New Temperature Dependent Thermal Conductivity Data of Water Based Nanofluids

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Abstract: -Thermal conductivity values for three types of wated-based nanofluids have been experimentally determined for various temperatures ranging between 20°C and 40°C. Nanofluids considered in this paper are composed of 29 nm CuO particles as well as 36 nm and 47 nm Al_2O_3 particles. The measuring technique used is based on the transient hot wire method. Results clearly show the increase in effective thermal conductivity of nanofluids with particle volume fraction, with temperature and as well as with a reduction in particle size.

Key-Words: - nanofluids, nanoparticles, thermal conductivity, heat transfer enhancement.

1 Introduction

It is well known that metals and metal oxides have higher thermal properties compared to conventional fluids. It is therefore conceivable that small particles of such materials placed in suspension inside typical cooling fluids can effectively enhance the thermal qualities of those fluids. This concept was considered in the past with relatively large particles (in the micrometer range). These experimentations showed that a fluid with metallic particle suspension can effectively yield better heat transfer characteristics than the same fluid without particles. Unfortunately, important sedimentation, shear stresses and agglomeration problems also appeared and therefore limited the practical applications of such mixtures. Recently, advances in manufacturing technology have permitted the production of particles in the 10 nm to 100 nm range. A "nanofluid" is therefore a typical fluid in which particles of this magnitude are introduced. Oxide nanoparticles are preferred over purely metallic particles since they offer more stable suspensions. Studies show that nanofluids are more stable and homogeneous than "microfluids" over longer periods of time [1]. Earlier published results show an important increase in heat transfer qualities of nanofluids over traditional coolants. For example, an alumina/water based nanofluid containing 4% volume fraction of particles yields approximately an increase in thermal conductivity of 25% [2]. Furthermore, a copper oxide/water nanofuid with 5% volume fraction of particles has shown to increase the thermal conductivity of 22.4% [3]. Several theories have surfaced trying to explain the reasons of the spectacular heat transfer enhancements of nanofluids. Others show that a low surface to volume ratio of particles produce better thermal efficiencies [4], [5]. Several authors state Brownian motion of particles as a prime factor of the thermal enhancement in nanofluids. The results of Kumar et al. [6] and those of Koo and Kleinstreuer [7] show the strong relationship between this Brownian motion and temperature. It has been shown that the increase of temperature enhances the heat transfer of nanofluids [8]. Several authors also consider the effect of the interfacial layer between the fluid and the particle [9], [10]. Typically, they find that the increase of layer thickness increases the thermal conductivity of the nanofluid. Others investigate the behavior of nanofluids in confined flows [2], [11], [12]. Again, results show an important increase in heat transfer with the use of nanofluids. However, an important increase in shear stresses is also noticed with an increase in particle volume fraction.

The bulk of research efforts so far on this fascinating subject has been on the evaluation of nanofluid properties. Naturally, a good proportion of the work has been experimental in nature and includes the evaluation of properties such as the effective thermal conductivity and viscosity of various types of nanofluids. An evaluation of available literature clearly shows an important dispersion between data obtained by different authors. Furthermore, the effect of temperature on thermal conductivity is not very well understood and documented. Indeed, only a few papers discuss this important parameter. Due in great part to this lack of experimental data, theoretical expressions of the thermal conductivity of nanofluids are generally not accurate and not versatile. The conclusions of theoretical studies clearly express the need of more experimental data [7].

The main objective of this present work is therefore to contribute to the nanofluid properties database in current literature in order to better understand the effects of various parameters such as particle size and temperature. Thermal conductivities of three different water based nanofluids are measured as a function of temperature. Average particle sizes considered are 29nm for the water-CuO nanofluid and 36nm and 47 nm for water-Al_2O_3 nanofluid. The temperature range considered lies between 20°C and 40°C.

2 Instruments and Experimental Procedures

Thermal conductivity measurements were made using the Decagon devices KD2 Thermal analyser, Figure 1. This hand held device uses the transient line heat source technique to evaluate the fluid thermal properties. The unit has 5 % accuracy over the 5°C to 40°C temperature range and also meets the standards of both ASTM D5334 and IEEE 442-1981. It basically comprises a hand-held readout unit and a single-needle sensor that is inserted into the fluid. A single reading generally takes 2 minutes. The first 90 seconds are used to ensure temperature stability, after which the probe is heated for 30 seconds using a known amount of current. The probe also contains a thermistor which measures the changing temperature while the microprocessor stores the data. At the end of reading, the thermal conductivity of the fluid is computed using the temperature difference vs. time data. More information on the theory behind the technique is available in the operating manual of the device (available online at www.decagon.com) as well as in [13].

