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Experimental investigation on the effect of particle concentration and temperature on thermophysical properties of water based metal oxide nanofluids

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The dimensionless heat transfer parameters such as Nusselt number, Reynolds number and Prandtl number are function of thermophysical properties of the nanofluids and these numbers strongly influences the convective heat transfer coefficient. In thermal systems, the heat transfer coefficient quantifies the rate of heat transfer. The thermophysical properties of the nanofluid vary with particle concentration and temperature. Therefore, in the present study experimental analysis has been performed to evaluate the influence of particle concentration and temperature on thermophysical properties of various metal oxide nanofluids. For this study aluminium oxide (Al_2O_3), copper oxide (CuO), titanium dioxide (TiO_2), silicon dioxide (SiO_2) nanoparticles with De-Ionized water are chosen and all the experimental results are compared with pure water. The experimentally measured thermophysical properties of the various nanofluids with the empirical correlations are compared. A considerable deviation is observed between the measured results and the empirical solutions. Finally, from the results it can concluded that, nanofluids have enhanced thermo-physical properties, they may be considered as a suitable fluid for various heat transfer applications.

***Keywords*:** Nanofluid, Particle concentration, Temperature, Thermophysical properties

1. Introduction

Nanofluids are relatively new class fluids for heat transfer enhancement and spread over all fields of technology and engineering due to their prevalent properties. As nanofluids have enhanced thermal conductivity encourages and attracts researchers to use them in many technological applications. The other pivotal thermophysical property is viscosity, which defines the hydrodynamic behaviour of a fluid. Both thermal conductivity and viscosity increase with that particle concentration. Along with particle concentration, another considerable parameter that influence the thermophysical properties of nanofluid are temperature, size of particle, properties of base fluid etc. Suspension of solid particles in fluids to promote their thermal properties is not a new idea. To enhance the thermal conductivity of the working fluid Maxwell et al. [1] dispersed solid particles in liquid medium and developed a correlation to estimate the thermal conductivity of particle suspended fluid. Hamilton et al. [2] extended the Maxwell research and modified Maxwell thermal conductivity correlation for more precise prediction. But both researchers [1], [2] suspended micro-size particles in flowing fluids.

The capability to produce nano sized solid particle with the advanced material technology create a new platform for a new class of innovative heat transfer fluids. For the first time Choi et al. [3] explained the physics of suspending nano sized solid particles in a base fluid to augment its thermal and flow properties and labelled such fluid as nanofluids.

2. Nanofluid Preparation

For the current research, all the nanoparticles (Al_2O_3, CuO, TiO_2 and SiO_2) with sizes of 30-50 nm are purchased from SISCO Research Laboratory (SRL) Pvt. Ltd., Mumbai, India. The size of particles is assumed to be the same as quoted by the supplier. All the nanofluids were prepared by two step method and water is taken as the base fluid. Nanoparticles were dispersed in the base fluid using an ultra - sonicator (supplied by Electrostatic Industries, India) to break the agglomerated particles and to obtain a stable and homogeneous suspension. The fluid was subjected to continuous sonication for 2 hrs and the sonicator produced ultrasonic waves at 180 W. C-TAB was used as a surfactant to increase the dispersion stability of nanoparticles in base fluid. Both sonication and surfactant were used to control the agglomeration while preparing stable nanofluid. All the nanofluids were prepared at 0.5%, 1.0%, 1.5%, 2%. 2.5% and 3% particle concentrations, which are the suitable particle concentration for heat transfer applications. It is noticed that all the nanofluids have been stable for 72 hours at least without forming any sediment or agglomerating.

3. Estimation of thermophysical properties of the nanofluids

Among all the thermophysical properties, viscosity and thermal conductivity are key properties, which govern the fluid flow and heat transfer behaviour of a nanofluid. Many engineering applications demand a trade-off between thermal conductivity and dynamic viscosity of a nanofluid. Enhanced thermal transport properties along with minimal augment of viscosity are favourable for better thermal performance of an NCL. Both viscosity and thermal conductivity of water and all nanofluids have been experimentally measured. Experiments were conducted for all the nanofluids at different particle concentrations from 0.5% to 3% over 20°C to 70°C temperature range.

In the current research Al_2O_3, CuO, TiO_2 and SiO_2 nanoparticles with an average particle size of 30-50 nm were considered for the analysis. The particle concentrations for this analysis 0.5%, 1.0%, 1.5%, 2%. 2.5% and 3% were chosen to precisely predict the thermo-physical properties. The properties of water and various nanoparticles are presented in table 1.

