Effect of Low Volume Concentration on Heat Transfer Enhancement of EG-Water Based Fe_3O_4 Nanofluid

T. Kanthimathi, P. Bhramara, Ayub Shaik

Abstract: ***Customization of thermophysical properties of the working fluids has tremendous potential in heat transfer enhancement. In the present paper, experimentation is conducted to determine the heat transfer coefficient and friction factor of 20:80 Ethylene Glycol-Water(20:80 EG-Water) based Fe_3O_4 nanofluid in a Double Pipe Heat Exchanger with U Bend (DPHE). Experiments are performed in the turbulent flow regime at an operating temperature of 47.5°C. Fe_3O_4 nanoparticles of size less than 50 nm are mixed with 20:80 EG-Water solution in the volume concentration range of 0.02% to 0.08%. Results indicate that as the concentration of nanoparticles increase, the heat transfer coefficient of the nanofluid increases up to 0.04% concentration and then decreases, while the friction factor is observed to increase with the increase of volume concentration. Within the Reynolds number range considered in the analysis, the average enhancement in the heat transfer coefficient is 24.1% at 0.04% concentration compared to that of the base fluid. The average enhancement in the friction factor is observed to be 25.58% at 0.08% concentration of Fe_3O_4/ 20:80 EG-Water nanofluid compared to that of base fluid.***

Keywords: ***Nanofluid, Heat transfer coefficient, Volume Concentration, Friction Factor, Turbulent Flow, Thermal Conductivity, Viscosity.***

I. INTRODUCTION

Enhancement in the heat transfer rate is an important aspect of enhancing the energy efficiency of the components in industries like automobile, power, electronics, textiles, etc. The thermophysical properties of the working fluids play a major role in heat transfer. To enhance the thermophysical properties of the conventional fluids like water, oil, EG-Water etc., a new class of fluids is introduced by Pak and Choi [1], called nanofluids. Nanofluids are the fluids with nanometer-sized suspensions of either metallic, metal oxides, ceramic or metal nitride particles.

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Raei et al., [2] conducted an experimental investigation to determine the heat transfer coefficient of γ-Al_2O_3/Water nanofluid in DPHE for a volume concentration range of 0.05 to 0.15%. Results indicate that there is no significant increase in the ratio of heat transfer of nanofluid with that of base fluid with the increase in particle concentration at the operating temperature of 45°C, for the low volume concentrations considered in the analysis. Ali Kia et al., [3] conducted experiments in DPHE with CuO-Water nanofluid in the volume concentration range of 0.1 to 0.5% under laminar and turbulent flow conditions. Their results indicate that for a volume concentration of 0.5% the maximum increment in overall heat transfer coefficient and Nusselt number is reported to be 15% and 23% respectively. Zarringhalam Majid et al., [4] conducted experimentation on heat transfer coefficient and pressure drop of CuO-Water nanofluid in a DPHE for a volume fractions of 0 to 2% in the Reynolds number range of 2900 to 18500. The heat transfer coefficient and the pressure drop of the nanofluid increased with an increase in the nanofluid volume concentration. The maximum value of thermal performance factor at 2% volume concentration of nanofluid is reported to be 7.89% greater than that at 1.5% volume concentration. In the present work also, DPHE with U bend is used to determine the effect of nanofluids on heat transfer enhancement.

Aghayari et al., [5] investigated the heat transfer coefficient of Fe_3O_4/Water nanofluid in the volume concentration of 0.08 to 0.1% under turbulent conditions. They concluded that the Nusselt number of nanofluid is 19% and 25% greater than the base fluid at a concentration of 0.1% and for temperatures of 35°C and 40°C respectively. Azmi [6] conducted an experimental study to determine the heat transfer coefficient in a circular tube with TiO_2 in 40:60 EG-Water nanofluid under turbulent flow in the volume concentration range of 0.5 to 1.5% under operating temperatures of 50°C and 70°C. Maximum enhancement of Nusselt number at 1.5% volume concentration is reported as 22.8% and 28.9% at 50°C and 70°C respectively with that of the base fluid. Friction factor is reported to be 1.1 times greater than the base fluid at 1.5% concentration. He reported that with the increase of working temperature, enhancement becomes more noticeable, particularly at higher concentrations. These results show the effect of operating temperature on the thermal performance of nanofluids. Selvan et al., [7] conducted an experimental investigation of convective heat transfer coefficient of Silver/EG-Water(30:70) nanofluid under laminar, transition and turbulent flow regimes in a DPHE for particle concentrations ranging from 0.05-0.45% at operating temperatures of 35 and 45°C.

