Investigation of Heat Transfer Coefficients for CuO Based Nanofluids

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Abstract

Experimental data with CuO nanoparticles dispersed in water and ethylene glycol water mixture ratios of 60:40 (EG-W 60-40) was available in literature. Theoretical analysis have been undertaken in the turbulent range of Reynolds number to determine the effect of liquid mixture ratio on thermal properties, heat transfer coefficients and enhancement ratio. The heat transfer coefficients with EG-W 60-40 mixture ratio is greater than the values with water. Temperature effect and concentration effect on heat transfer coefficients of nanofluids were analyzed and observed that heat transfer coefficient increases with concentration and decreases with temperature.

Index Terms: Nanofluids, thermo-physical properties, turbulent flow in a tube; heat transfer coefficient, Friction factor.
1. Introduction

Nanofluids are nothing but the dispersions of nanoparticles in liquids uniformly with metal or metal oxide nanometer sized spherical particles. The stable nanofluids have higher property values than that of base fluids as reported in literature. Research studies have been undertaken with conventional base fluids such as water, ethylene glycol (EG) and their mixtures to determine the properties and heat transfer coefficients of nanofluids. It is quite known fact that the thermal conductivity of water is pretty higher than EG. It is also known that EG has lower freezing and higher boiling point compared to water. It is reported that higher enhancements in thermal conductivity is obtained with EG compared to water based nanofluids. Hence, authors have intended to use EG and water mixture ratios dispersed with nanoparticles for evaluating thermal properties and heat transfer characteristics under different flow conditions.

2. Literature Review

The thermal properties of nanoparticles suspended in EG as base fluid were undertaken for various nanoparticles such as Al₂O₃ [1-3], CuO[4], and ZnO [5, 6] are available in literature as stated. While, investigators have shown interests in undertaking the experiments with EG-W 60-40 mixture ratio. Vajjha et al. [7-9] in their experiments have determined the thermal properties of Al₂O₃, CuO, SiO₂ and ZnO nanofluids. Namburu et al. [10] have determined the properties of CuO nanofluids, Kulkarni et al. [11] and Sahoo et al. [12] have performed investigations with SiO₂ nanoparticles dispersed in EG-W 60-40 base fluid.

The rheological behavior of Al₂O₃/EG-Wnanofluids are studied by Sahoo et al. [13] in their experimental investigations and have observed increment in viscosity with concentration and decrement with temperature. They have formulated two correlations for viscosity with temperature and concentration as functions. Sundar et al.[14] have also reported enhancements in the thermal properties of nano-diamond nanofluid. All these investigators aimed at determining the properties at various operating parameters of concentrations and temperatures.

Experimental determinations for the investigations of heat transfer coefficients were undertaken with various nanofluids such as Al₂O₃, CuO, and SiO₂ with particles diameters in the range of 20 to 100nm for a maximum volume concentration of 10% by Vajjha et al. [15]. The experiments were carried out with EG-W 60-40 base fluid and have reported an enhancement of 80% in heat transfer coefficient for Al₂O₃ nanofluid. The authors have developed an equation as a function of temperature and concentration for the estimation of thermo physical properties and Nusselt number. The experimental data of Nusselt is subjected to regression and developed as:

\[ \text{Nu} = 0.065(\text{Re}^{0.65} - 60.22) \left( 1 + 0.0169 \left( \frac{\text{Pr}}{1100} \right)^{0.42} \right) \text{Pr}^{0.542} \] (1)

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Kulkarni et al. [11] have evaluated the convective heat transfer and pressure drop of SiO$_2$ nanofluids suspended in EG-W 60-40 ratio for a maximum volume concentration of 10%. The enhancement in heat transfer coefficient is observed to be 16% at 10% concentration with SiO$_2$ nanofluid dispersed with 20nm size particle at a Reynolds number of 10000.

Usri et al. [16] in their work on estimating the convective heat transfer coefficient of Al$_2$O$_3$ nano particles dispersed in EG-water in 40:60 ratio with particle size 30-50nm for a maximum concentration of 0.6% and the temperature maintained at 50°C in the Reynolds range of 1500-18000. They reported an enhancement of 14.6% in heat transfer for Al$_2$O$_3$ nanofluid at a concentration of 0.6%.

Seshu et al.[17, 18] have performed numerical analysis on Al$_2$O$_3$ dispersed in ethylene glycol water mixture in 40:60 ratio by volume and predicted the heat transfer coefficients using their own developed equations. In another work they have predicted heat transfer coefficients of SiO$_2$ nanoparticles dispersed in EG-W 60-40 ration by volume using the equations formulated by them.