Fig.1 KD2 Thermal properties Analyzer

The three types of nanofluids used for the experiments presented in this paper were purchased from Nanophase Technologies, Ilinois, USA. The delivered products were in a considerably concentrated form (i.e. approximately 50 % wt, or 15 to 20% in volume). For applications as a heat transfer medium, lower volume fractions are preferred, thus the original mixtures required dilution to obtained more practical concentrations (typically, in the 1% to 5% particle volume fraction). In order to determine the volume fraction of the solution, equation (1) was used, where ϕ denotes the volume fraction of nanoparticles:

$$\rho_{nf} = \phi.\rho_p + (1-\phi).\rho_{fb} \qquad (1)$$

In this last equation, ρ_{nf}, ρ_p, ρ_{fb} are the respective density of nanofluid, nanoparticles and base fluid.

Figure 2 illustrates the experimental setup used for nanofluid thermal conductivity measurements. Since measurements at various temperatures were required, the fluid specimen is placed inside an insulated, heated enclosure. Furthermore, in order to minimize possible particle sedimentation, a miniature, mechanical type mixer was used to periodically stir the nanofluid inside the enclosure. The mixer was activated via a switch placed outside the enclosure. The distance between the position of the KD2 probe and that of the mixer shaft is approximately 15 mm. Heating of the enclosure was stopped when the temperature reached approximately 42°C. The normal temperature drop inside was 1°C every 30 minutes. Below 33°C, the rate of cooling was considerably slower. For every considered volume fraction of particles, a measurement was taken every 30 minutes. The mixer was activated for approximately 60 seconds about 10 minutes before each reading.

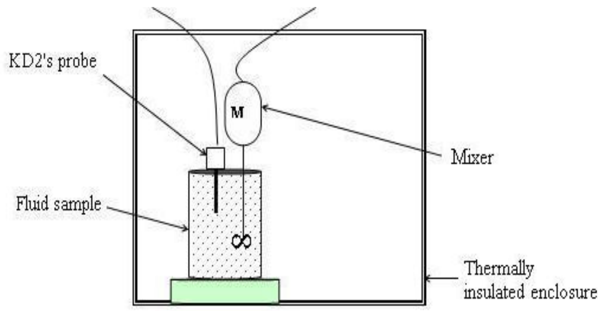

Fig.2 Experimental setup

Validation of the apparatus and procedure was done by comparing results obtained for distilled water with available correlations/data in literature [14]. As one can see, good agreement is found between data obtained with the thermal properties analyzer and available correlation. The maximum relative error determined experimentally on the collected data is 8%.

