found that antiwear additives (zinc dialkyl dithiophosphate ZDDP) decompose yielding products that react with the metal surface to form a film that is highly wear resistant. This observations confirm the necessity to extend the operating time of the used oil up to 5000 km running distance to make full use of the improvement of the lubricating properties of used oil during usage. Besides, considering the measurements of both kinematic viscosity and total base number, it can be concluded that the tested used oils were still efficient and their use can be extended for longer running distance. The application of a by-pass oil cleaners containing a super fine filtering materials which absorb contaminants down to the size of 0.1 µm is necessary to remove most of the solid and liquid contaminants in the lubricating oil. The proposed oil cleaners can trap sludge and carbon soots. This helps to prevent wear of engine and reduce the cost of lubricating oil, which occupies a great portion of the maintenance cost.

KEYWORDS

Used engine oils, friction coefficient, wear, lubricating properties, antiwear additives.

INTRODUCTION

Experiments have been carried out to investigate the lubricating properties of fresh, used and filtered oil, [1]. Oil samples taken from three cars were tested using a test rig designed especially for that purpose. Test results show that wear and friction displayed by used oil represented higher values compared to fresh and filtered oil. As for filtered oil, wear and friction decreased with the running distance due to the decomposition of lubricant additive. Two super fine filtration methods are proposed to extend the serviceable life of the lubricating oil and reduce engine wear.

The lubricating properties of engine oil change with running time owing to the effects of such factors as oxidation, thermal degradation, reaction with sliding surfaces, contamination by engine blow-by and additive depletion. Since these changes start as soon as an engine is used, almost all engines should be considered to be lubricated by used oil. Therefore, investigation of engine lubrication should be carried out using both fresh and used oils, but little work on used oils has been reported, [2 - 4]. 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 additive which reduces wear and friction as it decomposes in the oil. The oil contains the Zink dialkyl dithiophosphate (ZnDTP) which is one of the most effective additives influencing the lubricating properties of engine oil. It was found that 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, [2, 3,5].

The working clearances in the engine are sufficiently great to enable the small carbon particles to pass between them without causing wear. But under the influence of high temperature, the soft carbon particles harden and agglomerate into larger and more abrasive particles, [6]. The common types of oil filters are not sufficiently fine to remove most of the potentially abrasive particles. If a filter is to be increased with filtering accuracy, the flow rate of the oil passing through the filter decreases as the filter quickly becomes clogged. Application of a by-pass system containing a super fine oil cleaner which absorb contaminants down to the size of 0.1 μm, [7], can trap sludge and carbon and cosequently viscosity of the oil can be recovered to certain levels. This helps to prevent wear of engine. The cost of lubricating oil, which occupies a great portion of the maintenance cost, can be substantially reduced. Some of the good oil cleaners can extend oil service life to about 60,000 - 100,000 km or it requires an oil change once a year.

It was found that for used oil, the friction coefficient has an erratic behaviour like that observed in previous experiments, [8, 9], when the lubricant was contaminated by abrasive particles. The microscopic inspection was used to check the cleanliness of fresh and used oil samples. It was surprising that the fresh oil samples contain a lot of abrasive particles up to 150 μm while in used oil samples the abrasive contaminant concentration is relatively high, [10]. These photomicrographs confirm that the increase of wear with running distance is due to the progressive quantity of abrasive contaminants circulating in the used oil. Test results show that wear and friction displayed by used oil represented higher values compared to fresh and filtered oil. As for fi1tered oil, wear and friction decreased with the running distance due to the decomposition of lubricant additive. Two super fine filtration methods were proposed to extend the serviceable life of the lubricating oil and reduce engine wear.

It was shown that, used oils possess relatively better lubricating properties than the fresh oils, [11, 12]. 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.