Sharma et al.[19] have made comparisons with base fluid effect of EG-W 60:40 and EG-W 40-60 with respect to Al$_2$O$_3$ nanoparticles. Comparisons were available for Al$_2$O$_3$ and SiO$_2$ but, comparisons for CuOnanoparticles were not available. Hence this paper focuses on comparison of heat transfer coefficients of CuOnanoparticles in water and EG-W 60-40 as base fluids and base fluid effect can be identified. The particle size was considered as 30nm as available in literature for volume concentration range of 0.0-4.0% and temperature range of 50°C-80°C.

3. Base Fluid Properties and Nanofluid Properties

Density, viscosity, specific heat, and thermal conductivity values of base fluids water and EG-W mixture were predicted using the equations of Sharma et al. Nanofluid properties are required for the estimation of heat transfer coefficients and friction factor. The properties of nanofluid such as density and specific heat are taken from standard mixture relation as given in the work of Pak and Cho [20]. The thermal conductivity and viscosity of water and EG-W based nanofluids are predicted using the equations developed by Sharma et al.[19, 21] Similarly, the heat transfer and friction factor values are predicted using equations from Sharma et al. The Nusselt number equation given by Sharma et al is given as,

$$\text{Nu} = 0.0257\text{Re}^{0.8}\text{Pr}_{bf}^{0.4}(1 + \text{Pr}_{nf})^{-0.04297}(1 + \frac{\text{Pr}_{nf}}{100})^{5.205}$$

(2)

where Nu is Nusselt number, Re is Reynolds number while Pr$_{bf}$ and Pr$_{nf}$ are prandtl number of base fluid and nanofluid respectively.
The Eq. (4) was reported to have an average deviation of 7.8% and a standard deviation of 9.3%. The equation is reported to be applicable in the temperature range of 20-90°C at a maximum concentration of 4% for particle diameters not greater than 53nm. It is quite clear that the Eq. (4) has been formulated on the basis of Dittus-Boelter equation with the substitution of $\phi = 0$ and $Pr_n = 0$ in Eq. (4) transforms to,

$$Nu = 0.0257Re^{0.8}Pr_{bf}^{0.4}$$

(3)

### 4. Results and Discussions

Thermal conductivity values of water based nanofluids and EG-W based nanofluids are predicted using equations given by Sharma et al.[19, 21]. Comparisons were made for the thermal conductivity values of CuO nanoparticles dispersed in water and EG-W 60-40 as shown plotted in Figure 1. It is quite evident that water based nanofluids predict higher thermal conductivities than EG-W based nanofluids. As observed, thermal conductivity of nanofluid increases with concentration and temperature.

![Figure 1: Thermal Conductivity Values of Water based and EG-W Based Nanofluids](image)

Viscosity of CuO nanoparticles were also predicted using the equations of Sharma et al.[19, 21] and comparisons were made between water and EG-W based nanofluids as plotted in Figure 2. It is quite evident that viscosity of EG is quite higher than water, hence water based nanofluids predicts lower viscosity values than EG-W based nanofluids.

Heat transfer coefficients are predicted from the formulated Nusselt equations...
of Sharma et al. [19, 21]. The effect of temperature and concentration on CuO water based nanofluids are shown in Figure 3. The heat transfer coefficients are high at low temperatures, indicating heat transfer coefficient is increasing with decrease in temperature. While, the heat transfer coefficients are increasing with increase in concentration.

Similar observations were observed in case of CuO nanofluids in EG-W based nanofluids as plotted in Figure 4. Heat transfer coefficients are increasing with concentration and decreasing with temperature which goes back to the standard heat transfer equation.

Figure 5, evaluates the base fluid effect on the heat transfer coefficients of CuO based nanofluids.

As observed, EG-W based nanofluids predicts higher heat transfer coefficients when compared to water based nanofluids in CuO nanoparticles. This observation can be due to the combined effect of thermal conductivity and viscosity of the given nanofluids.

Figure 6, compares the Nusselt number values of CuO nanofluids in both the base fluids. As observed in Figure 5, EG-W based nanofluids are predicting higher heat transfer coefficients when compared to water based nanofluids. This is due to the higher thermal conductivities of water based nanofluids as observed in Figure 1.

Figure 2: Viscosity Values of Water based and EG-W based Nanofluids
Figure 3: Heat Transfer Coefficients Water based Nanofluids

Figure 4: Heat Transfer Coefficients EG-W based Nanofluids
Conclusion

Though water based nanofluids predicts higher thermal conductivities, the comparisons among the base fluid suggest that EG-W based nanofluids shows a higher heat transfer coefficients and high Nusselt numbers when compared to
water based nanofluids in CuO nanoparticles. Heat transfer coefficients are increasing with decrease in temperature indicating that low temperature regions are good enough to attain higher heat transfer coefficients. The volume concentration has also good impact on heat transfer coefficient as seen Figure 3 and Figure 4. The concentration can be increased to attain higher heat transfer coefficients.

References


