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A Review on the Effects of Nanolubricant Addition into Lube Oil on the Performance of Spark Ignition Engines

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Abstract – Every year there is a rise in energy demand due to the rapid development in industrialization and automotive sector, demand and depletion of fossil fuels, fuel price instabilities, diminished energy security, uncertainty in oil supply to the consuming nations, fuel import costs, increased harmful environmental effects due to various pollutants are the main driving forces to search for new alternative fuels that are renewable, eco–friendly and harmless in nowadays. Most researchers have focused on developing a wide range of renewable energies including oxygenated fuels, biofuels, fuel cell, and solar energy technologies to reduce the consumption of fossil fuels and control the emission of greenhouse gases to emit the atmosphere. The novel application in transportation and power generation sectors has shown development in the past decades to ensure a low emission level, energy savings, and high performance and efficiency. A new research area grows rapidly which is called nanotechnologies are considered nowadays one of the most recommended choices to solve the problem of the production and use of energy. Nanotechnology can be used to improve the efficiency and performance of both of conventional and renewable resources and also fuels. Nanofuels consist of a nano–sized metal particle having size ranging from 1 to 100 nm is mixed inside the base fluid by means of ultrasonication process. The nano fuel additive has a higher surface to volume ratio and act as a catalyst that results in enhanced characteristics of fuels and oils which leads to enhanced performance and combustion characteristics of internal combustion engines. This review study investigates the effects of nanolubricant addition into lube oil on the performance of spark ignition engines.

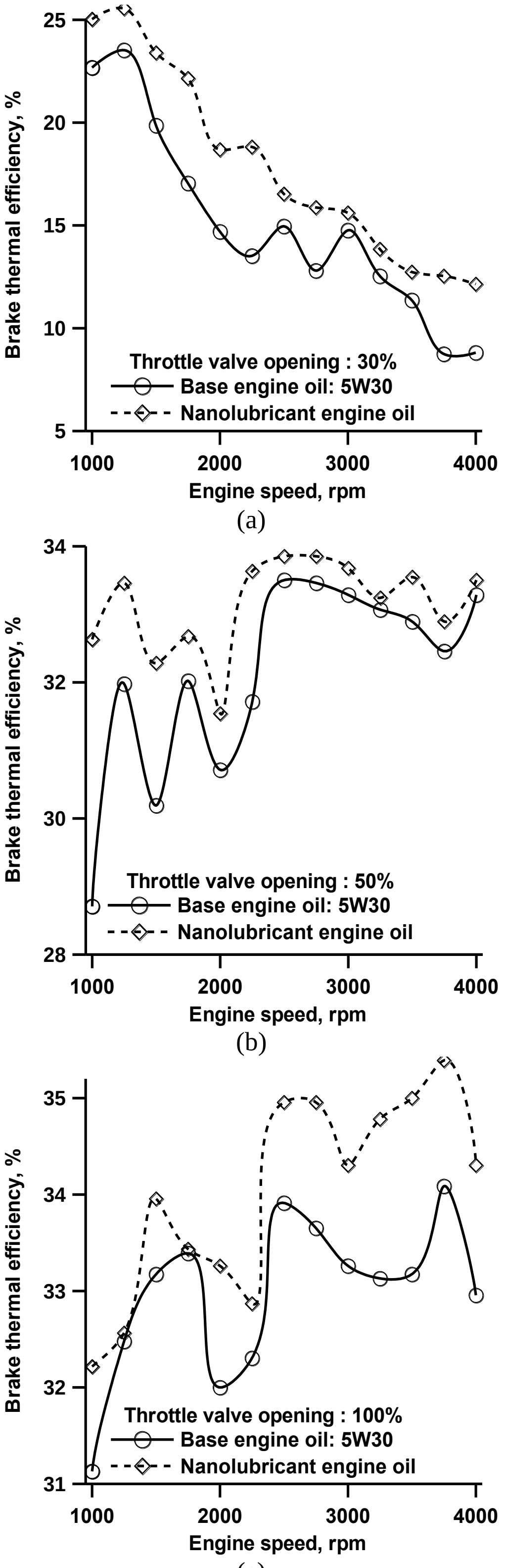
Keywords – Combustion, Emissions, Fuel additives, Nanofuel, Nanolubricant

I. INTRODUCTION

The internal combustion engine has become the foundation for vehicles, agriculture, and military operations as well as electricity generation [1, 2]. The energy consumption and harmful emissions emitted from the vehicles have increased continuously [3, 4]. The use of alternative fuels especially renewable ones in the vehicles has become an urgent priority in nowadays due to prevent environmental problems, reduce the consumption of limited petroleum resources and meet the current stringent emissions regulations [5, 6]. However, technical and raw material problems related to renewable alternative fuels hinder a rapid and complete transformation. Improving the properties of existing petroleum fuels is considered as a short–term and temporary solution. The use of renewable alternative fuels together with petroleum fuels and blending of various additives to conventional fuels is considered as an economical and practical method [7, 8]. In this way, the problems such as stringent emission regulations, encouragement of renewable biofuels content and sustaining the improved engine efficiency and reduced petroleum fuel consumption can be partially resolved [9, 10]. The additives including nano–sized materials i.e. nanofluid is seemed as promising for both of petroleum and alternative fuels. The nanofluid can improve heat transfer properties and promotes high energy efficiency in a wide spectrum of engineering applications. Late years, the using of nanofluid particularly in the automotive industry especially in diesel engines has become an attractive approach to promote enhancing of combustion efficiency and reducing of emissions due to their superior thermo physical properties [11]. Nano additives i.e. aluminum (Al), aluminum oxide (Al_2O_3), barium (Ba), boron (B), cerium (Ce), cerium oxide (CeO), copper (Cu), iron (Fe), iron oxide (Fe_2O_3), manganese (Mn), platinum (Pt), titanium oxide (TiO_2), zinc oxide (ZnO), graphene oxide etc. are identified as combustion improving catalyst which could results in reduced fuel consumption and emissions [12, 13]. This review study investigates the effects of nanolubricant addition into lube oil on the performance of spark ignition engines.