The effect of preheating oil and additives on their lubricating properties was discussed, [13]. Zinc dialkyl dithiophosphates were added to the base oil at different concentrations after prehearing to 150°C for 50, 100 and 150 hours. Wear scar diameter of the stationary pin in the cross pin wear tester was considered as a measure of the lubricating property of the tested additives. The experiments showed that addition of zinc dialkyl dithiophosphate to as received oil up to 0.5 wt. % zinc content caused significant wear decrease. Further increase of zinc dialkyl dithiophosphate increased wear. Besides, dilution of the preheated additives in the as received oil did not enhance the wear resistance, while addition of preheated zinc dialkyl dithiophosphates to the preheated oil showed 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. Dilution of the preheated calcium sulphonate in the preheated oil for 150 hours at 150 ºC displayed significant wear reduction. It was observed that the addition of sulphur to as received oil up to 8 wt. % can reduce wear, [14]. Further increase of sulphur causes wear increase. Zinc dialkyl dithiophosphates can significantly improve the lubricating properties of as received oil containing sulphur additive. The addition of ZDDP can reduce the optimum sulphur content to 4 wt. % for minimum wear. Besides, addition of the preheated additives to the as received oil does not enhance the wear resistance. The best wear resistance can be obtained by preheating both the oil and the additives for 150 hours at 150 ºC.

The aim of the present work is to investigate the lubricating properties of the engine oils as a function of the running distance aiming to extend the actual period of oil change of the used oils.

EXPERIMENTAL

The tested used oils samples were used to lubricate three passenger cars running in Al-Taif City in Saudi Arabia. 100 ml samples of the used oil were taken from the port of the oil-level stick. Experiments were carried out using a cross pin wear tester, Fig. 1. It consists, mainly, of rotating and stationary pins of 20 mm diameter and 100 mm long. The material of the pins is carbon steel (St. 60), (0.6 % C, 0.25 % Si, 0.65 % Mn, 0.045 % P and 0.045 % S) of 1800 MPa hardness. The rotating pin was attached to a chuck mounted on the main shaft of the test rig. The stationary pin was fixed to the loading block where the load is applied. The main shaft of the test machine is driven by DC motor (300 watt, 250 volt) through a V-belt drive unit. Moreover, the motor speed is adjustable and can be controlled by varying the input voltage. The test rig is fitted by a load cell to measure the frictional torque generated in the contact zone between the rotating and stationary pins.

Normal loads were applied by means of weights attached to the loading lever. A counter weight is used to balance the weights of the loading lever, the loading block and the stationary specimen. The tests were carried out at 300 rev/mm (0.32 m/sec), load of 6, 10 and 16 N and for a test time of 5 minutes.

The wear scar diameter was measured for the upper stationary pin using an optical microscope within an accuracy of ±1 µm. The contact area was lubricated by the tested oil at the beginning of the test and every minute of the testing time. The wear tests were repeated three times and the mean values of friction coefficient and wear scar diameter were considered. The lubrication tests were carried out to measure friction coefficient and wear using the tested used oils taken from the three cars I, II and III. Fresh oil used for every car was tested as a base of comparison.

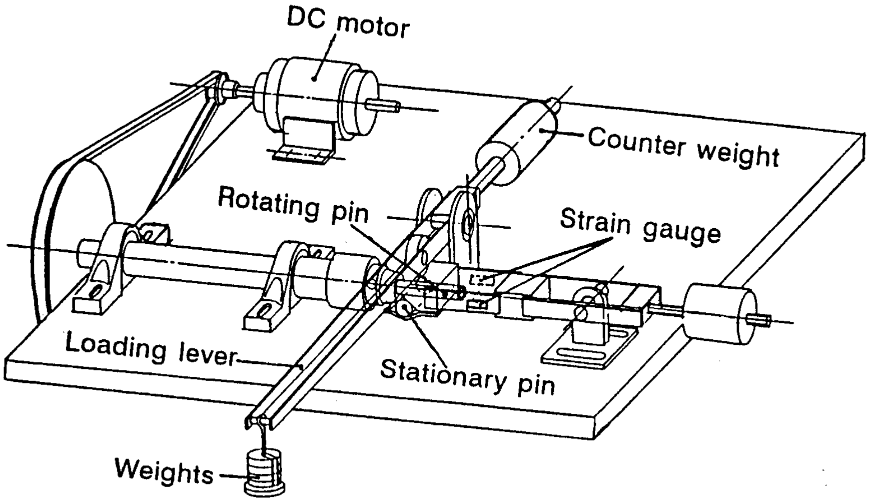

Fig. 1 Arrangement of the test rig.

