Computational analysis to determine the heat transfer coefficients for SiO_2/60EGW and SiO_2/40EGW based nano-fluids

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ABSTRACT. *The purpose of the current research is to investigate the computational heat transfer coefficients of SiO_2 nanoparticles dispersed in ethylene glycol (EG) and water (W) mixtures in 60:40 (60EGW) and 40:60 (40EGW) by volume and evaluate the influence of base fluid. The thermophysical properties of SiO_2, based nanoparticles dispersed in 60EGW and 40EGW base fluid were taken from available literature and regression analysis was performed for formulating equations. The theoretical data was used as input in computational analysis for the investigation of heat transfer coefficients. The results indicate that the heat transfer coefficients for SiO_2/60EGW and SiO_2/40EGW based nanofluids have shown an enhancement of 25% and 55% respectively when compared with base fluids. Hence, it can be concluded that SiO_2/40EGW nanofluids show a better heat transfer rates than SiO_2/60EGW nanofluids.*

RÉSUMÉ. *L'objet de la recherche actuelle est d'étudier les coefficients de transfert de chaleur calculés de nanoparticules de SiO_2 dispersées dans des mélanges d'éthylène glycol (EG) et d'eau (W) à 60 :40 (60EGW) et 40 :60 (40EGW) en volume, et d'évaluer de fluide de base. Les propriétés thermo physiques de nanoparticules à base de SiO_2, dispersées dans un fluide de base 60EGW et 40EGW ont été tirées de la littérature disponible et une analyse de régression a été réalisée pour la formulation d'équations. Les données théoriques ont été utilisées comme entrée dans l'analyse informatique pour l'étude des coefficients de transfert de chaleur. Les résultats indiquent que les coefficients de transfert de chaleur pour les nano fluides à base de SiO_2 / 60EGW et de SiO_2 / 40EGW ont montré une amélioration de 25% et 55% respectivement par rapport aux fluides de base. On peut donc en conclure que les nano fluides SiO_2 / 40EGW présentent un meilleur taux de transfert de chaleur que les nano fluides SiO_2 / 60EGW.*

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1. Introduction

The common technique used is maximizing the heat transfer area in heat exchangers which can be cost effective. The alternate possible solution could be by increasing the heat transfer coefficient that depends on the thermal properties of the fluid as determined in passive techniques. So, the heat transfer efficiency can also be improved by increasing the thermal conductivity of the working fluid, where, thermal conductivity is defined as the property of the material to conduct heat. With developments in manufacturing technologies, there has been an interest in using nano-sized particles as additives to modify the properties of fluids such as water, Ethylene glycol or oil. The dilute solid suspensions referred as “nanofluids” such as carbides, carbon, metals, metal oxides, etc. with at least one of their principal dimensions smaller than 100nm is used for dispersions. Engineered nanofluids are observed to possess long time stability and greater thermal conductivity. Most common nanofluids could be classified as SiO_2 in water, TiO_2 in water, CuO in water, Al_2O_3 in water etc. The trends shown by the nanofluid in enhancing the heat transfer is due to the fact that the nanoparticles present in the base fluid increases the thermal conductivity and the viscosity of the base liquid at the same time. Therefore, the enhancement of thermal conductivity leads to increase in the heat transfer performance as well as viscosity of the fluid which in turn results in increase in friction factor. Apart from the influence of nanoparticles, the thermal conductivity, temperature and viscosity of base fluids also has an impact on the enhancement of thermal conductivity of nanofluids. The trends shown by the nanofluid in enhancing the heat transfer is since the nanoparticles present in the base fluid increases the thermal conductivity and the viscosity of the base liquid at the same time. Therefore, the enhancement of thermal conductivity leads to increase in the heat transfer performance as well as viscosity of the fluid which in turn results in increase in friction factor. Hence, there is a need to evaluate the influence of base fluid effect on nanoparticle heat transfer coefficient.

