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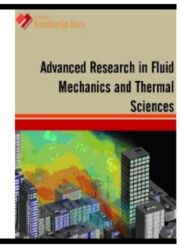

Friction Factor Analysis of SiO_2 and Al_2O_3 Nanofluids dispersed in 60 EGW and 40 EGW Base Fluids

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ABSTRACT

The purpose of the current research is to investigate the friction factors for SiO_2 and Al_2O_3 nanoparticles dispersed in ethylene glycol (EG) and water (W) mixtures in 60:40 (60EGW) and 40:60 (40EGW). 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 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. Different solvers and turbulence models are used to try to determine the most accurate CFD method for predicting friction factor in plain tube heat exchanger. 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. 60EGW based nanofluids show higher friction factor when compared to the 40EGW based nanofluids which can be attributed to density and viscosity of the nanofluids.

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. A working fluid can be defined as a pressurized gas or liquid that actuates a machine such as steam in steam engine, air in hot air engine. More specifically, a working fluid is liquid or gas that absorbs or transmits energy.

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The most commonly used heat transfer working fluids such as water, transformer oil, ethylene glycol (EG), propylene glycol (PG), kerosene, ethanol, methanol, are widely used in many industrial fields like heating or cooling processes, chemical production, micro-electronics, power generation, air-conditioning, and transportation. These conventional heat transfer fluids have inherently low thermophysical properties as compared with solids. It is well known that metals in solid form have higher thermal conductivities than fluids at room temperature. The thermal conductivity values of various heat transfer fluids are tabulated in Table 1.

Among all the fluids that we use currently, water has the highest thermal conductivity, though it amounts to approximately 0.6 W/mK under ambient temperatures, which is very much lower than most metals or metal oxides. Hence, it is quite logical to add certain solid particles into a base fluid to enhance its thermal conductivity, a concept that has been practiced for a long time. This is where the concept of nanofluids has started. Commonly used metals are Cu (copper), Aluminium (Al) and Silver (Ag) and metal oxides such as, Aluminium oxide (Al_2O_3), Silicon dioxide (SiO_2), Titanium dioxide (TiO_2), Copper oxide (CuO), Zinc oxide (ZnO), Iron (II,III) oxide (Fe_3O_4), Magnesium oxide (MgO).

Table 1
Thermal Conductivity of Common Heat Transfer Fluid

Number	Heat Transfer Fluid	Thermal Conductivity, k (W/mK)	Reference
1	Water	0.6155	[1]
2	Ethylene Glycol	0.2524	[1]
3	Propylene Glycol	0.197	[2]

Nanotechnology extends a wide range of potential applications in electronics, medicine, materials, etc. More prominently, many of the potential uses for nanofluids lies in heat transfer applications. Nanofluids are considered as potential working fluids primarily used in high heat flux systems such as electronic cooling systems, solar applications [3], heat pipes, and nuclear reactors. While as secondary fluids, they can be applied in chillers, refrigeration, solar panels in absorption systems and also as lubricants.

Nanotechnology in the form of nano-lubricants can improve thermal dissipation, anti-wear and pressure properties of compressors lubricants. The dispersion of nanoparticles directly in the refrigerant can improve the thermodynamic performance of refrigerating machines. On the other hand, adding nanoparticles to lubricants can improve their tribological properties, with benefits to the life cycle of machines with moving parts in addition to thermal properties [4].

Nanofluids are being used for a wide variety of industries, such as transportation like cooling liquids, electronics like microprocessors, Micro-Electro-Mechanical Systems (MEMS), medicine like nano drug delivery and more importantly in energy production like heat exchangers, heat pipes, and nuclear reactors. Other fields are drilling, defense, space, coolers in welding, high-power lasers, biomedical applications, drag reductions and many more.

