Physical Properties Investigation and Performance Behavior of Lube Oil Graphene Blends used in Diesel Engine

Sabry Allam[1], Sherif Mahrous[2] and A. B. El Basaty[3]

[1]Professor of Automotive Engineering, Dept. of Automotive technology, Faculty of Technology and Education, Helwan University, 11281 Cairo, Egypt.
[2]M Sc. Student at Dept. of Automotive Technology, Faculty of Technology and Education, Helwan University, 11281 Cairo, Egypt.
[3]Associate Professor of Material Science, Dept. of Basic Science, Faculty of Technology and Education, Helwan University, 11281 Cairo, Egypt.

---***---

Abstract - *In the present study, the effect of blended thermal reduced graphene oxide (TRGO) on properties of commercial lube oil is illustrated. In practically, the efficiency substantiation of both commercial lube oil and blended lube oil is confirmed by measuring the wear in both piston and cylinder of diesel engine for 72 h operation with maximum load power. The results approved that the blended lube oil reduced the wear and noticeable reduction in bsfc was noticed where it reduced from 242 to 230 g/kw.hr at the same working condition. Furthermore, the physical oil properties during operation are studied by measuring the density and viscosity at different engine operation time. The density for both commercial and blended lube oil has not a remarkable change with different operation time. In same time, the viscosity @40 0C and @100 0C for blended oil show a better behavior comparing to commercial lube oil in different operation time. This study confirms that TRGO could be considered a good candidate for improving the properties of commercial lube oil as a Nano-additive.*

***Key Words*: Lube oil, graphene, blends, diesel engine, Physical Properties, Performance Behaviour.**

1. INTRODUCTION

Internal combustion engines (ICE) are considered one of the largest energies converting units worldwide. Every day, billions of transportations such as automobiles, boats, ships, airplanes, and trains consumed millions of liters of fuel converted into mechanical energy using these engines [1,2]. A considerable amount of the energy produced by engines is spent overcoming the friction in moving its mechanical systems such as piston ring cylinder assembly. So, reducing the friction play a vital role in improving ICE performance. Due to that, the lube oil performance, and quality of combustion in ICE have a special interest in the current research of ICE performance.

The lube oil offers main role in reducing the friction inside ICE. Furthermore, it has other important functions such as cleaning, preventing the corrosion, and reducing the temperature of the internal engine components. Also, it affords a dynamic seal in locations like piston, rings, and cylinder [3]. As a result of improving the lube oil performance, the maintenance cost is reduced, as well as the machine's parts lifetime is increased [4].

Nanomaterials, with their astonishing properties and functionalities, offer the magical and effective solution to improve and develop the industrial manufactures and products. Where, the control of dimensions and shapes of materials in nanometer scale, play a crucial role in tuning the properties and gadget characteristics in phenomenal ways. Due to that, recent studies explore the use of nanoparticles (NPs) as additives in conventional lubricants [4]. Where, they explore the used of NP as an additive in conventional lubricants decreasing the coefficient of refraction (COF) at different loads [5]. Furthermore, the selection of NP is considered an important issue for the environmental and health concerns. Due to that, the recent studies argue the use of ecofriendly NP is reducing COF and improving the lubrication behavior of the lube oil [6].

Graphene is recently considered as one of the most promising material, where it has distinguished properties such as high thermal, electrical, and hardness properties. Moreover, it has atomically smooth surface, high chemical inertness, and easy shear capability [7–9]. If it exists in stable and dispersion as ultrathin layers in lubricant, it could be a suitable material additive for lubricant to improve friction and wear resistance of lubricant. Kinoshita et al. [10] shows that the COF of 1 wt.% of graphene oxide (GO) in water decreased by 57% comparing pure water [10]. In addition, Berman et al. [11] demonstrate that even that fraction reduced in good manner for graphene dispersed in ethanol, but it is removed from the sliding surface under an load applied [11]. Jankhan et al. [12] investigates the tribological properties such as wear, and friction of reduced graphene blended in pure mineral oil with 0.01 wt.%.

