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EXPERIMENTAL STUDY ON THERMAL PROPERTIES OF BRINES CONTAINING NANOPARTICLES

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Abstract. This paper examines the thermal properties of brines containing nanoparticles using the transient hot-wire method. Two nanofluids are fabricated by the Submerged Arc Nanoparticle Synthesis System (SANSS) with water and ethylene glycol, respectively as base solvents at different volume fractions. Compared with those of aqueous solutions of ethylene glycol, both the thermal conductivity and thermal diffusivity of the two brines containing nanoparticles were increased. The enhanced ratio of thermal diffusivity of the two nanofluids are several folds higher than that of thermal conductivity. Our study shows that better heat transfer performance can be obtained by adding nanoparticles to brines.

1. INTRODUCTION

Enhancing heat transfer for operation and maintenance of equipment has been the research focus in many fields. In many studies, small particles have been added to fluids in order to improve thermal conductivity. However, these particles, though minute, still cause blockage and wearing of the equipment. With advances in nanotechnology, problems of deposition and wearing of the heat exchanger rarely occur because the solid particles added are of nano-scale. In addition, for equal volume of particles added, the solid-liquid surface contact area of nanoparticles is greater that of micro-scale particles. The greater the surface contact area, the higher the thermal conductivity will be. Hence, the size and diameter of the particles added has a significant influence on the heat transfer capacity [1-6].

According to the research of Xuan and Li [7] as well as Eastman *et al.* [8], the thermal conductivity of nanofluids depend strongly on the volume fraction and properties of nanoparticles added. Hence, compared with mathematical calculation, experimental measurement of thermal conductivity of nanofluids may be a more direct method of greater accuracy. The transient hot-wire method has often been employed to obtain the thermal conductivity of fluids and powders [10,11]. To reduce the measurement errors of conductive fluids, the platinum sensing wires were covered with insulating materials [12].

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This study aims to investigate the thermal properties of newly developed brines. Aqueous solutions of ethylene glycol is the most commonly used brine and is employed as the working fluid in low-temperature refrigeration system and high-temperature heat dissipation equipment in vehicles. Adding ethylene glycol to fluids can achieve the effect of lowering the freezing point and raising the boiling point. However, the thermal conductivity of ethylene glycol is lower than that of water; hence when added to fluid, it can affect the heat transfer performance. This problem can be resolved by adding nanoparticles with high thermal conductivity to aqueous solutions of ethylene glycol. In this study, nanoparticles of different volume fractions are added to aqueous solutions of ethylene glycol to form nanobrines. The thermal conductivity and thermal diffusivity of brines with and without nanoparticles added are measured and compared.

2. PREPARATION OF SPECIMENS

The two sample nanofluids used in this study were prepared by the submerged arc nanoparticle synthesis system (SANSS). When the applied electrical energy produces a heating source for generating an adequate arc of high temperature, ranging from 6000 to 1200 °C [13], the bulk metal, copper in this study, is melted and vaporized. In addition, the dielectric liquid is also heated and vaporized rapidly by part of the submerged arc. The increase in volume as a result promotes a quick removal of the vaporized aerosol from the surface of the metal electrodes. The vaporized metal present in the base solvent within the vacuum chamber changes its current phase state through the nucleation, growth and solidification stages, and eventually becomes nanoparticles dispersed in the base solvent, forming nanofluids.

The TEM image of the two nanofluids obtained by the SANSS are displayed in Fig.1. Fig.1a shows the nanobrine mixed with deionized water as the base liquid containing 2.2 wt.% of copper oxide nanoparticles having a secondary diameter of 85 nm; while Fig. 1b shows the ethylene-glycol-based nanofluid containing 0.15 wt.% of copper nanoparticles having a secondary diameter of 6 nm. The diameter of the nanoparticles was obtained by the dynamic light scattering particle size distribution analyzer (HORIBA, LB-500). X-ray diffraction analysis confirmed the components of nanoparticles. The concentration of the nanofluids was measured by UV-visible spectrophotometers and compared with samples of standard weight fraction.