The experimental data of friction factor were undertaken by various researchers in both laminar and turbulent range of Reynolds number. Hwang *et al.*[5] and Ahmad *et al*. [6] have observed that correlation is in agreement with the experimental data in laminar region,

$$f = 64/Re \quad (1)$$

The Blasius equation given for the prediction of friction factor applicable for single phase fluids and turbulent flow in smooth is presented as,

$$f_B = 0.3164Re^{-0.25} \tag{2}$$

The experimental friction factor is usually determined by employing Darcy friction factor correlation which is given as follows,

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho V^2}{2}\right)} \tag{3}$$

Fotukian and Esfahany [7] have observed greater values of friction factor at a low volume concentration of 0.2% for Al2O3/water nanofluid by 30% in the turbulent range of Reynolds number. While Azmi *et al.* [8] with SiO2/water nanofluid for 3% volume concentration have observed greater values by 17.1%, Duangthongsuk and Wongwises [9] with TiO_2/water nanofluid at 2.0% concentration have observed by 19% when compared to the values that are estimated from Blasius correlation.

Sundar *et al*. [10] have reported an enhancement of 10% in friction factor at a low concentration of 0.6% by volume with Fe_3O_4/water nanofluid. Sharma *et al*.[11] with their experiments on Al_2O_3/water have observed an enhancement of 21% in friction factor at a very low 0.1% nanofluid concentration. Vajjha *et al*. [12] have formulated an equation for the prediction of friction factor valid for EGW mixtures and is given as,

$$f_r = \frac{f_{nf}}{f_B} = 1.0\left[\left(\frac{\rho_{nf}}{\rho_{bf}}\right)^{0.797}\left(\frac{\mu_{nf}}{\mu_{bf}}\right)^{0.108}\right] \tag{4}$$

Similarly, Sharma *et al*. [13] have developed an correlation for the friction factor valid for water based nanofluids and is given as,

$$f_r = \frac{f_{nf}}{f_B} = 1.0\left[\left(\frac{\rho_{nf}}{\rho_{bf}}\right)^{1.3}\left(\frac{\mu_{nf}}{\mu_{bf}}\right)^{0.3}\right] \tag{5}$$

Based on the experimental investigations on nanofluid flow and heat transfer performed by various researchers, it can be observed that, the surface temperature of the tube with nanofluid flow is lower than with water. The flow velocity of nanofluids is lower than the base liquid for the same mass. The nanofluid convective heat transfer coefficient is greater than the base liquid under similar operating conditions of flow and temperature. Heat transfer coefficient and Nusselt number increase with concentration and flow Reynolds number. The ratio of convective heat transfer coefficient of nanofluid to that of pure water decrease with increase in Reynolds number. The friction factor of water based nanofluid is greater than EG-W mixture for the same density and viscosity ratio.

2. Computational Heat Transfer Characteristics

Turbulent flow and heat transfer of various nanofluids such as Al_2O_3, SiO_2 and CuO in different base fluids and mixtures flowing through a circular tube under constant heat flux condition or constant wall condition have been numerically analyzed by various researchers. Namburu *et al*. [14]

has observed that at a fixed Reynolds number of 20000 Nusselt number for 6% CuO nanofluids increases by 1.35 times over the base fluid. At a fixed Reynolds number of 20000 heat transfer coefficient for 6% CuO nanofluids increases by 1.75 times over the base fluid. Heat transfer coefficient of nanofluids increases with increase in the volume concentration of nanofluids and Reynolds number. Higher temperature operation of the nanofluids yields higher percentage increase in heat transfer rate. Pressure loss increases with increase in the volume concentration of the nanofluids.

Maiga *et al*. [15] conducted a numerical study on γ –Al_2O_3 nanofluids flow under forced laminar convection in circular tubes and between parallel disks. For a range of Reynolds number from 250 to 1000 they concluded that the heat transfer enhancement is much more pronounced with the increase in particle concentration. However, they observed a drastic adverse effect on wall shear stress in comparison to the base fluid. For the analysis of flow between discs, they found insignificant effect on heat transfer with the variation of gap between the discs.

