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HEAT TRANSFER ENHANCEMENT UNDER TURBULENT FLOW FOR EG-WATER MIXTURE OF 40:60 RATIO

Seshu Kumar Vandrangi[1], K.V.Sharma[1], Subhash Kamal[2] and S. Akilu[1]
[1]Department of Mechanical Engineering, Universiti Teknologi Petronas Tronoh, Malaysia
[2]Department of Petroleum Engineering, Universiti Teknologi Petronas Tronoh, Malaysia
E-Mail: seshu1353@gmail.com

ABSTRACT

A theoretical model for the estimation of turbulent heat transfer has been developed employing the eddy diffusivity equation of Van Driest. Experiments have been undertaken for turbulent flow with Al_2O_3 nanofluid in base liquid Ethylene Glycol-water (EG-W) mixture of ratio 40:60 for a maximum concentration of 1.5% at a bulk temperature of 50 and 70 ºC. The numerical results for heat transfer are observed to be in good agreement with the experimental data with the nanofluid property equations developed. The maximum concentrations for which heat transfer enhancement can be attained are estimated to be 1.4% and 2.05% at 50 and 70 ºC respectively under turbulent flow.

Keywords: nanofluids, thermo-physical properties, turbulent flow in a tube, heat transfer coefficient, friction factor.

INTRODUCTION

Nanofluids are prepared by the dispersion of small quantities of nano sized metal and metal oxide particles in base liquids. For the last few years, nanofluid properties were studied because of its extraordinary thermal properties. Accordingly satisfying results were observed as well. Initially water, ethylene glycol (EG) and engine oil are used as base fluids based on the requirements. Gradually, researchers started working on mixtures such as EG and water in different ratios of 20:80, 60:40 and 40:60.

The thermo-physical properties of nanoparticles dispersed in EG as base fluid were determined by various authors Beck *et al*. [1], Esfe *et al*. [2] and Mohammadiun *et al*. [3] for Al_2O_3, Barbes *et al*. [4] for CuO, Li *et al*. [5] for SiC, Li *et al*. [6], Suganthi *et al*. [7] and Pastoriza-Gallego *et al*. [8] for ZnO. Experiments were performed with nanoparticles dispersed in EG-water mixture as base fluid in 60:40 ratio. Vajjha *et al*. [9-11] have performed experiments to determine the properties of various nanofluids. Similarly, Praveen *et al*. [12], Sundar *et al*. [13], Sahoo *et al*. [14, 15] and Kulkarni *et al*. [16] have performed various experiments with several nanofluids such as Al_2O_3, CuO and SiO_2 nanofluids to obtain the properties of the base liquid EG-water mixed in 60:40 ratio.

Experiments for the determination of nanofluid thermal conductivity and viscosity for Al_2O_3(36nm)/EG-Water 40:60 ratio were performed by Sundar *et al*. [17] for the temperatures varying between 20-60 ºC for a maximum concentration of 1.5%. Experiments for the estimation of nanofluid forced convection heat transfer coefficients in the turbulent range are undertaken with Al_2O_3 (13nm), TiO_2 (50nm) for a maximum concentration of 1.5% for temperature varying between 50-70 ºC by Usri *et al*. [18, 19] in base liquid EG-water mixture in 40:60 ratio. They reported an enhancement of 14.6% in heat transfer for Al_2O_3 nanofluid at a concentration of 0.6% whereas the enhancement was observed to be 33.9% with TiO_2 nanofluid at 1.5% volume concentration.

Usri *et al*. [18] in their experiments with Al_2O_3(30-50nm) nanoparticles to estimate the forced convective heat transfer dispersed in EG-water in 40:60 ratio for a maximum concentration of 1.5% at an operating temperature of 50 ºC in the Reynolds range of 1500-18000.

Usri *et al.* [19] have estimated the convective heat transfer coefficient of TiO_2 (30-50nm)/EG-water in 40:60 ratio for a maximum concentration of 1.5% at an operating temperature of 70 ºC. The experiments were undertaken under constant heat flux boundary condition for Reynolds number greater than 10,000. A maximum heat transfer enhancement of 34% was reported with 1.5% volume concentration.

