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ORIGINAL ARTICLE

EXPERIMENTAL INVESTIGATION OF THERMAL CONDUCTIVITY AND VISCOSITY OF FE-WATER NANOFLUID: EFFECT OF DIAMETER OF NANOPARTICLES AND SOLID CONCENTRATION

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ABSTRACT: There are growing needs to measure the thermal properties using low volume fluid samples in various fields such as biotechnology and nanofluids and there has been significant research toward miniaturization of this measurement device. In this paper, a device that uses transient hot wire method for the purpose of thermal conductivity measurement is utilized. Using the device, the thermal conductivity of Fe-water nanofluids with different diameter of nanoparticle is measured for volume fractions of nanoparticles namely 0.01 (1.0%), 0.005 (0.5%), 0.0025 (0.25%), 0.00125(0.125%), 0.000625(0.0625%) and 0.000313(0.0313%) for room temperature.
KEYWORDS: Thermal Conductivity, Viscosity, Fe-Water Nanofluid.

INTRODUCTION

Research in the field of cooling systems is reaching new depths with improvements at macro and micro-levels. There are growing concerns for cooling high localized heat flux devices such as super computer micro-processors, electronics in avionics, and X-rays. An effective and relatively new technology addressing this concern is nanofluid technology employing liquid nano-composites and miniaturized heat exchangers. Choi, (1995) defined nanofluid as an engineered colloidal mixture of nano-meter sized particles (metals, oxides, carbides, nitrides, or nanotubes) in base fluids like water or organic fluids. The primary aspect of any heat transfer fluid is to characterize its thermo-physical properties; with thermal conductivity being a fundamental one. Since metals or oxides possess higher orders of thermal conductivity than fluids, they were presumed to enhance thermal properties when dispersed in a base fluid (Das *et al.*, 2007). A variety of theories like Brownian motion, effective medium theory, etc. had been proposed to explain this behavior. Application of nanofluid are expanding into energy conservation, faster and efficient cooling, which lead to greater processing speeds in electronics and hence better performance in a wide variety of practical applications. Even though numerous investigations were conducted in the past which present contradicting enhancement of Thermal conductivity of nanofluids, the problem has been resolved and has been clarified based on cooperation from a large number of organizations worldwide (Buongiorno *et al.*, 2009). Transient hot wire techniques (Perkins *et al.*, 1991; Duangthongsuk and Wongwises, 2009) rely on transient information.

Laser flash method (Chu *et al.*, 1980), thermo reflectance techniques (Zawilski *et al.*, 2001), 3-omega technique (Corbino, 1912; Cahill and Pohl, 1987; Cahill, 1989; Cahill, 1990; Dames and Chen, 2005; Wang and Sen, 2009; Lu *et al.*, 2001), etc. are gaining importance since these measures properties based on either steady state or pseudo steady state solutions.

To now, more than twenty laboratories worldwide have published experimental data on the thermal conductivity of nanofluids, and the results show that nanofluids exhibit substantially higher thermal properties particularly thermal conductivity even when the concentration of suspended nanoparticles is lower than 5% in volume fraction (Sastry *et al.*, 2008). At present the thermal conductivity data measured by different groups are scattered. A literature (Kabelac and Kuhnke, 2006) divided the experimental thermal conductivity values into “low group” and “high group”. The dispersion is believed to be due to various factors such as the measuring techniques, the particle size and shape, the particle clustering and sedimentation. Many papers neglect some important factors including the stabilities of nanofluids, the measured temperature, and the setting time after nanofluid preparation.

The enhancement of thermal conductivity achieved in nanofluids is much greater than what has been predicted by conventional

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theories such as Maxwell, (1904) or Hamilton and Crosser, (1962). Several experimental studies have explained the reason behind the enhancement of effective thermal conductivity such as the effect of the solid/liquid interfacial layer and the Brownian motion (Xue, 2003; Yu and Choi, 2003; Yu and Choi, 2004; Jang and Choi, 2004; Prasher *et al.*, 2005). For example, Xuan and Li, (2000) summarized all existing experimental observations.