II. EFFECTS OF NANOLUBRICANTS ON ENGINE PERFORMANCE

Figs. 1(a)–(c) show the variation of brake thermal efficiency (BTE) for 5W30 base engine oil and nanolubricants additives namely Al_2O_3 and TiO_2. BTE is defined as ratio of engine brake power (BP) to fuel chemical energy. It is declared that different trends were observed in brake thermal efficiency for both nanolubricants and reference engine oil with various throttle valve openings (engine loads). BTE of engine for all lubricants declined with rising engine speed at throttle valve opening of 30%. The reason for decrease in BTE with raising engine speeds particularly at lower load (30%) is the reduction in engine volumetric efficiency resulting in a decrease of engine torque. Furthermore, it declared that this is because frictional losses increased with engine speed increase and become the governing factor resulting in a higher fuel consumption rate for generated BP. It is also declared that BTE was raised as engine speed increased until it was peaked in the ranges 2500–3500 rpm, and then it declined during high engine speeds at 3750–4000 rpm during various loads (50%, 75% and 100%). At lower engine speeds, the time available for heat to be transferred to cylinder walls is relatively longer per operating cycle that allows more heat loss occurs resulting in lesser BTE. BP increased leading to higher BTE as engine speed increases, while BTE was decreased between engine speeds of 3750 and 4000 rpm due to rapid increase in friction. It is determined that BTE of nanolubricants improved in the range of 3.9–8.6% compared to base engine oil. It is declared that reasons for this improvement are associated with thermal stability and heat transfer capabilities of nanolubricants which allow to be used in a wide temperatures range with higher fuel economy in vehicle engines [14].



(a)

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Fig. 1. Variation of brake thermal efficiency with engine speed at throttle valve openings of a) 30%, b) 50% and c) 100% for Al_2O_3 and TiO_2 nanolubricants [14]

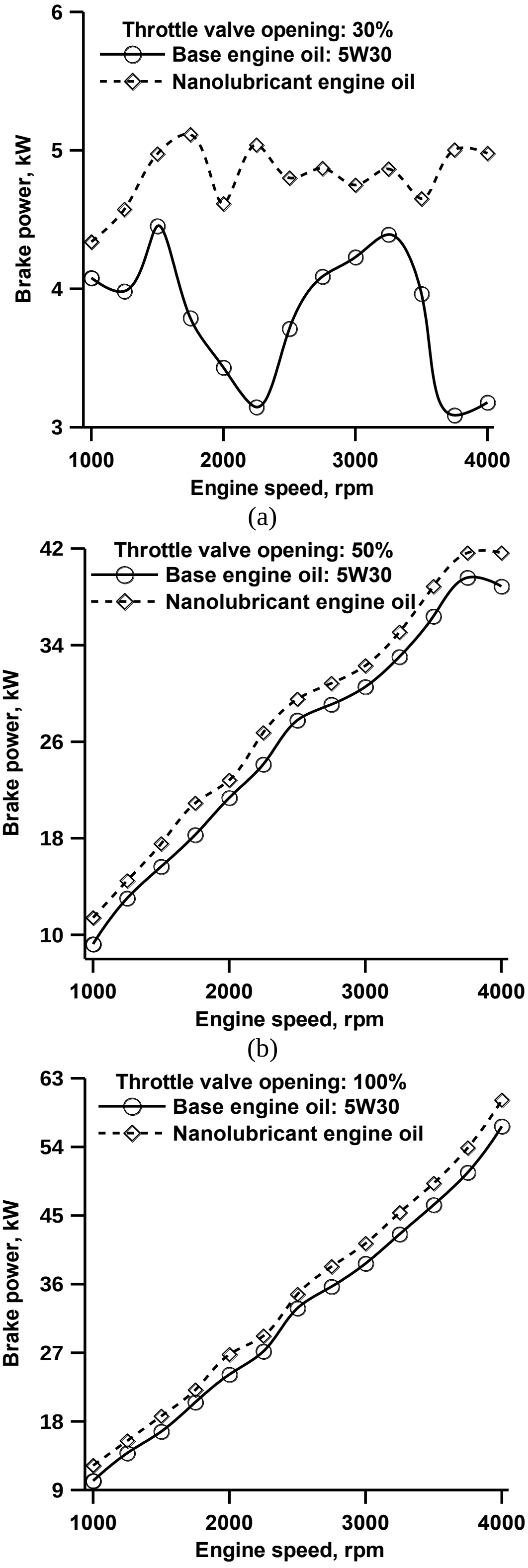

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Fig. 2. Variation of brake power with engine speed at throttle valve openings of a) 30%, b) 50% and c) 100% for Al_2O_3 and TiO_2 nanolubricants [15]