Several researchers have performed studies on the convective heat transfer enhancements with various nanoparticles such as Aluminum Dioxide (Al_2O_3), Copper Oxide (CuO), Zinc Oxide (ZnO), Titanium Dioxide (TiO_2), Silicon Dioxide (SiO_2) etc. are dispersed in water and have observed good results. In addition to water many other base fluids such as oil, ethylene glycol and glycerin were used as base fluids. On the other hand, promising results were observed with ethylene glycol and water mixtures as base fluid in 60:40 (60EGW) and 40:60 (40EGW) ratios by volume. Hence this paper focuses on computational analysis of SiO_2 nanoparticles in 60EGW base fluid.

Vajjha *et al.* (2010) have developed various correlations for the estimation of convective heat transfer coefficients and friction factor considering the experimental data of Al_2O_3 (45nm), CuO(29nm), and SiO_2(20-100nm) nanoparticles dispersed in 60EGW mixture ratio. They have observed enhancements of 40%, 43% and 29% for Al_2O_3, CuO and SiO_2 nanoparticles respectively. The SiO_2 nanoparticles were used in estimating the convective heat transfer properties and pressure loss by Kulkarni *et al.* (2008) with EG-water mixture as base fluid in 60:40 ratio for a maximum concentration of 10% vol. in the temperatures range of 20-90oC. An enhancement of 16% in heat transfer at 10% concentration was reported with 20 nm particle size at Re = 10000. A comparison of heat transfer and fluid dynamic performance of SiO_2, Al_2O_3 and CuO nanofluids were made by Kulkarni *et al.* (2016) with the aid of the equation developed. Among the three, CuO nanofluids have shown an enhancement of 61% followed by Al_2O_3, SiO_2 with 35% and 18% enhancements respectively. Usri *et al.* (2015) and Azmi *et al.* have performed experiments for evaluating heat transfer characteristics for Al_2O_3 nanofluids dispersed in 40EGW base fluid and have observed an enhancement around 14.6 and 24.6% respectively.

Qin *et al.* (2014) have reported that the heat transfer coefficient gradually increases with the temperature difference of heat sink and ambient temperature. On the other hand, the thermal resistance decreases increase of porosity until it reaches the minimum and increases subsequently. Namburu *et al.* (2009) have compared the CFD results for EG-water mixture of 60:40 ratio for a maximum concentration of 6% with the experimental data of Vajjha *et al.*, (2010) Kulkarni *et al.* (2008) and reported to be in good agreement. Wong *et al.* (2015) have presented a numerical turbulence flow study which was modeled using the “standard k-ε, realizable k-ε, and shear stress transport (SST) k-ω models”. The results suggested that the SST k-ω model has been the best in predicting the separation flow when compared to other two. Jehad and Hashim (2015) have performed a numerical analysis on turbulent forced convection flow inside a horizontal circular channel with water at a constant heat flux wall. They have reported that the heat transfer rate increases with increase in Reynolds number. While, the friction factor increases with the decrease of the Reynolds number.

Early researchers have performed experimental studies on the forced convective heat transfer with various nanoparticles such as Aluminum dioxide (Al_2O_3), Copper oxide (CuO), Zinc oxide (ZnO), Titanium dioxide (TiO_2), Silicon dioxide (SiO_2), etc. dispersed in water. Studies indicate that the stability of water based nanofluids have limited stability. Experimental results are reported with other base fluids such as oil, ethylene glycol and glycerin are reported. On the other hand, promising results were observed with ethylene glycol and water mixtures as base fluid in 60:40 (60EGW). But the research related to 40:60 (40EGW) ratios by volume is in initial stages. And, investigation of heat transfer characteristics of SiO_2/40EGW is not available in literature. Hence there is a need to investigate the heat transfer characteristics of the SiO_2/40EGW nanofluid and to evaluate the influence of base fluids on heat transfer characteristics.

