Measurement of Thermal Properties of Suspensions of Nanoparticles in Engine Oil

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ABSTRACT

Nanofluids refer to new kinds of engineering fluids which are prepared by dispersing nanometer sized particles (smaller than 100 nm) in a base fluid. It has been recognized in the past decade that nanofluids have higher thermal properties compared with the base fluids. In this investigation, nanofluids were prepared by dispersing γ-Al_2O_3 and CuO nanoparticles in engine oil. The thermal conductivity and the heat capacity were measured at different temperatures and for different nanoparticle concentrations up to 2 %vol. Experiments revealed the enhancement of the thermal conductivity and the decrease of the heat capacity.

Keywords: nanofluid, thermal conductivity, heat capacity, nanoparticle

1 INTRODUCTION

The progress made in the field of nanotechnology in early 90's made possible the manufacture of particles from molecules and atoms at the nanoscale level. The production of nanoparticles allowed to explore the possibility of enhancing thermal properties of conventional coolant fluids by adding nanoscale solid particles to them. This led to the production of nanofluids. Nanofluids are prepared by suspending nanosize, metallic, metal oxide or nonmetallic particles into heat transfer fluids like water, ethylene glycol and oils [1]. Because of the very small size of nanoparticles they are very stable in static conditions and their flow in channels do not cause corrosion or clogging, in comparison to micro and milli-size particles [2].

The first attempt to measure the thermal conductivity of nanofluids was done by Masuda et al. in 1993. Their results showed an increase in thermal conductivity of a maximum of 30% for 4.3 %vol of Al_2O_3, SiO_2, and TiO_2 nanoparticles in water [3]. In 1995, Choi, a member of the Argonne National Laboratory, measured the thermal conductivity of Al_2O_3 and CuO nanoparticles suspensions in water and reported a maximum increase about 20% for a 4 %vol CuO nanoparticles; and for the first time the name "nanofluid" was used to describe these new series of materials [2]. Since that time, a large number of researchers have performed studies on nanofluids, including measuring their flow and thermal properties and searching to explain the mechanisms contributing to their improved thermal properties [4].

In the present study, the thermal conductivity and the heat capacity of γ- Al_2O_3 and CuO nanoparticles suspensions in engine oil were measured with good accuracy. This investigation addresses two new aspects: (1) using engine oil as the base fluid and (2) measuring both heat capacity and thermal conductivity of nanofluids. The effects of temperature and nanoparticle concentration on thermal properties were investigated during this project.

2 EXPERIMENTAL SET UP

γ- Al_2O_3 and CuO nanoparticles were purchased from Nanoamor company. Alumina nanoparticles were white, nearly spherical with an average size (APS) between 20 and 30 nm. Copper oxide nanoparticles were black, nearly spherical with an average size between 30 and 50 nm. Engine oil, a product of Total Oil Company, was used as the base fluid.

A 100 Watt ultrasonic processor (Hielscher Company) was used as an homogenizer along with a mechanical blender (Pars Company).

A needle type KD2 device was purchased from Decagon Device Inc. and used to measure thermal conductivity of nanofluids.

Preparation of nanofluids included weighing the required amount of nanoparticles to achieve the desired volume fraction, adding them to the base fluid and forming a homogeneous solution using sonication. Sonication is a process whereby nanoparticles are uniformly dispersed in the fluid using ultrasound waves. This process lasted for approximately forty minutes.

Thermal conductivity measurement was performed using a hot wire transient method. This method is based on the radial distribution of heat from a continuous line source in an infinite media and by determining the temperature at the center of the wire at different time intervals. The thermal conductivity was then evaluated from Equation (1):

$$k = \frac{Q}{4\pi} \frac{\ln\left(t_2/t_1\right)}{\left(T_2 - T_1\right)} \tag{1}$$

where t_1 and t_2 are the time intervals from the beginning of the heating process at which the corresponding temperatures T_1 and T_2 were measured at the center of the wire . Q is the rate of heat generation of the line source.