The related properties of aqueous solution of ethylene glycol are described in detail in [14]. This study employs the SANSS to synthesize two brines containing nanoparticles. One nanobrine has deionized water as the base solvent containing copper oxide nanoparticles with different volume fractions of ethylene glycol added; while the other nanobrine has ethylene glycol as the base solvent containing copper nanoparticles with different volume fractions of water added. The abovementioned nanobrines are mixed using an ultrasonic device and left to stand for 72 hours to yield a stable suspension with no deposition. Experimental measurements are made to determine the thermal properties of the two nanobrines containing different nanoparticles and of different concentrations.

3. EXPERIMENTAL THEORY AND DESIGN

3.1. Experimental device and its theory

The KD2 thermal properties analyzer [15,16] is employed to measure the thermal conductivity, thermal resistivity and thermal diffusivity of the nanofluids fabricated. This device is developed according to the transient hot-wire theory and can measure the thermal properties of both fluid and powder. The governing equation of the transient hot-wire method can be expressed as follows:

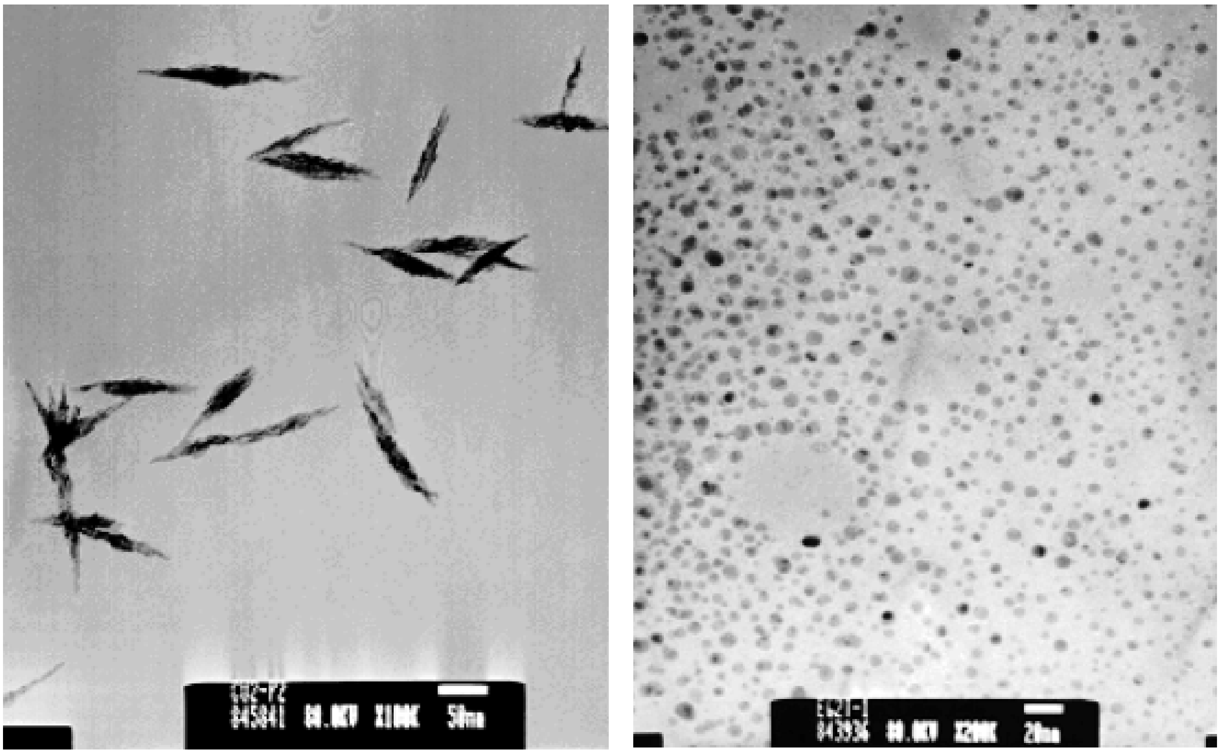
$$T(t) - T_1 = \frac{q}{4\pi k} \ln\left(\frac{4Dt}{r^2 C}\right), \tag{1}$$