This study presents the physical properties of commercial lube oil graphene blended in the actual working diesel engine are investigated and compared with the properties of virgin lube oil at same operation condition. To the knowledge of authors, this study presents pioneer results about the investigation the properties of graphene as an additive to lube oil inside actual diesel engine working at normal operating conditions and this is essential and new study for improving the lube oil properties.

2. Experimental Procedure

2.1 Nano Materials Preparation

Modified hummer method was utilized to prepare graphene oxide (GO) nano-sheets. The synthesized GO was thermally reduced at 350 0C for 20 min, and more details about the synthesis and reduction procedure can be found elsewhere [7–9]. In the preparation processes, all chemicals used has highly purveyed quality, and are used as received without any modifications. The product of GO reduction is called thermal reduced graphene oxide (TRGO).

In this study, the Mobil DELVAC 1350 (Mono grade SAE 50) heavy duty diesel oil was used as base oil. Furthermore, TRGO powder is blended with this oil to have new lube oil. In detail, the TRGO powder (0.092 g) is dispersed in 1 L stirred lube oil for 20 min. After that the solution is verges ultrasonication for 2 hr [7-9].

2.2 Nano Materials Characterizations

To ensure quality of the synthesized TRGO, it was analyzed using high resolution transmission electron microscopy (TEM). TEM images was taken by a microscopy model JEM 1230 (JEOL JAPAN). Densitometer (DST-2000 Density) with hydrometer is used to measure the density of oil samples at 20 0C. Furthermore, the viscosity with different temperature 40 0C, and 100 0C is one of most important required to characterize the oil. RM 100 CP2000 PLUS is a device able to measure the viscosity at different temperature [].

2.3 Test rig Preparation

In this study, a special test rig is constructed and used throughout as shown in Fig. 1. It is consists of a single cylinder air cooled diesel engine with maximum power of 5 hp at 2000 rpm, electric generator as a load cell, load board consist of 25 electric lamp as a load, and all needed measuring equipment were installed such as; temperature sensor as well as power meter. The engine fuel tank is calibrated to estimate fuel consumption during and after measurements. The engine and accompany components were completely new during the first set of the measurements and they have complete maintenance before the second set of operation. In addition, for each operation the inner part of engine (cylinder, piston rings and piston) was replaced with new ones. All measurements were performed at maximum engine speed (2000 rpm) and a maximum load (3.8 Kw).

3. Measuring Procedure

This study was done through two phases; the 1st phase was done by using base lube oil in the test rig operation for 72 hr. The oil sample (50 ml) was taken every 8 hr of, and it was compensated the same amount and the same type of oil, to maintain the oil level in engine. At the end of 1st phase the oil samples were characterized, and the dimensions of the engine internal parts were measured. The same procedures were applied in the second phase where another type of lube oil (TRGO blended oil) is used. The dimensions of cylinder (Top dead center, Center, and Bottom dead center) and piston (Crown, Body, Benz, and Skirt) were measured at our and certified workshops before and after the measurements. The fuel consumption accompany each test was measured using a calibrated tank.

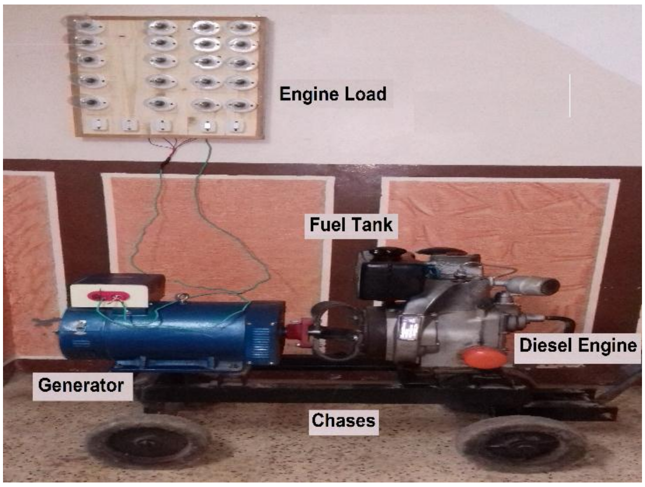


Figure 1: Photograph of the test rig setup.