Figs. 2(a)–(c) show that variation of BP with engine speed when using nanolubricants and base engine oil. It was determined that BP with Al_2O_3 and TiO_2 nanolubricants increased about 20% compared to base engine oil by 30% load and BP oscillates with increasing engine speeds at lower engine load. As seen from Fig. 2 (b) and (c), BP increase with increasing engine speed for all lubricants by 50% and 100% loads. It is declared that this is due to power stroke increase per unit time. It is determined that a small increase in BP for Al_2O_3 and TiO_2 nanolubricants by 50, 75 and 100% loads. It declared that the peak BP for all lubricants was determined at 3750 rpm at 50% load, which is 42.19 kW for Al_2O_3 and TiO_2 nanolubricants and 40.05 kW for base engine oil and then decreased as seen in Fig. 2(b). It is explained that this is because increasing frictional losses with speed and it becomes the dominant factor. It is determined that BP of engine improved by 5% when using Al_2O_3 and TiO_2 nanolubricants at 50% load [15].

Figs. 3(a)–(c) show the variation of engine torque (ET) with engine speed for nanolubricants and base engine oil at 30, 50 and 100% loads. As seen in Fig. 3(a), ET decreased when engine speed increased. It is declared that main reasons for this decrease in ET with increasing engine speeds specifically at lower load (30%) are shortening of intake stroke that engine cylinder cannot be fully charged due to reduction in engine volumetric efficiency. The variation of ET with engine speed at 50% load is a typical manner of a naturally aspirated engine. ET reaches a maximum at 1500–3500 rpm and then drops as seen in Fig. 3(b). It is stated that decline in ET is attributed to longer combustion process of the same amount of injected fuel at lowering engine speed. Moreover, engine is incapable to use full charge of air at higher speeds, which causes a reduction in engine volumetric efficiency and increased frictional losses. As seen in Fig. 2(c), an increase in ET with increasing engine speed for nanolubricants and base engine oil at 100% load. It is determined that ET values obtained by Al_2O_3 and TiO_2 nanolubricants at all engine speeds are generally higher under different loads [15].

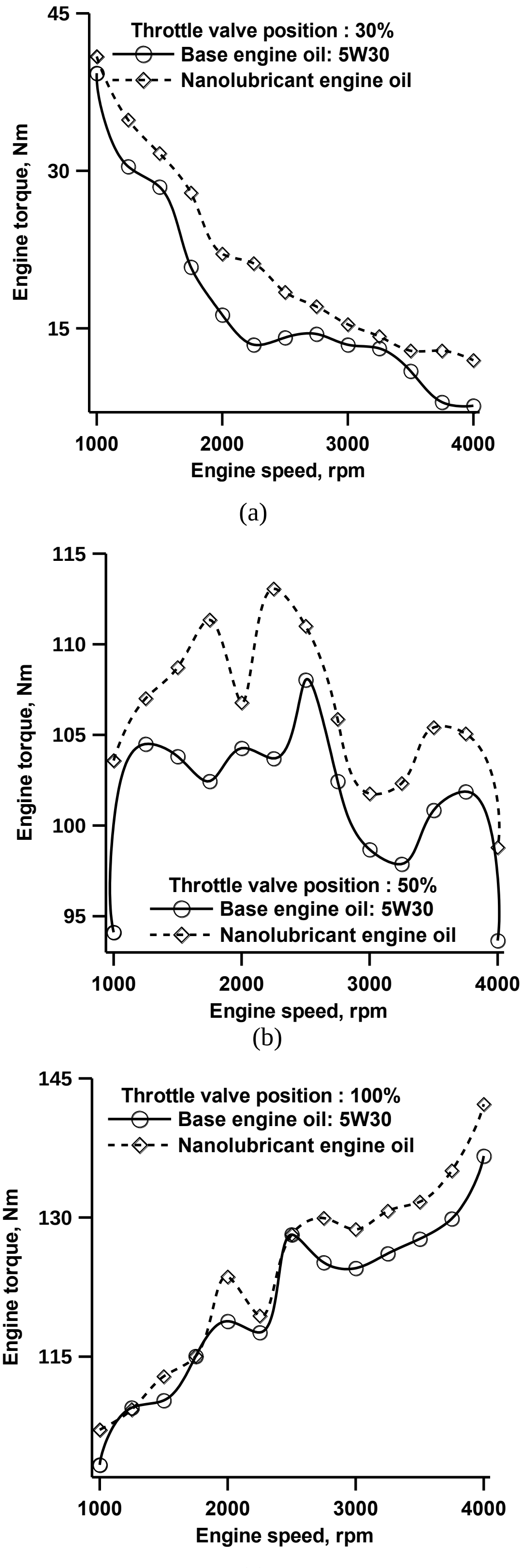

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Fig. 3. Variation of engine torque with engine speed at throttle valve openings of a) 30%, b) 50% and c) 100% for Al_2O_3 and TiO_2 nanolubricants [15]