where $T(t)$ is the temperature of the wire in the fluids at time t, T_1 is the initial temperature of the fluid in the container, q is the input power per meter of sensing wire, k is the thermal conductivity, D is the thermal diffusivity of the fluid, r is the radius of the sensing wire, and $-\ln C$ is Euler's constant. Assuming that there exists a linear relationship between changes in $\ln t$ and temperature, thermal conductivity k can be calculated according to Fourier's principle as follows:

$$k = \frac{q}{4\pi(T_2 - T_1)} \ln\left(\frac{t_2}{t_1}\right), \tag{2}$$

where q can be taken as the input power per meter of sensing wire, t_1 and t_2 both denote time, T_1 and T_2 are temperatures.

Without changes in temperature ($\Delta T = 0$), the thermal diffusivity can also be obtained from Eq. (1)



(a) (b)

Fig. 1. TEM image of nanofluids (a) TEM image of deionized water-based nanofluid containing copper oxide particles, and (b) TEM image of ethylene glycol-based nanofluid containing copper particles.

from the intersection of the regression line with the t axis as follows:

$$\ln(t_0) = \left[\ln C + \ln\left(\frac{r^2}{4D}\right)\right]. \qquad (3)$$

3.2. Experimental procedures

The sample specimens are put inside a circulating system of constant temperature. With the temperature of the sample nanofluids maintained at 30±1 °C, the thermal conductivity and thermal diffusivity are measured using the thermal properties analyzer. Since the thermal conductivity coefficients are very close to each other, better resolutions can be achieved by using the reciprocal of thermal resistivity to obtain the thermal conductivity. The average of 20 measurements of each sample is obtained to reduce experimental error and yield better accuracy.

Traditional aqueous solutions of ethylene glycol with volume fractions ranging from 10% to 90% are mixed for comparison with brines containing nanoparticles of the same volume fractions in terms of their thermal conductivity and thermal diffusivity to shed light on the enhanced ratio in thermal properties of brines with nanoparticles added.

4. RESULTS AND DISCUSSION

Table 1 displays the thermal measurements of the two nanofluids and two base solvents. As can be seen, the thermal conductivity of deionized water-based nanofluid containing copper oxide nanoparticles (N.W.) is 9.8% higher than that of deionized water. Similarly, the thermal conductivity of ethylene glycol-based nanofluid containing copper nanoparticles (N.E.G) is 5.1% higher than that of ethylene glycol. In the same way, the thermal diffusivity of N.W. is 14.6% higher than that of deionized water; while the thermal diffusivity of N.E.G. is 12.2% higher than that of ethylene glycol. Although the thermal conductivity of copper is higher than that of copper oxide, more copper oxide nanoparticles are added to the deionized water than the copper nanoparticles added to the ethylene gly-

Table 1. Comparison of thermal properties between nanofluids and base solvents.

	Deionized water	N.W.[a]	Ethylene glycol	N.E.G.[b]
K (W/m.°C)	0.612	0.672	0.256	0.269
D (mm^2/s)	0.151	0.173	0.09	0.101
$k_{E.R}$[c]	–	9.8%	–	5.1%
$D_{E.R}$[c]	–	14.6%	–	12.2%

[a] N.W. is the deionized water-based nanofluid containing copper oxide particles
[b] N.E.G. is the ethylene glycol-based nanofluid containing copper particles
[c] The subscript $_{E.R}$ is the enhanced ratio compared with the thermal properties of base solvent

col. In addition, the difference in geometrical shapes of the copper oxide nanoparticles will cause them to rotate in the fluid. This will then lead to convection-like effect in some regions which attain higher thermal conductivity. The enhanced ratio of thermal diffusivity of the two nanofluids are several folds higher than that of thermal conductivity. This reveals that the heat transfer of a nanofluid is faster than that of a base solvent, which can achieve more even distribution of temperature.

