Role of Nanolubricants Formulated in Improving Vehicle Engines Performance

Mohamed Kamal Ahmed Ali1,2, Hou Xianjun1,2,*, Mohamed A. A. Abdelkareem1,2, Ammar H. Elsheikh3

1Hubei Key Laboratory of Advanced Technology for Automotive Components, Wuhan University of Technology, Wuhan 430070, China.
2Automotive and Tractors Engineering Department, Faculty of Engineering, Minia University, El-Minia 61111, Egypt.
3Department of Production Engineering and Mechanical Design, Tanta University, Tanta 31527, Egypt.

First Author: E-mail: eng.m.kamal@mu.edu.eg & * Corresponding Author: E-mail: houxj@whut.edu.cn

Abstract. Transportation sector is a primary consumer of different energy resources, especially in vehicles. Accordingly, industrial society needs novel affordable strategies, accessible and sustainable for fuel economy and reducing the exhaust emissions from combustion engines. The wear and friction are a principal reason for energy dissipation owing to the frictional losses that reach 17-19% of the engine output power. Improving the tribological properties and engines performance is a straightforward approach for saving energy and decreasing emissions using nanomaterials as eco-friendly based nanolubricants to replace the environmentally harmful additives of the traditional commercial engine oils. This study summarizes the recent advances in the area of nanolubricant additives and engine performance lubricated by nanolubricants additives.

1. Introduction
The ability of lube oils to get better fuel economy is critical in automotive engines worldwide. With increasing concern about energy shortage and environmental protection, transportation vehicles account for about 19% of the world’s energy consumption and 23% of the total greenhouse emissions every year [1, 2]. The research trend on fuel economy and reducing frictional power losses have become the principal research aspect regarding automotive engines performance. The world needs novel strategies in which our sources of energy are affordable, accessible and sustainable, as well as reducing the carbon emissions from the energy are essential [3]. Furthermore, this distribution of oil supply generally does not coincide with where the demand is located. Therefore, many countries import oil at an unprecedented scale, which can lead to a significant balance of trade and national security challenges.

The wear and friction for the mechanical elements is a primary cause of energy dissipation in vehicle engines. The engine generated power is diminished in the range of 17-19% due to the frictional losses [4]. Future automotive engines require more efficient engine oils, a state that appears a new challenge for designers and researchers worldwide regarding enhancing the vehicular engine tribology while achieving improving both the lube oil and fuel consumption [5]. Accordingly, the studies on frictional power losses reduction have gained prominent attention as a promising trend in improving the
performance of vehicle engines for saving energy [4, 6]. Additionally, the emission standards imposed on transportation sectors have been the principal aspect upon the expansion of cleaner and fuel-efficient lube oils over the years. Commercially, 90% of lube oils are included of hydrocarbon molecules and the rest are additives controlling their performance [7]. For engine efficiency enhancement, it is necessary exploring novel ways to replace the use of environmentally harmful additives, which generate adverse emissions (ZDDP, zinc dialkyldithio-phosphate) and other additives that include sulfated ash, phosphorous and sulphur, without compromising on tribological behavior for automotive engines with eco-friendly additives such as the nanoparticles and ionic liquids [8].

2. Nanoparticles Dispersion Stability in Lube Oils
The mixing of nano-additives with the lube oils is a significant step towards the enhancement in the quality of nanolubricants. The nanomaterials in engine oil might be stuck together and produce larger agglomerates, and thereby settle down due to gravity. The aggregation occurred whenever the Van der Wall (attractive forces) and Brownian motion of the nanomaterials were larger than the repulsive forces [9]. The agglomeration of nanomaterials issues not only in sedimentation but a negative influence on the frictional performance. Consequently, the dispersion stability is very desirable for reliable nanolubricants formulation. The stability of nano-lubricants means that the nanomaterials do not accumulate at a significant rate with the storage period.

Ali et al. [9] studied the frictional behavior of the ring-liner contact in the engine utilizing Al2O3 and TiO2 nanolubricant additives under 0.25 wt.% concentration. The average diameter of the nanomaterials was 8-12 nm. The stability of the nanoparticles in engine oil (5W-30) was characterized by using ultraviolet (UV). The results inferred that the nanoparticles sedimentation was noted after 14 days at room temperature.

Li et al. [10] reported that ZrO2/SiO2 nanoparticles under a concentration of 0.1 wt.% and 50-80 nm grain size in the base oil. The solution was dispersed using ultrasonic at room temperature for 30 min and then nano-lubricant was obtained. The nanoparticles stability in base oil was characterized by the Zeta potential value. The results presented that the absorbency of nanolubricant with ZrO2/SiO2 nanoparticles was still stable after 56 h. but, at 76 h the nanoparticles stability was decreased by 3.5%.