Table 1 Thermophysical properties of water and various nanoparticles

Material	Specific heat (J/kgK)	Density (kg/m^3)	Thermal conductivity (W/mK)
Water	4181.3	997	0.6
SiO_2	692	2648	1.4
TiO_2	686	4250	8.9
Al_2O_3	785.2	3900	40
CuO	502.8	6350	69

4. Results and discussion

4.1. Viscosity

4.1.1. Analytical method

Einstein [4] developed a correlation to estimate the effective viscosity of solution having spherical solid particles in the base fluid using hydrodynamic equations and it is given in Eq. (1). Brinkman [5] modified Einstein's correlation for use in particle concentrations of 4% and it is shown in Eq. (2). Batchelor [6] further modified Einstein's correlation by considering the effect of Brownian motion as given in Eq. (3).

$$\mu_{nf} = (1 + 2.5\emptyset)\mu_{bf} \quad (1)$$

$$\mu_{nf} = (1 - \emptyset)^{2.5}\mu_{bf} \quad (2)$$

$$\mu_{nf} = (1 + 2.5\emptyset + 6.2\emptyset^2)\mu_{bf} \quad (3)$$

4.1.2. Experimental method

The dynamic viscosity of water, and nanofluids at different particle concentrations and temperatures were measured using a Rheolab QC rotational rheometer (Anton Paar supplier, India).

The viscosity of a CuO-water nanofluid at different particle concentrations is experimentally measured and compared with several existing empirical correlations. Figure 1 shows the variation of empirically estimated and experimentally measured viscosity of a CuO/water nanofluid as a function of particle concentration. It can be observed from the experimental results that viscosity of a nanofluid increases with particle concentration and this increment is relatively more at higher concentrations. The increasing particle concentration amplifies the entanglement and resistance between adjacent layers and leads to an increase in the viscosity of a nanofluid. Many other factors related to intermolecular interactions at the microscopic level also play an indirect role in the enhancement of dynamic viscosity of a nanofluid.

The variation in dynamic viscosity of distilled water and various nanofluids (CuO-water, Al_2O_3-water, TiO_2-water and SiO_2-water) with the temperature at 1% particle concentration is presented in fig. 2. The viscosity of all nanofluids is decreasing with an increase in temperature and this decrement is relatively more at high temperatures. As the temperature of nanofluid increases, Van Der Waals forces of attractions gradually cease and lead to a reduction in the viscosity of a nanofluid.

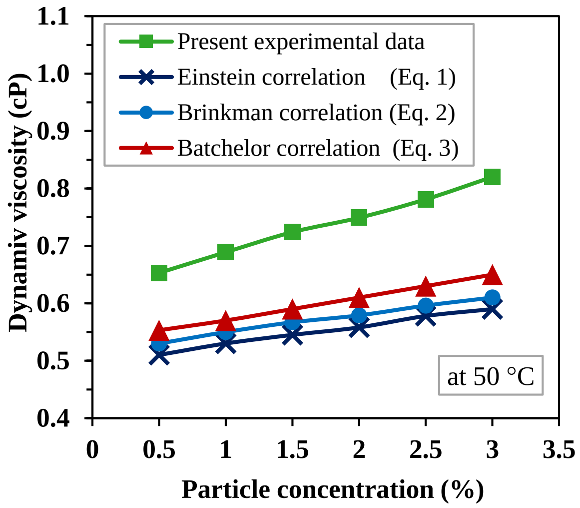

Fig. 1. Comparison of empirical and experimentally measured viscosity of CuO/water nanofluid

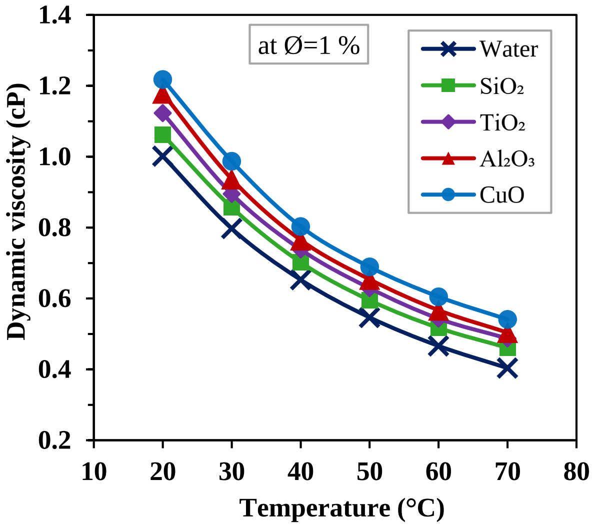

Fig. 2. Experimentally measured viscosity of water and different nanofluids as a function of temperature

4.2. Thermal conductivity

4.2.1. Analytical method

To determine the effective thermal conductivity of solid particle suspensions in liquids Maxwell [1] proposed a theoretical model which is given in Eq. (4). Bruggeman [7] proposed a correlation for spherical nanoparticles by considering the influence of nano clusters on thermal conductivity of nanofluid, and it is given in Eq. (5). Koo and Kleinstreuer [8] introduced a new correlation to precisely predict the thermal conductivity of nanofluid by considering both the effects of static and dynamic motion of nanoparticles and it is given in Eq. (6).