RESULTS AND DISCUSSION

The measurements of the change of kinematics viscosity, at 40 and 100 °C and total base number (TBN), with increasing of the running distance of the tested oils are shown in Figs. 2 – 4. It is clearly seen that kinematic viscosity slightly increased with increasing the running distance due to the generation of wear particles and carbon soots as well as foreign solid particles entered to the engine through air, fuel and oil. The viscosity increase is lower than 5 % relative to the fresh oil. The total base number of the tested used oils significantly decreased with increasing the running distance, where the lowest value exceeded 8 mg KOH/g. Based on the above measurements it can concluded that the tested used oils were still efficient and their use can be extended for longer running distance.

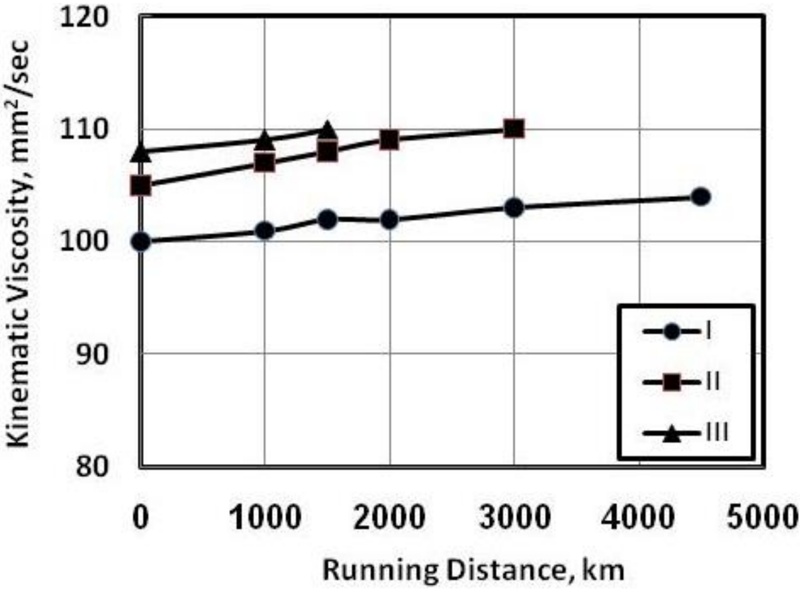

Fig. 2 Kinematic viscosity of the tested used oils at 40 °C.

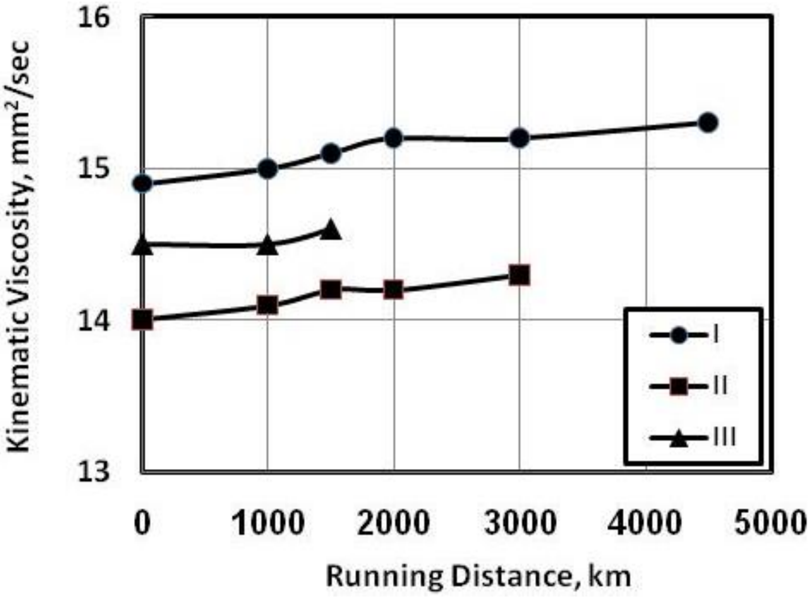

Fig. 3 Kinematic viscosity of the tested used oils at 100 °C.