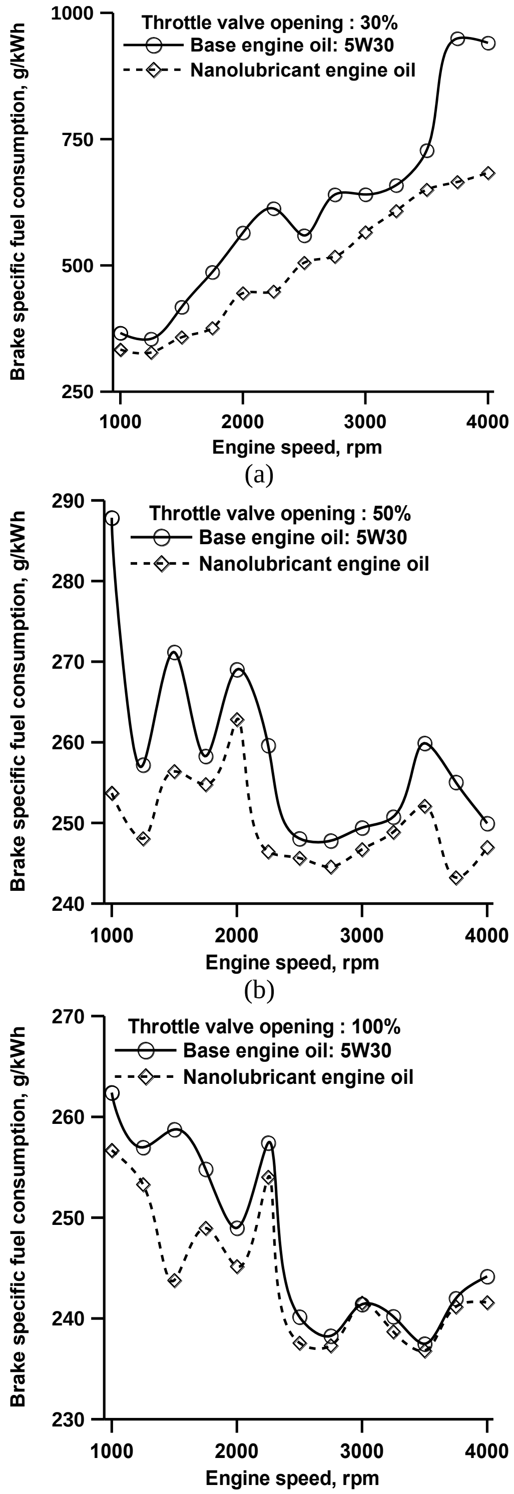

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Fig. 4. Variation of brake specific fuel consumption with engine speed at throttle valve openings of a) 30%, b) 50% and c) 100% for Al_2O_3 and TiO_2 nanolubricants [15]

Figs. 4(a)–(c) show the variation of brake specific fuel consumption (BSFC) with engine speed at different loads. As seen in Fig. 4(a), BSFC increases for al lubricants with increasing engine speed at 30% load. The reason for this rapid increase in BSFC at low load is that frictional power losses remains essentially constant, while indicated power (IP) is reduced. It is known that BSFC inversely proportional to BP. As a result, BP decreases faster than fuel consumption and hence BSFC rises as seen in Fig. 4(a). Figs. 4(b)–(c) present the variation of BSFC with engine speed at 50 and 100% loads. The graphics show that BSFC decreases as engine speed increases, until it reaches a minimum value and then it increases with high engine speed due to over–fueling. This is due to longer time available for heat transfer to cylinder walls at low engine speeds, and it allows more heat loss, resulting in poorer combustion efficiency. As a result, higher fuel consumption is required per unit power produced. BSFC again increases due to the higher friction power losses and pumping work at higher speeds. It is seen from Fig. 4 that Al_2O_3 and TiO_2 nanolubricants give constantly the less BSFC than base engine oil all engine speeds and loads. It is determined that the lowest BSFC is obtained at 75 and 100% loads for both Al_2O_3 and TiO_2 nanolubricants and base engine oil in the range of 2500–3500 rpm [15].

Figs. 5(a)–(c) show the variation of BP, ET and BSFC with engine load for Al_2O_3 and TiO_2 nanolubricants and base engine oil under engine speed of 3000 rpm. The figures illustrate that BP and ET increase with increasing load. The best torque and power can be obtained at a wide–open throttle due to higher volumetric efficiency. Exhaust gases inertia is relatively higher at wide–open throttle valve opening for medium or high engine speed. Higher exhaust gases inertia makes a vacuum that sucks a fresh charge inside the cylinder through valves overlapping. Thus, a longer overlapping period leads to a better cylinder filling and increase the engine volumetric efficiency. The better power and torque were also obtained with Al_2O_3 and TiO_2 nanolubricants than base engine oil at all loads and differences decreased in power and torque obtained with al lubricants with increase of load as seen in the figures. Fig. 5(c) shows the effect of engine load on BSFC for all lubricants at engine speed of 3000 rpm. BSFC increased especially during low load at high engine speed due to rapid increase in frictional losses. Thus, there is no significant variation in BSFC in the range of 50–100% loads. BSFC were reduced using Al_2O_3 and TiO_2 nanolubricants as compared to base engine oil as a general trend [15].

