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# Effect of Base Fluid on the Thermal Performance of $Fe_3O_4$ Nanofluid

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## ABSTRACT

The preparation of nanofluids with a wide range of thermophysical properties is possible by dispersing nanoparticles in different base fluids. In the present study, the effect of three different base fluids when dispersed with $Fe_3O_4$ nanoparticles is experimentally investigated by measuring their thermophysical properties as well as by determining their thermohydraulic performance using a Double Pipe Heat Exchanger (DPHE). The base fluids considered for the experimentation are Distilled water (DW), a mixture of Ethylene glycol and water in the ratio of 20:80 (20:80 EG-Water) and 40:60 (40:60 EG-Water) by volume. $Fe_3O_4$ nanoparticles are dispersed in these base fluids in the volume concentration ranging from 0.02% to 0.08%. The experiments are performed in the turbulent regime at an operating temperature of 45°C. A significant variation in the thermophysical properties is observed with volume concentration for EG-Water based nanofluid compared to that of water. With higher thermal conductivity, lower viscosity, higher specific heat and lower density, DW based $Fe_3O_4$ nanofluid has exhibited a higher heat transfer coefficient among the three different $Fe_3O_4$ based nanofluids. However, higher heat transfer enhancement compared to that of respective base fluid is observed for $Fe_3O_4$/40:60 EG-Water nanofluid. Accordingly higher Thermal Performance Factor has resulted in $Fe_3O_4$/40:60 EG-Water nanofluid.

**Keywords:** Base Fluid, Nanofluid, Heat Transfer Performance, Thermo-physical properties, Turbulent flow, Double Pipe Heat Exchanger (DPHE).

## 1. Introduction

Enhancing the heat transfer performance of conventional fluids by dispersing them with nanoparticles is one of the major areas of research. Nanofluids are being extensively studied since the last two decades for heat removal processes due to the scope of enhancement in their thermophysical properties compared to that of base fluids. The most commonly used base fluids include water, engine oil, propylene glycol, ethylene glycol, a mixture of water and ethylene glycol in various proportions, etc., Recent literature on $Fe_3O_4$ based nanofluids is presented as follows.

Sundar et al. [1] had experimentally investigated the thermal conductivity of $Fe_3O_4$ nanoparticles suspended in Ethylene Glycol and Water mixture in the ratio of 20:80, 40:60, and 60:40. The experiments were conducted in the volume concentrations ranging from 0.2% to 2.0% in the temperature range of 20°C to 60°C. They had reported a maximum enhancement of 46% in thermal conductivity for 20:80 EG-Water based $Fe_3O_4$ nanofluid for 2% volume concentration at 60°C. They also concluded that the Hamilton Crosser correlation for the thermal conductivity had failed to predict the thermal conductivity of the nanofluid with respect to temperature. Afrand et al.[2] experimentally investigated the thermal conductivity of $Fe_3O_4$/Water nanofluid for volume concentrations of 0.1%, 0.2%, 0.4%, 1%, 2%, and 3% at temperatures ranging from 20°C to 55°C. Results indicated that a maximum enhancement of 90% in thermal conductivity was obtained for a 3% volume concentration, at 55°C. Banisharif et al. [3] experimentally evaluated the thermal conductivity, viscosity and surface tension of $Fe_3O_4$/50:50 EG-Water nanofluid for volume concentrations of 0.01, 0.05 and 0.1% at temperatures ranging from 253.15 K to 293.15K. Sodium Dodecyl Sulfonate and Oleic acid were used as surfactants for stability. A maximum thermal conductivity ratio ($K_{nf}/K_{bf}$) of 14.3% was reported at 293.15 K for 0.1% volume concentration. The viscosity of the nanofluid, on the other hand, was reported to decrease with increase in particle concentration and this decrease was attributed to the presence of oleic acid as a surfactant which reduces the viscosity and in particular, at 0.1% volume concentration, the decrease was up to 40% for temperatures below 273.15K. The surface tension of the nanofluid was decreased due to the addition of surfactant and increased with a volume fraction of $Fe_3O_4$ nanofluid. At 0.1% volume concentration, the enhancement in surface tension was reported to be 38% and 33% at 253.15K and 293.15K.

Sundar et al. [4] had experimentally investigated the forced convection heat transfer and friction factor of $Fe_3O_4$/water nanofluid in a circular tube for volume concentrations ranging from 0 to 0.6% under turbulent conditions with Reynolds number varying from 3000 to 22000. They had reported a maximum enhancement of 30.96% and 10.01% in heat transfer coefficient and friction factor respectively for 0.6% volume concentration at a Reynolds number of 22000 compared to that of the base fluid. Rong Fu et al. [5] had investigated the heat transfer coefficient of highly disaggregated $Fe_3O_4$ nanoparticles in 1: 1 EG-Water base fluid in a circular tube for a volume concentration of 0.23% for the Reynolds number varying from 3500 to 6000. The surface of the nanoparticles was coated with citric acid in order to increase stability. They reported that due to the surface modification of the nanoparticles the nanofluid was stable for about 17 months. The heat transfer coefficient of the nanofluid was reported to decrease by 7% compared to that of the base fluid and the reason was explained as due to thickening of boundary layer resulting from the particle migration toward the interface between the pipe wall and fluid in favor of interfacial energy reduction thereby increasing the viscosity. They concluded that an enhanced heat transfer coefficient with highly disaggregated nanoparticles may be obtained at higher heat flux, flow rate, and temperatures. Reza Aghayari et al. [6] investigated the heat transfer coefficient of $Fe_3O_4$/Water nanofluid for the volume concentration of 0.08 to 0.1% under turbulent conditions. They concluded that Nusselt number of nanofluid was 19% and 25% greater than that of base fluid for a concentration of 0.1%, at the operating temperature of 35°C and 40°C respectively. These results show the effect of operating temperature on the thermal performance of nanofluids. Jospin Zupan et al. [7] investigated thermal conductivity and viscosity of Iron (II, III) oxide nanoparticles with water as the base fluid for the concentrations of 0 to 1 gram per liter (g/l). A maximum increase of 37% in thermal conductivity and 40 % in viscosity compared to that of base fluid was reported at 20°C for 1 g/l concentration.

