Thermophysical Properties of Nanostructured Heat Transfer Fluids

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Abstract

Cooling is one of the most important technical challenges facing a range of diverse industries and military needs, including microelectronics, optoelectronics, transportation, and manufacturing. There is an urgent need for innovative heat transfer fluids with improved thermal properties relative to those currently available. The strategy of adding solid, highly conductive particles to improve thermal conductivity of fluids has been pursued since Maxwell's theoretical work was first published more than 100 years ago. Early-stage studies have been confined to millimeter or micrometer-sized solid particles dispersed in fluids. In the past decade, researchers have primarily focused on suspensions of nanometer-sized solid particles, known as nanofluids. This paper will discuss three generations of nanostructured heat transfer fluids that have been investigated at the University of Maryland [1-6].

1. Generation I: Suspensions of Solid Nanoparticles (Nanofluids)

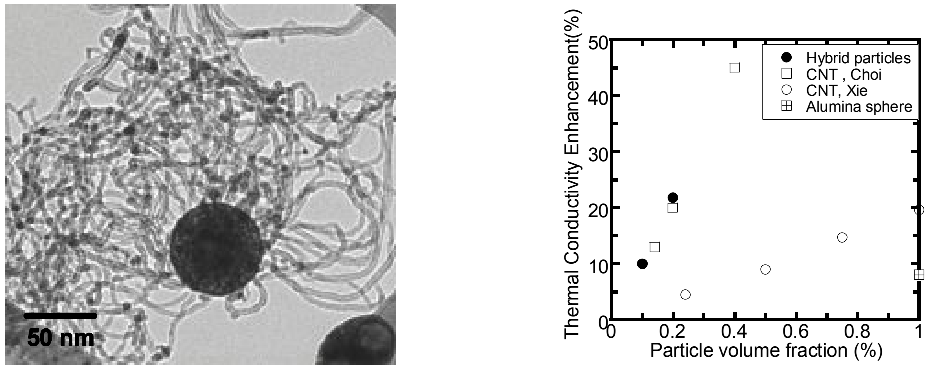
Hybrid sphere/carbon nanotube (CNT) particles are used as an example for conventional nanofluids, as shown in Figure 1a. The hybrid sphere/CNT particles are synthesized by a spray pyrolysis followed by catalytic growth of CNTs. The spheres are about 70 nm in diameter in average, and the attached CNTs have a length up to 2 μm. In such hybrid nanoparticles, heat is expected to transport rapidly from one CNT to another through the center sphere and thus leading to less thermal-contact-resistance between CNTs when compared to simple CNTs dispersed in fluids. The hybrid sphere/CNT particles have been shown to increase the thermal conductivity of the PAO oil by about 21% for volume fractions of only 0.2% at room temperature, a much higher enhancement in thermal conductivity as compared to simple spheres at the same particle loadings (see Figure 1b).

2. Generation II: Suspensions of Liquid Nanodroplets (Nanoemulsion Fluids)

Recently, the UMD group developed a radically new design for heat transfer fluids that completely eliminates solid particles, and instead, uses liquid nanostructures assembled from surfactant molecules. Initial experiments were done with a thermal fluid used in electronic cooling, termed FC-72, which is one of a line of Fluorinert™ Electronic Liquids developed by 3M Inc. The preliminary results on nanoemulsion fluids are very promising. The enhancement in conductivity and viscosity of the fluids is found to be nonlinear with water loading, indicating an important role of the hydrodynamic interaction of nanodroplets. The presence of 12 vol % of water raised the thermal conductivity by 52% compared to that of pure FC-72, as shown in Figure 2.