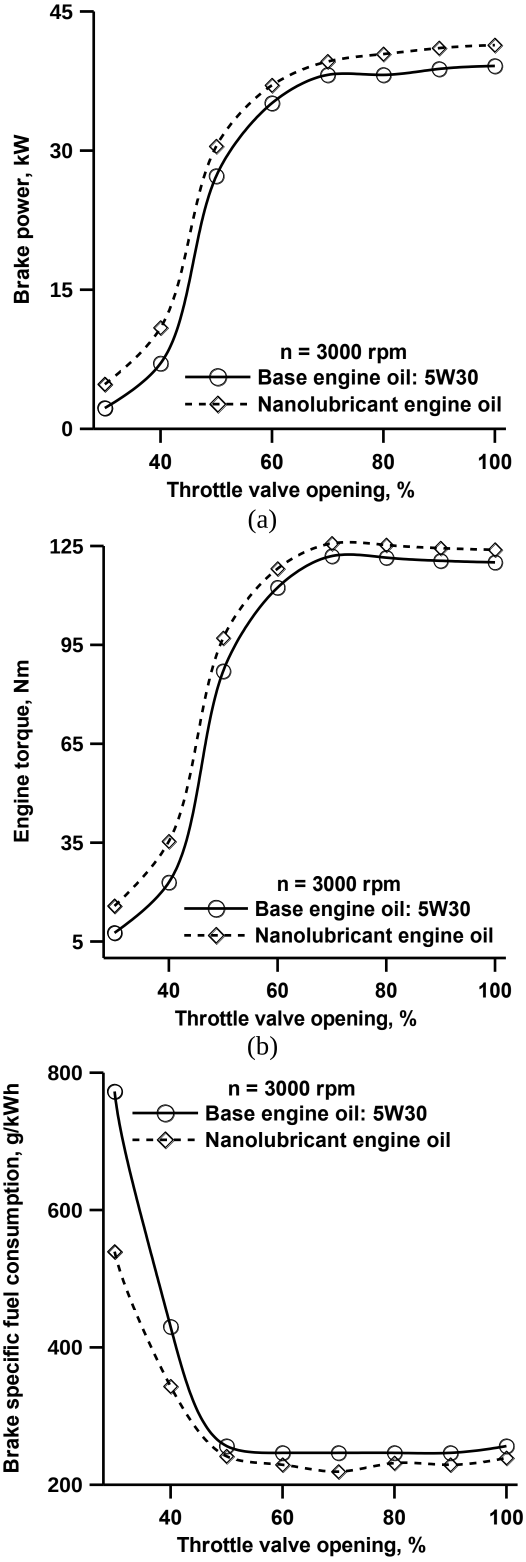

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Fig. 5. Variation of a) brake power, b) engine torque and c) brake specific fuel consumption by throttle valve opening for Al_2O_3 and TiO_2 nanolubricants [15]

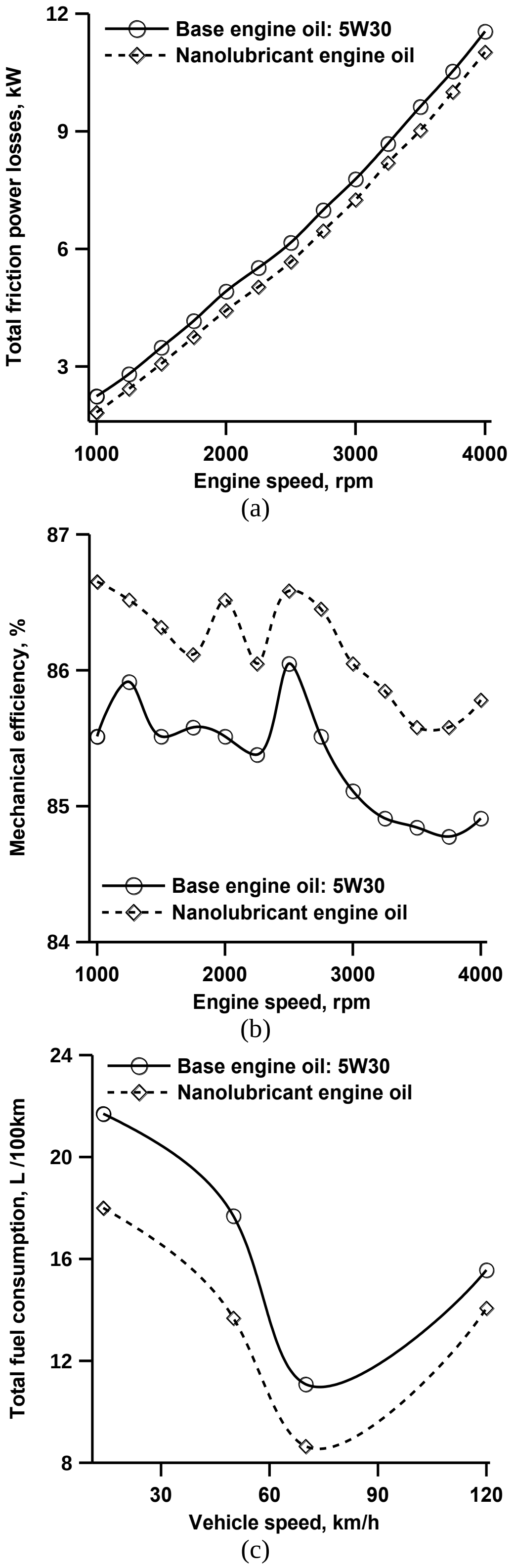

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Fig. 6. Variation of a) total friction power losses, b) mechanical efficiency and c) total fuel consumption by for Al_2O_3 and TiO_2 nanolubricants [15]