Results indicate that the maximum enhancement in the convective heat transfer coefficient is observed when the particle concentration increased from 0 to 0.15% at 35°C. Beyond 0.15% the enhancement is limited due to the increase in the viscosity. At 45°C heat transfer coefficient is enhanced up to 42% at 0.45% particle concentration due to the decrease in viscosity with the increase in temperature. Yanjan Li et al., [8] conducted an experimental investigation to determine heat transfer enhancement of ZnO/EG-Water (50:50) nanofluid in a circular pipe in transition regime for a volume concentration range of 0 to 5% in the temperature range of 20 to 40°C. They concluded that the maximum enhancement in heat transfer coefficient is 29.8% at 2.5% concentration. At 5% concentration, the maximum enhancement in heat transfer coefficient is 5% less than that of 2.5% concentration. This decrease at higher volume concentration is attributed to the conflict between the increase in thermal conductivity and viscosity with the increase in volume concentration, apart from many other aspects. They described that the heat transfer with nanofluids is a rather complex phenomenon. However, the pressure drop is observed to increase with the increase of volume concentration of the nanofluid. Thus, the interdependence of thermophysical properties plays a major role in determining the heat transfer aspect of the nanofluid.

Azmi et al., [9] conducted a review on heat transfer augmentation of EG and EG-water based nanofluids. Based on the review they concluded that EG-Water based nanofluids are stable and show significant enhancement of heat transfer performance.

Jospin Zupan et al., [10] investigated thermal conductivity and viscosity of Iron (II, III) oxide nanoparticles with water as a base fluid in the concentrations of 0 to 1 gram per liter (g/l). Results indicate that the maximum increase of 37% in thermal conductivity was obtained at 20°C for 1 g/l concentration when compared to that of the base fluid. Ravi Kumar et al., [11] conducted experiments using Double Pipe Heat Exchanger with Fe_3O_4/water nanofluid in the volume concentrations of 0.005 to 0.06% in the turbulent regime. Results indicate that the maximum enhancement in Nusselt number is 14.7% at 0.06% volume concentration hen compared to that of the base fluid. A maximum enhancement of 25.99% compared to that of base fluid is reported in friction factor at 0.06% concentration of nanofluid.

Based on the review of the literature, the base fluid is selected as 20:80 Ethylene Glycol – Water (EG-Water). The effect of low volume concentrations, in the range of 0.02% to 0.08% of Fe_3O_4/ 20:80 EG-water on the heat transfer coefficient and friction factor is determined experimentally using a DPHE with U bend at an operating temperature of 47.5^0C.

II. PREPARATION OF NANOFLUID

Nanofluid is prepared using a two-step method. The base fluid considered is a mixture of EG and water in the proportions of 20:80. Fe_3O_4 nanoparticles of less than 50 nm size with 99% purity procured from Nano Amor Texas, USA. The mass of the nanoparticles to prepare 0.02%, 0.04%, 0.06%, 0.08% volume concentrations are calculated using Eq.1.

$$\phi = \frac{\text{Volume of Nanoparticles}}{(\text{Volume of Nanoparticles+Volume of EG-Water})} \times 100 \quad (1)$$

These nanoparticles are suspended in the base fluid 20:80 EG-Water and are kept agitated using mechanical stirrer for about 24-36 hours to avoid sedimentation.

III. ESTIMATION OF PROPERTIES

A. Measurement of Viscosity

The viscosity of Fe_3O_4/20:80 EG-Water nanofluid is determined using DV3T Rheometer as shown in Fig.1

Fig.1. DV3T Rheometer

The viscosities of the Fe_3O_4 / 20:80 EG-water nanofluid are measured at different volume concentrations and at an operating temperature of 47.5°C. As shown in Fig. 2, the viscosity of nanofluid increases with an increase in volume concentration. The maximum percentage increase in the viscosity is observed to be 38.62% at 0.08% volume concentration and the minimum increase is 30.46% at 0.02% volume concentration of Fe_3O_4/ 20:80 EG-water nanofluid at 47.5°C.

