Thermophysical Properties, Pool Boiling Characteristics, and Heat Pipe Application of Nanofluids

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Cooling is one of the most technical challenges facing many diverse industries, including microelectronics, transportation, etc. The conventional way to enhance heat transfer in thermal systems is to increase the heat transfer surface area of cooling devices and flow velocity or to disperse solid particles (usually millimetre or micrometer-sized) in heat transfer fluids, generally having low thermal conductivity. The dispersion technique, though attractive, could not be used for practical applications due to various problems viz., sedimentation, erosion, fouling and increased pressure drop in the flow channel. Choi in 1995 prepared a new kind of novel heat transfer liquid "Nanofluids" that displayed anomalously high thermal conductivity. Nanofluids are a new kind of novel heat transfer fluid containing nanometric-sized (<100 nm) solid particles that are uniformly and stably suspended in conventional heat transfer fluids, viz., water, ethylene glycol, etc. It is important that engineering applications of nanofluids that employ fluid flow, not only require information of their thermal properties, the appropriate rheological properties of the nanofluids are also very critical. As nanofluids have a higher thermal conductivity than base fluids, the heat transfer properties of nanofluids are expected to be higher than those of the base fluids, which make them more attractive for heat transfer applications. Moreover, encouraged by the enhanced heat transfer of nanofluids, some researchers have applied various nanofluids in heat pipes as the working fluids to enhance their heat transfer performance.

The objectives of the present programme are to investigate and understand the mechanisms responsible for enhanced thermal conductivity and viscosity of coolants (Engine coolant, M/S HP India; ethylene glycol (EG); distilled water; and mixture of EG and distilled water) and lubricant (Gear oil, M/S IBP, India, Haulic-68) based nanofluids containing alumina, copper oxide, zinc oxide, copper nanoparticles, and graphene nano-sheets. Experiments are also conducted to study the pool boiling characteristics of some selected nanofluids and the thermal performance of Cu-distilled water nanofluids as the working fluid in commercially available screen mesh wick heat pipes are investigated. All the nanofluids for the present study are prepared by two-step process, viz., calculated amount of nanoparticles or nanosheets are dispersed in the measured quantity of base liquids in presence or absence of a surfactant by intense ultrasonication followed by homogenization (magnetic stirring) for several hours. Dynamic Light Scattering (DLS) measurements are taken to ensure the average size of the nanoparticles clusters in the nanofluid. All the experimental facilities required for the above investigations, namely, the measurement of thermal conductivity (Transient Hot Wire technique) and viscosity, the pool boiling characteristics and critical heat flux (CHF) of the prepared nanofluids, as well as, the system for the evaluation of heat pipes have been designed, fabricated, calibrated and tested in the laboratory.

Well dispersed alumina-engine coolant nanofluids have been prepared using oleic acid (surfactant), having stability >80 days. Thermal conductivity of HP car engine coolant enhances by ~10.5% for a loading of 3.5 vol% Al_2O_3 at room temperature, which further increases to ~11.25% at 80℃. Viscosity also increases appreciably with volume concentration and decreases with temperature. Our analysis confirmed that the volume concentration dependence of thermal conductivity enhancement observed in Al_2O_3-engine coolant nanofluid is in excellent agreement with the model proposed by Prasher et al. (2005), which takes into account the role of translational Brownian motion, interparticle potential and micro-convection due to the Brownian motion in transfer of thermal energy in nanofluids. We have also shown the superiority of a Brownian motion based nanofluid viscosity model of Masoumi et al. (2009) over the classical models to predict the relative viscosity of alumina-car engine nanofluids.