Nishant et al. [8] had experimentally studied the heat transfer characteristics of $Fe_2O_3$/Water and $Fe_2O_3$/ EG nanofluids for volume concentrations ranging from 0.02% to 0.08% for a Reynolds number range of 1000 to 7000 and at operating temperature of 50°C and 80°C. They had observed higher enhancement in heat transfer coefficient for water-based nanofluid compared to that of EG based nanofluid. They had reported a maximum enhancement of 29% and 14% respectively in Nusselt number for $Fe_2O_3$/Water and $Fe_2O_3$/EG nanofluids for 0.08% volume fraction, at a temperature of 80°C. Azmi et al. [9] experimentally investigated the forced convection heat transfer of $Al_2O_3$ nanoparticles suspended in Water and Ethylene Glycol mixture in the ratio 60:40, 50:50, 40:60. They conducted experiments for the volume concentrations ranging from 0.2% to 1% at an operating temperature of 30, 50, and 70°C under the Reynolds number range of 3000 to 25000. They reported that maximum enhancement in heat transfer coefficient of 24.6% is obtained for 60:40 W-EG based $Al_2O_3$ nanofluid at 70°C whereas 24.2% and 19% enhancement in heat transfer coefficient is obtained for 40:60 Water-EG and 50:50 Water-EG based $Al_2O_3$ nanofluid respectively at 70°C, compared to that of the corresponding base fluid. They had reported that the operating temperature and thermophysical properties of the base mixtures greatly influence the heat transfer coefficient of nanofluids and also indicated that detailed investigations on base fluid effects are to be carried out.

The literature shows the use of different base fluids with $Fe_3O_4$ nanoparticles. However, there is scope to comprehensively study the effect of base fluids by dispersing the same volume concentration of $Fe_3O_4$ nanoparticles. In the present study the heat transfer performance of Demineralized Water (DW), two different mixtures of Ethylene Glycol and Water in the volume ratio of 20:80 and 40:60 is studied when these base fluids are dispersed with 0.02 to 0.08% volume concentrations of $Fe_3O_4$ nanoparticles, using a Double Pipe Heat Exchanger with U-bend. The experiments are performed in the turbulent flow regime at an operating temperature of $45^0$C.

## 2. Preparation of Nanofluids

$Fe_3O_4$ nanoparticles are procured from Nanoamor Texas USA. The properties of these nanoparticles are presented in Table1.

**Table 1.** Properties of Nanoparticles

| **Properties** | **$Fe_3O_4$** |
|---|---|
| Density(ρ, kg/m$^3$) | 4950 |
| Specific Heat(J/kgK) | 670 |
| Thermal Conductivity(W/m) | 95 |
| Purity | 99.5% |
| Size | 20-30nm |

.

The $Fe_3O_4$ nanoparticles are mixed in three different base fluids viz., Distilled water, 20:80 EG-Water, and 40:60 EG-water in the volume concentrations of 0.02%, 0.04%, 0.06%, and 0.08% respectively. The percentage volume concentration of nanofluid is calculated using Eq. (1), where *Ø* is the volume concentration of the nanofluid.

$$\phi = \frac{\frac{Wnp}{\rho np}}{\left(\frac{Wnp}{\rho np}+\frac{Wbf}{\rho bf}\right)}\times 100 \qquad (1)$$

Nanofluid at various volume concentrations is prepared using the two-step method. In order to avoid the sedimentation of the nanoparticles, the mechanical stirrer is used continuously for 24-48 hours depending on the volume concentration. Among the three different types of nanofluids considered in the analysis, $Fe_3O_4$/DW nanofluid is observed to be comparatively less stable. The particle size analysis of $Fe_3O_4$ nanoparticles is performed using the transmission electron microscope. Fig. 1 shows the TEM images of $Fe_3O_4$ nanoparticles at a magnification of 50nm, which clearly indicates that these particles are of spherical shape.

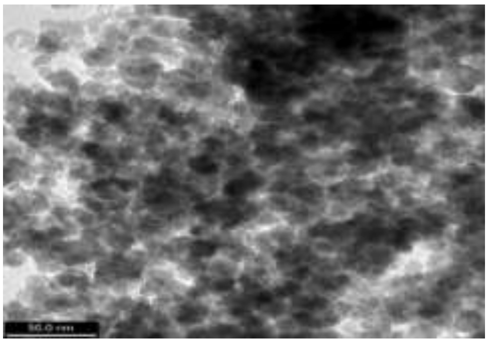


Fig. 1. TEM Image of $Fe_3O_4$ Nanoparticles at 50nm Scale

The Zeta potential of $Fe_3O_4$/DW, $Fe_3O_4$/20:80 EG-Water, and $Fe_3O_4$/40:60 EG-Water nanofluids at 0.08% volume concentrations are tested using Nanoparticle Analyser (Horiba, Japan). For the three different base fluids, the Zeta potential values are observed to be greater than ±30mV, when dispersed with $Fe_3O_4$ nanoparticles, showing the stability of these colloidal solutions.