They concluded that keff is a function of both thermal conductivities of the nano-material as well as carrier fluid, particle volume fraction, distribution, surface area, and shape. Keblinski *et al.*, (2002) listed four possible explanations for the cause of an anomalous increase of thermal conductivity: Brownian motion of the nanoparticles, molecular-level layering of the liquid at the liquid/particle interface, the nature of heat transport in the nanoparticles, and the effects of nanoparticle clustering. They ruled out the possibility of the Brownian motion effect by comparing the time scales of Brownian motion and the thermal response. Xue, (2003) proposed a thermal conductivity model based on Maxwell's theory and average polarization theory to take care of the interfacial effect (i.e., liquid nano-layer).

Bhattacharya *et al.*, (2004) investigated the effect of particle Brownian motion by using a molecular dynamics type approach which does not consider the motion of fluid molecules and requires two experimentally determined parameters. Keblinski *et al.*, (2005) made an interesting simple review to discuss the properties of nanofluids and future challenges.

PREPARATION OF NANOFLUID

Preparation of nanofluids is the first key step in experimental studies with nanofluids. In this paper, several nanofluids were prepared by dispersing pre-weighed quantities of Fe particles in DI Water as base liquid, at ambient conditions. The desired volume concentrations used in this study are 0.01 (1.0%), 0.005 (0.5%), 0.0025 (0.25%), 0.00125(0.125%), 0.000625(0.0625%) and 0.000313(0.0313%).

In this work, Fe-Water nanofluid was prepared utilizing two step methods. The two-step methods are extensively used in the synthesis of nanofluids considering the available nanopowders. In this method, In order to prepare the nanofluid, nanoparticles were first produced and then dispersed the base fluids. Generally, ultrasonic equipment is used to intensively disperse the particles and reduce the agglomeration of particles. The applied nanoparticles with different diameters were produced by US Research Nanomaterial, Inc.

No surfactant was used as they may have some influence on the effective thermal conductivity of nanofluids.

The typical TEM (transmission electron microscope) micrographs of the Fe nanoparticles with nominal particle sizes of35-45 nm, 65-75 nm, and 95-105 nm are shown in Figure 1. the Fe nanoparticles were dispersed in deionized Water successfully using a homogenizer, electromagnetic agitation, and ultrasonic vibration, forming Fe/Water nanofluid with no addition of any dispersant and surfactant Hence, It was observed that the Fe nanoparticles have spherical shapes.

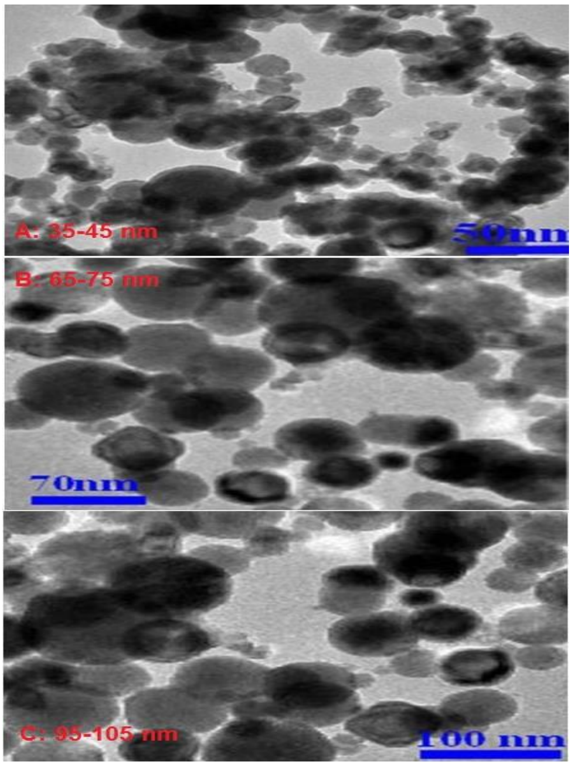

Figure 1: Transmission electron microscopy (TEM) image of Fe nanoparticles.

