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Effect of aggregation on the viscosity of copper oxide–gear oil nanofluids

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ABSTRACT

Results on viscosity of the stable nanofluids, prepared by dispersing 40 nm diameter spherical CuO nanoparticles in gear oil are presented. Viscosity of the studied nanofluids displays strong dependence both on CuO loading in the base fluid, as well as, on temperature between 10 and 80 °C. Presence of aggregated CuO nanoparticles in the fluid, with average cluster size ~7 times the primary diameter of CuO nanoparticles, have been confirmed by DLS data. Viscosity of the nanofluids is enhanced by ~3 times of the base fluid with CuO volume fraction of 0.025, while it decreases significantly with the rise of temperature. Newtonian behavior of the gear oil changes to non-Newtonian with increase of CuO loading. Shear thinning is observed for nanofluids containing CuO volume fraction >0.005. CuO volume fraction dependence of the viscosity of CuO–gear oil nanofluids is predicted well using the modified Krieger–Dougherty equation derived taking into account the aggregation mechanism. Temperature variation of the nanofluid viscosity agrees very well with the modified Andrade equation, reported by Chen et al.

1. Introduction

Cooling and lubricating are important in many industries, especially in transportation and energy production. Advanced developments in operating high-speed, high-power, and high efficiency engines and turbines with significantly higher thermal loads require more efficient cooling and lubricating technology. To increase heat dissipation, the usual approach is to increase the surface area available for the lubrication fluid. This approach, however, is not desirable because a larger heat exchange system is required which acts as a primary barrier to the development of energy-efficient compact heat exchangers. Therefore the development of more efficient heat transfer fluids with higher thermal conductivity is considered urgent. Over the years, many researchers focused their attention to create new kinds of heat transfer fluids by suspending tiny (micrometer sized) particles in the conventional liquids to enhance their heat transport performances. Choi [1] in 1995 created *Nanofluids* by suspending nanoparticles in common heat transfer fluids (viz, water, ethylene glycol etc.) and reported dramatic enhancement of their thermal properties.

Since then, most of the published reports on nanofluids concentrated on the heat transfer behavior including thermal conduction [1–4], phase change (boiling) heat transfer [5–8], and convective heat transfer [9–12]. In comparison, very few studies, however, have been devoted on the rheological behavior of nanofluids. A number of review articles [13–15] emphasized the significance of investigating the viscosity of nanofluids and it is believed that viscosity is as critical as thermal conductivity in establishing adequate pumping power as well as the heat transfer coefficient in engineering systems that employ fluid flow. This is because; pumping power is proportional to the pressure drop, which in turn is related to fluid viscosity and also both Reynolds and Prandtl numbers depend upon the viscosity.

Prasher et al. [16] reported effects of shear rate, nanoparticle size, volume fraction and temperature on the viscosity of alumina-based nanofluids. Their data demonstrated that viscosity is independent of shear rate, proving that the nanofluids are Newtonian in nature. Namburu et al. [17] studied the viscosity of copper oxide nanoparticles dispersed in ethylene glycol (EG) and water mixture. They also concluded that copper oxide nanofluids exhibit Newtonian behavior in EG–water mixture for particle volume fraction varying up to 0.0612. Viscosity of EG based nanofluids containing titania nanoparticles was measured by Chen et al. [18] and Newtonian behavior was observed over a wide shear rate range at temperatures between 293 and 333K. Kwak et al. [19] studied the viscosity and thermal conductivity of copper oxide–EG nanofluids, containing rod shaped particles having an aspect ratio of about three. Kulkarni et al. [20] observed that copper oxide nanoparticles with volume fractions between 0.05 and 0.15 in water behaved as non-Newtonian fluids in the temperature range of 5–50 °C. Phuoc et al. [21] reported the effects of the shear rate and particle volume fraction on the shear stress and the viscosity of Fe_2O_3–distilled water nanofluid and confirmed the existence of yield stress even at

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