Hence, convective heat transfer of a nanofluid under various operating conditions viz. temperature, concentration, particle size and different nanofluids such as SiO_2/EGW and SiO_2/40EGW ratios can be evaluated. Therefore, using computational fluid dynamics (CFD) simulations in determining the heat transfer coefficient helps in investigating at different operating conditions in less time. In the present study, the influence of two different base liquid mixtures of EG and water mixed in 60:40 and 40:60 ratios by volume are is compared with the numerical results obtained. The results from the analysis is validated with the experimental data of Vajjha *et al.* for SiO_2/EG-W in 60:40 ratio. The variations of Nusselt number and friction factor with Reynolds number for SiO_2 nanoparticles suspended in EG-W in 40:60 ratio is predicted with the help of numerical analysis.

The remainder of this paper is organized as follows: Section 2 details the methodology and approach used to perform the research which includes, regression analysis and computational analysis. Section 3 describes about grid optimization which is major part in computational analysis which is also known as grid independency test. The penultimate section i.e. section 3, details the results obtained from computational analysis and discuss about the results. The final part, section 5 concludes the research which details about the ideal nanofluid for a better heat transfer rate.

2. Methodology

Theoretical analysis of thermo-physical properties was carried with the help of literature experimental data. Regression analysis has been carried out for all the thermo-physical properties such as density, specific heat, viscosity, and thermal conductivity. Equations for both base fluids and nanofluids were developed for the respective thermo-physical properties. The equations were used as input data to CFD as boundary conditions.

The sole purpose of this project is to use open-source CFD software to simulate pressure loss and heat transfer in a plain tube and validate the simulation with the actual experimental results from the literature. The three-dimensional geometry of plain tube heat exchanger is drawn using ICEM-CFD software with the dimensions that are taken from Vajjha *et al.* After completing the geometry, structured meshing is done with necessary quality checks. The mesh files are imported in FLUENT for further simulations. The required numerical calculations are formulated using ANSYS FLUENT software. The results are exported to CFD-Post and heat transfer characteristics are analyzed. The dimensions of the given copper plain tube are taken from Vajjha *et al.* with length of tube as 1168mm and diameter of the tube as 3.14mm as shown in Fig 1.

The nanoparticles dispersed in the given base fluids are fluidized and eventually the resultant mixture is considered as a single phase fluid (Xuan and Roetzel, 2000; Xuan & Li, 2003). While, it is also assumed that the fluid phase and nanoparticles are in thermal equilibrium with zero relative velocity. As the nanoparticles are quite smaller than micro particles, the relative velocity decreases as the particle size decreases. The effective mixture can be considered as a traditional single-phase fluid. The thermal and physical properties are dependent on temperature under the operating conditions and the resultant effective thermo-physical properties are dependent on both the temperature and volume concentration. In addition, the assumption of single phase for a nanofluid is validated to an extent through the experimental results of Pak and Cho (1998) and Xuan and Li. Based on these validations, the classical theory of single-phase fluid can be applied to the nanofluids and simulations can be performed.

Figure 1. Geometry of the plain tube

3. Grid ooptimization

The results are compared for different grid compositions and grid independency test is performed. To ensure that results are independent of grids, eight different mesh compositions were studied. The simulations were performed for SiO_2/60EGW for 2.0% volume concentration and at five different Reynolds numbers varying from 3500-12500 and are shown plotted in Fig 2. As shown in Fig 2 the simulation results are compared with experimental results, it is observed that the grid with 500 and 10 nodes show good results with an average deviation of less than 5%. The simulations results didn't vary much after increasing the nodes from this mesh composition (Moghadassi *et al.*, 2015).