Fig. 6(a) shows the total friction power losses (TFPL) with engine speed. TFPL included the pumping losses and frictional losses for mechanical components. It was declared that TFPL were determined by the hot motoring test at wide open throttle (WOT) due to pumping losses close to zero. During the hot motoring tests, engine oil and water temperatures were maintained at 70–90 °C and 85 °C via heated before starting the test as could be in fired engine. TFPL raises with increasing engine speed for both Al_2O_3 and TiO_2 nanolubricants and base engine oil as seen in Fig. 6(a). It declared that the reason of this is dominance of hydrodynamic friction at high speed causes increase in viscous friction due to the shearing resistance of oil film. Therefore, engine speed is the major operation parameter that controls TFPL. Al_2O_3 and TiO_2 nanolubricants at different engine speeds showed reduction in TFPL and it decreased in the range of 5–7% due to improving engine tribological behavior such as low viscosity and high viscosity index, which could support an increasing in BP, ET, and automotive fuel economy. For this reason, Al_2O_3 and TiO_2 nanolubricants are most effective under different lubrication conditions [15]. Fig. 6(b) shows the variation of mechanical efficiency (ME) with engine speed for Al_2O_3 and TiO_2 nanolubricants and base engine oil. ME is an indicator of the total frictional power losses in automotive engines. It depends on the operating conditions especially BP, engine speed and engine oil. Therefore, ME is defined as the ratio of BP to IP. It is determined that ME for Al_2O_3 and TiO_2 nanolubricants improved in the range of 1.7–2.5% compared to base engine oil. This indicated that the greatest effect on ME is the frictional power losses within the engine [15]. Fig. 6(c) shows the relationship between vehicle speed and fuel consumption in L/100 km to signify the economical profit of using nanolubricants in automotive engines. For this purpose, engine fuel consumption results per 100 km were compared each other for using of Al_2O_3 and TiO_2 nanolubricants and base engine oil. It is determined that using of Al_2O_3 and TiO_2 nanolubricants may save up to 4 L/100 km in low speed, 2.4 L/100 km in economical speed (70 km/h) and 1.5 L/100 km in high speed compared to base engine oil [15].

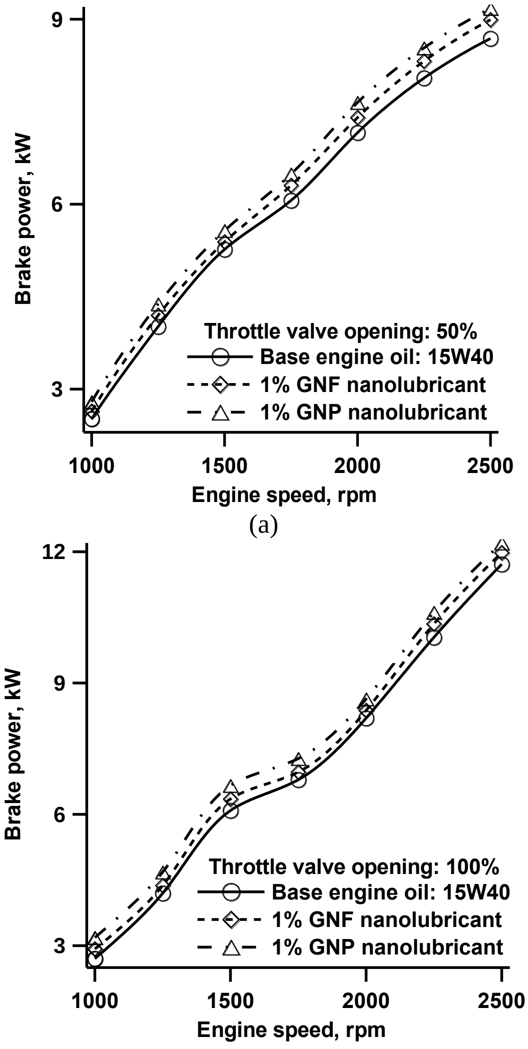

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Fig. 7. Variation of brake power with engine speed at throttle valve openings of a) 50% and b) 100% for GNF and GNP Nanolubricants [16]