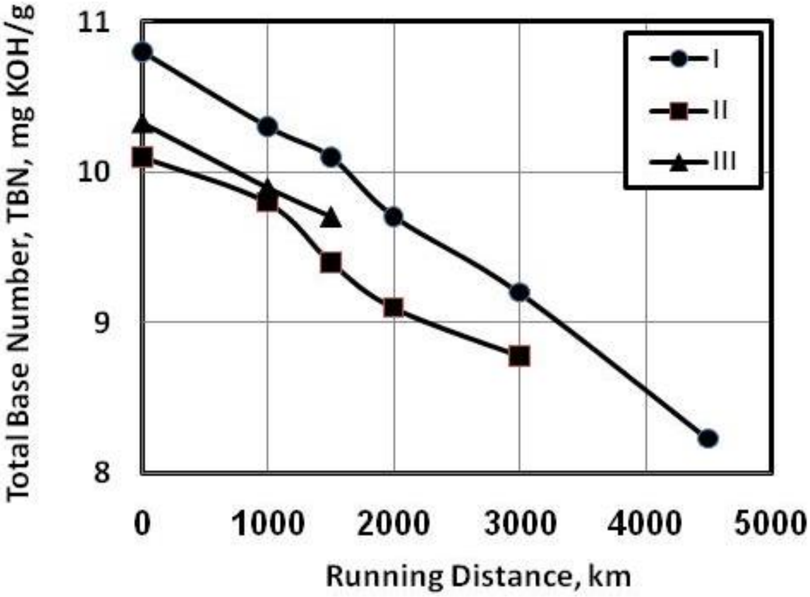

Fig. 4 The total base number (TBN) of the tested used oils.

The lubricating properties of the tested used oils are illustrated in Figs. 5 – 10. Friction coefficient displayed by used oil (I) is shown in Fig. 5. Fresh oil displayed relatively lower friction values of 0.22, 0.3 and 0.32 at 6, 10 and 16 N respectively. After 1000 km running distance, friction coefficient increased up to 0.42, 0.57 and 0.58 at 6, 10 and 16 N respectively. Further slight friction increase was observed after 2000 km running distance. As the running distance increased to 3000 km, significant friction decrease was observed. Further friction decrease was displayed after 4500 km running distance.

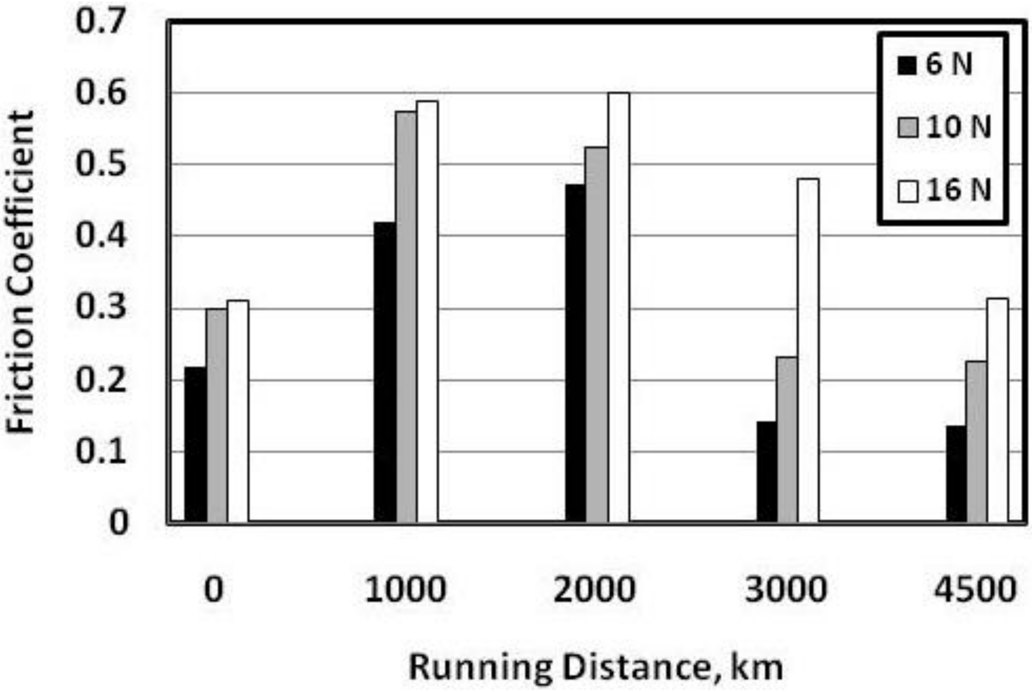

Fig. 5 Friction coefficient displayed by used oil (I).