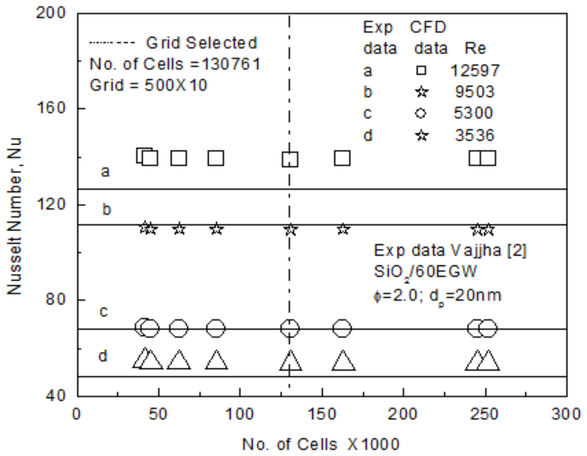

Figure 2. Grid independency results

4. Results and discussions

The experimental heat transfer coefficient of SiO_2/60EGW nanofluids at 2.0% volume concentration for a particle size of 50nm were performed by Vajjha *et al.* (2010) and the results are compared with CFD simulations. The temperatures were not mentioned by the authors, so the inlet temperature was assumed to be 80oC. The CFD results were observed to be in less than 12% deviation with the experimental data and is shown plotted in Fig 3. The reason for the deviations can be because of the temperatures that was assumed as they were not specified in the literature and it can be attributed to the deviations occurred in regression analysis made for the development of equations. Similarly, the experimental data of Vajjha *et al.* (2010) for SiO_2/60EGW at 4.0% volume concentration was compared with CFD results and deviation less than 14% was observed and is shown plotted in Fig 4.

The experimental data of heat transfer coefficients for the three concentrations were compared with CFD results and predicted for a Reynolds number varying from 5000-100000 and are plotted in Fig 5. It can be observed that heat transfer coefficient increases with increase in concentration when plotted against Reynolds number. A maximum deviation of 22% was observed for SiO_2/60EGW at a volume concentration of 6.0% when compared experimental data.

The experimental data of heat transfer coefficients is plotted against velocity in Fig 6 for three concentrations and predicted for a Reynolds number varying from 5000-100000. The heat transfer coefficient decreases with increase in concentration when plotted against velocity, which is quite opposite to the heat transfer coefficient plotted against Reynolds number.