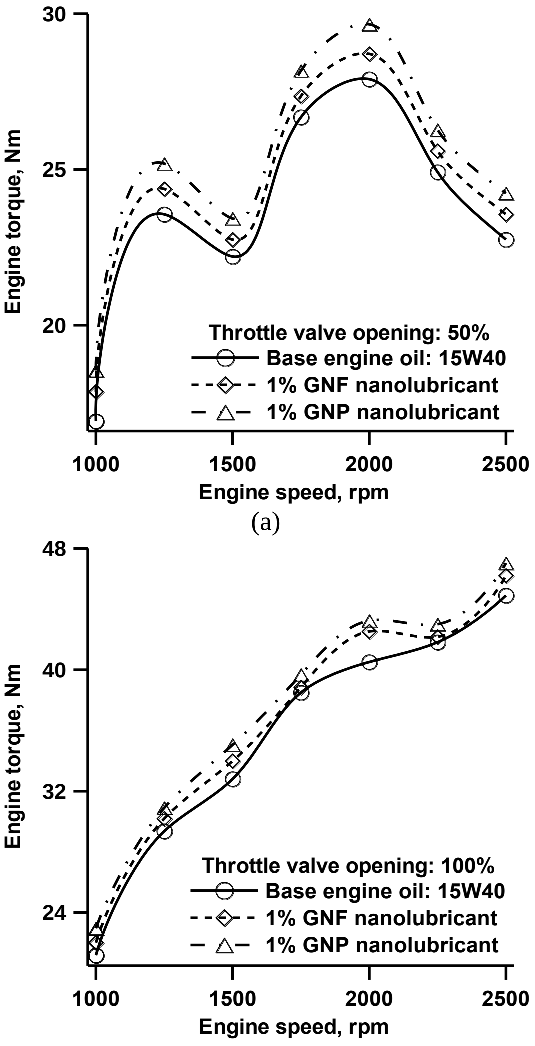

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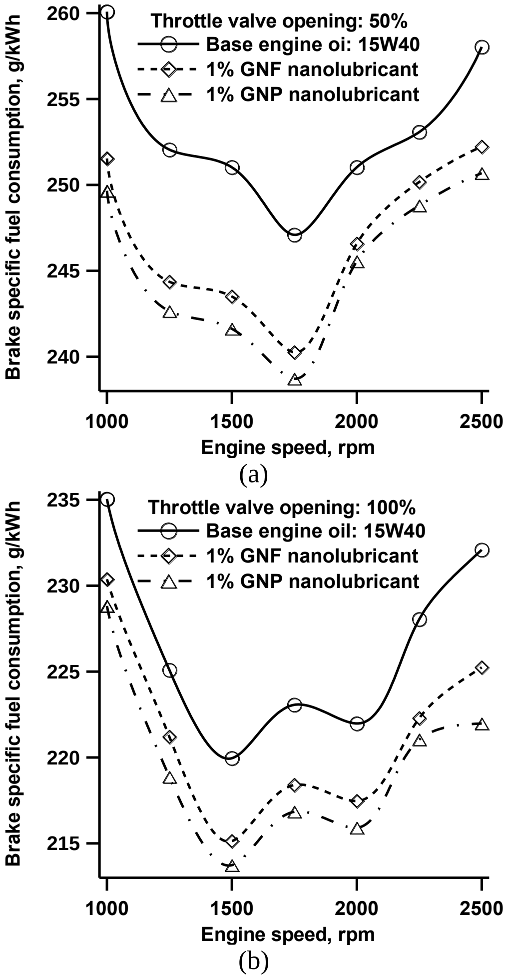
Fig. 8. Variation of engine torque with engine speed at throttle valve openings of a) 50% and b) 100% for GNF and GNP Nanolubricants [16]

Figs. 7(a) and (b) show the variation of BP at various engine speeds and loads by using 15W40 base engine oil and nanolubricants i.e. graphite nano–flakes (GNF) and graphene nano–platelets (GNP). As seen in the figures, BP increases by increasing engine speed for all lubricants at 50 and 100% loads. It declared that this is because of increased power stroke per unit time with increase in engine speed. The results showed a small fluctuation in BP for GNF and GNP at 50% and 100% loads. The highest BP for each lubricant was obtained at 2500 rpm during 100% load which is 12 kW with GNF, 11.9 kW with GNP, and 11.8 kW for base engine oil as seen in Fig. 7(b). It is determined that BP at 50% load for GNP and GNF increased by 3.7–4.8% and 1.8–3.8% respectively in comparison with base engine oil. It is declared that tested engine characteristics are similar to regular trends of naturally aspired SI engines [16].

Figs. 8(a) and (b) show the variation of ET with engine speed for all lubricants at 50% and 100% loads. ET reaches maximum and then falls at 2000 rpm, as seen in Fig. 8(a). The steady drop in ET is due to extended combustion of fuel at lower engine speed. It is declared that engine cannot take in maximum volume of air with increasing engine speed, thus lowering volumetric efficiency and increasing frictional losses. These results showed an improvement in ET with increasing engine speed with all lubricants as seen in Fig. 8(b). It is determined that ET increased in the range of 3.1–6.3% and 2.3–5.2% respectively when using GNP and GNF. It is also determined that BP and ET rise with increasing loads as seen in Figs. 7(b) and 8(b). Higher ET and BP is obtained at 100% load due to delay in overlapping of valves thus causing the cylinder to fill constantly and hence enhancing engine volumetric efficiency [16].



(a)

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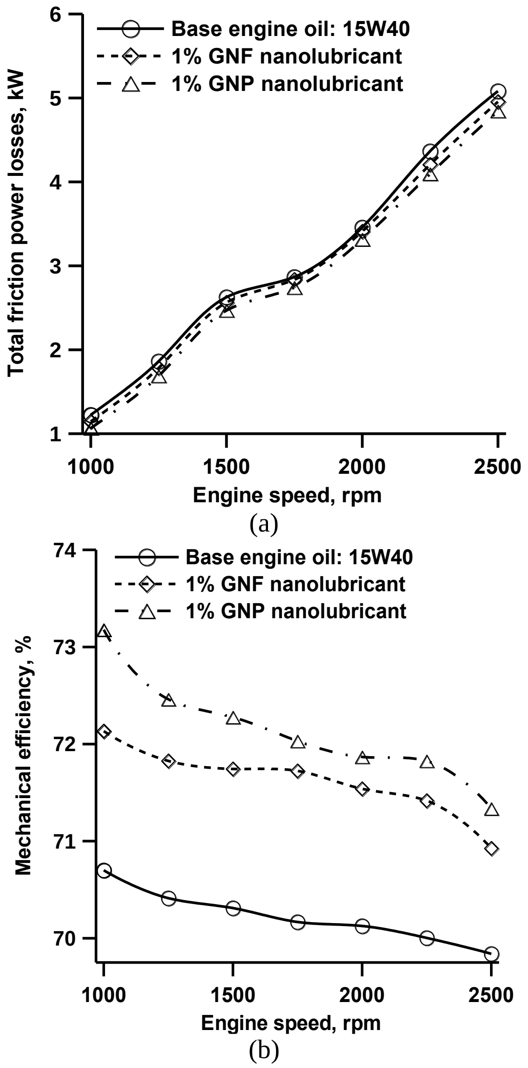
Fig. 9. Variation of brake specific fuel consumption with engine speed at throttle valve openings of a) 50% and b) 100% for GNF and GNP Nanolubricants [16]

Figs. 9(a) and (b) show the variation of BSFC for all lubricants and it is evident from the figure that BSFC decreases with rising of engine speed until a minimum value is obtained and then increases with higher engine speed due to over–fuelling. At low engine speeds, the time interval available for heat transfer to cylinder wall is relatively increased per cycle allowing further heat loss resulting in low combustion efficiency. The increase in BSFC is also attributed to the raised total friction power losses at higher speeds. It determined that BSFC results obtained with GNF and GNP nanolubricants were always less than base engine oil for variations in engine speed and loads. GNP gave a lower fuel consumption of 1.7–3.8% compared to GNF. The reduction in BSFC is attributed to nanolubricants having high viscosity index and low viscosity that enhanced the engine tribological performance [16].