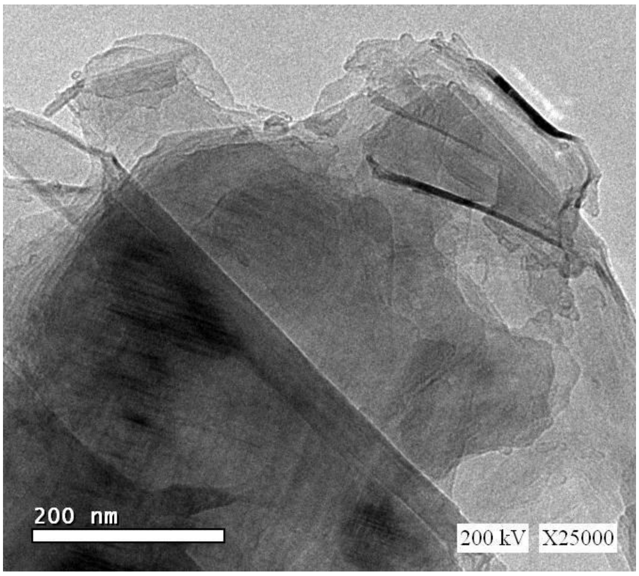


Figure 2: TEM image of thermal reduced graphene oxide (TRGO).

4. Results and discussion

4.1 TRGO morphology

The quality of the synthesized TRGO was confirmed using transmission electron microscopy (TEM) measurement. Fig. 2 showed some exfoliated layers of graphene nano sheets with wide area. It was noticeable some features in the sheets such as crumbles, wrinkles, and folds at the edges, because of the reduction process was done by thermal energy.

4.2 Density of lube oil

One of most important properties of the lube oil is its density. The density performs a vital function in how a lubricant feature, in addition to how machines work efficiently. Lube oil must have a specific density value, where for instance the density of a lubricant increases, the fluid becomes thicker and could not be a sufficient for its application. So, it is important to test the density of lube oil. Fig. 3 represent the behavior of tested lube oil (with and without TRGO) density with test rig operation time. It is notice that 0.1 wt% of TRGO blended to lube oil did not change its density. Furthermore, in general speaking, it is found that the densities of both test lube oil were invariant during operation time. The virgin lube oil density is 0.9 kg/m3, where its density reduced to 0.893 kg/m3 after 72 h operation time. Similarly, the density of lube oil/TRGO approximately did not change except at 24 h.

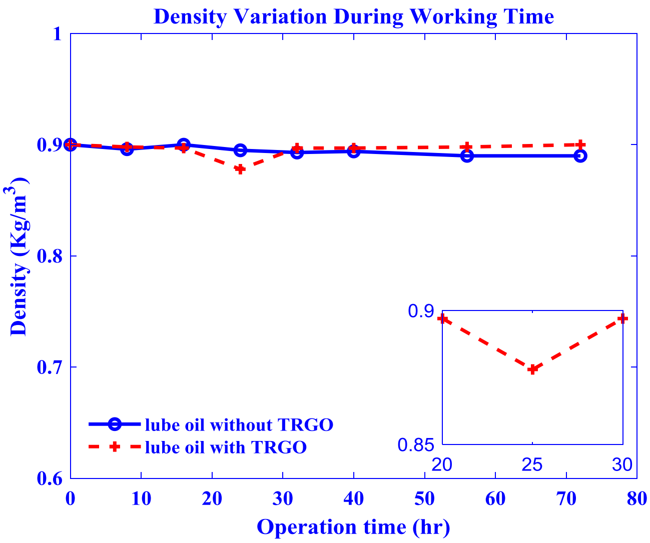


Figure 3: Density variation versus working time for lube oil with and without TRGO.