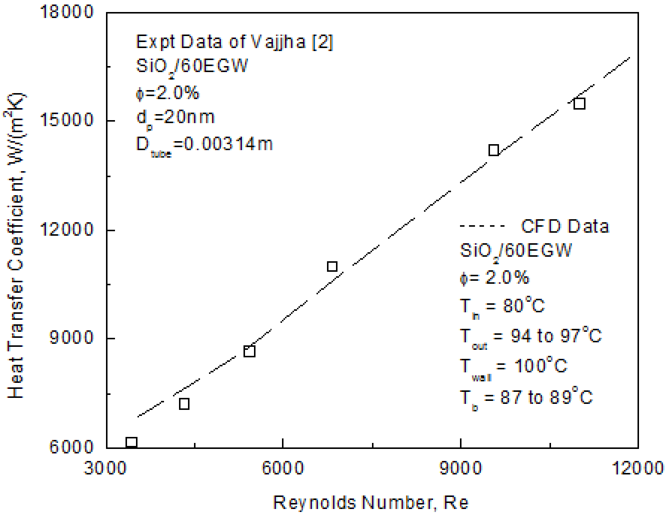

Figure 3. CFD data of SiO_2/60EGW nanofluids at 2% volume concentration

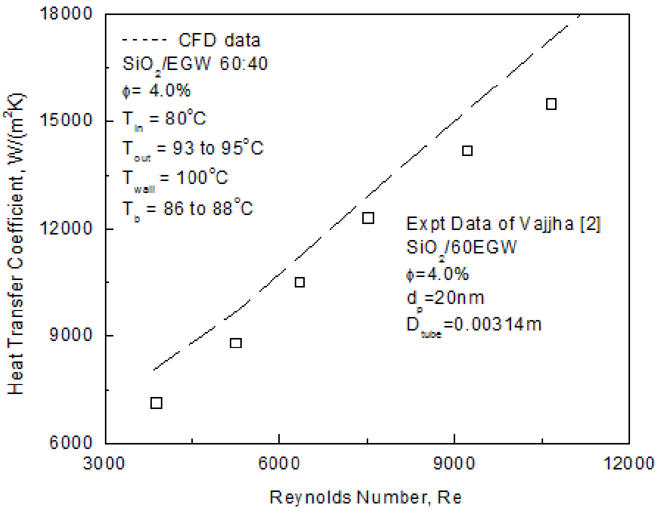

Figure 4. CFD data of SiO_2/60EGW nanofluids at 4% volume concentration

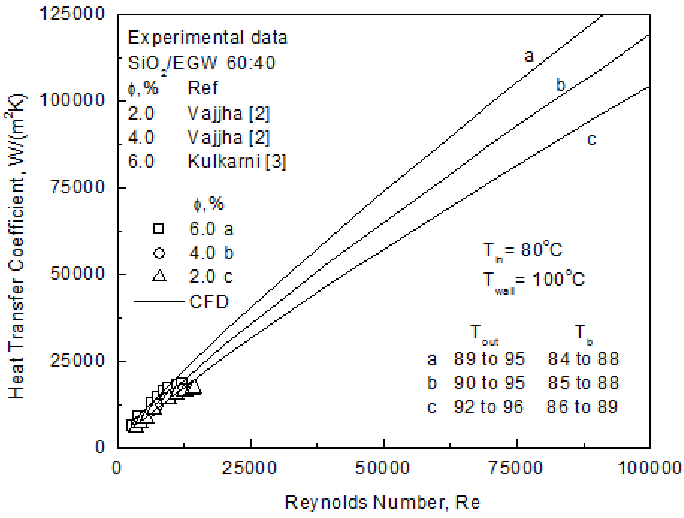

Figure 5. CFD data for SiO_2/60EGW at various concentrations

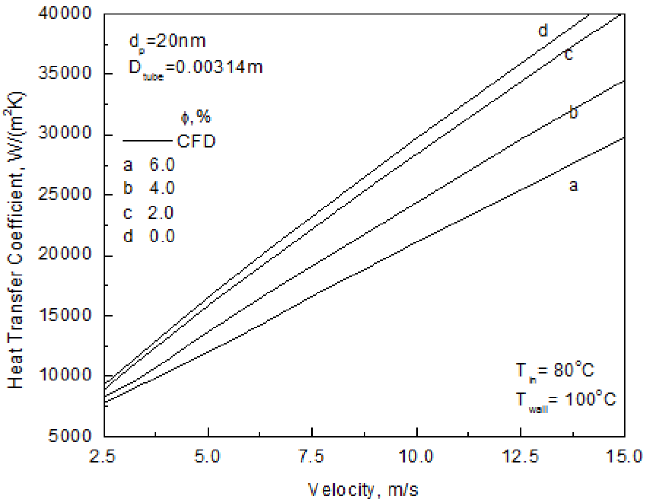

Figure 6. CFD data for SiO_2/60EGW nanofluids vs velocity

The heat transfer enhancements are calculated for the two given nanofluids for various concentrations to select the perfect nanoparticles with ideal base fluid and their concentrations. The heat transfer enhancement is nothing but the ratio of heat transfer coefficient of nanofluid to base fluid. The heat transfer coefficient for various nanofluids are predicted at various operating conditions and the data is used in analysing the heat transfer enhancements.

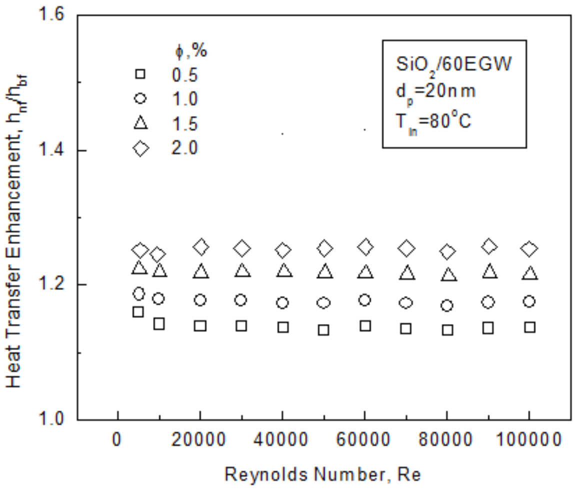

Figure 7. Heat transfer enhancement for SiO_2/60EGW nanofluids

The heat transfer enhancement for SiO_2/60EGW nanofluids for a particle size of 20nm at various concentrations varying from 0.5% to 2.0% data at a temperature of 80oC is predicted and analysis is performed which are plotted Fig 7.