Measurement of the heat capacity was done using an adiabatic calorimeter, which was designed and constructed to meet the desired accuracy. All the components and devices used in the manufacture of the adiabatic calorimeter were chosen for their high quality and accuracy. The heat capacity measurement consisted in transferring a determined rate of heat to the sample in an adiabatic environment and measuring the temperature rise. Equation (2) was used calculate the heat capacity:

$$Q = m\,\bar{C}_p\,\Delta T \tag{2}$$

3 RESULTS AND DISCUSSIONS

Figure 1 presents the relative thermal conductivity of the two nanofluids as a function of the nanoparticle volume fraction at a temperature of 40°C. Results for the engine oil-based γ- Al_2O_3 suspensions revealed an improvement in the thermal conductivity with an increase in the volume fraction of nanoparticles. The enhancement in the thermal conductivity is almost a linear function of the percentage nanoparticle volume. An increase of 5% was observed for a volume fraction of 0.02. The same trend was observed for CuO-Engine Oil nanofluids and, in this case, the maximum increase in the thermal conductivity was about 8% for a CuO volume fraction of 0.02.

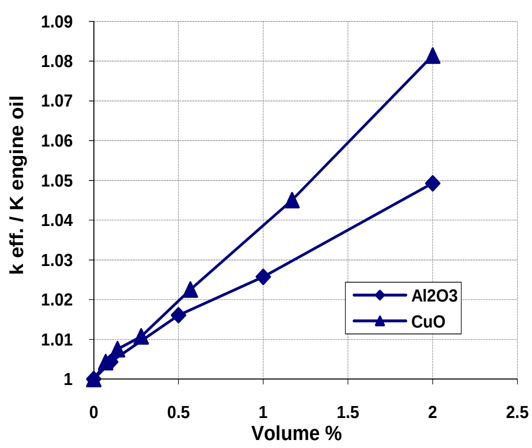

Figure 1: Variation of the thermal conductivity with volume percent of Al_2O_3 and CuO nanoparticles suspended in engine oil.

Figure 2 presents the variation of the relative heat capacity as a function of the nanoparticle volume fraction at a temperature of 45°C. It is observed that the heat capacity decreases with the nanoparticle concentration. For γ-Al_2O_3/engine oil nanofluids, the heat capacity decreased by about 5% for a 2 %vol concentration. For CuO/engine oil nanofluids a similar trend was seen, except that a 5% reduction in the heat capacity occurred at 1.2% volume concentration.

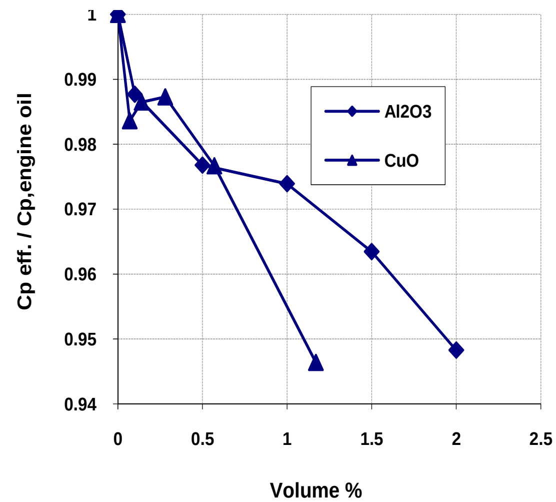

Figure 2: Variation of the heat capacity with the volume fraction of Al_2O_3 and CuO nanoparticles suspended in engine oil.

The operating temperature is a factor which significantly affects the physical properties of nanofluids. Figures 3-4 and 5-6 present the thermal conductivity and heat capacity variations of pure oil and the two nanofluids with temperature, respectively. Based on the results, the temperature has a significant effect on both the thermal conductivity and the heat capacity. As the temperature increases, the thermal conductivity decreases whereas the heat capacity increases.