## 3. Experimental

### *3.1 Measurement of Density and Specific Heat*

The density of the nanofluids is measured using Antonpaar Density Measuring Instrument. It works on the principle of Oscillating U-tube, which is a technique used to determine the density of liquids or gases based on the electronic measurement of the frequency of oscillation.

The specific heat of the nanofluid is measured using Mentos Heat Capacity Apparatus. It consists of a water bath with a heater to raise the temperature of the fluid under test. The data is logged into a USB drive for every 0.1°C of temperature rise. The Specific heat of the test fluid is calculated using the Eq. 2.

$$c_p = (W_s - P_{av} / \Delta) / m \qquad (2)$$

Where $W_s$ is the specific heat equivalent of water, $P_{av}$ is the average power consumed in watts to raise the temperature of the fluid for a given time. $\Delta = (T_1 - T_2) / t$. Where $T_1$ and $T_2$ are the temperatures for a given time $t$.

### *3.2 Measurement of Viscosity and Thermal Conductivity*

The viscosity of $Fe_3O_4$ nanoparticle suspensions in DW, 20:80 EG-Water, and 40:60 EG-Water is measured using the DV2T Viscometer, for different volume concentrations ranging from 0.02 to 0.08%. The viscosity of these nanofluids is measured at a temperature of $45^0$C.

The thermal conductivity of $Fe_3O_4$/DW, $Fe_3O_4$/ 20:80 EG-Water and $Fe_3O_4$/40;60 EG-Water nanofluids are measured using Tempos thermal property analyzer at 45°C.

### *3.3 Experimental Setup and Procedure*

The test section consists of a Double Pipe Heat Exchanger (DPHE) with U bend as shown in the schematic diagram of the experimental setup in Fig. 2. Hot fluid (test fluid) flows through the inner tube and water at room temperature passes through the annulus at a constant flow rate. The inner pipe of the heat exchanger is made of stainless steel with a 19mm inner diameter and 25mm outer diameter. The outer pipe is made up of galvanized iron with a 56mm outer diameter and 50mm inner diameter. The total length of the pipe is 4.52m. The other parts of the setup include two reservoirs for hot and cold water, a temperature controller, and a data logger for the measurement of all relevant parameters, viz., flow rate, temperature, and pressure drop. The validation of the experimental setup and the detailed data analysis is presented by authors in their related paper, Kanthimathi et al. [10].

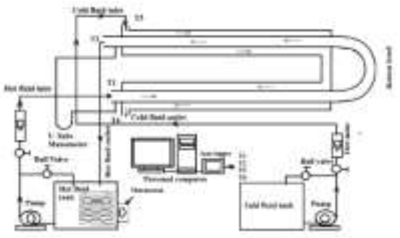


Fig. 2. Schematic of the Experimental Setup

Based on the accuracy of the measuring devices, viz., thermocouples, flowmeter, and pressure transducer, the uncertainties in the estimation of Reynolds number, heat transfer coefficient, and friction factor are calculated using Eqs. (3) to (5)

$$\frac{U_{\mathrm{Re}}}{\mathrm{Re}} = \sqrt{(\frac{U_{\rho}}{\rho})^2 + (\frac{U_V}{V})^2 + (\frac{U_{\mu}}{\mu})^2} \qquad (3)$$

$$\frac{U_{h_i}}{h_i} = \sqrt{\left(\frac{U_{U_i}}{U_i}\right)^2 + \left(\frac{U_{k_p}}{k_p}\right)^2 + \left(\frac{U_{h_o}}{h_o}\right)^2} \qquad (4)$$

$$\frac{U_{f_i}}{f_i} = \sqrt{\left(\frac{U_{\Delta P}}{\Delta P}\right)^2 + \left(\frac{U_{\rho}}{\rho}\right)^2 + \left(\frac{2 \times U_V}{V}\right)^2} \qquad (5)$$

The maximum percentage uncertainty in Reynolds number, heat transfer coefficient and friction factor is found to be 0.2768%, 0.387%, and 0.3932% respectively.

## 4. Results and Discussion

### *4.1 Thermophysical Properties of DW, 20:80 EG-Water and 40:60 EG-Water based $Fe_3O_4$ Nanofluids*

#### *4.1.1 Density*

Fig. 3 shows the variation of density of $Fe_3O_4$/DW, $Fe_3O_4$/20:80 EG-Water, and $Fe_3O_4$/40:60 EG-Water nanofluids with volume concentration. Among the three different $Fe_3O_4$ based nanofluids, $Fe_3O_4$/DW nanofluid has exhibited a lower density and $Fe_3O_4$/40:60 EG-Water nanofluid has exhibited higher density. The measured density of 20:80 EG-Water and 40:60 EG-Water based $Fe_3O_4$ nanofluids is observed to be almost the same. For the three different $Fe_3O_4$ based nanofluids, the variation of density with the volume concentration is not significant from that of the corresponding base fluid, for the range of volume concentrations considered in the analysis. The measured values of density are compared with Pak and Cho [11] correlation, given by Eq. (6). The average percentage deviation of the theoretical correlations from that of measured values is observed to be 0.68%, 1.53%, and 0.12% for $Fe_3O_4$/DW, $Fe_3O_4$/20:80 EG-Water and $Fe_3O_4$/40:60 EG-Water nanofluids respectively, thus showing that the Pak and Cho [11] correlation had predicted the experimental data with good agreement, for all the three different base fluid-based $Fe_3O_4$ nanofluids.