4.3 Viscosity of lube oil

The viscosity plays a crucial role on lube oil properties. Where the viscosity plays an impact on the quality, fatigue life of machinery, engines, and plays a major role in determining the oxidative stability of engine oils. Figure 4 depicts the variation of kinematic viscosity at 40 °C of lube oil and TRGO blended of lube oils with operation time. In same time, figure 5 depicts the variation of kinematic viscosity@ 100 °C of lube oil and TRGO blended of lube oil with operation time. In both figures, by comparing the viscosity of lube oil and after blended by TRGO, it is found the viscosity is remarkable increased. At 40 °C, the reduction of viscosity with operation time is consider an ordinary behavior, where lube oil degradation, and the wear product will decrease the viscosity. But the result of figure 4 for blended oil confirm that the viscosity after the reduction in the first 8h, it has a saturation behavior. That indicated the improvement of lube oil due to TRGO blend. It is expected that adding agent could reduce the wear by forming thin film in the internal cylinder of the engine, furthermore, decrease the degradation process of lube oil. The trend of viscosity of lube oil @ 100 °C is slightly increased with operation time till 40 h after that it is decreased. Where the blended one behave in different way. It is decreased with operation time at 8h, after that tend to increase till it approaches to value of original viscosity of fresh lube oil at 72 h.

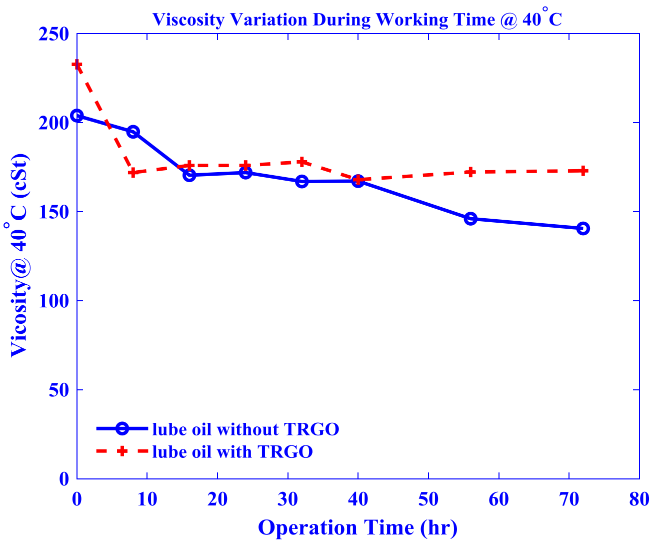


Figure 4: Variation of viscosity at 40 °C of lube oil with and without TRGO during operation time.

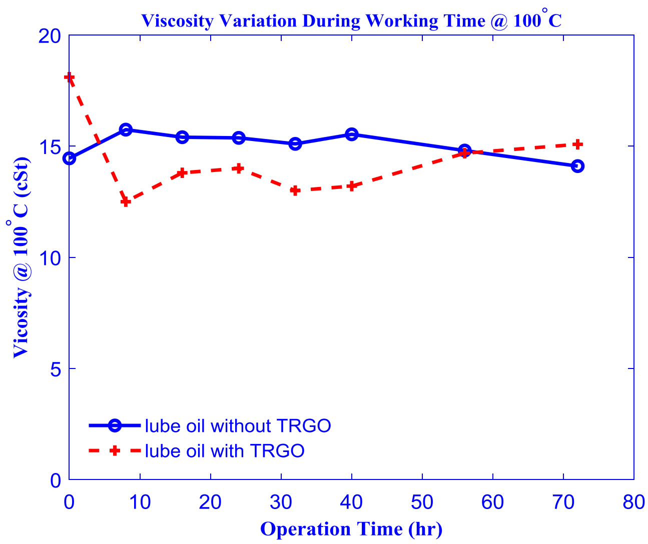


Figure 5: Variation of viscosity at 100 °C of lube oil with and without TRGO during operation time.