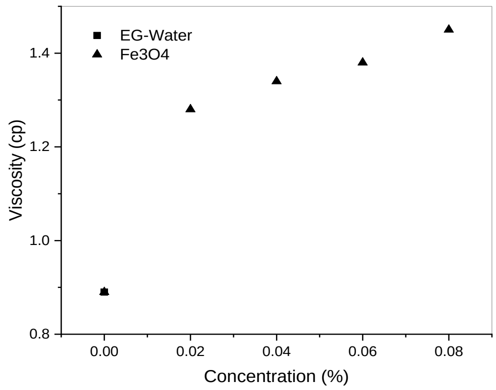

Fig.2 Viscosity of Fe_3O_4/EG-Water Nanofluid

B. Measurement of Thermal Conductivity

The thermal conductivity of nanofluids is measured using an ultrasonic interferometer as shown in Fig. 3. The apparatus measures the velocity of an ultrasonic wave in nanofluids to study the effect of temperature on velocity in nanofluids of different concentrations. Nanofluid interferometer generates sound waves in nanofluids of diverse concentrations at dissimilar temperatures.

These waves of known frequency are produced by a piezoelectric transducer and its wavelength is measured using a digital micrometer with high accuracy.

Fig.3 Ultrasonic Interferometer

Thermal conductivity of Fe_3O_4/20:80 EG-Water nanofluid at various concentrations are calculated using Eq.2.

$$k = 3\times\left(\frac{N}{V_m}\right)^{\frac{2}{3}} \times K \times V \quad (2)$$

The variation of thermal conductivity of Fe_3O_4/ 20:80 EG-water nanofluid with volume concentration at the operating temperature of 47.5°C is presented in Fig. 4. The maximum percentage increase of thermal conductivity is 21.22% at 0.08% volume concentration when compared to that of base fluid at the operating temperature of 47.5°C, while the increase in thermal conductivity at 0.02% volume concentration is observed to be 19.75% compared to that of the base fluid.

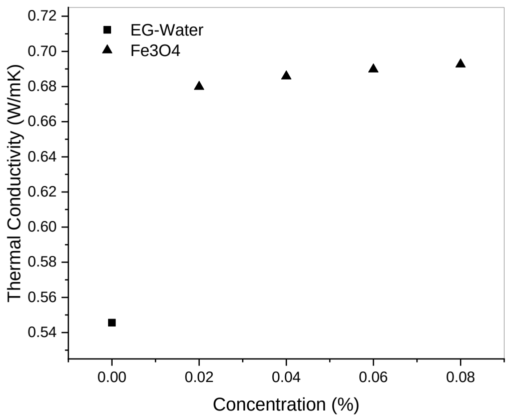

Fig.4 Thermal Conductivity of Fe_3O_4/EG-Water Nanofluid.

C. Measurement of Density and Specific Heat

The density and specific heat [1] of Fe_3O_4 in 20:80 EG/Water nanofluid is estimated using Eqs. (3) and (4).

$$\rho_{\mathrm{nf}} = (1-\phi)\,\rho_{\mathrm{bf}} + \phi\rho_{\mathrm{p}} \quad (3)$$

$$c_{\mathrm{p}} = \frac{(1-\phi)\,\rho c_{\mathrm{p}} + \phi\rho_{\mathrm{p}} c_{p_p}}{\rho_{\mathrm{nf}}} \quad (4)$$

IV. EXPERIMENTAL SETUP

Fig. 5 shows the schematic diagram of the experimental setup, where the test section consists of a Double Pipe Heat Exchanger (DPHE) with a U bend. Hot nanofluid flows through the inner tube and cold fluid which is water flows through the annulus. 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 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, two 2 KW immersion heater, a temperature controller and a data logger.

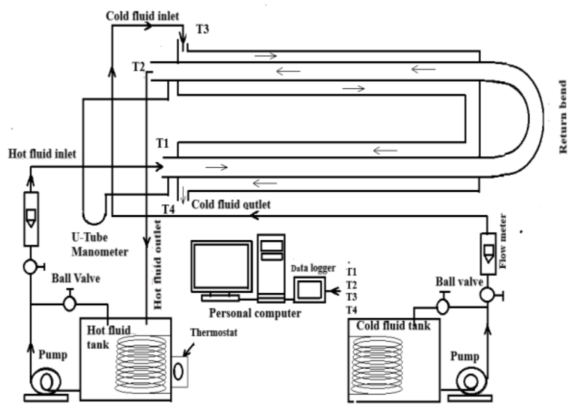

Fig 5. Schematic Diagram of Double Pipe Heat Exchanger with U-bend

The experimental setup is initially validated by comparing the experimental heat transfer coefficient and friction factor of water with that of correlations available in the literature, viz., Dittus Boelter [12] equation and Gnielinski [13] correlations for heat transfer coefficient and Colebrook correlation [14] for friction factor. After, the validation, the experiments are repeated with EG-Water in the ratio of 20:80 and Fe_3O_4/ 20:80 EG-Water nanofluid at different concentrations ranging from 0.02 to 0.08% at hot water flow rates of 6 to 14 lpm, while maintaining the flow rate of the cold water constant.