Wear scar diameter as a measure of the antiwear properties of the used oil (I) is shown in Fig. 6. Wear behaviour showed the same trend observed for the friction coefficient. The wear scar diameter increased with the running distance up to 2000 km and then decreased. The results suggested that a new agent which may contribute to the antiwear behaviour was formed. 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 [14 - 16]. The thickness and coverage of these films on the surface is important in determining the wear resistance under boundary lubrication. The stable film has been shown by several earlier studies to be composed of polyphosphates of Zn and Fe and sulfides and sulfates of Zn and Fe. 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. The eventual breakdown of the film corresponds to the exhaustion of the ZDDP in the oil coupled with increase in the extent of wear debris. The duration and failure of the friction process depend greatly on the nature of the protective antiwear film, amount of lubricant used and the applied load. It was found that antiwear additives (zinc dialkyl dithiophosphate ZDDP) decompose yielding products that react with the metal surface to form a film that is highly wear resistant. A spectroscopy study using X-ray absorption, [17], was carried out to identify sulfur and phosphorus containing species. It was revealed that the tribofilms consist of long chain polyphosphates. When just ZDDP is used at high pressure it is possible to form a heavily crosslinked polyphosphate film, [18].

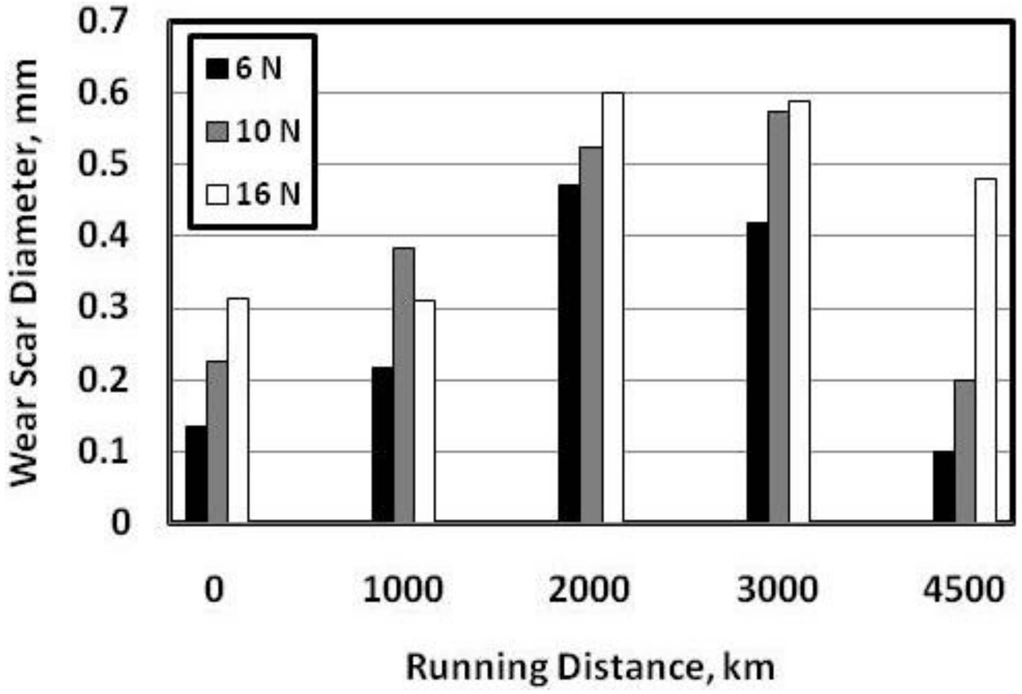

Fig. 6 Wear scar diameter of stationery test specimen lubricated by used oil (I).