According to the comparison of the recent experimental studies to 2018 [11], the development of nano-lubricants with a high concentration of nanoparticles is difficult because of agglomeration problem. Hence, the dispersion stability of the nanoparticles in lubricant oils remains a key challenge in the formulation of nano-lubricants owing to the short time of the stability. Therefore, it is substantial to study the related influencing factors to improve the nanoparticles stability in lube oils.

3. Thermophysical and Chemical Properties
The thermophysical and chemical properties of nano-lubricants are important factors for heat transfer performance and provide better resistance to lubricant thinning and film strength retention on the worn interfaces in the engine. Ali et al. [12] explored the effect of both Al2O3, TiO2 and Al2O3/TiO2 nanomaterials (8-12 nm) additive into lube oil (5W-30) on the thermophysical parameters (thermal conductivity, viscosity, and viscosity index). Nanolubricants comprised of 2 wt.% nano-additive (Al2O3/TiO2+oleic acid) and 98 wt.% lube oil (5W-30). The results displayed that the nanolubricants presented low kinematic viscosity with an enhanced viscosity index by 2%. Besides, the thermal conductivity was improved by 12-16% for temperatures ranged from 10-130 °C, compared with the case of lube oil without nanomaterials.

Aberoumand et al. [13] examined the rheological performance of silver-heat transfer nanofluid. The mean diameter of Ag nanomaterials and concentration were reported 20 nm and 0.72 wt.% respectively. The results displayed an enhancement in the thermal conductivity of Ag nanofluid. Moreover, an enhanced viscosity was observed with increasing weight fraction at lower temperatures. Furthermore, the study by Agarwal et al. [14] prepared kerosene-graphene nanofluids and exhibited 23% enhanced thermal conductivity and enhanced viscosity by 8% at room temperature.
4. Tribological Performance of the Piston Ring Assembly

The friction between the rubbing interfaces is the main cause of energy dissipation in vehicle engines. The ring-liner interface makes a meaningful contribution towards the frictional power losses. The vehicle engine power losses is about 17-19% of the output energy [5]. Improving the frictional performance of the lube oils and the sliding contact interfaces lead to improved efficiency and fuel economy of engines owing to the friction between the ring and liner accounts for approximately 40% to 50% of the total power losses [15].

Ali et al. [9, 16] studied the tribological characteristics (Figure 1) and the frictional power losses for the ring-liner contact during various lubrication regimes using Al2O3 and TiO2 nanolubricants. The friction results indicated that the coefficient of friction lowered by 48-50%, 33-44% and 9-13% for the boundary, mixed and hydrodynamic lubrication regimes, respectively, compared to a reference oil.

![Figure 1. Tribological behavior of piston ring assembly versus crank angle. Reprinted (adapted) with permission from Ref. [9].](image)

Ingole, et al. [17] investigated the effects of TiO2 nano-additives in mineral oil on the behavior of friction and wear. Grain sizes of TiO2 nanomaterials were 20-25 nm at different concentrations (0.2, 0.25, 1, and 2 wt.%). The results inferred that the friction coefficient and wear declined. Furthermore, the results by Guzman et al. [18] showed that Cu nanomaterials significantly reduced the wear and friction. The friction is reduced for most experimental conditions tested with mineral oil, especially at the concentration of 0.3 wt.%.

5. Engine Performance

The investigations on the fuel consumption reduction in automotive have become the essential research trend for different countries. Ali et al. [4] explored the effect of Al2O3/TiO2 nano-lubricants on the behavior of the gasoline engine. The results explained that using nano-lubricants improves the engine behavior. Furthermore, the results revealed that the fuel consumption corresponding to Al2O3/TiO2 nano-lubricants declined by 16-20%. Hence, the decrease in fuel consumption shown during the NEDC test causes a fuel economy of about 4 L/100 km (Figure 2a).
In another study, AVL dynamometer experiments by Ali et al. [11] demonstrated that the lubrication of the engine by graphene nano-additives achieved 17% decline in the consumed cumulative fuel mass with road load simulation under NEDC as shown in Figure 2b. Furthermore, the emissions results revealed that CO₂, HC and NOx gaseous reduced by 2.79-5.42% when the engine lubricated by graphene nano-additives. According to the presentation of the recent studies till 2018, the results affirmed that using nano-lubricants provides fuel economy as compared with different methodologies.

6. Conclusions
This paper reviewed the recent advances in nanolubricants formulated for improving vehicle engines performance. The recent advances act as a guiding path to frame the correct methodologies to improve engine performance, highlights the importance of nanolubricants aspects and develop the breadth of understanding of the nanolubricants. The objective of the previous survey is to explore the areas where there are openings for further research contributions to improving the performance of automotive engines. For example, significant effort is still required to overcome the sedimentation problem of the nanomaterials in lube oils regarding longer-term stability. Heretofore, understanding the major mechanisms of the addition of nano-additives to lube oils on the engine performance and exhaust emission remain a key challenge for the researchers. As a future direction, further investigations should provide the key mechanisms responsible for fuel economy and reduction of the exhaust emissions in automobile engines.