$$\rho_{\mathrm{nf}} = (1-\phi)\rho_{\mathrm{bf}} + \phi\rho_{\mathrm{p}} \qquad (6)$$

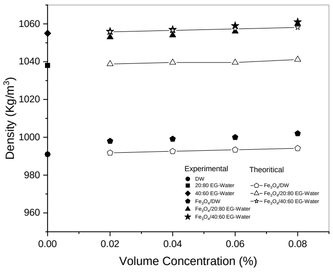


Fig. 3. Density of the Nanofluids

### *4.1.2. Specific Heat*

The variation of specific heat of nanofluids with the volume concentration is shown in Fig. 4. The specific heat of DW based $Fe_3O_4$ nanofluid is the highest and with an increase of volume percentage of EG content, the specific heat is decreased. The variation of specific heat with volume concentration is observed to be negligible, with less than 2% compared to that of the corresponding base fluid, for three different nanofluids, over the range of volume concentrations considered in the analysis. The measured values of specific heat are compared with that of Pak and Cho [11] correlation, given by Eq. (7). The theoretical values are observed to match perfectly with those of the measured values with less than 0.2% deviation.

$$c_{\mathrm{p}} = \frac{(1-\phi)\,\rho c_{\mathrm{p}} + \phi\rho_{\mathrm{p}} c_{p_p}}{\rho_{\mathrm{nf}}} \qquad (7)$$

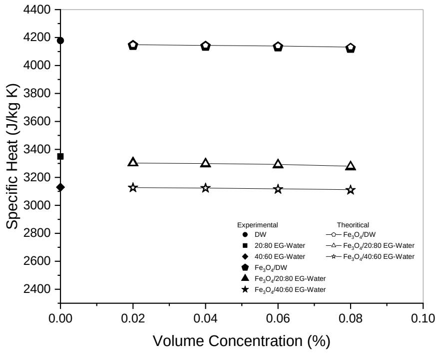


Fig. 4. Specific Heat of Nanofluids

### *4.1.3 Viscosity*

Both EG-Water based nanofluids have exhibited higher viscosity than that of water-based nanofluid, with the viscosity being increased with the increase of volume percentage of EG in the base fluid as shown in Fig.5. The higher enhancement in viscosity compared to that of the corresponding base fluid, however, is exhibited by 20:80 EG-Water based nanofluid, with an enhancement of 43.82% to 62.92%, while DW based nanofluid has exhibited a lower enhancement of 11.29% to 20.96%. The viscosity of $Fe_3O_4$/40:60 EG-Water nanofluid is 2.4 times higher than $Fe_3O_4$/DW and 1.24 times higher than $Fe_3O_4$/20:80 EG-Water nanofluid for 0.08% volume concentration and at the operating temperature of $45^0$C. A similar trend of results for viscosity, viz., an increase of viscosity with the increase of the percentage of EG in EG-Water base fluid, was reported by Sundar et al. [12] with $Fe_3O_4$ nanoparticles dispersed in 60:40, 40:60 and 20:80 EG-Water. They indicated that 60:40 EG/Water-based nanofluid is 2.94 times, 40:60 EG-Water based nanofluid is 1.61 times, and 20:80 EG-Water based nanofluid is 1.42 times more viscous than their respective base fluids.

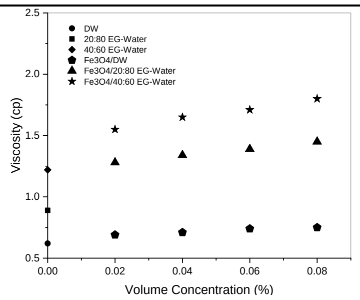


***Fig. 5***. Viscosity of Nanofluids

### *4.1.4 Thermal Conductivity*

Fig. 6 shows the variation of thermal conductivity of nanofluids with volume concentration at the operating temperature of 45°C. There observed to be a negligible variation in the thermal conductivity of 20:80 EG-Water based and water-based nanofluid at all the volume concentrations considered in the analysis. The thermal conductivity of the nanofluid is observed to decrease with the increase of volume percentage of EG in EG-Water base fluid. An increment of up to 11.07%, 26.94%, and 32.85% compared to that of corresponding base fluid is observed for $Fe_3O_4$/DW, $Fe_3O_4$/20:80 EG-Water and $Fe_3O_4$/40:60 EG-Water respectively with the variation of volume concentration. The thermal conductivity $Fe_3O_4$/DW nanofluid is observed to be 1.07 times than that of $Fe_3O_4$/40:60 EG-Water nanofluid at 0.08% volume concentration.

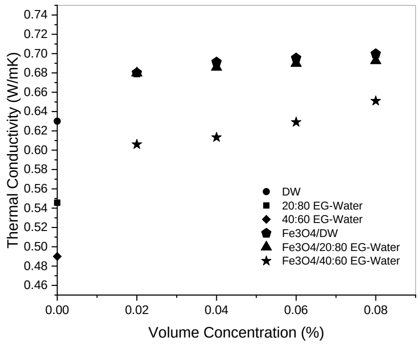


Fig. 6. Thermal Conductivity of Nanofluids

The analysis of thermophysical properties of three different base fluid-based $Fe_3O_4$ nanofluids show that DW based nanofluid has exhibited superior properties. In addition, the variation of properties with the addition of $Fe_3O_4$ nanoparticles is not as significant in DW based nanofluid as that of EG- Water-based nanofluids. Even for the very low volume concentrations considered in the analysis. EG-Water based nanofluids have resulted in significant variation in thermophysical properties, particularly in viscosity and thermal conductivity.