BASE FLUID PROPERTIES

The EG-W base fluid properties were obtained from regression equations using ASHRAE [20] data,

$$\rho_{bf} = 1066.79734 - 0.3071 T_{nf} - 0.00243 T_{nf}^2 \tag{1}$$

$$C_{p\,bf} = 3401.21248 + 3.3443 T_{nf} + 9.04977 \times 10^{-5} T_{nf}^2 \tag{2}$$

$$k_{bf} = 0.39441 + 0.00112 T_{nf} - 5.00323 \times 10^{-6} T_{nf}^2 \tag{3}$$

$$\mu_{bf} = 0.00492 - 1.24056 \times 10^{-4} T + 1.35632 \times \times 10^{-6} T_{nf}^2 - 5.56393 \times 10^{-9} T_{nf}^3 \tag{4}$$

NANOFLUID PROPERTIES

The nanofluid thermo physical properties such as density and specific heat which are required for the estimation of heat transfer coefficients can be determined with mixture relations and they are given as follows:

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$$\rho_{nf} = (\varnothing_p / 100)\rho_p + \left(1 - \varnothing / 100\right)\rho_{bf} \qquad (5)$$

$$C_{p\,nf} = \left[\left(1-\phi/100\right)\left(\rho C_p\right)_{bf} + \left(\phi/100\right)\left(\rho C_p\right)_p\right] \times (1/\rho_{nf}) \qquad (6)$$

A correlation for the thermal conductivity correlation was developed assuming that that nanofluid thermal conductivity increases linearly with particle concentrations by Sundar *et al*. [17] given by,

$$k_{nf} = k_{bf}\left(A + B\varnothing\right) \qquad (7)$$

where A = 1.0806 and B = 10.164. Similarly, viscosity correlation was developed considering the nanofluid viscosity to increase exponentially with the volume concentration is given as,

$$\mu_{nf} = \mu_{bf} A e^{B\varnothing} \qquad (8)$$

where A = 0.9299 and B = 67.43.

The experimental data available for Al_2O_3 nanofluid from the literature is used in the development of regression Equation. (9) and (10) for determining viscosity and thermal conductivity respectively considering concentration, temperature and particle size given by,

$$\mu_{nf} = \mu_{bf} \times 1.364\left(1+\varnothing\right)^{1.098}\left(1+T_{nf}/70\right)^{-0.6532} \times \left(1+d_p/50\right)^{-0.3712} \qquad (9)$$

The average deviation and standard deviation is estimated to be 6.8% and of 8.5% respectively. The thermal conductivity equation is given by Equation.(10) obtained with an average deviation and standard deviation of 1.9% and 2.8% respectively. It is given by

$$k_{nf} = k_{bf} \times 0.9431\left(1+\varnothing\right)^{0.1612}\left(1+T_{nf}/70\right)^{0.1115} \times \left(1+d_p/50\right)^{0.003986}\left(\alpha_p/\alpha_{bf}\right)^{0.006978} \qquad (10)$$

The Equations. (9) and (10) are observed to be valid in the range of $0 \le \varnothing \le 1.5\%$; $20 \le T_{nf} \le 70$°C; $13 \le d_p \le 50\text{nm}$.

The experimental values of forced convection nanofluid Nusselt number in base liquid EG-water mixture in 40:60 ratio is subjected to regression given by Equation. (11) employing the data of Usri *et al.* [18, 19]

$$Nu = 0.023Re^{0.8}Pr_{bf}^{\ 0.4}\left(1+Pr_{nf}\right)^{-0.08177}\left(1+\varnothing\right)^{-0.402} \qquad (11)$$

Equation. (11) is obtained with an average deviation of 7.8% and standard deviation of 9.3%. The equation is applicable in the given range of temperature from 20-70 ºC for a maximum concentration of 1.5% for particle diameters lower than 50nm. The equation can be reduced to Dittus-Boelter equation applicable for pure fluids by substituting $\varnothing = 0$ and Pr_{nf} = 0 in Equation. (11)

$$Nu = 0.023Re^{0.8}Pr^{0.4} \qquad (12)$$

RESULTS AND DISCUSSIONS

The thermal conductivity Equation. (3) of EG-W base liquid determined using the regressional investigation is kept in comparison with the ASHRAE data [20] and is observed to be in agreement with a deviation of less than 1%. The nanofluid thermal conductivity Equation.(7) given by Sundar *et al*. [17] and the present Equation.(10) is shown in comparison with the experimental data of Sundar *et al*. [17] in Figure-1. Similarly, the base fluid viscosity Equation.(4) is validated using ASHRAE data [20] with a maximum deviation of 1%. The Al_2O_3/EG-W nanofluid experimental data is compared with Equations. (8) and (9) and shown as Figure-2.

Experimental estimation of forced convective heat transfer coefficients with base liquid EG-water 40:60 mixture were performed by Usri *et al*. [18, 19] in the turbulent range of Reynolds Number at nanofluid bulk temperatures of 50 and 70 ºC.