Maiga *et al*. [16] in their paper, have investigated with the help of numerical simulations, the thermal performance of a nanofluid, water-Al_2O_3 mixture, which flows under turbulent regime inside a uniformly heated tube. Results have clearly shown that with the presence of nanoparticles, heat transfer of a resulting nanofluid has, by far, considerably increased while compared to that of saturated water. Such an enhancement has been found to become more pronounced with the increase of the particle volume concentration as well as with the flow Reynolds number. They have observed that for Re = 10^4 in particular, a heat transfer enhancement is estimated to be 5%, 10%, 23%, 35% and 50%, respectively, for $\emptyset$ = 1%, 2.5%, 5%, 7.5% and 10%. It is also observed that, for high Reynolds numbers, $Re = 5 \times 10^4$, the influence of this parameter Re on the heat transfer coefficient ratio tends to become negligible.

Behzadmehr *et al*. [17] and Mirmasoumi *et al*. [18] have used two-phase model for prediction of turbulent forced convection of a nanofluid in a tube with uniform heat flux. In their work the mixture model, based on the single fluid two-phase model was employed in the CFD simulation. Delavari *et al*. [19] have observed that, the average heat transfer coefficient and Nusselt number increases with Reynolds number. Increasing in the concentration of nanoparticles in a constant Reynolds number enhances the average Nusselt number. For a Reynolds number of 23,000, a 1% nanofluid produced an average Nusselt number that was 205% higher than for pure water whereas for a Reynolds number of 2440, the 1% nanofluid produced a Nusselt number that is 237% higher than that for pure ethylene glycol.

Akbarinia and Behzadmehr [20] presented a numerical study of nanofluids under mixed laminar convection in a curved tube. They compared the variations of Nusselt number with Grashof number for various volume percentages of Al_2O_3 nanoparticles in water. They found that at large Grashof number the skin friction was reduced. Heris *et al*. [21] have observed that nanofluids containing CuO and $A_{l2}O_3$ oxide nanoparticles in water as base fluid in different concentrations produced and the laminar flow convective heat transfer through circular tube with constant wall temperature boundary condition were examined. The experimental results emphasize that the single phase correlation with nanofluids properties (Homogeneous Model) is not able to predict heat transfer coefficient enhancement of nanofluids. The comparison between experimental results obtained for CuO/water and Al_2O_3/water nanofluids indicates that heat transfer coefficient ratios for nanofluid to homogeneous model in low concentration are close to each other but by increasing the volume fraction, higher heat transfer enhancement for Al_2O_3/water can be observed.

Moraveji *et al*. [22] used CFD tools to simulate convective heat transfer effect on the nanofluid flow in the developing region of a tube with constant heat flux. The results were presented for the Reynolds number range of 500–2500, nanoparticle concentration of 0–6% and the nanoparticle diameter of 45nm and 150nm. The comparison results between the experimental data [23] and the predictions of the heat transfer coefficients of the nanofluids were at maximum error of 10%. Further, the heat transfer coefficient enhanced with increasing the nanoparticle concentration and Reynolds number, and decreased with increasing the axial location and nanoparticle diameter.

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. Similar 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. Researches have been performed dispersing SiO_2 nanoparticles in 60EGW and results were observed to be encouraging. A prime focus is needed on SiO_2 nanoparticles dispersed in 40EGW base fluid as well. The investigation on the influence of different ratios of base fluid on the thermal properties and heat transfer characteristics are quite important. Hence, convective heat transfer and friction factor of a nanofluid under various operating conditions viz. temperature, concentration, particle size and different materials like SiO_2 and Al_2O_3, in 60EGW and 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 a recent study [24], sedimentation behavior of clay, Al_2O_3 and CeO_2 in water, EG and water/EG mixture (50 vol%) was observed using photographic method. It was found that nano suspensions with low nanoparticle concentration showed better stability than concentrated nano suspensions. Manjula *et al*.[25] investigated dispersion behavior of alumina nanoparticles in water and reported the effect of pH and stabilizer on the sediment heights of the nano suspension. They found that stability of nano suspensions can be improved by optimizing pH level and addition of stabilizer. In our previous work [26], dispersion behavior of ZnO nanoparticles in ethanol-water mixture was studies at different concentrations with and without sonication. It was observed that stability of the nanofluids can be improved using ultra-sonication.