The enhancement is observed to be increasing with the concentration for this nanofluid. The maximum enhancements in SiO_2/60EGW nanofluids for 0.5% to 2.0% volume concentrations is observed to 1.25 times that of base fluid. It implies that an enhancement of 25% is observed at these operating conditions. While the enhancements are not that significantly changing with Reynolds number.

Based on the validations presented, the heat transfer coefficients are predicted for SiO_2/40EGW nanofluids for a maximum concentration of 1.5% and Reynolds number varying from 5000-100000 as plotted in Fig 8. The inlet temparature and wall temperature are given as 60oC and 90oC. As observed for other nanofluids, heat transfer coefficient increases with increase in concentration when plotted against Reynolds number.

The heat transfer coefficients are predicted for the same operating conditions as mentioned for SiO_2/40EGW nanofluids. Here, the heat transfer coefficients are observed to be decreasing with concentration when plotted against velocity as shown in Fig 9.

The heat transfer enhancements are plotted for SiO_2/40EGW based nanofluids for a volume concentrations of 0.5% to 2.0%. The enhancement is observed to be increasing with the concentration for this nanofluid. The maximum enhancements in SiO_2/40EGW nanofluids for 0.5% to 2.0% volume concentrations is observed to 1.55 times that is 55% that of the base fluid.

