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Specific Heat of Nanofluids - An Experimental Investigation

Tushar Anand and Soumya Suddha Mallick

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Specific Heat of Nanofluids - An Experimental Investigation

Tushar Anand
Mechanical Engineering Department
Satyug Darshan Institute of Engineering and Technology, Faridabad-121002, Haryana, India
Email: tusharanand.sinha@gmail.com

Soumya Suddha Mallick
Mechanical Engineering Department
Thapar University, Patiala-147001, Punjab
Email:ssmallick@thapar.edu

Abstract
This paper presents an experimental investigation of the specific heat of nanofluids. While a lot of research has been done on nanofluids, it is still inconclusive and there is no agreement on the findings between various research groups. Also, most of the research has been done in areas of improvement of thermal conductivity but not of specific heat which is equally important since it influences the heat carrying capacity of a system. In the present work the specific heat of different nanoparticles – Silver, SWCNT, Zinc Oxide, Aluminium Oxide have been investigated experimentally at different temperatures and particle sizes. Deficiencies of existing models is brought out and a new correlation is presented.
Keywords: *Particle size distribution; Nanofluid; Heat transfer; Nanoparticles; Temperature*

I. INTRODUCTION

Nanofluids are a new class of engineered fluids obtained by suspending nano-size (**10^{-9}** m) particles with average size below 100 nm in heat transfer fluids (Choi et al.1999). Oxides, metals, nitrides and non metals, such as carbon nanotubes are used as nanoparticles, while water, ethylene glycol, oils, and polymer solutions, conventional coolants are used as base fluids. The smaller size of nanofluids offer several advantages over conventional heat transfer fluids, such as long term stability, low abrasion, low pumping power, homogeneity and minimum clogging in flow passages (Gallego and Wang, 2002). These benefits make nanofluids potentially attractive to various industries having heat transfer applications such as microelectronics, transportation, biomedical, micro-fluids, nuclear, automobile, power generation, x-ray, refrigerators etc (Chandrasekar and Khanafer 2010). Miniaturized systems will reduce heat transfer fluid inventory and successful employment of nanofluids will result in significant energy and cost savings because heat exchange systems can be made smaller and lighter.

In spite of such merits and wide spread potential applications of nanofluids, nanofluid technology is still limited for commercial use because there is yet no proven standardized design process for accurately predicting important heat transfer properties, such as the nanofluids specific heat, thermal conductivity and viscosity because of the influence of various particle and fluid properties, such as the shape and size distribution of nanoparticles (Chon, 2004; Murshed, 2008; Mintsa, 2007; Teng, 2010), volume concentration of nanoparticles in base fluids (Wang, 1999; Li, 2006; Timofeeva, 2007;Madhu, 2017), ultrasonication and storage time to prepare nanofluids (Timofeeva, 2007), use of surfactants (Murshed, 2008; Li, 2006), pH value (Xie, 2002) and temperature (Murshed, 2008; Mintsa, 2007; Li, 2006; Das 2003). Developing accurate fundamental model for the specific heat of nanofluids is a
challenging task. As a thermodynamic property, the specific heat capacity of a nanofluid dictates the nanoparticle and fluid temperature changes, which affect the temperature field of the nanofluid and hence the heat transfer and flow status in any application, e.g., systems for utilizing low-temperature solar thermal energy include means for heat collection, usually heat storage, either short-term or interseasonal and distribution within a structure or a district heating network.

Hence, the purpose of this paper is to firstly construct a setup and validate it. Secondly to carry out experimental work to find out the effect of different particle sizes, volumetric concentration, sonication time, frequency on specific heat of different nanofluid. Thirdly to develop improved model for specific heat using the data obtained.

II. EXPERIMENTAL SETUP AND PROCEDURE

The experimental setup used is shown in Fig. 1. The apparatus consists of a 20cm long and 7cm inside borosilicate container. . The apparatus is designed to hold about 900 ml of liquid. The nanofluids are heated from about 298K to 323K by using an electrical immersion heater. Ten copper-constantan thermocouples are placed in the apparatus. Four thermocouples are placed within the liquid volume to get the average temperature of the liquid and one on the heating Two thermocouple are placed on the outer surface of the container and two on the outer surface of second insulation and one at the

midpoint of the last insulation coil.These thermocouples are connected to a data logger that records the temperature data at every 5 min interval.