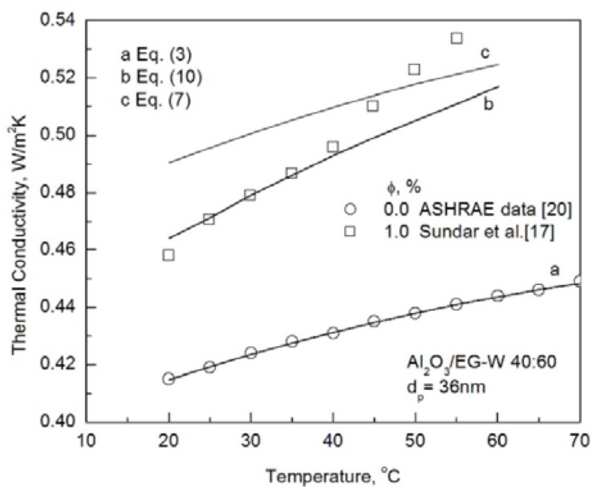

Figure-1. Comparison of experimental data of thermal conductivity with theoretical results for base fluid and nanofluids.

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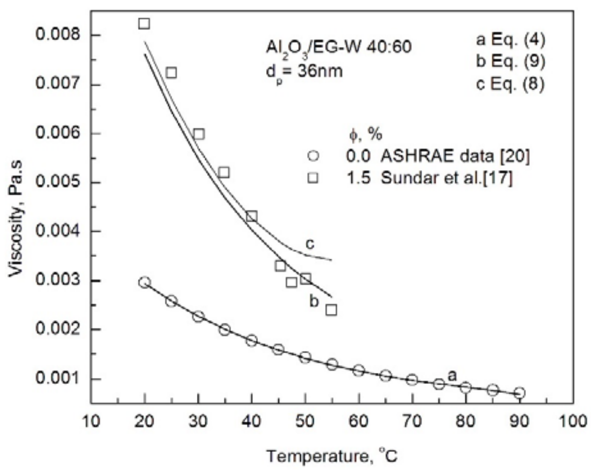

Figure-2. Comparison of experimental data of viscosity with theoretical results for base fluid and nanofluids.

The theoretical results of base liquid heat transfer coefficients are validated with experimental data of Usri *et al*. [18, 19] are shown plotted in Figure-3 with a maximum deviation of 2.5% and 7.6% respectively.

The predicted values of Nusselt number are plotted against Reynolds number for different concentrations varying from 0.2 to 1.4 % at a temperature of 50°C for a particle size of 50nm in Figure-4. It is clear that the increase in nanofluid volume concentration results in the increase of Nusselt number.

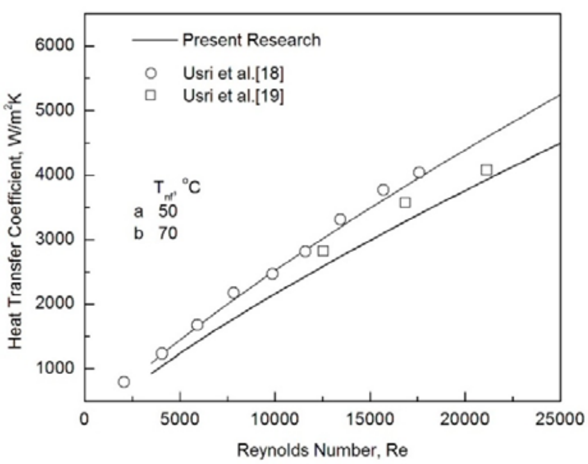

Figure-3. Validation of theoretical heat transfer coefficient values experimental values for a base fluid.

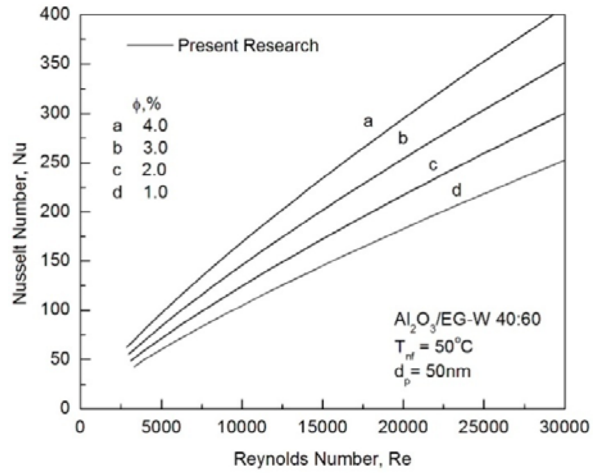

Figure-4. Nusselt number varying with Reynolds number for different concentrations with Al_2O_3 nanofluid.

The variation of Nusselt with Reynolds number for three temperatures between 25 and 70 °C is plotted in Figure-5 for a volume concentration of 1.0% and particle size of 50nm. It is quite clear from the Figure-5 that increases in temperature of the nanofluid leads to the decrease in Nusselt number.

The equations (9) and (10) can be employed for the determination of optimum nanofluid concentration which is advantageous over the base liquid for different nanofluid operating temperatures. The concentration at which optimum heat transfer enhancement is possible can be estimated with Enhancement Ratio (ER).