Several models are available for the prediction of the thermal behavior of nanofluids. For the thermal conductivity, the model proposed by Hamilton and Crosser [5] considers the effects of the particle concentration, the particle shape, and the thermal conductivities of the base fluid and the particle. On the other hand, the particle size is not included as a parameter of the model.The model of Hamilton and Crosser for spherical particles is given in Equation (3).

$$k_{nf} = k_w \left[\frac{k_s + 2k_w - 2\nu(k_w - k_s)}{k_s + 2k_w + \nu(k_w - k_s)} \right] \tag{3}$$

where subscripts nf, s, and w refer to the nanofluid, solid nanoparticle, and base fluid, respectively. ν is the volume fraction of nanoparticles in the base fluid.

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Figures 7 and 8 compare the results for γ- Al_2O_3 /engine oil and CuO/engine oil with the values predicted by Hamilton and Crosser model, respectively. For both nanofluids, at low concentration the agreement is very good while a significant deviation is observed when the nanoparticle concentration is increased. For γ- Al_2O_3 /engine oil nanofluid, the model overestimates the thermal conductivity whereas it underestimates the CuO/engine oil nanofluid thermal conductivity. The reason may be related to the size and the thermal conductivity of nanoparticles.

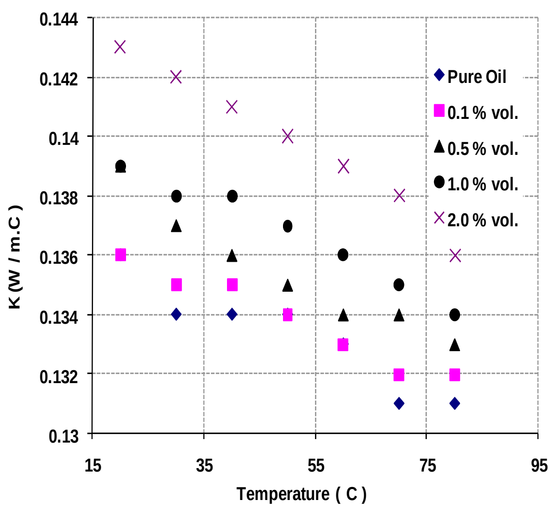

Figure 3: Variation of the thermal conductivity with temperature for pure oil and γ-Al_2O_3/engine oil nanofluid with different concentrations.

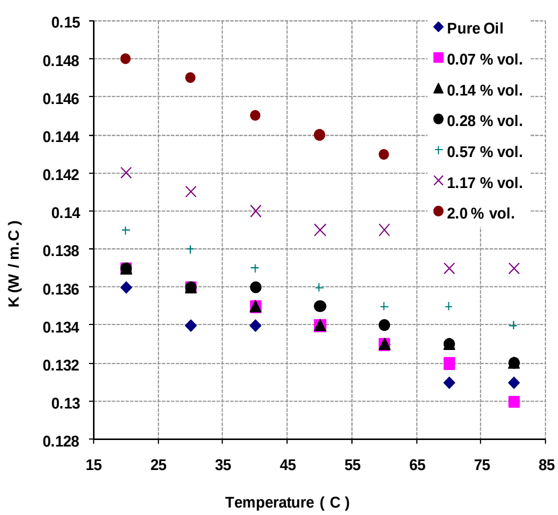

Figure 4: Variation of the thermal conductivity with temperature for pure oil and CuO/engine oil nanofluid with different concentrations.

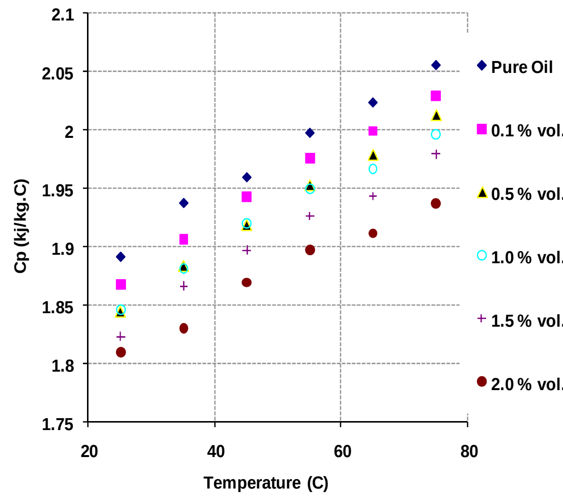

Figure 5: Variation of the heat capacity with temperature for pure oil and γ-Al_2O_3/engine oil nanofluid with different concentrations.