Acknowledgments
The authors acknowledgments the financial support by the National Natural Science Foundation of China (Grant No. 51875423). M.K.A. Ali acknowledges the financial support by Minia University during the postdoctoral mission.

References
[1] Erdemir A, Ramirez G, Eryilmaz OL, Narayanan B, Liao Y, Kamath G, et al. Carbon-based tribofilms from lubricating oils. Nature. 2016;536:67.
[2] Ali MKA, Xianjun H, Essa F, Abdelkareem MA, Elagouz A, Sharshir S. Friction and wear reduction mechanisms of the reciprocating contact interfaces using nanolubricant under different loads and speeds. Journal of Tribology. 2018;140:051606.
[3] Turkson RF, Yan F, Ali MKA, Liu B, Hu J. Modeling and multi-objective optimization of engine performance and hydrocarbon emissions via the use of a computer aided engineering code and the NSGA-II genetic algorithm. Sustainability. 2016;8:72.
[4] Ali MKA, Fuming P, Younus HA, Abdelkareem MAA, Essa FA, Elagouz A, et al. Fuel economy in gasoline engines using Al₂O₃/TiO₂ nanomaterials as nanolubricant additives. Applied Energy. 2018;211:461-78.
[5] Ali MKA, Xianjun H. Improving the tribological behavior of internal combustion engines via the addition of nanoparticles to engine oils. Nanotechnology Reviews. 2015;4:347-58.

[6] Ali MKA, Xianjun H, Elagouz A, Essa F, Abdelkareem MA. Minimizing the boundary friction coefficient in automotive engines using Al₂O₃ and TiO₂ nanoparticles. Journal of Nanoparticle Research. 2016;18:377.

[7] Ali MKA, Xianjun H, Fiifi Turkson R, Ezzat M. An analytical study of tribological parameters between piston ring and cylinder liner in internal combustion engines. Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics. 2016;230:329-49.

[8] Kheireddin BA, Lu W, Chen I-C, Akbulut M. Inorganic nanoparticle-based ionic liquid lubricants. Wear. 2013;303:185-90.

[9] Ali MKA, Xianjun H, Mai L, Qingping C, Turkson RF, Bicheng C. Improving the tribological characteristics of piston ring assembly in automotive engines using Al₂O₃ and TiO₂ nanomaterials as nano-lubricant additives. Tribology International. 2016;103:540-54.

[10] Li W, Zheng S, Cao B, Ma S. Friction and wear properties of ZrO₂/SiO₂ composite nanoparticles. Journal of Nanoparticle Research. 2011;13:2129-37.

[11] Ali MKA, Xianjun H, Abdelkareem MA, Gulzar M, Elsheikh A. Novel approach of the graphene nanolubricant for energy saving via anti-friction/wear in automobile engines. Tribology International. 2018;124:209-29.

[12] Ali MKA, Xianjun H, Turkson RF, Peng Z, Chen X. Enhancing the thermophysical properties and tribological behaviour of engine oils using nano-lubricant additives. RSC Advances. 2016;6:77913-24.

[13] Aberoumand S, Jafarimoghaddam A, Moravej M, Aberoumand H, Javaherdeh K. Experimental study on the rheological behavior of silver-heat transfer oil nanofluid and suggesting two empirical based correlations for thermal conductivity and viscosity of oil based nanofluids. Applied Thermal Engineering. 2016;101:362-72.

[14] Agarwal DK, Vaidyanathan A, Kumar SS. Experimental investigation on thermal performance of kerosene–graphene nanofluid. Experimental Thermal and Fluid Science. 2016;71:126-37.

[15] Ali MKA. Improving the performance of automotive engines and tribological behavior of the piston ring assembly using nanomaterials as smart nano-lubricant additives. Preprint, 2018.

[16] Ali MKA, Xianjun H, Mai L, Bicheng C, Turkson RF, Qingping C. Reducing frictional power losses and improving the scuffing resistance in automotive engines using hybrid nanomaterials as nano-lubricant additives. Wear. 2016;364:270-81.

[17] Ingole S, Charanpahari A, Kakade A, Umare S, Bhatt D, Menghani J. Tribological behavior of nano TiO₂ as an additive in base oil. Wear. 2013;301:776-85.

[18] Guzman Borda FL, Ribeiro de Oliveira SJ, Seabra Monteiro Lazaro LM, Kalab Leiróz AJ. Experimental investigation of the tribological behavior of lubricants with additive containing copper nanoparticles. Tribology International. 2018;117:52-8.