V. DATA ANALYSIS

A. Estimation of Heat Transfer Coefficient

The heat lost by the hot fluid and heat gained by the cold fluid is calculated using the Eqs. (5) and (6). Eq. (7) gives the average heat duty of the heat exchanger.

$$Q_h = m_h c_{\mathrm{nf}} \left(T_{hi} - T_{ho}\right) \quad (5)$$

$$Q_c = m_c c_{pc} \left(T_{co} - T_{ci}\right) \quad (6)$$

$$Q_{\mathrm{avg}} = \frac{Q_h + Q_c}{2} \quad (7)$$

Based on the recorded temperature readings, Logarithmic Mean Temperature Difference (LMTD) is calculated using Eq. (8).

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (8)$$

Where $\Delta T_1 = T_{hi} - T_{co}$ And $\Delta T_2 = T_{ho} - T_{ci}$

Using Eqs. (7) and (8), the overall heat transfer coefficient based on the inner surface area of the inner pipe is calculated using Eq. (9).

$$U_i = \frac{Q_{avg}}{A_{si}\left(LMTD\right)} \quad (9)$$

Where $A_{si} = \pi d_i l$ inside surface area.

Nusselt number for the annulus pipe is calculated using the Gnielinski[13] equation as presented by Eq. (10).

$$Nu_o = \frac{\left(\frac{f}{8}\right)(\mathrm{Re}-1000)\mathrm{Pr}}{1+12.7\left(\frac{f}{8}\right)^{0.5}\left(\mathrm{Pr}^{\frac{2}{3}}-1\right)} \quad (10)$$

Where Reynolds number

$$\mathrm{Re} = \frac{\rho_c V_c d_h}{\mu_c}$$

Hydraulic diameter $d_h = d_o - d_i$ and Pr is the Prandtl number

Friction factor *f* is calculated using Petkhov's[15] equation as given by Eq. (11)

$$f = \left(0.79\ln\mathrm{Re} - 1.64\right)^{-2}$$

(11)

Using Eq. (10), the annulus heat transfer coefficient is calculated by Eq. (12)

$$h_o = \frac{Nu_o \times k_o}{d_h} \quad (12)$$

Eq. (13) shows the calculation of Heat transfer coefficient of the hot fluid using Eqs. (9) and (12).

$$\frac{1}{h_i} = \frac{1}{U_i} - \frac{r_i}{k}\ln\left(\frac{r_o}{r_i}\right) - \frac{1}{h_o}$$

(13)

Where *k* is the thermal conductivity of the inner tube, r_i is the inner radius of the inner tube, and r_o is the outer radius of the inner tube.

B. Estimation of Friction Factor

Friction factor of the inner tube is calculated based on the experimentally determined pressure drop across the inner tube, using the Eq. (14)

$$f = \frac{2\Delta P d}{\rho l v^2} \quad (14)$$

where ΔP is the pressure drop of inner pipe, *d* is the inner diameter, *l* is the length of the pipe, *v* is the velocity of flow, and ρ is the density of the hot fluid.

VI. RESULTS AND DISCUSSION

Based on the data analysis, the experimental results Fe_3O_4/ 20:80 EG-Water nanofluid for heat transfer coefficient, friction factor and pressure drop are plotted as follows.

A. Heat Transfer Coefficient of Nano Fluids

Fig. 6 shows the variation of Nusselt number of Fe_3O_4/in 20:80 EG-water nanofluid, with Reynolds Number. The graph clearly shows the effect of thermophysical properties on the thermal performance of the Fe_3O_4/ 20:80 EG-water nanofluid. Due to a significant increase in the viscosity of Fe_3O_4/ 20:80 EG-water nanofluid, the Reynold Number decreases with the increase of volume concentration for the same flow rate. The Nu for 0.04% of nanofluid is observed to be higher than that at 0.08% of nanofluid at the flow rates considered in the analysis. Within the Re range of 5000 to 12500, the average increase in the Nu is 15.77% at 0.02%, 29.32% at 0.04%, 27.94% at 0.06% and 27.58% at 0.08% of the nanofluid, compared to that of the base fluid, at an operating temperature of 47.5°C.