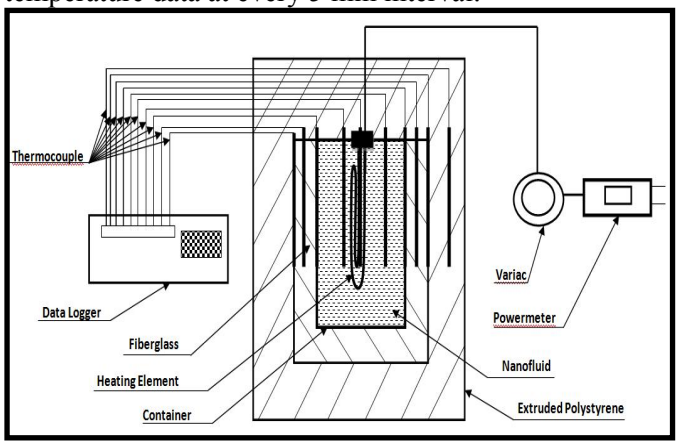

Fig. 1: Layout of Experimental Set Up For Specific Heat

. The container is well insulated to minimizes the heat loss. The specific heat of a nanofluid was calculated from the following equation:

$$C_{P_{nf}} = \frac{\dot{Q}\Delta t - m_C C_{PC}\Delta T_C - m_{co} C_{PCO}\Delta T_{CO} - m_{in} C_{PIN} - \dot{q}_L \Delta t}{m_{nf}\Delta T_{nf}} \quad (1)$$

where Q is the heat supplied to the electrical heater in watts. The time interval Δt is measured by the data logger, ΔT is the temperature rise in K, m is the mass in kg, c_p is the specific heat in J /kg K, and q_L is the heat transfer to the environment (W). The subscripts c represents the container, co the heating coil, and in the insulation. The masses of the container, coil, and insulation are measured individually by an electronic mass balance. The temperature change ΔT is recorded at every 15 s interval. The data values used are taken from standard sources. The setup has been validated satisfactorily with experiments on water and ethyl glycol (25%, 30% and50%).

A. Modelling

There are two specific heat models widely used in the nanofluid literature. Model I is similar to mixing theory for ideal gas mixtures (Cho et al, 1998). This is macroscopic, that is, the specific heat capacity of a nanofluid is equal to average of the specific heat capacities of base fluid and nanoparticles.

$$C_{pnf} = (1-\phi)C_{fs} + \phi C_{pbf} \quad (2)$$

Model II (Murshed et al., 2006 and Venerus et al., 2006) is based on the assumption of thermal equilibrium between the particles and the surrounding fluid. The is microscopic, which assumes the base fluid and the nanoparticles are in thermal equilibrium. The nanofluid specific heat capacity per unit mass of nanofluid, that is, the nanofluid specific heat is

$$C_{nf} = \frac{\left(C_{ps}\phi\rho_s + C_{pbf}\,(1-\phi)\,\rho_{bf} \right)}{\rho_{nf}} \quad (3)$$

where ρ_s is the density of the solid nanoparticle, ρ_{bf} is the density of the base fluid, and ρ_{nf} is the density of the nanofluid. The product of density and specific heat is the volumetric heat capacity of each constituent and that of the nanofluid.