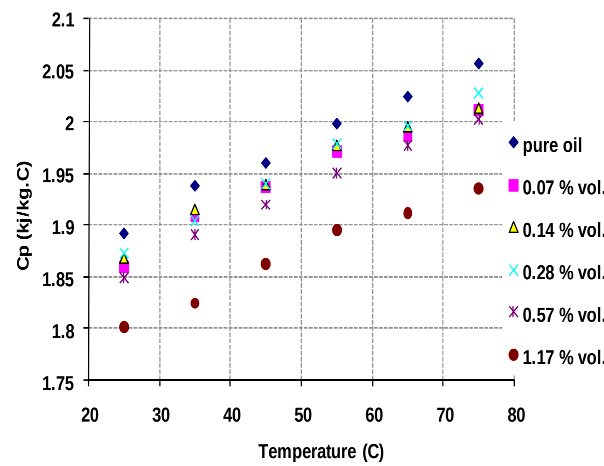

Figure 6: Variation of the heat capacity with temperature for pure oil and CuO/engine oil nanofluid with different concentrations.

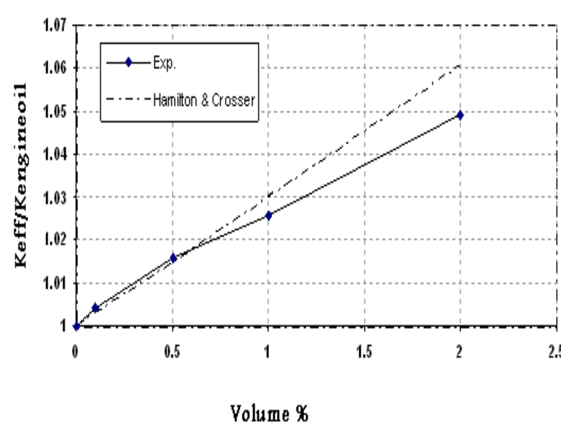

Figure 7: Comparison of experimental thermal conductivity data of γ-Al_2O_3/engine oil nanofluid with the prediction of Hamilton and Crosser model.

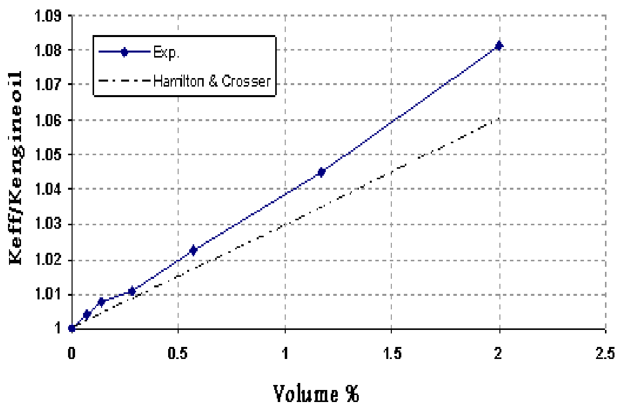

Figure 8: Comparison of experimental thermal conductivity data of CuO/engine oil nanofluid with the prediction of Hamilton and Crosser model.

4 CONCLUSIONS

Experimental measurements showed an improvement of the thermal conductivity and a reduction of the heat capacity of nanofluids in comparison to their base fluid. Both trends were accentuated in the case of CuO nanoparticle suspensions.

For the thermal conductivity, an increase was observed when the nanoparticle volume fraction was increased. On the other hand, the heat capacity was decreased when the nanoparticle concentration was increased. A sharp decrease at lower concentration of nanoparticles was observed where the it was smoother and linear at higher concentrations. The thermal conductivity decreased with an increase in temperature whereas the heat capacity increased with temperature, akin to what occurs for pure engine oil, and the presence of nanoparticles produced no additional effects for this variable.

ACKNOWLEDGMENTS

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