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Wear and performance analysis of a 4-stroke diesel engine employing nanolubricants

Ankit Kotia[a,b], Sheeba Borkakoti[b], Subrata Kumar Ghosh[b,*]

[a] Department of Mechanical Engineering, DIT University, Dehradun, India
[b] Department of Mechanical Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, India

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ABSTRACT

In the present study, the performance of a 4-stroke diesel engine was experimentally evaluated upon adding Al_2O_3 or SiO_2 nanoparticles to the engine oil (SAE15W40). The viscosity and density of the resulting nanolubricants were determined while varying both the nanoparticle volume fraction and the temperature. Field emission scanning electron microscopy (FE–SEM) showed that the nanoparticles had a spherical morphology and dynamic light scattering analysis determined some aggregation of the nanoparticles in the engine oil. A pin-on-disc test apparatus was used for friction and wear analysis in the presence of the nanolubricants. Examination of wear scars by FE–SEM and energy dispersive spectroscopy found evidence of ball bearing and surface polishing effects, which were responsible for improvements in the tribological properties of the oil. The performance of these nanolubricants in a 4-stroke diesel engine test rig was assessed, and the greatest improvements in the tribological behavior and engine performance were observed when employing 0.3 vol% Al_2O_3.

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Introduction

Lubricant plays an essential role in the efficient performance of an engine, and additives contained in the lubricating oil can either enhance or reduce the properties of the base oil. Improvements in nanotechnology have demonstrated the potential for nanoparticle additives to improve the thermal properties of such lubricants. Various researchers have reported that well-dispersed nanoparticles increase the thermal conductivity of oil and also improve heat transfer performance (Choi, Zhang, Yu, Lockwood, & Grulke, 2001; Eastman, Choi, Li, Yu, & Thompson, 2001; Nisha & Jacob, 2011; Xuan, Li, & Hu, 2003). Recent studies have also shown that nanoparticles can work to improve the lubrication performance. As such, there has been an interest in dispersing nanoparticles in base lubricants to obtain suspensions referred to as nanolubricants (Kole & Dey, 2011a; Kotia & Ghosh, 2015; Thottackkad, Perikinalil, & Kumarapillai, 2012; Wu, Tsui, & Liu, 2007). The resulting modification of the lubricant properties depends on the characteristics of the nanoparticles, such as morphology, size, and volume fraction. Dai, Kheireddin, Gao, and Ling (2016) observed that nanoparticles with onion-like, sheet and spherical morphologies display superior tribological performance compared with granular particles and nanotubes. A spherical morphology is favorable for rolling mechanism which contributed in improvement of anti-wear performance. Hwang et al. (2011) investigated the effect of morphology of carbon based nanoparticles on the lubrication performance. They determined that a fibrous morphology reduces the lubrication performance owing to higher degrees of agglomeration, while spherical particles improve the anti-friction performance.

Nanoparticle dispersions can significantly modify the viscosity of the base lubricant, which is an essential property determining load carrying capacity and viscous friction. This parameter is also responsible for the formation of lubricating films under both thick and thin film conditions (Vishweshwara & Badi, 2015). Piston ring-pack friction is responsible for approximately 25% of the mechanical losses in an internal combustion engine, and lubricant viscosity produces a shear effect between the piston and cylinder walls that reduces this friction and thus increases engine efficiency (Takata, 2006). Researchers have reported incremental changes in the viscosity of lubricating oil with the addition of nanoparticles (Aftab, Ismail, Khokhar, & Ibupoto, 2016; Ismail, Aftab, Ibupoto, & Zolkifile, 2016; Thottackkad et al., 2012). Ettefaghi, Ahmadi, Rashidi, Mohtasebi, and Alaei (2013) used 0.5 vol% CuO nanoparticles in engine oil (SAE 20W50) and found an increase in the viscosity of 5.7%. This increment was attributed to the agglomeration of nanoparticles, which prevents the movement of adjacent

* Corresponding author.
E-mail addresses: subratarec@yahoo.co.in, subratarkl@gmail.com (S.K. Ghosh).