B. Evaluation of existing Models

Models given in the equations are being compared with the experimental data for the same range of volume fraction, temperature and particle size. Lines of best fit have been drawn through the experimental data to indicate their trends. The following parameters are considered for the purpose of calculation in this paper: (a) Specific heat and density of water are as 4.186 kJ/kgK and 1000 kg/m3, respectively; (b) Density of Al_2O_3 particles were as mentioned in their respective references, such as ρ_p: 3965 kg/m3. (c) Specific heat of Al_2O_3 is 880 J/kg K;

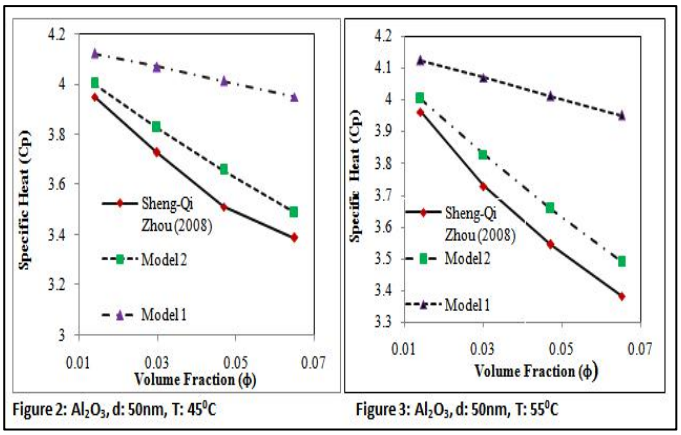

Figure 2: Al_2O_3, d: 50nm, T: 45°C

Figure 3: Al_2O_3, d: 50nm, T: 55°C

Figure 2: shows that with increase in nanoparticle volume fraction, the predicted values increase for all the models, also the amount of inaccuracy increases.

It is seen that the above models do not fit the experimental data .therefore a model using the dimensional analysis was used to develop a correlation fitting the experimental data. The variables like diameter, temperature, viscosity of the fluid, density of particle and base fluid, specific heat of particle and that of nanofluid and volume fraction are taken. Specific heat of nanofluid is believed to be depending on various particle and fluid properties, as given by:

$$C_{pnf} = f(d,T,Ц\,\rho_f,\rho_P,C_{P_P},C_{P_f},\emptyset) \quad (3)$$

or $$f_1(d,T,Ц\,\rho_f,\rho_P,C_{P_P},C_{P_f},\emptyset)$$

Using Buckingham Pi theorem, the following dimensionless groups have been obtained:

$$\pi_1 = \frac{d^2\, T\rho_p^2 C_{pf}}{\mu^2}, \qquad \pi_2 = \frac{\rho_f}{\rho_p}, \qquad \pi_3 = \frac{d^2 T\rho_p^2\, c_{P_p}}{\mu^2}, \qquad \pi_4 = \frac{d^2 T\rho_{pC_{P_f}}^2}{\mu^2}, \quad \pi_5 = \emptyset \tag{4}$$

Experimental data for Al_2O_3-water, ZnO-water nanofluids and SWCNT for a wide range of volume fraction, particle size and temperature is taken, the following models has been derived using regression analysis.

$$C_{nf} = 0.152 \frac{\mu^2}{d^2\, T\rho_p^2} \left(\frac{\rho_f}{\rho_p}\right)^{2.28} \left(\frac{d^2 T\rho_p^2\, c_{P_p}}{\mu^2}\right)^{-1.62} \left(\frac{d^2 T\rho_{pC_{P_f}}^2}{\mu^2}\right)^{2.81} \emptyset \tag{5}$$

Model given in equation 5 is for Al_2O_3-water nanofluids, ZnO, SWCNT. The temperature range for which the relation is valid upto 338K.

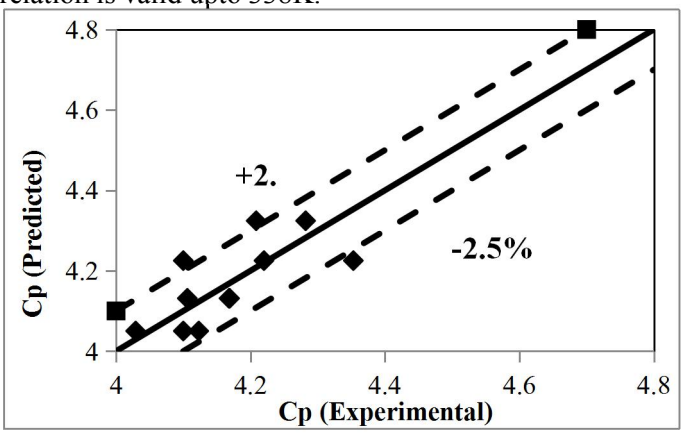

Figure 3: Experimental versus predicted values of specific heat for Al_2O_3-water(alpha) nanofluids using new model given (equation 5).