2. Results and Discussions

The friction factor is calculated by using the correlations from the pressure drop data values taken from the CFD simulations. The experimental data is kept in comparison with the CFD data for 60EGW and 40EGW based nanofluids. The deviation between the experimental data of base fluid 60EGW and CFD data of friction factor were observed to be less than 8% except for two pints which are deviating above 20% and the deviation with Blasius correaltion was less than 4% except two points which are deviating above 16%.

The experimental friction factor values of Vajjha *et al*. [12] plotted against Reynolds number in Figure 1 are compared with CFD data for two the nanofluids Al_2O_3 and SiO_2 in 60EGW base fluid including the base fluid data. The deviation was observed to be less than 14% except for two points which are above 20% for the 60EGW base fluid and SiO_2/60EGW nanofluids. While for Al_2O_3/60EGW nanofluids, the deviation is less than 18%. The researchers have not mentioned any parameters like volume concentrations and temperature as such, hence the CFD simulations were performed assuming the concentrations as 2.0% and the temperatures were assumed as mentioned earlier.

Based on the experimental validations, the friction factor data is predicted for Reynolds number varying from 10000 to 100000 for the two given nanofluids at two different concentrations. As plotted in Figure 2, the friction factor values are quite high for Al_2O_3/60EGW nanofluids when compared to SiO2/60EGW nanofluids. The same behaviour was observed in experimental results as well. On the other hand, friction factor values seem to be increasing with volume concentration and decreasing with Reynolds number. The friction factor seems to be increasing with particle concentration, this may be due to the viscosity of the nanofluid which increases with concentration.