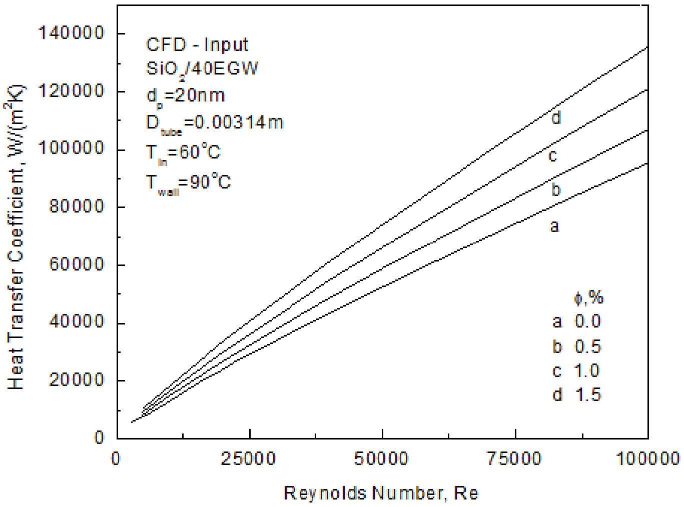

Figure 8. CFD data of Heat transfer coefficients for SiO_2/40EGW nanofluids

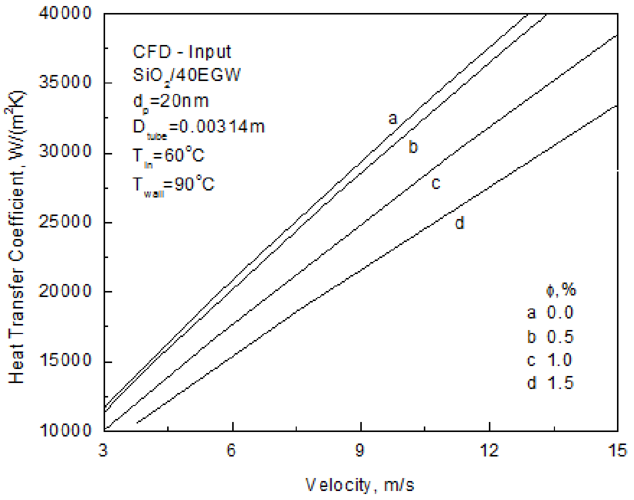

Figure 9. CFD data for SiO_2/60EGW nanofluids vs velocity

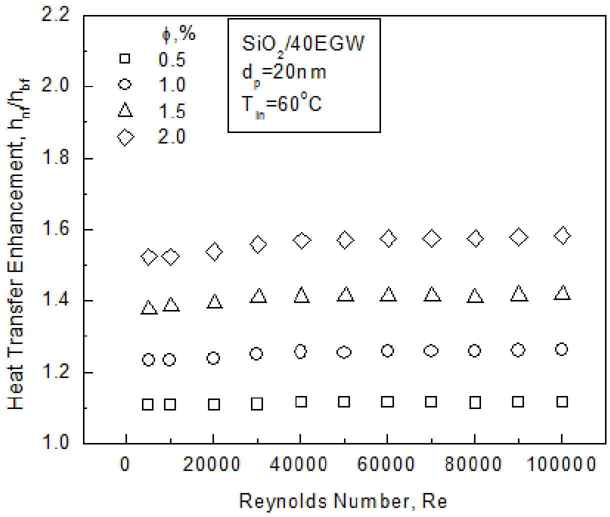

Figure 10. Heat transfer enhancement for SiO_2/40EGW nanofluids

The enhancements are compared based on the influence of the base fluid effect on SiO_2 nanoparticles. The enhancements are observed and compared for

SiO_2/60EGW and SiO_2/40EGW nanofluids for two concentrations such as 1.0% and 2.0% at 60oC inlet temperature and are plotted in Fig 11. As observed 40EGW based shows an higher heat transfer enhancement when compared with 60EGW based nanofluids.

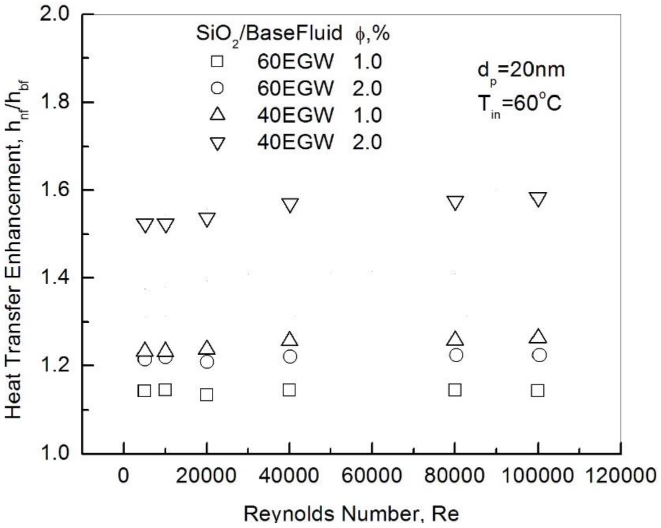

Figure 11. Effect of base fluid on heat transfer enhancement

5. Conclusions

Computational analysis is performed to evaluate the heat transfer coefficients for the given nanofluids at different concentrations and temperatures. The experimental thermo-physical properties were given as input data for the properties of nanofluid and the simulations were performed in plain tube geometry prepared using ICEM CFD software. And the simulations were performed in FLUENT software at different operating conditions. The results were analysed in CFD-POST software for heat transfer coefficient, outlet temperature and pressure drop-values. The computational results were compared with existing literature data and predicted for other operating parameters that are not available in literature. The simulations were performed for the given nanofluids for the volume concentrations 0.0-2.0% and in the temperature range of 60-80oC for a particle size of 20nm. The heat transfer coefficients seem to be increasing with Reynolds number, volume concentration and decreases with temperature. Interestingly, when heat transfer coefficient is plotted against velocity, the values though increase with velocity, but decreases with increase in concentration due to the viscosity of nanofluid. A maximum of 55% was observed for SiO_2/40EGW nanofluids at 2.0% volume concentration, where as an enhancement of 22% was observed for SiO_2/60EGW at same concentration.

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