The ER can be defined as the ratio of viscosity enhancement by thermal conductivity enhancement. It can be stated as,

$$ER = \left(\mu_{nf} / \mu_{bf} - 1\right) / \left(k_{nf} / k_{bf} - 1\right) \tag{13}$$

The variation of ER for Al_2O_3 nanofluid concentration of 1.4% with temperature is shown plotted in Figure.6.

It can be deduced by an order of magnitude analysis that heat transfer enhancements of nanofluid will terminate if the ER is greater than five under turbulent flow.

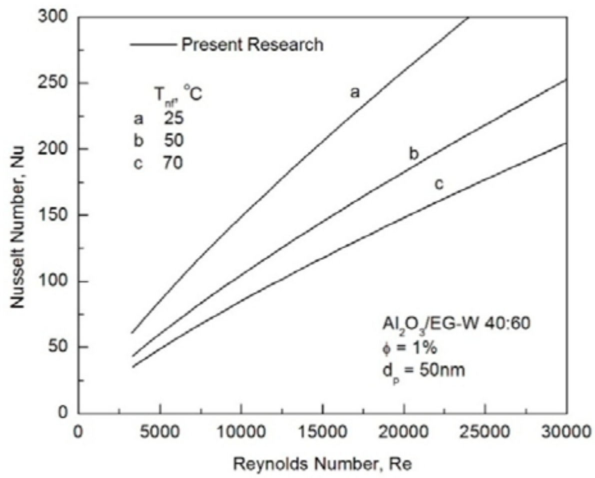

Figure-5. The Nusselt number variation with Reynolds number obtained for various temperatures for Al_2O_3 nanofluid.

It can be observed from Figure-6 for the experimental operating temperature of 50ºC the corresponding value of ER=5.0. This suggests that the maximum volume concentration $\varnothing$ for enhancement in heat transfer is 1.4%. A further increase in the concentration of the nanofluid does not enhance the heat transfer coefficient. However, the effect of particle size on Nusselt number is observed to be insignificant. Further studies are undertaken in this regard.

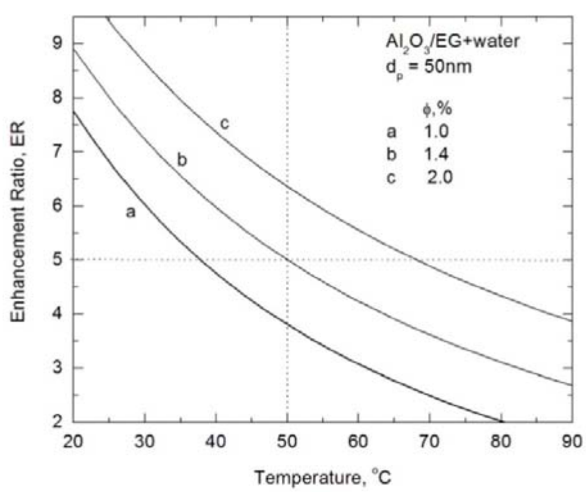

Figure-6. Variation of property enhancement ratio with temperature for turbulent flow condition.

CONCLUSIONS

The following observations are made from the theoretical results on the nanofluid properties and heat transfer coefficients:

a) The thermal conductivity increase with temperature of the nanofluid.
b) Nanofluid viscosity decrease with increase in temperature
c) The thermal conductivity and viscosity increase with nanofluid concentration.
d) The equations for viscosity and thermal conductivity of Al_2O_3 nanofluid dispersed in base liquid EG-W mixture (40:60 ratio) can be predicted using Equations. (9) and (10) respectively for concentration $\varnothing \leq 1.5\%$, $13 \leq d_p \leq 50$ and $20 \leq T_{nf} \leq 90$.
e) For the determination of density and specific heat of nanofluids, the mixture equation can be used which are given in Equations. (5) and (6) respectively.
f) The property correlations of thermal conductivity and viscosity developed for Al_2O_3 nanofluid given by Equations. (9) and (10) could predict the experimental values of heat transfer coefficients closely.
g) The Enhancement Ratio Equation. (13) predict a decrease in experimental heat transfer coefficients when nanofluid concentration is greater than 1.4% at an operating temperature of 50 ºC.

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NOMENCLATURE

C_p Specific Heat (J/kgK)
d_p Particle diameter (nm)
ER Enhancement Ratio
k Thermal conductivity (W/mK)
Nu Nusselt number
Pr Prandtl number
Re Reynolds number
T Temperature (K)

Greek letters

α Thermal diffusivity (m^2/s)
ρ Density (kg/m^3)
μ Viscosity (Pa.s)
ϑ Kinematic viscosity (m^2/s)
$\varnothing$ Volume fraction

Subscripts

bf basefluid
nf nanofluid
r ratio
p particle

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