### *4.1.5 Prandtl Number*

Based on the measured thermophysical properties of the three different $Fe_3O_4$ based nanofluids, their Prandtl number is calculated and the same is presented in Table 2. The table clearly shows that the Prandtl number of three fluids increases with the increase of volume concentration. 40:60 EG-Water based $Fe_3O_4$ nanofluid has exhibited higher Prandtl number, while that of DW based nanofluid has exhibited lower Prandtl number for all the volume concentrations considered in the analysis.

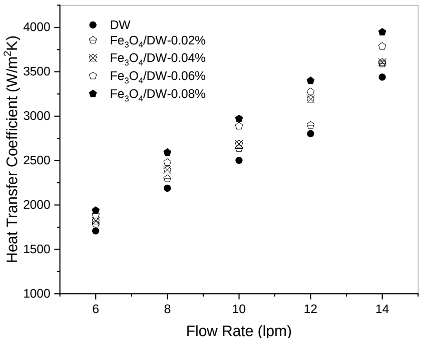
Table 2. Prandtl Number of Nanofluids

| Volume concentration | $Fe_3O_4$/DW | $Fe_3O_4$/20:80 EG-Water | $Fe_3O_4$/40:60 EG-Water |
|---|---|---|---|
| 0 | 4.11 | 5.46 | 7.79 |
| 0.02 | 4.20 | 6.22 | 7.99 |
| 0.04 | 4.25 | 6.44 | 8.4 |
| 0.06 | 4.39 | 6.62 | 8.46 |
| 0.08 | 4.41 | 6.85 | 8.82 |

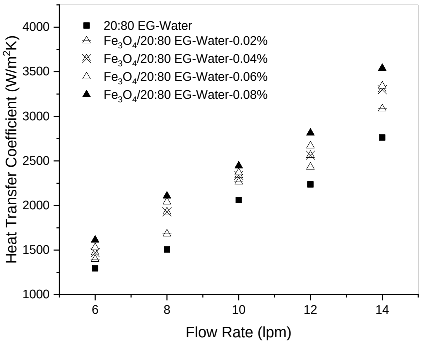
### *4.2 Thermo-hydraulic Performance of Nanofluids*

### *4.2.1 Heat Transfer Coefficient of Nanofluids*

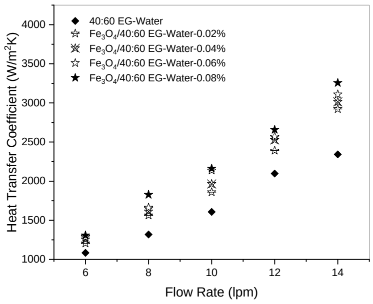
The variation of heat transfer coefficient with the flow rate for $Fe_3O_4$/ DW, $Fe_3O_4$/20:80 EG-Water, and $Fe_3O_4$/40:60 EG-Water nanofluids is shown in Figs. 7 (a), (b), (c) for the range of volume concentration from 0.02 to 0.08%.



(a) ) $Fe_3O_4$/ DW



(b) $Fe_3O_4$/20:80 EG-Water



(c) $Fe_3O_4$/40:60 EG-Water

Fig. 7. Heat Transfer Coefficient of nanofluids

The average enhancement in heat transfer coefficient for DW based $Fe_3O_4$ nanofluid over the range of flow rates considered in the analysis is observed to vary from 4.53% to 17.35% with the variation of volume concentration from 0.02% to 0.08% as shown in Fig. 12 (a). Similarly for 20:80 and 40:60 based EG-Water based $Fe_3O_4$ nanofluids, it is 9.99% to 27.41% and 16.1% to 31.88% respectively as shown in Figs. 12 (b) and 12 (c). The higher heat transfer enhancement with the increase of volume concentration is observed for 40:60 EG – Water-based $Fe_3O_4$ nanofluid, compared to the other two nanofluids, with a maximum enhancement of 39.82% for a volume concentration of 0.08% at a flow rate of 14 lpm. The higher enhancement in heat transfer coefficient of 40:60 EG-Water based nanofluid is due to its higher enhancement in thermal conductivity associated with a relatively lower enhancement in viscosity compared to that of base fluid as shown in Figs. 11 and 10 respectively.

### *4.2.2 Comparison of Nusselt Number*

The variation of Nusselt number of the nanofluids with flow rate for a volume concentration of 0.08% is shown in Fig. 8 along with the Nusselt number of corresponding base fluids. The average percentage increase in Nusselt number is 5.65% and 0.36% for $Fe_3O_4$/DW and $Fe_3O_4$/20:80 EG-Water nanofluid respectively, whereas the average percentage decrease in Nusselt number for $Fe_3O_4$/40:60 EG-Water nanofluid is 0.74% compared to that of the base fluid. The results show a negligible variation in Nusselt number, particularly for both EG-Water based $Fe_3O_4$ nanofluids. This is the indication of increased heat conduction due to the Brownian motion of $Fe_3O_4$ nanoparticles in these base fluids compared to that of water. Thus, higher enhancement in heat transfer coefficient is resulted in EG-Water based $Fe_3O_4$ nanofluids, compared to that of the corresponding base fluid.

