Applied Energy 211 (2018) 461–478

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Fuel economy in gasoline engines using Al_2O_3/TiO_2 nanomaterials as nanolubricant additives

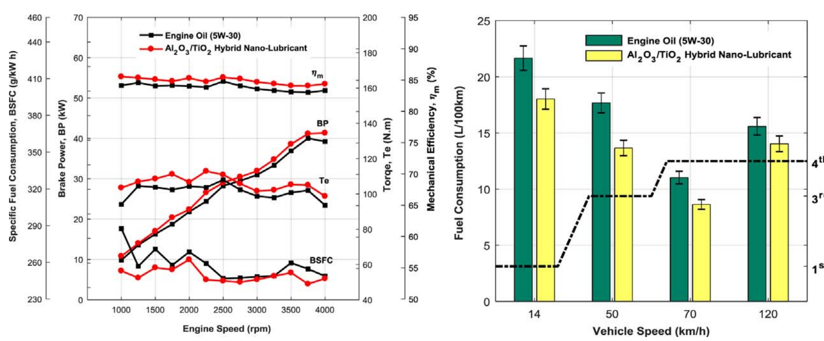
Mohamed Kamal Ahmed Ali[a,b,c], Peng Fuming[a,b], Hussein A. Younus[d,f], Mohamed A.A. Abdelkareem[a,b,c], F.A. Essa[e], Ahmed Elagouz[a,b,c], Hou Xianjun[a,b,*]

[a] Hubei Key Laboratory of Advanced Technology for Automotive Components, Wuhan University of Technology, Wuhan 430070, China
[b] Hubei Collaborative Innovation Center for Automotive Components Technology, Wuhan 430070, China
[c] Automotive and Tractors Engineering Department, Faculty of Engineering, Minia University, El-Minia 61111, Egypt
[d] Chemistry Department, Faculty of Science, Fayoum University, Fayoum 63514, Egypt
[e] Mechanical Engineering Department, Faculty of Engineering, Kafrelsheikh University, Kafrelsheikh 33516, Egypt
[f] State Key Laboratory of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan 430070, China

HIGHLIGHTS

- Fuel economy is improved by Al_2O_3/TiO_2 nanolubricants strategy under NEDC.
- The vehicle fuel consumption during NEDC was reduced by 4 L/100 km.
- The engine brake power and engine torque improved during urban and motorway.
- Total frictional power losses of gasoline engine were reduced by 5–7%.
- The mechanical efficiency of gasoline engine improved in the range 1.7–2.5%.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Fuel economy
Gasoline engines
Warm-up phase
Nanolubricants
Nanomaterials
NEDC driving cycle

ABSTRACT

Energy resources are of strategic interest worldwide. Transportation sector is a principal consumer of different energy resources, therefore reducing the consumption of vital energy resources is critical in automobiles. The friction and wear issues impact the energy efficiency of engines, therefore it is an important development of the lubricant for saving energy. The current study supports that goal. This study deals contribution of Al_2O_3/TiO_2 hybrid nanoparticles as nanolubricants to improve gasoline engine efficiency and fuel economy. The gasoline engine performance characteristics were evaluated experimentally using an AVL dynamometer under different operating conditions including the New European Driving Cycle (NEDC). Additionally, the engine was tested under critical operating conditions (warm-up phase). The results showed that using Al_2O_3/TiO_2 nanolubricants increases the brake power, torque, and mechanical efficiency, while the brake specific fuel consumption (BSFC) reduced owing to the mechanical efficiency of the engine improved by 1.7–2.5%, as compared to the engine oil without nanoparticles. Hence, the vehicle fuel consumption during NEDC could be improved up to 4 L per 100 km in the urban. Furthermore, FESEM, EDS line scanning, XPS, and Raman spectroscopy were conducted to understand the major tribological reasons for improving the engine performance to link tribological tests in the

* Corresponding author at: Hubei Key Laboratory of Advanced Technology for Automotive Components, Wuhan University of Technology, Wuhan 430070, China.
E-mail addresses: eng.m.kamal@mu.edu.eg (M.K.A. Ali), houxj@whut.edu.cn (H. Xianjun).

https://doi.org/10.1016/j.apenergy.2017.11.013
Received 4 September 2017; Received in revised form 8 October 2017; Accepted 2 November 2017

laboratory with actual engine performance. Eventually, the results suggest that nanolubricants provide economical engines with high efficiency that it may be an appropriate direction for vehicle manufacturers and users to suppress the engine fuel cost with engine durability under different operating conditions.

1. Introduction

With increasing concern about energy shortage and environmental protection, transportation vehicles account for about 19% of the world's energy consumption every year [1]. The friction between two worn surfaces is a principal cause of energy dissipation in automotive engines. Total power generated by the engine is reduced in the range 17–19% because of the frictional losses. The ability of lubricant oils to improve the fuel economy is critical in worldwide. Therefore, the investigations on frictional power losses reduction have gained tremendous attention as a promising direction in the performance of gasoline engines for fuel economy [2]. Reducing total frictional power losses in vehicles could save the US economy as much as US$ 120 billion per year [3]. The mechanical interfaces in automotive engines are usually lubricated by a blend of lube films and solid tribofilms [4]. Current challenges for improving the tribological behavior in automotive engines require lubricants that adapted to different operating conditions by replenishing mechanisms for reducing the friction and wear [5]. To solve this problem, we have focused on Nanotribology in the engines as the main strategy for minimizing frictional power losses, wear of sliding surfaces and excessive heat generation, in a manner that will ultimately lead to an improved performance of automotive engines.