4.4 Piston and Cylinder Wear

Tables 1 and 2 show the measurement results for outer piston diameter and inner cylinder diameter. The piston measurements were done in four points, at crown, piston body, piston bens and at piston stem. Also, the inner cylinder diameter was measured at three points, bottom dead point, upper dead point, and center point.

All the measurements were done in three cases: before operation with new components, after operation of 72 hours using lube oil without any addition, and after operation of 72 hours using lube oil blended by TRGO. Fig. 6 shows the measurement points for piston and cylinder and photograph while measurement process using micrometers.

During mechanical measurements of the piston and cylinder, after adding graphene nanostructures to the oil, it was found that thin film layer of TRGO was present on the piston body and the inner surface of the cylinder and this leads to decrease the wear in piston crown and piston stem also keep the bottom dead point of the cylinder without change.

The reduction of wear of piston and cylinder leads to reduce oil consumption and remarkable reduction of fuel consumption, so the maintenance cost will decrease, and the engine life will increase.

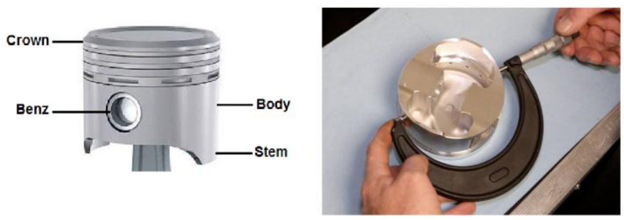
Table 1: Measurements of the outer piston diameter (mm)

Place of measurement	Before operation	After operation without TRGO	After operation with TRGO
Crown	79.60	79.55	79.57
Body	79.90	79.90	79.90
Benz	79.70	79.70	79.70
Stem	79.95	79.90	79.94

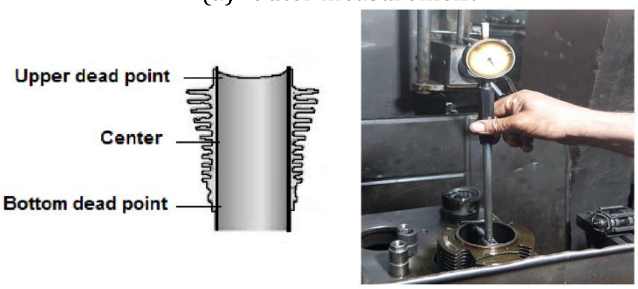
Table 2: Measurements of the inner piston diameter (mm)

Place of measurement	Before operation	After operation without TRGO	After operation with TRGO
BTD	80	79.95	80
TDC	80	79.95	79.95
Center	80	79.93	79.93

BDC is the bottom dead point, and TDC is top dead point.



(a) Outer measurement



(a) Inner measurement

Figure 6: Measuring internal and external diameter.

4.5 Engine Fuel Consumption

The calibrated tank and stopwatch were used to measured and calculated fuel consumption as;

$$m_f^{'} = \rho_f V / t \qquad (g/hr) \qquad (1)$$

Where, ρ_f is the measured fuel density (845 g/L) at 15 °C and V is the fuel consumption in a certain time (t). In addition, the brake specific fuel consumption of the engine is calculated as;

$$bsfc = m_f^{'} / BP \qquad (g/Kw.hr) \qquad (2)$$

Where BP is the measured engine brake power (Kw) at each measuring time. Based on the measured results the average bsfc accompany the commercial lube oil is 242 g/kw.hr, while its value with the using of TRGO blend becomes 230 g/kw.hr. This is due to the improvement in fuel viscosity and reduction in friction loss.

5. Conclusion

Density and kinematic viscosity of commercial lube oil and TRGO blended lube oil have been measured for 72 h test rig operation. Even if the density of the blended TRGO blended oil is invariant compared with commercial lube oil, the viscosity@40 0C and at 100 C is improved after the TRGO blended the lube oil. Furthermore, the comparison of the engine internal parts dimensions before and after operation shows that the blended lube oil reduces the rate of wear caused by the friction between the piston and the cylinder, and this leads to reduce oil consumption rate, fuel consumption rate, and maintenance cost, as well as it increases engine life. This study confirms that TRGO could be considered as a good candidate for improving the properties of commercial lube oil as a Nano-additive. A vital reduction in bsfc was noticed where it reduced from 242 to 230 g/kw.hr at the same working condition.