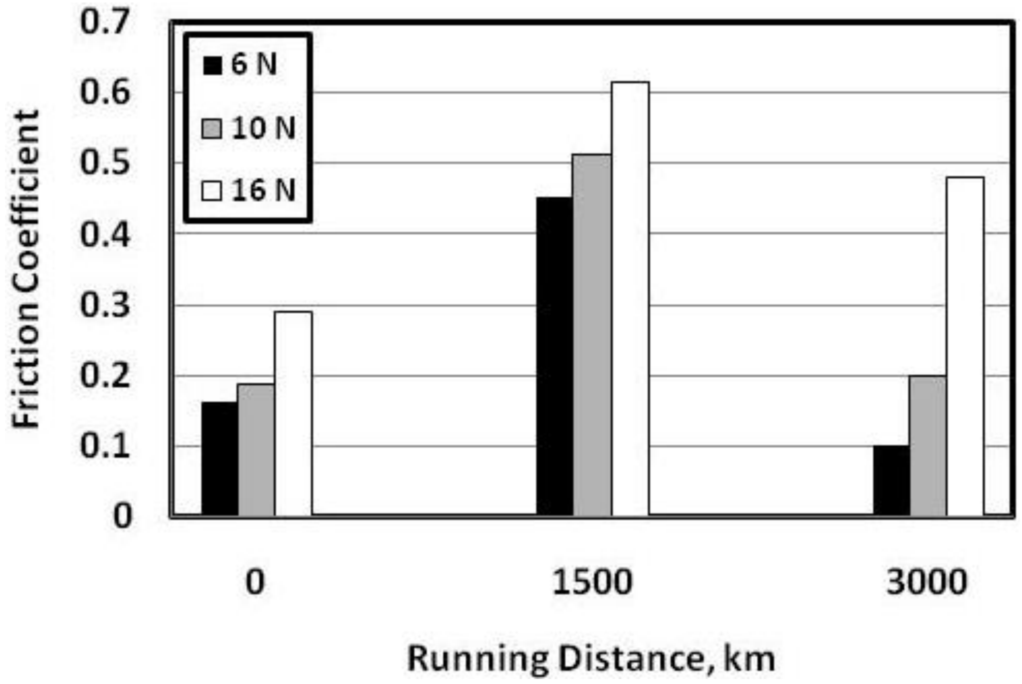

Fig. 7 Friction coefficient displayed by used oil (II).