Employing nanolubricant additives is considered as an accepted and attractive oil lubricant modification technique which is widely adopted since it does not need any major hardware modifications [6]. For engine efficiency improvement, it is desirable exploring new ways to replace the use of environmentally harmful additives which causes adverse emissions (zinc dialkyldithiophosphate (ZDDP)), without compromising on tribological performance for automotive engines with environmentally friendly additives such as ionic liquids and nanoparticles [7,8]. The study of the nanomaterials (1–100 nm) has become one of the fastest growing research areas in a lot of energy related fields owing to their excellent properties [9].

Nanolubricants have received a particular attention because of their great potentials such as friction modifiers, anti-wear additives, and solid lubricants on sliding worn interfaces in tribological applications [10]. While previous results on using Al_2O_3, TiO_2 and Al_2O_3/TiO_2 hybrid nanoparticles as nano-additives are promising in improving the engine tribological performance. According to the tribological results by Ali et al. [11], the Al_2O_3 and TiO_2 nano-additives into lube oil revealed that the friction coefficient decreased by 9–13%, 33–44%, 48–50% for the hydrodynamic, mixed and boundary lubrication regimes, respectively. However, the wear rate of the piston ring was declined by 29–21% for the use of Al_2O_3 and TiO_2 nanolubricants respectively, after a 50 km sliding distance, as compared to engine oil free of nanoparticles. Furthermore, the frictional power losses of piston ring assembly were also reduced by 39–53% for the Al_2O_3/TiO_2 hybrid nanolubricants [2]. Hence, the friction reduction by 10% in automotive engines has the potential to fuel economy by approximately 1%, although it depends on the vehicle models [12].

Rameshkumar et al. [13] studied the effect of the addition of iron oxide nanoparticles to lubricating oil (SAE 10W-30). The results revealed that using nanolubricants lead to improve fuel economy. Another study also demonstrated that using molybdenum improves gasoline engine fuel economy by 3–5% under full load [14,15]. A common route to obtain fuel economy from the lubricant is to reduce its viscosity and minimizing the boundary friction coefficient [16]. Tseregounis and McMillan [17] investigated a gasoline engine via shifting from 20W-50 to 5W-20 oil improved fuel economy by 4% due to lower viscosity. The fuel economy was reduced by 5–10% using the MoS_2 nanolubricants [18]. The results by Ali et al. [19] showed that Al_2O_3/TiO_2 hybrid nanoparticles provided low kinematic viscosity by 4.5% besides an increase in the viscosity index by ∼2%. Furthermore, thermal conductivity was reinforced by 16% for a temperature between 10–130 °C for helping to further enhancement of the heat transfer and maintain engine oil properties, comparing with lube oil (5-W30). Another study also showed that using Al_2O_3 nanolubricants improves the thermal conductivity by 9.52% [20].

The investigations on the decrease in the fuel consumption values in automotive have become the major research aspect for different countries. Fundamentally, brake specific fuel consumption (BSFC) of the engine demonstrates the amount of fuel consumed per unit work accomplished [21]. BSFC decreases with increasing load until the minimum BSFC is reached and then increases in a phenomenon called over-fueling [22]. In addition, engine load has a large effect on engine efficiency and BSFC [23]. The mechanical efficiency typically increases with engine load [24]. Nakamura et al. [25] investigated the fuel economy by optimizing viscosity characteristics of engine oil (5W-30). The results showed that the increasing of viscosity index of the lube oil increase the fuel economy improvement rate. TiO_2 nanolubricants reveals the increase in brake thermal efficiency by 4–7% as a promising approach in fuel economy [26].

Basically, the gasoline engines suffer from higher friction and less efficient combustion resulting in higher fuel consumption during the warm-up phase [27]. So, the engine heating during the cold start operating is helpful as it limits quenching of the cylinder liners and therefore enhances combustion quality and reduces the friction [28]. The increase in oil temperature decreases oil viscosity and improves organic efficiency and mechanical efficiency through engine cold starting [29]. According to the results by Will et al. [30], the total losses in the engine during the cold start phase increased approximately 2.5 times greater than those observed when the lube oil is warm. Therefore, it is imperative a high heating rate of the lubricant during the cold-start phase. Kunze et al. [31] stated that the fuel consumption declined by 10% when the temperature increased from 25 °C to 90 °C during NEDC driving cycle. Additionally, the results by Roberto et al. [32] exhibited that the fuel consumption during NEDC test reduced in the range of 2.8% resulting from heating of the lube oil.

The selection of nanoparticles is a very important step. Through statistical comparison of the tribological results, Dai et al. [33] exhibited the results of nanoparticles, which worked as nanolubricant additives. The results confirmed that the majority of nanolubricants consisted of metal oxides, metals, and sulfides. Furthermore, the majority of the nano-additives morphologies are spherical, followed by sheet, and nanotube. The spherical morphology of the nanoparticles showed superior tribological performance more than carbon nanotubes. The reason is strongly related to the rolling mechanisms between worn surfaces during the friction process [34].

The Main advantages of Al_2O_3/TiO_2 nanoparticles over carbon nanotubes are that Al_2O_3/TiO_2 nanoparticles are cheaper, more stable in lubricant oils and eco-friendly [35]. Al_2O_3 and TiO_2 nanoparticles are most appropriate for many environmental applications in which TiO_2 nanoparticles are environmentally friendly and non-toxic substance that can sometimes be used in food coloring as reported by [36]. Furthermore, Al_2O_3 and TiO_2 nanoparticles offer excellent tribological properties as a solid lubricant at high temperatures [11]. They also have been categorized as ceramic materials [2]. Al_2O_3/TiO_2 nanoparticles can provide properties that do not exist in an individual nanomaterial as well as the synergistic effect of the nanoparticles [37]. The nanoparticles such as Al_2O_3, TiO_2, ZnO, MnO, CuO, and CeO_2 are normally