ACKNOWLEDGEMENT

Technical supports during measuring and evaluating the results from Dr. Osama Yusef as well as Dr. Amany Elsayed Tayea at Helwan University, Faculty of Technology and Education are appreciated. Technical support during samples' properties analysis at Egyptian Ministry of Transport (EMT), Egypt Railways is acknowledged.

REFERENCES

[1] Zhao F, Chen K, Hao H, Liu Z. Challenges, potential and opportunities for internal combustion engines in China. Sustain. 2020;12(12):1–15.

[2] Gautam Kalghatgi, Saudi Aramco. ''Is it really the end of internal combustion engines and petroleum in transport'' . Appl Energy [Internet]. 2018;225(April):965–74. Available from: https://doi.org/10.1016/j.apenergy.2018.05.076

[3] Bernard J, Hamrock. Lubrication of Machine Elements. Chapter 32. Third Edition, Jhon Weily & Sons, 2006.

[4] Dong JX, Hu ZS. A study of the anti-wear and friction-reducing properties of the lubricant additive, nanometer zinc borate. Tribol Int. 1998;31(5):219–23.

[5] Chou CC, Lee SH. Tribological behavior of nanodiamond-dispersed lubricants on carbon steels and aluminum alloy. Wear [Internet]. 2010;269(11–12):757–62. Available from: http://dx.doi.org/10.1016/j.wear.2010.08.001

[6] Sukkar KA, Karamalluh AA, Jaber TN. Rheological and Thermal Properties of Lubricating Oil Enhanced by the Effect of CuO and TiO2 Nano-Additives. Al-Khwarizmi Eng J. 2019;15(2):24–33.

[7] Fouda AN, Assy MKA, El Enany G, Yousf N. Enhanced capacitance of thermally reduced hexagonal graphene oxide for high performance supercapacitor. Fullerenes Nanotub Carbon Nanostructures. 2015;23(7):618–22.

[8] Fouda AN, El Basaty AB, Eid EA. Photo-response of functionalized self-assembled graphene oxide on zinc oxide heterostructure to uv illumination. Nanoscale Res Lett. 2016;11(1).

[9] Fouda A., Abu-Assy M., Yousf N. Structural and capacitive characterizations of high temperature nitrogen annealed graphene oxide. IOSR J Appl Phys. 2014;6(2):33–7.

[10] KINOSHITA H, ONO H, ALIAS AA, NISHINA Y, FUJII M. Tribological properties of graphene oxide as a lubricating additive in water and lubricating oils. Mech Eng J. 2015;2(6):15-00323-15–00323.

[11] Berman D, Erdemir A, Sumant A V. Graphene : a new emerging lubricant §. 2014;17(1):31–42.

[12] Patel J, Pereira G, Irvine D, Kiani A. Friction and wear properties of base oil enhanced by different forms of reduced graph

BIOGRAPHIES

Sabry Allam is a Professor of Automotive Engineering, Dean of Faculty of Technology and Education, Helwan University (HU), Cairo, Egypt. He received his PhD from the Royal Institute of Technology, Stockholm, Sweden in 2004, while he earned his MSc from Technical University of Turin and HU in 1995. He is specialist in vehicle pollution and noise control and has almost 100 of research papers.

Sherif Mahrous has BSc in Industrial Education, From Helwan University, Cairo Egypt 2009. Trainer of Tractor Mechanics and Technology at the Technical Institute of Railways Technology - Wardian, The National Authority for Egyptian Railways. Maintenance and Support sector.

Ahmed El Basaty is Associate Professor of Engineering Physics, he earned his PhD from Japan Advanced Institute of Science and Technologyat 2011. His main research interest is material science '' Graphene preparation, decorated by nono material, organic thermoelectric material and composite material''.