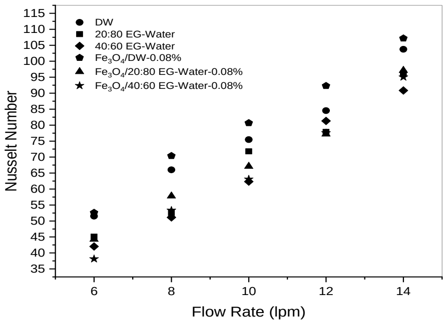


Fig. 8. Comparison of Nusselt Number of Nanofluids

### *4.2.3 Comparison of Experimental Nusselt Number with the Correlations*

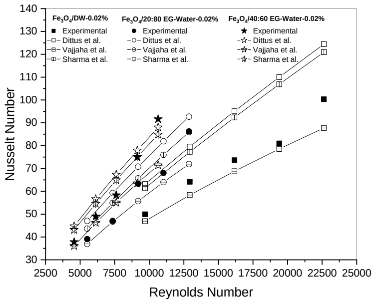
The experimental values of Nusselt number of nanofluids considered in the analysis are compared with the correlations of Dittus Boelter [13], Vajjha et al. [14], and Sharma et al. [15], given by Eqs. (8) to (10).

$$Nu = 0.023\, Re^{0.8}\, Pr^{0.4} \qquad (8)$$

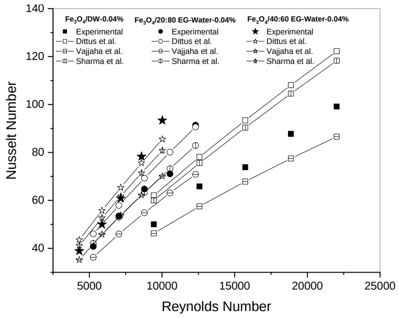
$$Nu=0.065(Re^{0.65} - 60.22)(1+0.0169\O^{0.15})Pr^{0.542} \qquad (9)$$

$$Nu=0.023\, Re^{0.8}\, Pr_w^{0.4}(1+Pr_{nf})^{-0.012}(1+\O)^{0.23} \qquad (10)$$

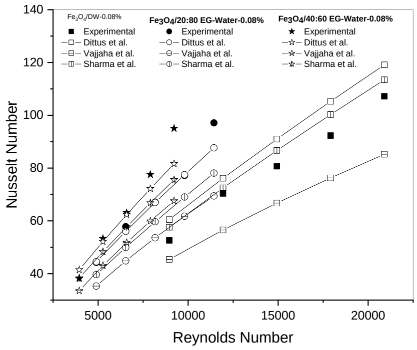
The comparison is presented for volume concentrations of 0.02%, 0.04%, and 0.08% of DW, 20:80 EG-Water and 40:60 EG-Water based $Fe_3O_4$ nanofluids in Figs. 9(a), (b) and (c). In general, the correlations had predicted the experimental data of EG-Water based $Fe_3O_4$ nanofluids with lesser deviation compared to that of DW based nanofluids, except Vajjaha et al. [14], which had shown the reverse trend. Among the three correlations, Sharma et al. [15] correlation have shown a minimum deviation of 6.8 to 24.3%, 1.2 to 13% and 1.9 to 10.3% from that of corresponding experimental data for DW, 20:40 EG – Water and 40:60 EG – Water-based nanofluids respectively as the volume concentration varied between 0.02% to 0.08%. Vajjha et al correlation has shown comparatively higher deviation from that of experimental data of EG-Water based $Fe_3O_4$ nanofluids. In general, the three correlations have predicted the experimental data well with a maximum deviation of 28% from that of experimental data which occurred with the Dittus-Boelter correlation for DW based nanofluid at a volume concentration of 0.02%.



(a) 0.02%,



(b) 0.04%



(c) 0.085

Fig. 9. Comparison of Experimental Nusselt Number of Nanofluids with the Correlations

### *4.2.4 Comparison of Heat transfer Coefficient*

Fig. 10 shows the variation of heat transfer coefficient of 0.08% volume concentration of DW, 20:80 EG-Water, and 40:60 EG-Water based $Fe_3O_4$ nanofluids. The DW based nanofluid has exhibited a higher heat transfer coefficient, while that of 40:60 EG-Water based nanofluid is found to be lowest among the three different nanofluids considered in the analysis. With the increase of EG percentage in EG-Water based nanofluids, the heat transfer coefficient is decreased. The Prandtl number of 40:60 EG-Water based nanofluid is higher than the other two fluids for the range of volume concentrations considered in the analysis, as shown in Table 2. This shows that the boundary layer of 40:60 EG-Water based nanofluid is thicker than that of the other two fluids, resulting in comparatively increased resistance to heat transfer, which has reflected in its lower values of heat transfer coefficient.