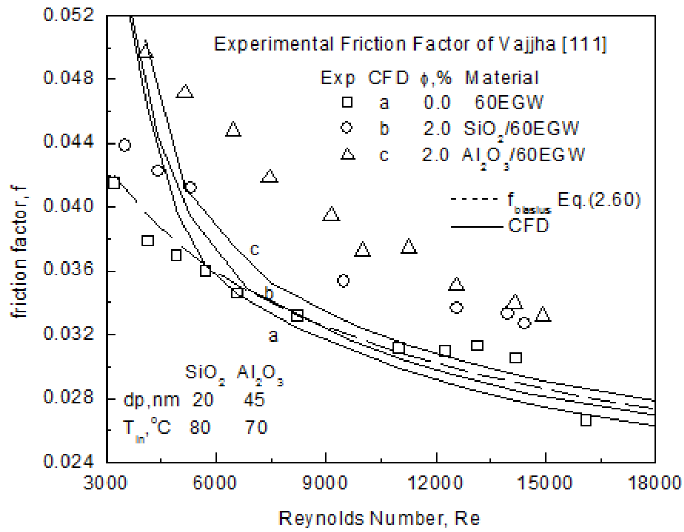

Fig. 1. Comparison of experimental friction factor with CFD data

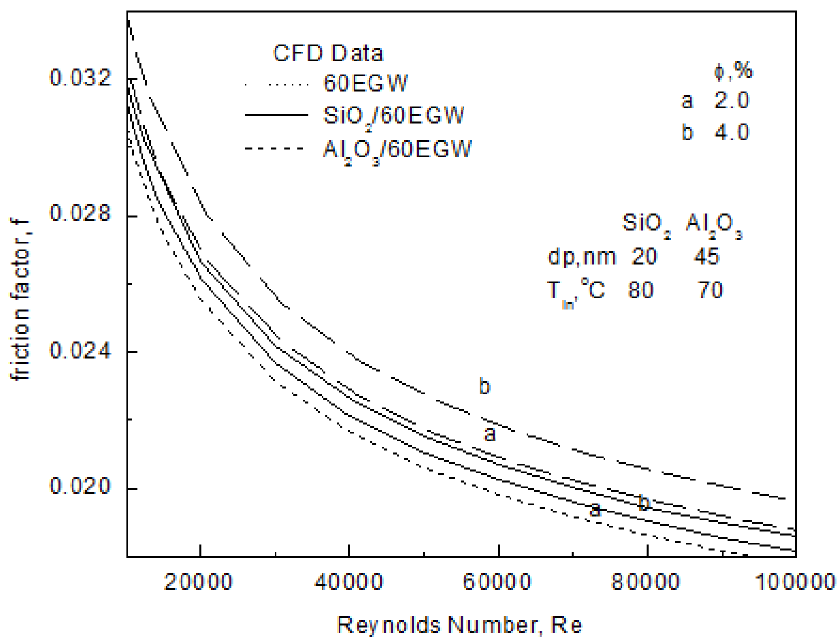

Fig. 2. Prediction of friction factor Vs Reynolds number in 60EGW base fluids

Similar predictions for friction factor of the two given nanofluids with 60EGW base fluid were plotted against velocity in Figure 3. The observations are very identical to that of friction factor plotted against Reynolds number. As observed, Al_2O_3/60EGW nanofluids shows higher values compared to SiO_2/60EGW nanofluids and friction factor increases with volume concentration and decreases with velocity.