(a)

(b)

Fig. 10. Variation of a) total friction power losses and b) mechanical efficiency with engine speed for GNF and GNP nanolubricants [16]

Fig. 10(a) shows the TFPL which includes the pumping losses and frictional losses. As seen from Fig. 10(a), it is clear that TFPL for all lubricants increase as engine speed increases. It is declared that this is the dominance of hydrodynamic friction at higher engine speed results in an increase in viscous friction due to the shearing resistance of oil film. Thus, engine speed is the primary operating feature that governs power loss due to friction. GNP and GNF reduced the total friction power losses by 1.5–5% and 1.5–4.2% respectively at different engine speeds due to the lowered friction and wear, viscidity and high viscosity index which provides a rise in BP, ET and BSFC. As seen in Fig. 10(a), GNP proves reduced the TFPL as compared to GNF because of a greater tendency to form a tribo–film and increased mechanical strength and hardness. It is declared that this drop in frictional and wear losses increase the performance of automotive engines [16]. Fig. 10(b) shows the variation of ME with engine speed for all lubricants. ME is determined depending on TFPL in engines and it completely depends on the working conditions of the engine, especially BP, lubricating oil and engine speed. ME is defined as the ratio of BP to IP. As seen in Fig. 10(b) GNP and GNF improved ME by 2% and 1.4%, respectively in comparison with base engine oil. This showed that TFPL had the greatest effect on mechanical performance due to friction. It is determined that GNF and GNP improved the engine performance as compared to base engine oil. However, GNP showed better results in comparison with GNF because of its greater surface area, high chemical stability, extremely fine thickness and very low shear strength thus allowing layers to easily slide against each other thereby forming film and preventing contact between mating surfaces [16].

III. CONCLUSION

The main conclusions of the study can be summarized as follow.

- It is determined that brake thermal efficiency improves by 3.9–8.6% when using Al_2O_3 and TiO_2 nanolubricants in compared to 5W30 base engine oil.
- It is determined that brake power increases about 20% with Al_2O_3 and TiO_2 nanolubricants compared to base engine oil at 30% engine load and brake power oscillates with increasing engine speeds at lower throttle valve position. It is also determined that a small increase in brake power with Al_2O_3 and TiO_2 nanolubricants by throttle valve openings of 50, 75 and 100%. Brake power improved by 5% when using Al_2O_3 and TiO_2 nanolubricants at 50% load.
- It is determined that engine torque decreased with increasing engine speeds specifically at lower opening (30%) of throttle valve due to shortening of intake stroke. It is also determined that engine torque obtained by Al_2O_3 and TiO_2 nanolubricants at all engine speeds are generally higher under different engine loads.
- It is determined that brake power and engine torque increases with increasing throttle valve opening. The best torque and power can be obtained at a wide–open throttle valve opening (100% load) due to higher volumetric efficiency. The better power and torque were obtained with Al_2O_3 and TiO_2 nanolubricants than base engine oil under all engine loads and differences decreases in power and torque for all lubricants with the increase of engine load.
- It is determined that brake specific fuel consumption increases for all lubricants with increasing engine speed at 30% engine load. It is also determined that Al_2O_3 and TiO_2 nanolubricants gives the less brake specific fuel consumption than base engine oil at all engine speeds and loads.
- It is determined that total frictional power losses decrease in the range of 5–7% and mechanical efficiency improved in the range of 1.7–2.5% due to improving engine tribological behavior by Al_2O3 and TiO_2 nanolubricants. Thus, fuel is saved up to 4 L/100 km in low speed, 2.4 L/100 km in economical middle speed and 1.5 L/100 km in high speed with Al_2O_3 and TiO_2 nanolubricants.
- It is determined that graphite nano–flakes (GNF) and graphene nano–platelets (GNP) nanolubricants increase brake power compared to 15W40 base engine oil. Brake power increased about 3.7–4.8% and 1.8–3.8% for GNP and GNF nanolubricants respectively compared to base engine oil under 50% engine load.
- It is determined that GNF and GNP nanolubricants improved engine torque. Engine torque increased in the range of 3.1–6.3% and 2.3–5.2% respectively for GNP and GNF nanolubricant compared to base engine oil.
- It determined that GNF and GNP nanolubricants give always less brake specific fuel consumption than base engine oil. GNP nanolubricant gives a lower fuel consumption of 1.7–3.8% compared to GNF nanolubricant.
- It is determined that GNP and GNF nanolubricants reduces the total friction power losses by 1.5–5% and 1.5–4.2% respectively due to the lowered friction and wear, viscidity and high viscosity index which provides a rise in brake power, engine torque and brake specific fuel consumption.
- It is determined that GNP and GNF nanolubricants improve engine mechanical efficiency by 2% and 1.4%, respectively in comparison with base engine oil.

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