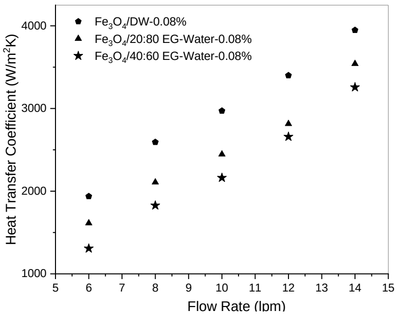
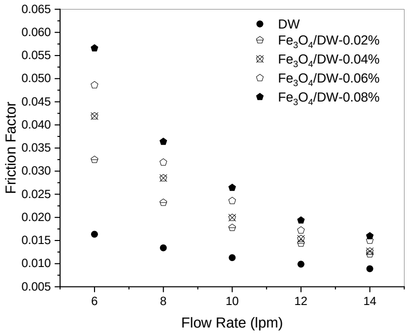


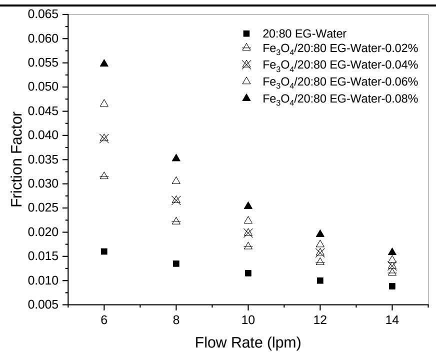
Fig. 10. Comparison of Heat Transfer coefficient of Nanofluids

*4.2.5 Friction Factor of Nanofluids*

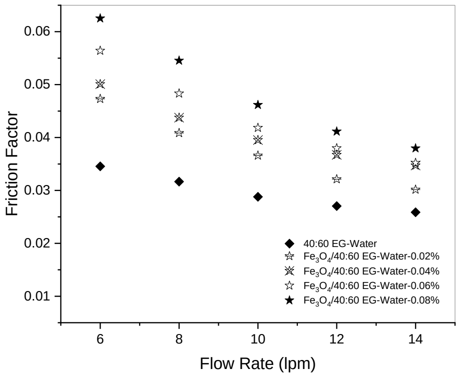
The variation of friction factor with the flow rate for $Fe_3O_4$/ DW, $Fe_3O_4$/20:80 EG-Water, and $Fe_3O_4$/40:60 EG-Water nanofluids is shown in Figs. 11 (a), (b), (c).



(a) $Fe_3O_4$/ DW



(b) $Fe_3O_4$/20:80 EG-Water



(c) $Fe_3O_4$/40:60 EG-Water

Fig. 11. Friction Factor of nanofluids

It is clearly indicated in Fig. 16 that the friction factor of the nanofluids considered in the analysis increase with the increase in volume concentration. With the increase of volume concentration, DW based $Fe_3O_4$ nanofluid has exhibited a higher increase in the friction factor with 62.08% to 145.51%, while 40:60 EG-Water based nanofluid has exhibited the lowest increment of 27.96% to 62.47%, with the variation of volume concentration. This variation in the increment of friction factor for three different nanofluids is due to the corresponding Reynolds number of the flow at the same flow rate. The increment in friction factor is decreased with the increase of flow rate for three different base fluid-based nanofluids, due to the dominance of fluid turbulence over that of variation in transport properties on friction factor.

Fig. 12 shows the comparative variation of friction factor of three different $Fe_3O_4$ nanofluids, for a volume concentration of 0.08%. It is clearly indicated from the figure that the friction factor of 40:60 EG-Water based nanofluid is higher than that of the other two nanofluids at all flow rates considered, which is due to its higher viscosity compared to that of other two fluids.

The friction factor of DW based and 20:80 EG-Water based nanofluids is observed to be almost the same for the range of flow rates considered in the analysis.

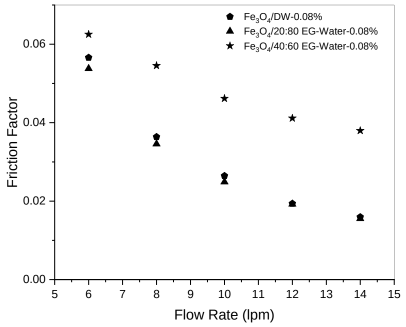


Fig. 12. Friction Factors of Nanofluids at 0.08% Volume Concentration

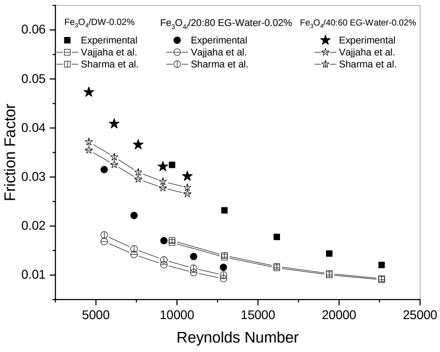
*4.2.6 Comparison of Experimental Friction Factor with Correlations*

The Experimental friction factor of the nanofluids considered in the analysis is compared with correlations given by Vajjah et al. [14] and Sharma et al. [15] given by Eqs. (11) and (12).

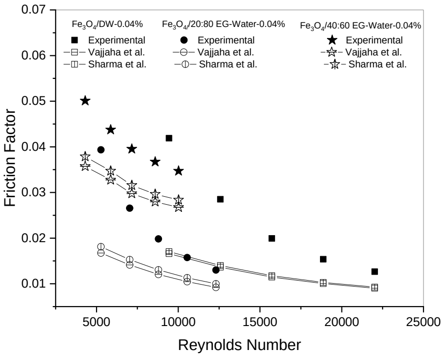
$$f_{nf} = f_{bf}((\rho_{nf}/\rho_{bf})^{0.797}(\mu_{nf}/\mu_{bf})^{0.108}) \tag{11}$$

$$f_{nf} = f_{bf}((\rho_{nf}/\rho_{bf})^{1.3}(\mu_{nf}/\mu_{bf})^{0.3}) \tag{12}$$

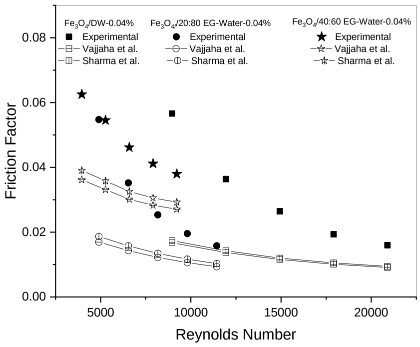
The comparison of experimental friction factor of the nanofluids in the analysis with the correlations is represented in Figs. 13 (a), (b) and (c) for volume concentration of 0.02%, 0.04% and 0.08% respectively.