MEASUREMENTS OF THERMO PHYSICAL PROPERTIES OF NANOFLUID

By assuming that the nanoparticles are well stable in the fluid, the solid volume fraction of nanoparticles may be considered uniform. Although this assumption may be not true in real condition due to some physical phenomena such as particle migration, it can be a useful tool to measure the physical properties of a nanofluid.

3.1. Thermal conductivity behavior

Figure 2 shows the effect of nanoparticle diameter and volume fraction of nanoparticles on thermal conductivity ratio of Water based nanofluid containing Fe nanoparticle. The nominal particle sizes of the nanoparticles were 35-45 nm, 65-75 nm, and 95-105 nm, respectively. It is evident from this figure the thermal conductivity increases as volume fraction increases and thermal conductivity of the nanofluid increase with reduction in nanoparticle size. The results show that particle diameter can enhance thermal conductivity. Under the same concentration conditions, smaller particle size directly correlated with greater surface area of solid-liquid interface. It helped to the enhancement of thermal conductivity.

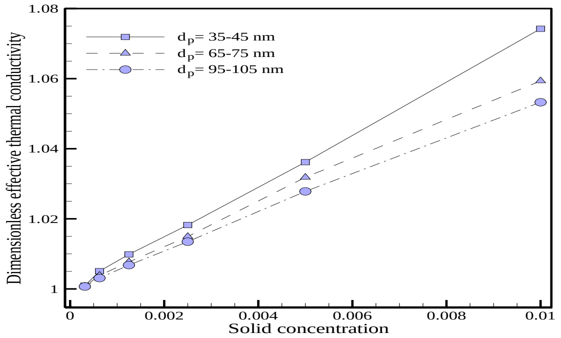

Figure 2: Thermal conductivity ratio of Fe-water nanofluid versus volume fraction for various nanoparticle diameters.

Therefore, particle diameter affected not only the suspension state, but also the thermal conductivity of nanofluid. The relationship between the relative thermal conductivity enhancement and the volume fraction is nearly linear and can be reproduced using the Hamilton and Crosser model, (1962) and Yu and Choi (2003). This linear behavior between the thermal conductivity enhancement and volume concentration can be attributed to large regions of particle-free liquid with high thermal resistances created by highly agglomerated nanoparticles.

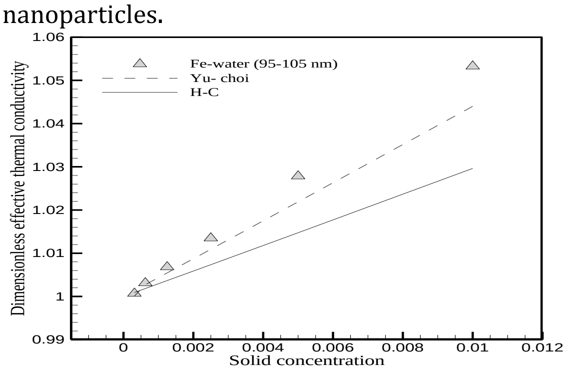

Figure 3: Relative thermal conductivity of nanofluid with respect to solid volume fraction for Exp. Data and H-C and Yu-Choi models.

Our results for Fe nanoparticles (95-105nm) were also compared with the experimental data of Yu and Choi, (2004) and Hamilton and Crosser model, (1962). The results in Figure 4 have obviously shown that both formulas proposed by Yu and Choi, (2004) and Hamilton and Crosser model, (1962) underestimate severely nanofluid thermal conductivity, especially for a very high particle fraction (higher than 0.004).

CONCLUSIONS

In this paper, we have experimentally investigated the effective thermal conductivities of Water-based nanofluids containing Fe nanoparticles (Fe-Water nanofluids). Well dispersed Water based- Fe nanofluids were obtained by dispersing Fe-nanoparticles into the water. The thermal conductivity has been obtained for different nominal diameter of nanoparticles, different concentrations of nanoparticles. Results show that thermal conductivity of nanofluid strongly depends on nominal diameter of nanoparticles and concentrations of nanoparticles. The thermal conductivity increases as volume fraction increases and thermal conductivity of the nanofluid increase with reduction in nanoparticle size.

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