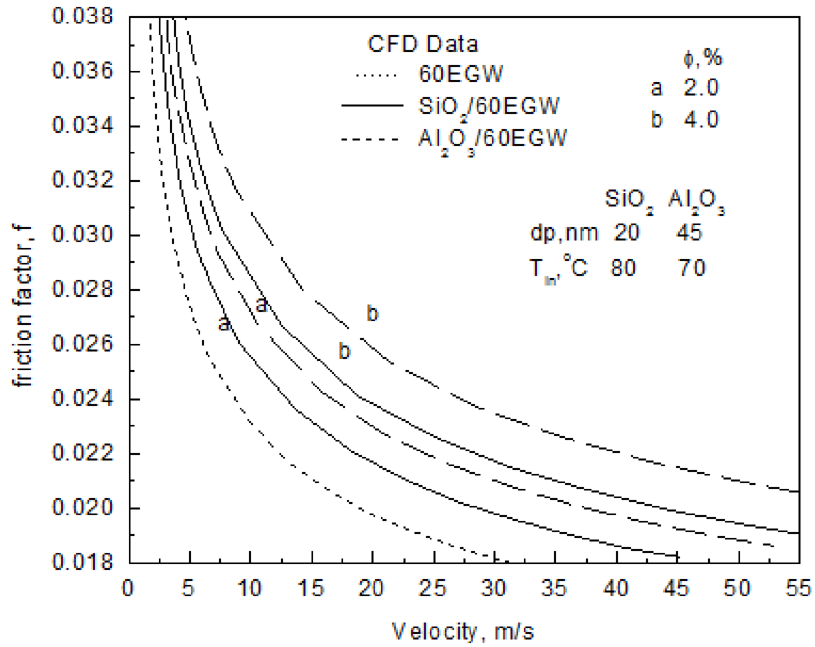

Fig. 3. Prediction of friction factor Vs velocity in 60EGW base fluids

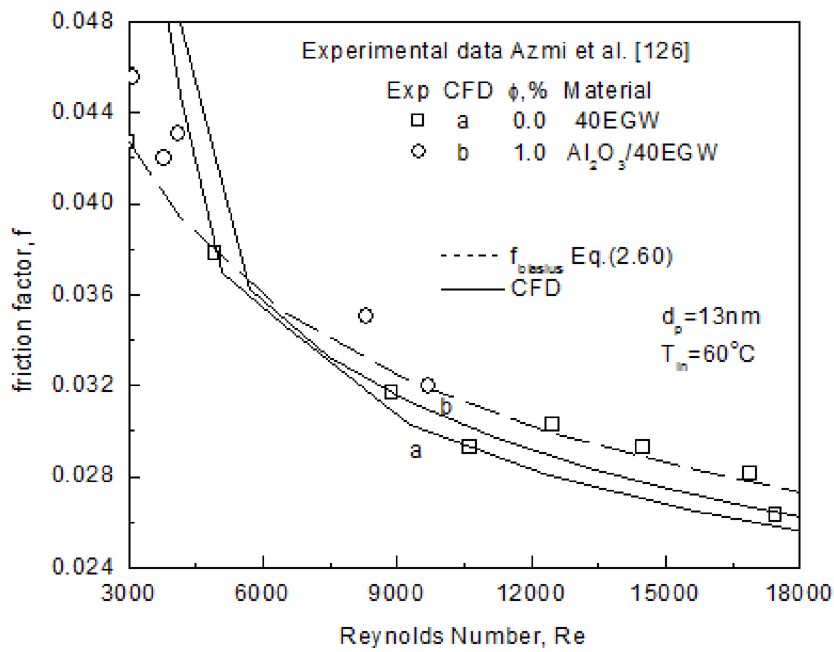

Fig. 4. Experimental friction factor Vs CFD data for Al2O3/40EGW nanofluids

The friction factor for 40EGW based nanofluids were compare with data of Azmi *et al*. [27] for Al_2O_3/40EGW nanofluids and is shown plotted in Figure 4. The CFD data is also compared with Blasius Equation and the deviation was observed to be less than 12% except for one point. As observed for other nanofluids, friction factor increases with concentration and decreases with Reynolds number.

On a whole, when the friction factor is compared for the two given base fluids and nanofluids, it is pretty clear that 60EGW based nanofluids show high values of friction factor than 40EGW based nanofluids as plotted in Figure 4.

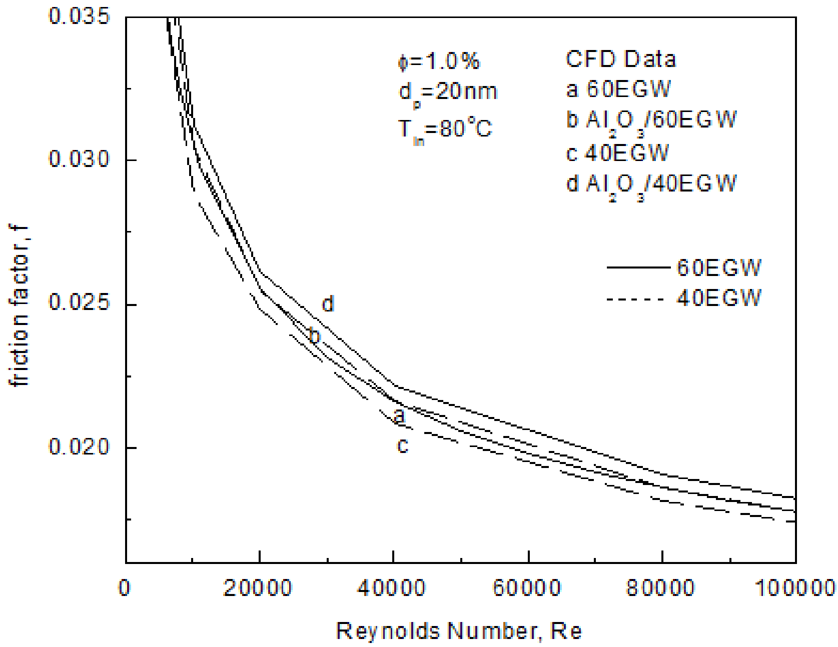

Fig. 5. Influence of base fluid on friction factor

5. Conclusions

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 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. Different solvers and turbulence models are used to try to determine the most accurate CFD method for predicting friction factor in plain tube heat exchanger. 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. 60EGW based nanofluids show higher friction factor when compared to the 40EGW based nanofluids which can be attributed to density and viscosity of the nanofluids.

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