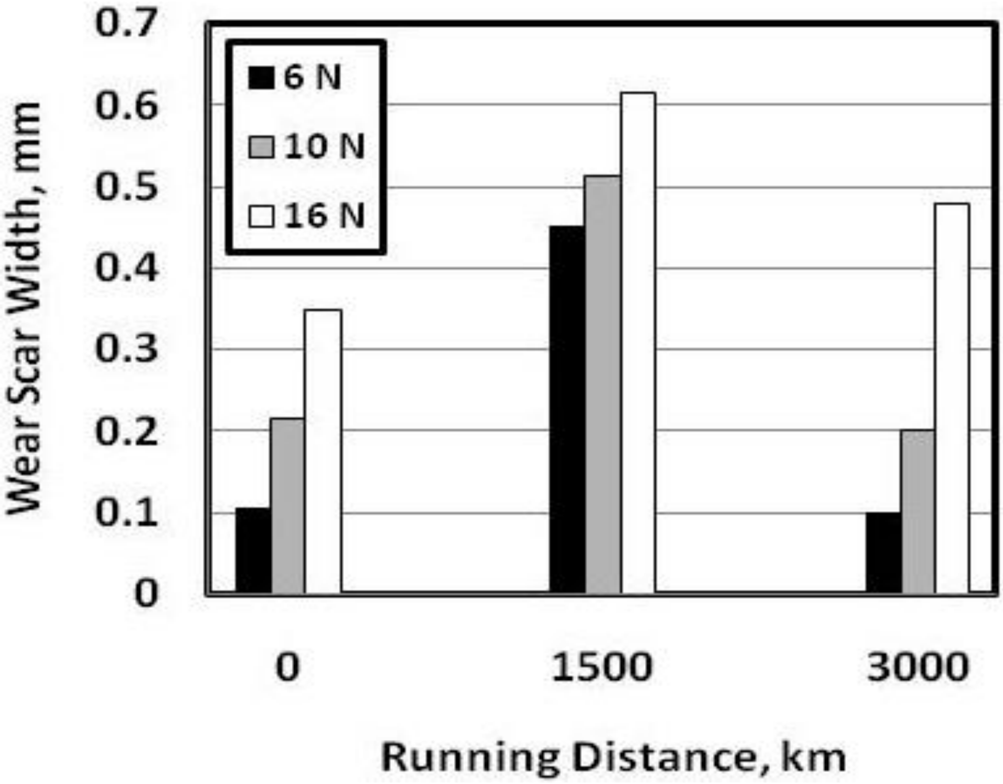

Fig. 8 Wear scar diameter of stationery test specimen lubricated by used oil (II).

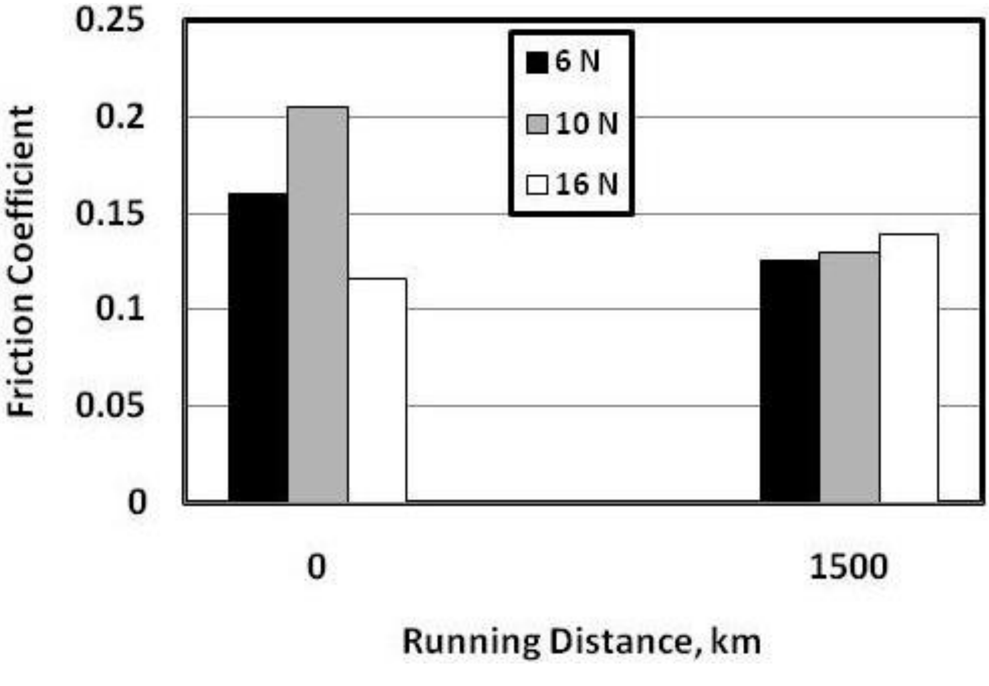

Fig. 9 Friction coefficient displayed by used oil (III).