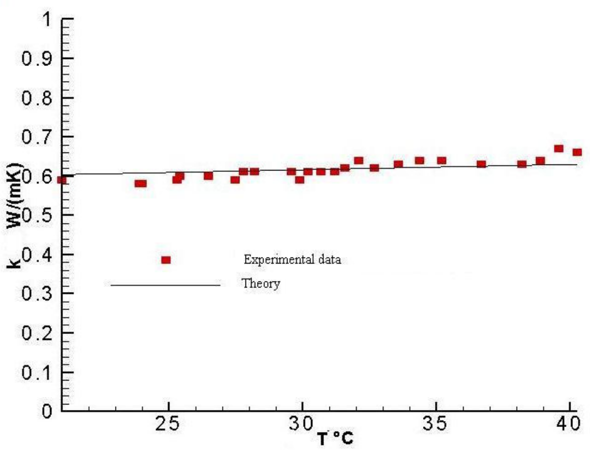

Fig.3 Validation of the thermal properties analyzer KD2 by distilled water

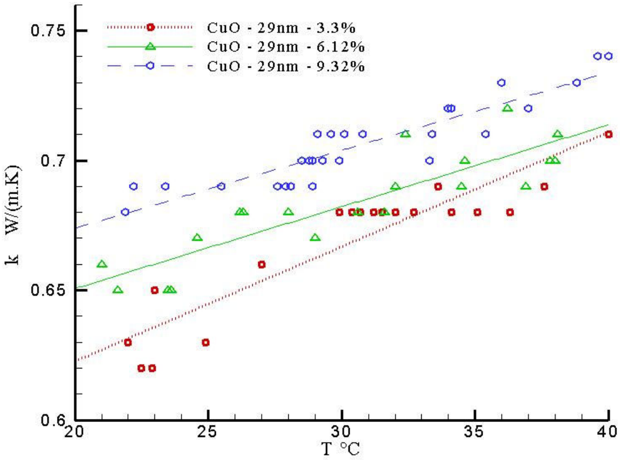

Fig.4 Thermal conductivity for water-CuO with 29nm particle-size

3 Results and Discussion

3.1 Effects of temperature on effective thermal conductivity

For each nanofluid considered, three volume fractions of particles are studied: 3%, 6% and 9% between 20°C and 40°C.

Figures 4, 5 and 6 present nanofluid thermal conductivity as a function of temperature. The results clearly show that the effective thermal conductivity of nanofluids increases with temperature. It is observed that the linear tendency fits of the measurements have geometrical slopes of more than 10°. Between 20°C and 40°C, one notes on the average an increase in thermal conductivity of approximately 16% for each type nanofluid. In comparison, the enhancement of thermal conductivity of pure distilled water is approximately 5% between 20°C and 40°C (see Figure 3). In comparison with distilled water, the addition of nanoparticles gives a better enhancement with temperature for low volume fraction of particles. As previously mentioned, some explain the enhancement of thermal conductivity of nanofluids with the temperature by Brownian motion [7], [14]. Typically, an increase in temperature increases the Brownian motion of particles.

The same figures also show the effect of volume fraction of nanoparticles on effective thermal conductivity. In general, the thermal conductivity of nanofluids increases with nanoparticle volume fraction. This is of course consistent with the majority of available literature on the subject. Figure 6 does however show a certain discrepancy as the linear fit for the results for a 6% volume fraction nanofluid is slightly above the one for a 9% volume fraction.