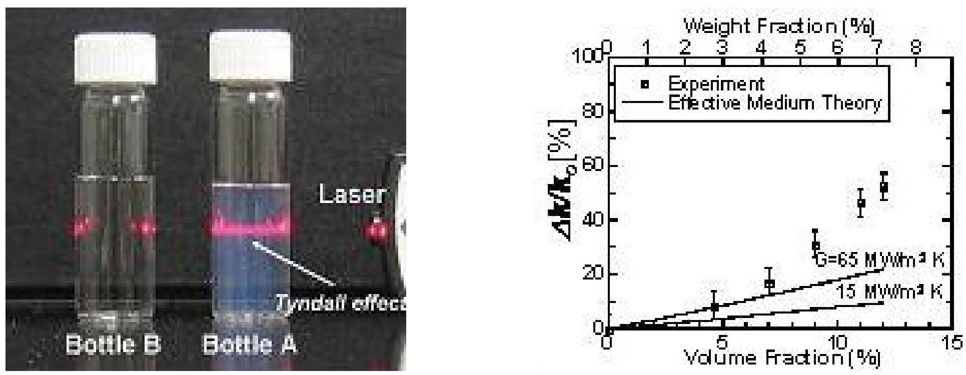
3. Generation III: Suspensions of PCM Nanoparticles (PCM Nanofluids)

The strategy of nanostructured fluids has been put forward by the UMD group with the use of phase-changeable nanoparticles in the fluids, termed "PCM nanofluids." As an example, a suspension of Indium nanoparticles (melting temperature, 157^{o}C) in polyalphaolefin (PAO) has been synthesized using a *one-step*, nanoemulsification method. The fluid's thermophysical properties, i.e., thermal conductivity, viscosity, and specific heat, and their temperature dependence have been investigated experimentally. The observed melting-freezing phase transition of the Indium nanoparticles would considerably augment the fluid's effective specific heat, as demonstrated in Figure 3. The use of phase changeable nanodroplets is expected to provide a new way to simultaneously increase the effective specific heat and thermal conductivity of conventional heat transfer fluids.



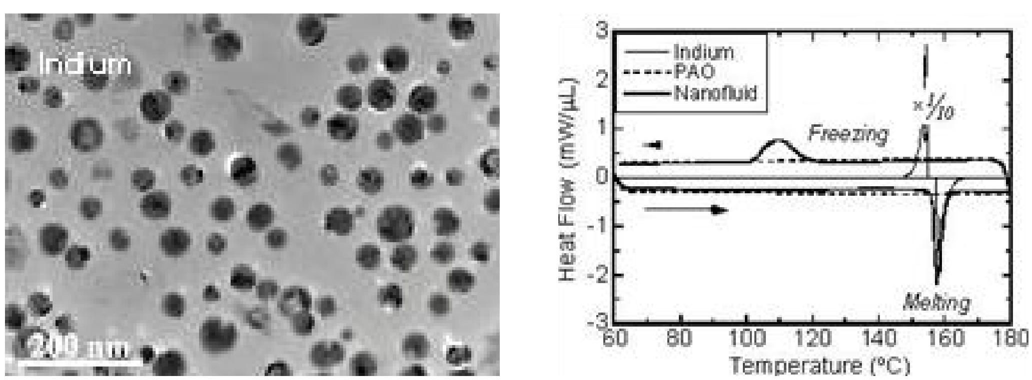
a) b)

Figure 1 a) TEM image of a sample hybrid sphere/CNT particle produced by the aerosol method; b) Performance comparison of particles with different morphologies, e.g., spheres, carbon nanotubes (CNTs), and hybrid sphere-CNT particles (urchin-like), in nanofluids [3].



a) b)

Figure 2 a) Pictures of water-in-FC72 nanoemulsion fluids (Bottle A) and pure FC72 (Bottle B). The Tyndall effect (i.e., a light beam can be seen when viewed from the side) can be observed only in Bottle A; b) Relative thermal conductivity of the water-in-FC72 nanoemulsion fluids as a function of water nanodroplet concentration [2, 5].



a) b)

Figure 3 a) TEM image of the Indium nanoparticles that were synthesized using the nanoemulsification method; b) DSC heating and cooling curves for as-prepared Indium/PAO PCM nanofluids [6].

4. References

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