Figs. 2 and 3 display the thermal conductivity and thermal diffusivity, respectively of the two brines containing nanoparticles. Compared with aqueous solution of ethylene glycol, the nanobrine with copper oxide nanoparticles had thermal conductivity improved by 6.3-8.2% and thermal diffusivity enhanced by 0.3 – 11.7%. Similarly, the thermal conductivity and thermal diffusivity of the nanobrine containing copper nanoparticles were increased by 2.0-4.5% and 1.3-10.8%, respectively. As can be seen, at all volume fractions, the enhanced ratio of thermal conductivity of nanobrine is higher than that of aqueous solution of ethylene glycol. As for thermal diffusivity, the same trend is seen for small volume fractions of 10% and 30%. Beginning from volume fraction of 50%, the thermal diffusivity of nanobrine containing copper nanoparticles is higher than that of nanobrine containing copper oxide nanoparticles. This change in trend can be attributed to the better thermal conductivity of copper. Moreover, pure water is added to the ethylene glycol-based nanofluid containing copper particles; hence, a higher volume fraction will imply a greater copper content. On the contrary, ethylene glycol is added to the deionized

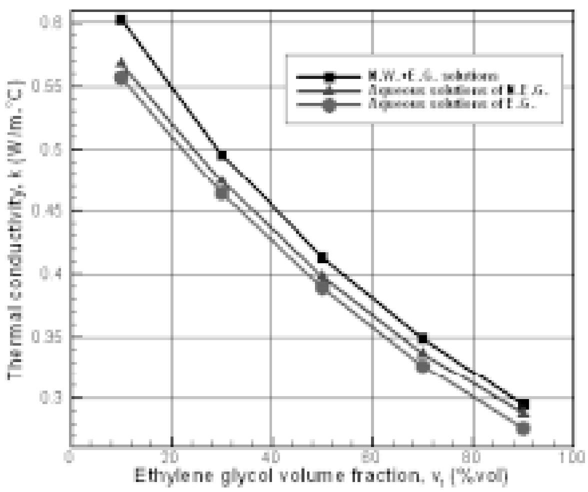


Fig. 2. The thermal conductivity of specimens of different ethylene glycol volume fractions.

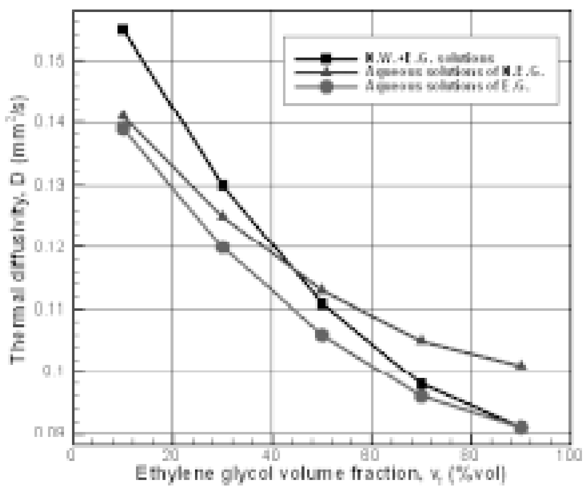


Fig. 3. The thermal diffusivity of specimens of different ethylene glycol volume fractions.

water nanofluid containing copper oxide particles, whose content will become smaller with increasing volume fraction. In addition, experimental measurements of the sample nanofluids show that the enhanced ratio of thermal diffusivity has all along been higher than that of thermal conductivity.

5. CONCLUSIONS

From the experimental results and discussion above, the following conclusions are made.

(1) Nanobrine with ethylene glycol of volume fractions ranging from 10% to 90% has better thermal properties than aqueous solution of ethylene glycol.

(2) For brine with high volume fraction of ethylene glycol, it is suggested that the nanoparticles should be dispersed in ethylene glycol to achieve greater nanoparticle concentration. In contrast, for brine with low volume fraction of ethylene glycol, the nanoparticles should be dispersed in deionized water to attain greater nanoparticle concentration.

(3) Nanofluids have high enhanced ratio of thermal diffusivity, indicating that heat transfer can lead to rapid change in temperature, resulting in more even temperature distribution.

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