VALIDATION OF TURBULENT FLOW HEAT TRANSFER DATA OF WATER BASED NANOFLUIDS

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1. Introduction

Experiments for the determination of thermo-physical properties and forced convection heat transfer coefficients with Al_2O_3 and TiO_2 submicron particles dispersed in water is due to **[1]**. Experiments are conducted **[2]** with Cu/water nanofluid at different particle volume concentrations of upto 2.0%. They opined that the dispersion will flatten the temperature distribution and makes the temperature gradient between the fluid and the wall steeper. The regression equation developed by them includes volume concentration and particle Peclet number. Turbulent convective heat transfer coefficients of Al_2O_3 and ZrO_2 nanofluids in water have been conducted by **[3]** while **[4]** conducted experiments with water based alumina and amorphous carbonic nanoparticles for flow in a tube under laminar and turbulent conditions. A 20 % increment in convective heat transfer coefficient at 3.0% volume concentration is reported with alumina nanofluid. They concluded from their experiments that carbonic nanofluid did not show promise as an enhanced heat transfer fluid in the turbulent range. Experiments with 170 nm SiC nanoparticles in water at volume concentration of 3.7% in the range $3300 < \text{Re} < 13000$, $4.6 < \text{Pr} < 7.1$ has been conducted by **[5]** who observed 50-60 percent enhancements in heat transfer. They concluded from their experimental analysis that SiC/water is a better heat transfer liquid and requires lower pumping power compared to Al_2O_3/water nanofluid. Brownian diffusion and thermophoresis are important mechanisms and that energy transfer by nanoparticle dispersion is negligible are the conclusions of **[6]** from theoretical analysis. CFD analysis for the determination of heat transfer coefficients with CuO, Al_2O_3 and SiO_2 nanofluids in 60:40 by mass ethylene glycol and water mixture at 6% volume concentration has been undertaken by **[7]** in the turbulent Reynolds number range. They observed that the values of friction factor obtained could be well represented with Blasius equation and the heat transfer coefficients with Gnielinski equation.

2. Mathematical model of Sarma et al. [8]

1. Making certain simplifications and introducing correction factor for mixing length, the eddy diffusivity for momentum is obtained as

$$\frac{\varepsilon_m}{\nu_{nf}} = 0.0213 u^+ y^+ \left[1 - \exp\left(-\frac{y^+}{15}\right)\right]^2 \quad (1)$$

2. The thermal eddy diffusivity is dependent on momentum eddy diffusivity through the relationship

$$\frac{\varepsilon_H}{\alpha_{nf}} = \left[\frac{\varepsilon_m}{\nu_{nf}}\right]\left(\text{Pr}_{nf}\right)^{\varsigma}$$ where

$$\varsigma = 7.45\left(R^+\right)^{0.236}\left[0.5 + \phi\right]^{0.448} \quad (2)$$

3. Validation of the theory

The theoretical results simulated for two different values of Prandtl numbers and for different values of Reynolds number is shown in Fig.1. Fig. 2 is shown with the Cu/water experimental data of **[2]** along with the theoretical results. Further comparisons with the experimental data of **[9]** with CuO/water nanofluid in the range $5000 < \text{Re} < 31000$, $0.015 < \phi < 0.24$ %, of **[5]** with SiC/water at volume concentration 3.7% in the range $3300 < \text{Re} < 13000$ and $4.6 < \text{Pr} < 7.1$ is in good agreement with theoretical values. The regression equation of **[10]** is observed to be in good agreement with the theoretical analysis and is tested for two different values of ϕ and for Pr=5.0. The agreement of heat transfer data of **[10]** and **[3]** in the turbulent region with the theory for a wide range of estimated values of Prandtl number is observed. The close agreement of the data of various investigators with the values simulated from the theoretical analysis ensures the reliability of the eddy diffusivity equations proposed by Sarma et al. [8]

4. Conclusions

The following conclusions are drawn from the investigation undertaken

1. The thermal conductivity increases whereas viscosity decreases with increase in temperature. The extent of variation reflected on the value of Prandtl number, determines the heat transfer enhancement of the nanofluid.
2. The friction factor estimated for nanofluids can be represented with the Blasius equation.
3. The eddy diffusivity equations proposed can be used to predict the heat transfer coefficients of water based nanofluids in the turbulent range.

4. Information regarding the properties of the nanoparticles such as density and specific heat with particle size is essential.
5. The deviation between the experiment and theory is also due to the absence of information regarding the bulk temperature of the fluid and/or Prandtl number.

Acknowledgement
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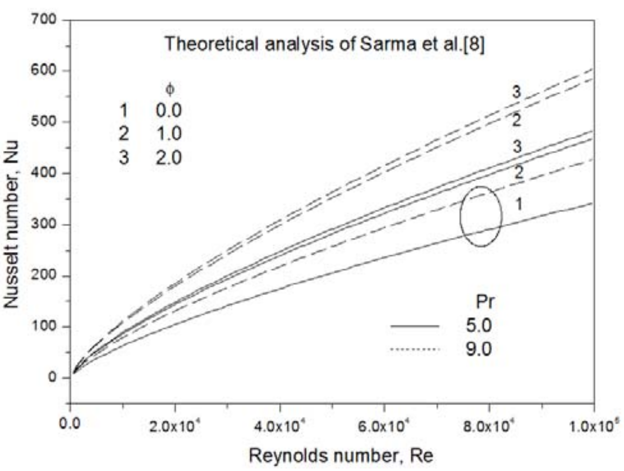

Figure 1 Variation of Nusselt with Reynolds for different volume concentrations at two values of Prandtl number

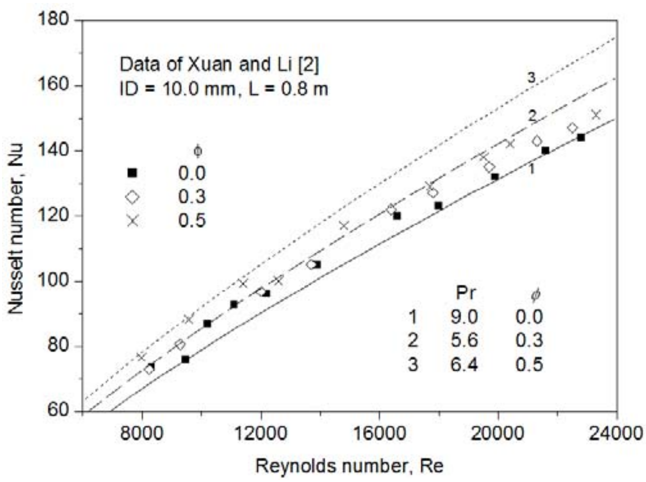

Figure 2 Comparison of experimental values with theory for different values of Prandtl number and $\phi < 0.5$