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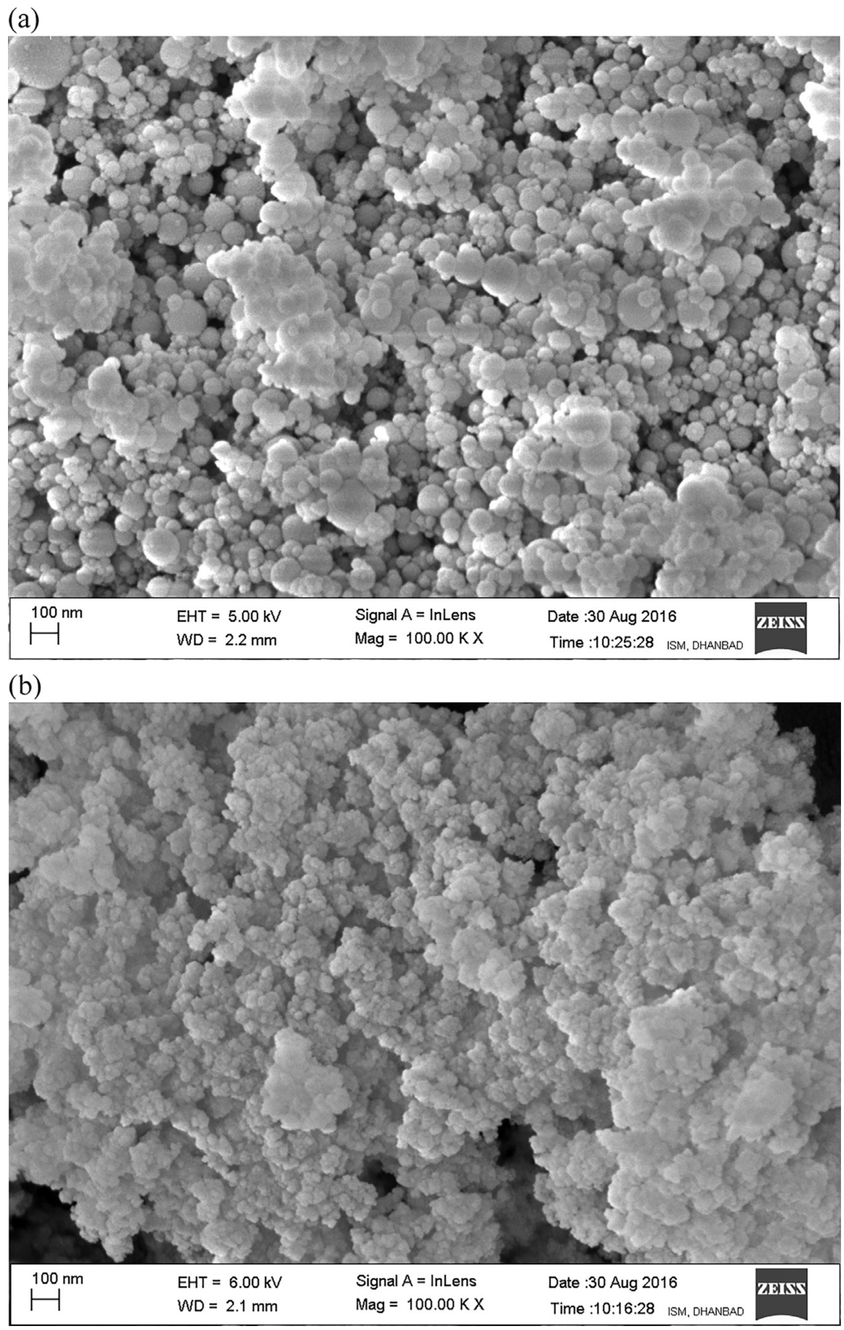

Fig. 1. Morphologies of the (a) Al_2O_3 and (b) SiO_2 nanoparticles used as additives in nanolubricant.

oil layers. Agarwal, Vaidyanathan, and Kumar (2013) used 0.5 vol% Al_2O_3 nanoparticles in engine oil (SAE 15W40) and observed a 10% increase in viscosity. Increasing the surface area of the nanoparticles also leads to greater interfacial resistance between the fluid layers, again increasing the viscosity. Kedzierski (2013) found a 10.9% increase in the viscosity of a commercial polyolester lubricant (RL68H) upon adding dispersed Al_2O_3 nanoparticles, while Kotia and Ghosh (2015) used 0.5 vol% Al_2O_3 nanoparticles in gear oil (SAE EP90) and observed a 10.5% increment in viscosity. Furthermore, Kotia, Haldar, Kumar, Deval, and Ghosh (2017) reported a 15% increase in the viscosity of hydraulic oil with the addition of 1.5 vol% CuO nanoparticles. The relative increase in the density of the nanolubricant will determine the time span over which the nanoparticles settle out of suspension, and Mahbubul, Saidur, and Amalina (2013) reported a 0.54% increase in the density of a refrigerant (R141b) following the dispersion of Al_2O_3 nanoparticles.

Mechanical friction can result in considerable decreases in fuel economy and performance while increasing emissions (Skjoedt, Butts, Assanis, & Bohac, 2008). Shahnazar, Bagheri, and Hamid (2016) reported that nanotechnology also offers a promising approach to enhancing friction and wear resistance. Marcano, Bensaid, Deorsola, Russo, and Fino (2014) observed that nanolubricants have improved anti-friction and anti-wear properties that are dependent on the shape, size, and volume fraction of the nanoparticles (Laad & Jatti, 2016). Wu et al. (2007) investigated the effects of CuO, TiO_2, and nano-diamond nanoparticle additives on the tribological properties of engine oil (API-SF SAE30 LB51153) and observed that CuO significantly enhanced the anti-friction and

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