$$k_{nf} = k_{bf}\left\{\frac{[k_{np}+2k_{bf}-2\emptyset(k_{bf}-k_{np})]}{[k_{np}+2k_{bf}+\emptyset(k_{bf}-k_{np})]}\right\} \tag{4}$$

$$k_{nf} = \frac{1}{4}(3\emptyset-1)k_{np} + \left[(2-3\emptyset)k_{bf}\right] + \frac{k_{bf}}{4}\sqrt{\Delta} \tag{5}$$

$$k_{nf} = k_{bf}\left\{\frac{k_{np}+2k_{bf}+2\emptyset(k_{np}-k_{bf})}{k_{np}+2k_{bf}-\emptyset(k_{np}-k_{bf})}\right\} + 5X10^4\beta\emptyset\rho_{bf}C_{p,bf}\sqrt{\frac{k_pT}{\rho_{np}d_{np}}}f \tag{6}$$

4.2.2. Experimental method

Thermal conductivity of all working fluids (water and nanofluids) considered in the current work were experimentally measured using thermal conductivity analyzer (TPS 500S, Therm. Test Inc., Fredericton, Canada). Thermal conductivity of CuO/water nanofluid at different particle concentrations was experimentally measured and the results were compared with the empirical correlations available in the literature as shown in fig. 3. It can be observed from fig. 3 that the thermal conductivity of CuO/water nanofluid is progressively increasing with the particle concentration and it is amplifying at higher concentrations. As the particle concentration increases, the mean free path of the nanoparticles is decreased, and this leads to lattice vibrations which are commonly known as percolation effect [9]; that may also be cause for the consequential enrichment of nanofluid thermal conductivity. The maximum deviation between experimental and empirical correlations of Maxwell i.e. Eq. (4), Bruggman, i.e. Eq. (5), and Koo i.e. Eq. (6) is 15%, 12% and 8% respectively.

Figure 4 shows the enhancement of thermal conductivity of nanofluids with the temperature at 1% particle concentration. It is clearly observed from fig. 4 that the thermal conductivity of any fluid increases with temperature. This is because the inter particle cohesive forces and corresponding viscosity are diminished with a rise in temperature which causes Brownian motion. The increased random movement of nanoparticles promotes micro convection between nanoparticle and base fluid and leads to enhancement the thermal conductivity of nanofluid.

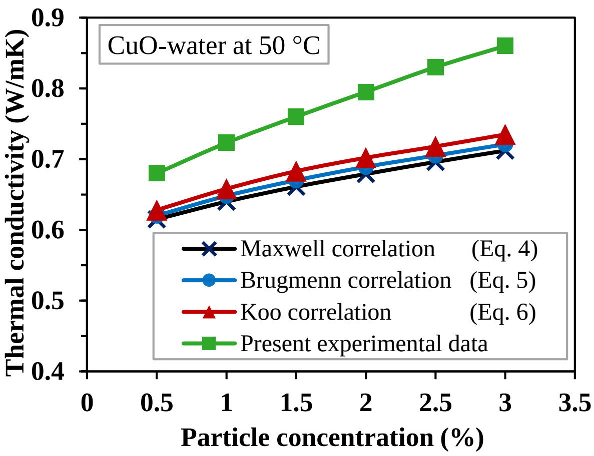

Fig. 3. Comparison of empirical and experimentally measured thermal conductivity of CuO/water nanofluid

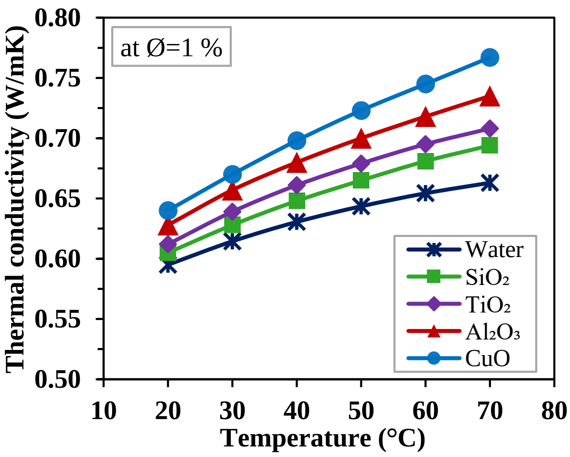

Fig. 4. Experimentally measured thermal conductivity of water and different nanofluids as a function of temperature

5. Conclusions

- Thermal conductivity of various nanofluids was estimated from the existing empirical correlations and results were compared with the experimental results. It is found to be less than 10 % variation between the empirical and measured readings.
- The thermal conductivity of CuO/water nanofluid is enhanced by 15.67% at 1.0% particle concentration and 70 °C temperature when compared with water.
- In case of viscosity, the results from the existing empirical correlations have a substantial deviation from experimental outcomes. For example, 18.58 % deviation is noticed at 1.0 % particle concentration of CuO/water nanofluid.
- Since nanofluids have enhanced thermo-physical properties, they may be considered as a suitable fluid in natural convection loops for solar and nuclear heat transfer applications.

Nomenclature

Symbol	*Name*	*Unit*
C_p	Specific heat	J kg^{-1} K^{-1}
k	Thermal conductivity	W m^{-1} K^{-1}
T	Temperature	K
Subscripts		
bf	base fluid	
nf	nanofluid	
np	nanoparticle	
Greek symbols		
ρ	Density	kg m^{-3}
ϕ	Particle volume concentration	
μ	Viscosity	N-S m^{-2}

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