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Role of interfacial layer and clustering on the effective thermal conductivity of CuO–gear oil nanofluids

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ABSTRACT

Copper oxide nanoparticles (∼40 nm) are dispersed in gear oil (IBP Haulic-68) at different volume fractions (0.005–0.025) with oleic acid added as a surfactant to stabilize the system. Prepared nanofluids are characterized by Fourier Transform Infrared spectroscopy (FTIR) and Dynamic light scattering (DLS) measurements. DLS data confirmed the presence of agglomerated nanoparticles in the prepared nanofluids. Thermal conductivity measurements are performed both as a function of CuO volume fraction and temperature between 5 and 80 °C. An enhancement in thermal conductivity at 30 °C of 10.4% with 0.025 volume fraction of CuO nanoparticle loading is observed. Measured volume fraction dependence of the thermal conductivity enhancement at room temperature is predicted fairly well considering contributions from both nanolayer at the solid–liquid interface and particle agglomeration in the suspension, as visualized by Feng et al.

1. Introduction

Increase of the effective thermal conductivity by dispersion of solid particles in liquids was recognized by Maxwell [1] more than a century back. However, despite considerable efforts, preparation of a stable, well dispersed, efficient and practical heat transfer fluid containing suspended solid particles was unsuccessful as these studies were confined to millimeter or, micrometer-sized particles. With the availability of nanoparticles with sizes <100 nm, liquids with uniformly dispersed nanoparticles (nanofluids) have been the subject of intensive research for enhanced thermal conductivity [2–9]. Significant enhancement of thermal conductivity of various fluids containing only a few volume percent of nanoparticles [10–14] or, carbon nanotubes [15–17] has opened up the possibilities of realization of more efficient compact cooling systems, micro-heat exchangers, as well as, applications of nanofluids in transportation, aerospace, microelectronics and medicine. Over the last few years, thermal conductivity enhancement of varying magnitudes has been reported on nanofluids prepared with both metallic and oxide nanoparticles. However, the largest increase in thermal conductivity has been reported only in carbon nanotubes based nanofluids [18,19]. It is now known that enhancement of thermal conductivity of nanofluids depends not only on the nature of the nanoparticle and fluid combinations, but also on several other factors, such as, volume and size of nanoparticles and their dispersion and stability in the fluid, clustering, pH value and the surfactant used. The experimental results of various groups are well documented in some of the recent reviews [20–22].

The original model developed by Maxwell [1] and Hamilton–Crosser [23], takes into account the volume fraction and the thermal conductivity ratio between the particles and the base fluid, the particle shape for prediction of the effective thermal conductivity. Particle size was included in the modified Maxwell–Garnet and the Hasselman and Johnson model [24]. However, none of these classical models could account for the observed enhancement of thermal conductivity of nanofluids. Koo and Kleinstreuer [25] considered the significance of Brownian motion of nanoparticles in transfer of energy. Role of interfacial effects and Brownian motion contribution to micro-convection was incorporated by Jang and Choi [26]. Later, Prasher et al. [27] considered translational Brownian motion, the existence of an interparticle potential and convection in liquid due to the Brownian motion. Nevertheless, the values predicted by these models agree with some of the available experimental data, significant deviations are also reported in many cases. Yu et al. [28] reported that the liquid molecules near to the nanoparticle surfaces form layered structures of thickness of order of few nanometers and behave much like a solid and the effect of liquid layering was proposed as the reason for enhanced thermal conductivity of nanofluids [29–32]. Yu and Choi [29] first attempted to model a theory based on liquid layering at the solid–liquid interface by renovating the Maxwell equation for the effective thermal conductivity of solid–liquid suspension. Xie et al. [30] investigated the impact of this interfacial nanolayer on the effective thermal conductivity of nanofluids and proposed a model from the general solution of the heat conduction equation in spherical

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