The above models have been used to predict the nanofluid specific heat and the predicted versus experimental values of specific heat of nanofluids are provided in Figure 3 (for of Al_2O_3-water nanofluids). The comparison plots show that the new model generally predicts within ± 2.5% accuracy range for Al_2O_3(alpha)-water nanofluids.

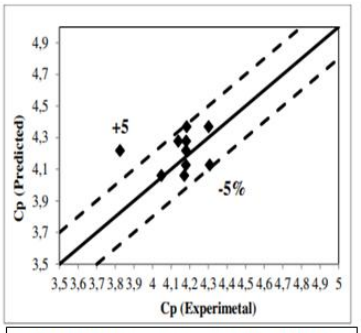

Figure 4: Experimental versus predicted values of specific heat for Al2O3- water(gamma) nanofluids using new model given (equation 5).

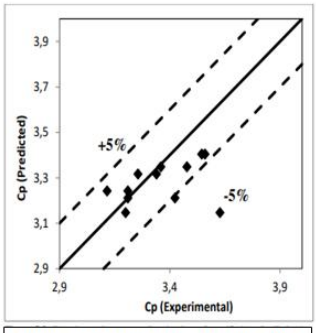

Figure 5: Experimental versus predicted values of specific heat for ZnO(14 nm) nanofluids using new model given (equation 5).

Figure 4: Experimental versus predicted values of specific heat for Al_2O_3-water(gamma) nanofluids using new model given (equation 5).

The comparison plots show that the new model generally predicts within ± 5% accuracy range for Al_2O_3-water(gamma) nanofluids. **Figure 5:** Experimental versus predicted values of specific heat for ZnO(14 nm) nanofluids using new model given (equation 5). The comparison plots show that the new model generally predicts within ± 5% accuracy range for ZnO (14 nm) nanofluids.

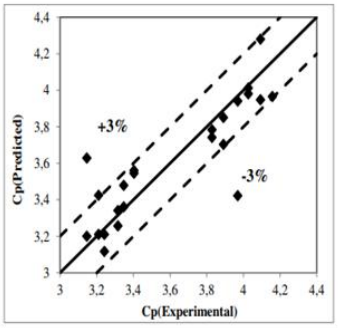

Figure 6: Experimental versus predicted values of specific heat for ZnO(24nm) nanofluids using new model given (equation 5).

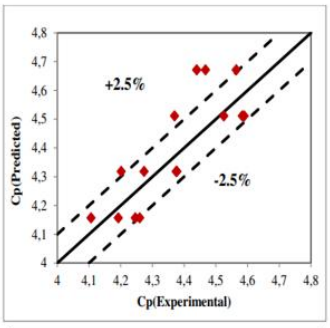

Figure 7: Experimental versus predicted values of specific heat for SWCNT (1nm) nanofluids using new model given (equation 5).

Figure 6: Experimental versus predicted values of specific heat for ZnO(24nm) nanofluids using new model given (equation 4). The comparison plots show that the new model generally predicts within ±3% accuracy range for ZnO (14 nm) nanofluids. **Figure 7:** Experimental versus predicted values of specific heat for SWCNT (1nm) nanofluids using new model given (equation 5). The comparison plots show that the new model generally predicts within ±2.5% accuracy range for SWCNT (1nm) nanofluids.

II. CONCLUSIONS

1. Specific heat of nanofluids increases with increase in temperature increase of volume fraction and also increases with size of nanoparticles.
2. A new specific heat model has been developed using dimensionless analysis. The new model has been found to generally predict specific heat of nanofluids within ± 2.5% accuracy range for Al2O3-water naofluids and ± 5% accuracy range for ZnO-water nanofluids and ± 5% accuracy range for SWCNT.
3. The new developed model gave good result when compared with different nanofluid of SWCNT, Al_2O_3, ZnO, Ethyl Glycol.

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