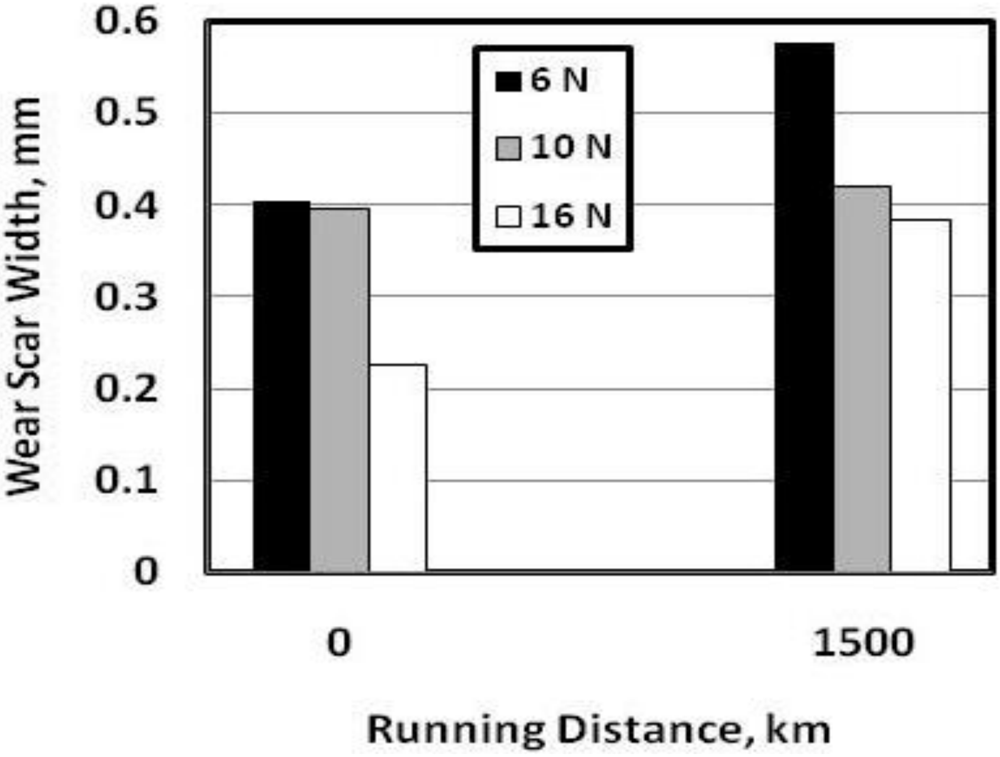

Fig. 10 Wear scar diameter of stationery test specimen lubricated by used oil (III).

The same trend of the behaviour of both friction coefficient and wear was observed for the used oil taken from the other two cars (II) and (III), Figs. 7 - 10. The increase of friction coefficient and wear in the first 2000 km running distance may be due to the increase of the soot particulate. The effect of soot particulate emission on the life of automotive engines was discussed, [19 - 23]. It was found that dispersed carbon black rapidly abraded ZDDP reaction films.

Moreover, it was seen that higher soot concentration in oil generates more wear whereas a higher concentration of phosphorus in the oil leads to less wear. It was concluded that the chemical activity of soot particles and their reaction with ZDDP prevent the formation of liquid boundary layers on metal surfaces. After 2000 km running distance, friction coefficient and wear decreased due to the decomposition product of the antiwear additives that dissolved in the lubricating oil. The observations suggest that the good antiwear properties of the used oil after 2000 km running distance may be attributed to the antiwear ability of the decomposition products of the antiwear additives.

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 [24 - 29]. 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. Ashless phosphorus containing antiwear additives have been found to be particularly effective at reducing friction and inhibiting wear. It was found that an ashless dialkyl dithiophosphate can have superior antiwear and antioxidation performance under extreme pressure conditions. On the other hand it was found that ZDDP has better wear protection compared with ashless dithiophosphates and a combination of ZDDP and ashless dithiophosphate can provide very good wear protection.

CONCLUSIONS

1. Based on the measurements of kinematic viscosity and total base number, it can be concluded that the tested used oils were still efficient and their use can be extended for longer running distance.
2. The lubricating properties of engine oil containing ZDDP increases with increasing the running distance due to the decomposition of ZDDP in oil solution to zink polyphosphate and a mixture of alkyl sulphides which provide the antiwear action of ZDDP.
3. The operating time of the used oil should be extended up to 5000 km running distance to make full use of the improvement of the lubricating properties of used oil during usage.
4. Application of a by-pass oil cleaners containing a super fine filtering materials which absorb contaminants down to the size of 0.1 µm is necessary to remove most of the solid and liquid contaminants in the lubricating oil. The proposed oil cleaners can trap sludge and carbon soots. This helps to prevent wear of engine and reduce the cost of lubricating oil, which occupies a great portion of the maintenance cost.

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