Gear oil based stable nanofluids containing CuO and Cu naoparticles are prepared with oleic acid (surfactant). The suspension stability of both CuO-gear oil and Cu-gear oil nanofluid are tested for 30 and 20 days respectively without any degradation in thermal conductivity. Dynamic light scattering (DLS) data of both the nanofluids confirm the presence of aggregates. Enhancement in thermal conductivity of ~10.4% and ~24% have been observed for nanofluids with 2.5 vol% CuO and 2 vol% Cu nanoparticles respectively at room temperature. Thermal conductivity enhancement of CuO-gear oil nanofluid is well predicted taking combined contributions from both nanolayer at the solid-liquid interface and the nanoparticle clusters [Feng et al. (2007)]. The formation of interfacial layer at the nanoparticle-liquid boundary and the ballistic transport of the phonons across the percolating nanoparticle aggregates are believed to be responsible for the enhanced thermal conductivity of Cu-gear oil nanofluid. The viscosity enhancement of both types of nanofluids containing CuO and Cu nanoparticles is explained fairly well by a modified Krieger-Dougherty expression (2007) derived with contributions from the agglomerations in the nanofluids.

Surfactant free, stable ZnO-EG nanofluids are prepared with prolonged sonication (~60 hours). Optimum sonication time for the present nanofluid is determined from measurements of both thermal conductivity and DLS on nanofluid at different intervals between 4 and 100 hours of sonication. DLS data confirms that ZnO clusters size decreases rapidly from ~459 nm to ~91 nm between 4 and 60 hours, and beyond which the clusters grow to 220 nm for 100 hours of sonication. TEM also support the DLS data. ZnO-EG nanofluid sonicated for 60 hours shows maximum thermal conductivity. Thermal conductivity of ZnO-EG nanofluids display significant enhancement of ~40% for 3.75 vol% loading of ZnO nanoparticles at 30℃. This is the highest enhancement till date reported for ZnO-EG nanofluids. The observed anomalous enhancement is explained quite well with a new expression proposed for the thermal conductivity of nanofluids based on contributions from interfacial layer and the Brownian motion of suspended nano-clusters. The effectiveness of the proposed expression has also been established using the earlier reported thermal conductivity enhancement on other types of nanofluids. Most important result obtained in our ZnO-EG nanofluids is the observation of “nearly zero viscosity penalty”, which is an important advantage for application of nanofluid as cooling fluid.

Functionalized graphene nano-sheets are prepared, characterized, and dispersed in EG-distilled water mixture (70:30 by volume) without adding any surfactant. The prepared nanofluids are very stable (>5 months). Thermal conductivity, viscosity and electrical conductivity enhances by ~1.15, 2 and 87 times of the base fluid respectively at room temperature for a loading of 0.395 vol% graphene nano-sheets. The observed features are discussed in terms of the relevant mechanisms and it is concluded that the thermophysical characteristics of graphene nanofluids are favourable for their utilization as efficient coolant.

In addition to above, investigations are undertaken on the pool boiling characteristics of two different types of nanofluids, (namely, ZnO-EG and Cu-distilled water). Pool boiling heat transfer coefficient (HTC) of ZnO-EG nanofluids over smooth copper surface enhances by ~22% for a loading of 1.6 vol% ZnO nanoparticles. The boiling HTC of Cu-distilled water nanofluids over smooth copper, brass and aluminium surfaces increase with nanoparticle concentration. Copper is found to be better as a boiling surface than identical brass surface. The dependence of pool boiling phenomenon on copper heater surface of varied roughness using Cu-distilled water nanofluids have been studied and efforts have been made to understand the possible mechanisms. The thermal resistance of commercially available screen mesh wick heat pipe mounted at different inclinations is investigated with Cu-distilled water nanofluid as working fluid. The thermal resistance of the vertically mounted heat pipe containing 0.5 wt% of Cu-distilled water nanofluid is reduced by ~27%. The observed thermal performance of the present nanofluid based heat pipe is discussed in light of the deposition of a layer of Cu nanoparticles at the evaporator section.

Key words: *Alumina-Car Engine Coolant Nanofluids, CuO-Gear Oil Nanofluids, Cu-Gear Oil Nanofluids, ZnO-Ethylene Glycol Nanofluids, Graphene- Mixture of Ethylene Glycol & Distilled Water Nanofluids, Cu-Distilled Water Nanofluids, Thermal Conductivity, Viscosity, Pool Boiling Characteristics, Critical Heat Flux, Heat Pipes.*