(a) 0.02%



(b) 0.04%



(c) 0.08%

Fig. 13. Comparison of Experimental Friction Factor with Correlations

The correlations are observed to show comparatively higher deviations in the range of 34.5% to 56% in the case of DW and 20:80 EG-Water based $Fe_3O_4$ nanofluids. For 40:60 EG -Water-based nanofluids, both the correlations have exhibited lesser deviation in the range of 14% to 35% from the experimental values. In general, the average deviation of correlations from that of experimental values is observed to increase with the increase of volume concentration. Also, the deviation is observed to decrease with the increase of the Reynolds number.

### *4.4 Thermal Performance Factor*

To compare the overall performance of the nanofluids the Thermal Performance Factor (TPF) represented by η given by Eq. (13) is evaluated.

$$\eta = \frac{\left(\frac{Nu_{nf}}{Nu_{bf}}\right)}{\left(\frac{f_{nf}}{f_{bf}}\right)^{\frac{1}{3}}} \qquad (13)$$

The TPF values of the three nanofluids considered in the analysis for 0.08% volume concentration are presented in Fig. 14. From Fig.14 it is clearly indicated that at 0.08% volume concentration the TPF values of $Fe_3O_4$/40:60 EG-Water nanofluid is higher than that of DW based and 20:80 EG-Water nanofluids. Among three different nanofluids considered in the analysis, DW based $Fe_3O_4$ nanofluid has exhibited higher heat transfer coefficient and lower friction factor compared to the corresponding values of other two nanofluids, while 40:60 EG-Water based nanofluid has exhibited a lower value of heat transfer coefficient and higher value of friction factor, as shown in Figs. 15 and 17 respectively. However, compared to the base fluid, 40:60 EG-Water based $Fe_3O_4$ nanofluid has exhibited higher enhancement in heat transfer coefficient and lower increment in the friction factor, which is being reflected in its higher value of thermal performance factor. Accordingly, though DW based $Fe_3O_4$ nanofluid has exhibited better thermo-hydraulic performance, it is not being represented by its TPF. This analysis shows that TPF does not make the right parameter for comparison of the overall performance of nanofluids prepared by dispersing the same nanoparticles in different base fluids.

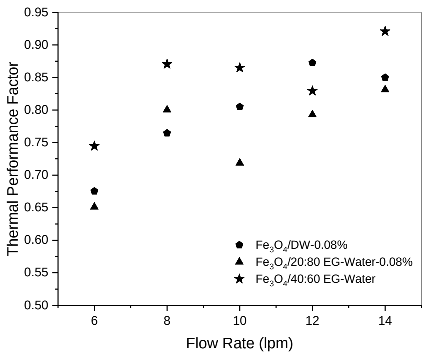


Fig. 14. Thermal Performance factor of Nanofluids

## 5. CONCLUSIONS

The thermo-hydraulic performance of DW, 20:80 EG-Water, and 40:60 EG-Water based $Fe_3O_4$ nanofluids is experimentally investigated in a double pipe heat exchanger with

U-bend for low volume concentrations varying from 0.02% to 0.08% under turbulent conditions. The following inferences are drawn from the analysis.

- The variation of thermophysical properties with the dispersion of $Fe_3O_4$ nanoparticles, particularly viscosity and thermal conductivity is observed to be significant with the increase of volume percentage of Ethylene Glycol (EG) in EG-Water based $Fe_3O_4$ nanofluids, at the operating temperature of $45^0$C.
- The most widely used Pak and Cho correlations for determination of density and specific heat of nanofluids have predicted the experimental data with excellent agreement.
- The higher Prandtl number of 40:60 EG-Water based $Fe_3O_4$ nanofluid has resulted in a lower heat transfer coefficient compared to that other two bases fluid-based $Fe_3O_4$ nanofluids.
- Significant variation in the thermo-hydraulic performance is resulted in the variation of volume concentration of nanoparticles for EG-Water based nanofluids, compared to that of DW based $Fe_3O_4$ nanofluid.
- DW based $Fe_3O_4$ nanofluid has exhibited superior thermo-hydraulic performance compared to that of EG-Water based nanofluids.
- The heat transfer coefficient of DW based nanofluid is 1.32 times that of 40:60 EG-Water based nanofluid and 1.18 times than that of 20:80 EG-Water based nanofluid for a volume concentration of 0.08%, over the range of flow rates considered in the analysis.
- Dittus Boelter [13], Vajjha et al. [14], and Sharma et al. [15] correlations have predicted the experimental data well with a maximum deviation of 28% in heat transfer coefficient.
- The Thermal Performance Factor is observed to be not a suitable parameter for the comparison of the overall performance of nanofluids prepared by dispersing the same nanoparticles in different base fluids.

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