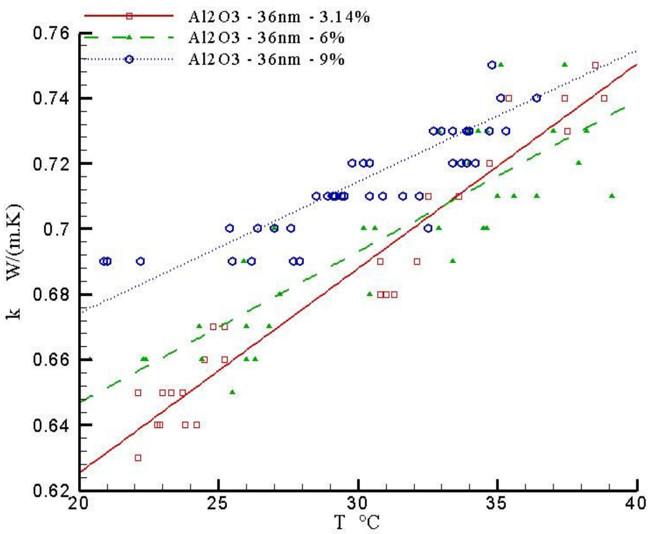

Fig.5 Thermal conductivity for water-Al_2O_3 with 36nm particle-size

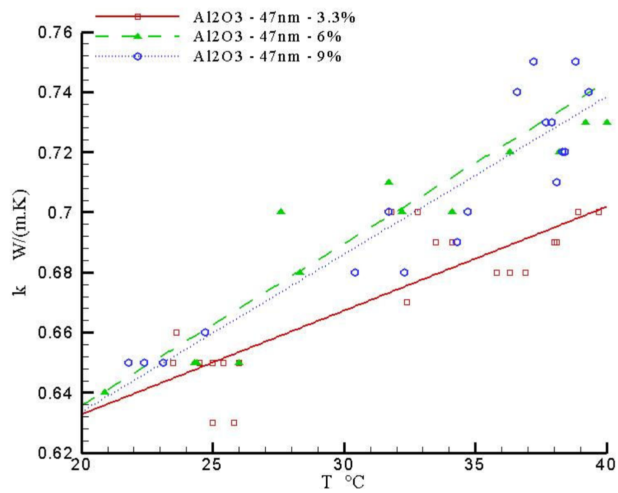

Fig.6 Thermal conductivity for water-Al_2O_3 with 47nm particle-size

3.2 Effects of nanofluid mixing

As previously mentioned, a mixing system was incorporated into the experimental setup in order to minimize possible sedimentation effects, especially at higher volume fractions. Our initial work on nanofluid effective thermal conductivity evaluation was conducted without such a system and nanoparticle sedimentation was suspected in high particle volume fraction situations [8]. As a point of interest, figures 7 and 8 show the results presented in [8] with results obtained in this present study (with the mixing system). The results shown from [8] were taken over a considerable period of time (a few days).

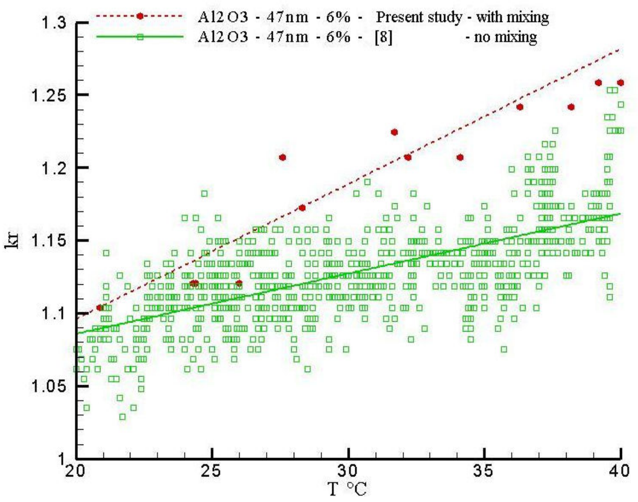

Fig.7 Effect mixing for water-Al_2O_3 with 47nm particle-size at 6%

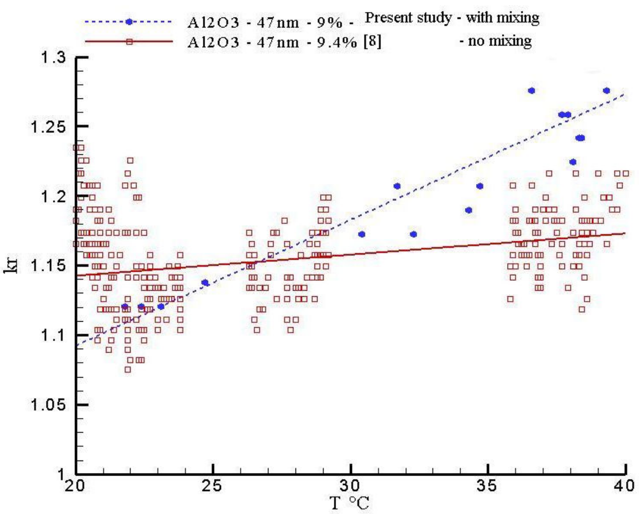

Fig.8 Effect mixing for water-Al_2O_3 with 47nm particle-size at 9%

As one can easily see, the results obtained with mixing and those without mixing (from [8]) are considerably different. It is important to also note that the comparisons are for the same type of nanofluid (i.e. 47 nm Al_2O_3 particles in water), with same volume fractions (6% and 9%) and measured using the same thermal properties analyzer. Results with mixing are clearly higher than those without mixing. This observation seems to confirm that sedimentation was present in our initial work on nanofluid effective thermal conductivity. The procedure used in this present study therefore seems more adequate.

4 Conclusion

Nanofluid effective thermal conductivity measurements were presented in this paper. Results have shown that the effective thermal conductivity of nanofluids increases with the volume fraction of nanoparticles as well as with temperature. Furthermore, in comparison with distilled water, the addition of nanoparticles gives a better enhancement with temperature for low volume fraction of particles. The effect of sedimentation in the evaluation of such properties was also discussed. The intermittent mixing of the nanofluids used in this study clearly gives higher values of thermal conductivity than those obtained without mixing, therefore implying the presence of sedimentation over a certain period of time.

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