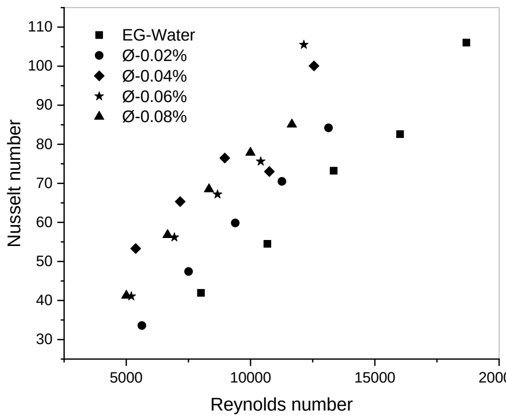

Fig.6 Nusselt Number of Fe_3O_4 / EG-Water Nanofluid.

To further observe the enhancement in the heat transfer coefficient at a given flow rate, Fig. 7 is plotted at all volume concentrations of the nanofluid considered in the analysis. The average increase in heat transfer coefficient is 5.2% at 0.02%, 24.1% at 0.04%, 18.07% at 0.06% and 15.67% at 0.08% of the nanofluid, compared to that of the base fluid at an operating temperature of 47.5°C. The enhancement in heat transfer coefficient is clearly higher at a volume concentration of 0.04% compared to that 0.06% and 0.08% Fe_3O_4/ 20:80 EG-water nanofluid by 6% and 9% respectively.

The increase in viscosity at 0.06% and 0.08% of Fe_3O_4/ 20:80 EG-water nanofluid is comparatively more than that of the increase in thermal conductivity at these volume concentrations from that of corresponding base fluid values. Thus, the heat transfer enhancement is affected by the interdependence of thermophysical properties of nanofluid, which vary with the variation of volume concentration as well as the operating temperature.

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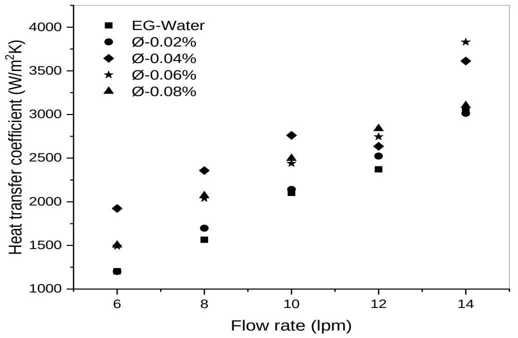

Fig 7. Heat Transfer Coefficient of Fe3O4/EG-Water Nanofluid

These results match with that of Selvan et al.,[7] for Silver/30:70 EG-Water nanofluid and Yanjan Li et al., [8] for ZnO/ 50:50 EG-Water nanofluid which show that the enhancement in Nu or heat transfer coefficient increases up to a particular volume concentration and then decreases.

B. Pressure Drop of Nanofluids

Fig. 8 shows the variation of the friction factor of Fe_3O_4/ 20:80 EG-water nanofluid with Re. The friction factor is observed to increase with the increase of volume concentration of nanofluid at all flow rates considered in the analysis. The average increase in the friction factor is 15.13% at 0.02% and 25.58% at 0.08% of the nanofluid, compared to that of the base fluid. The increment in the friction factor is observed to decrease with the increase of Reynolds number

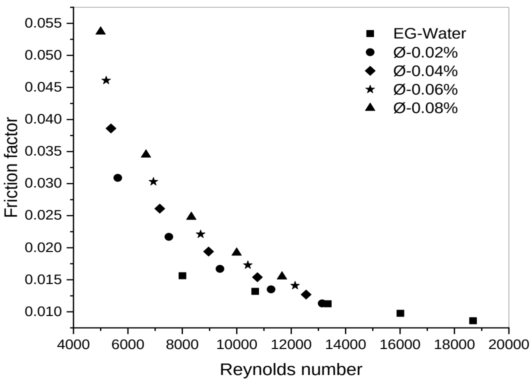

Fig.8. The friction factor of Fe3O4/EG-Water Nanofluid

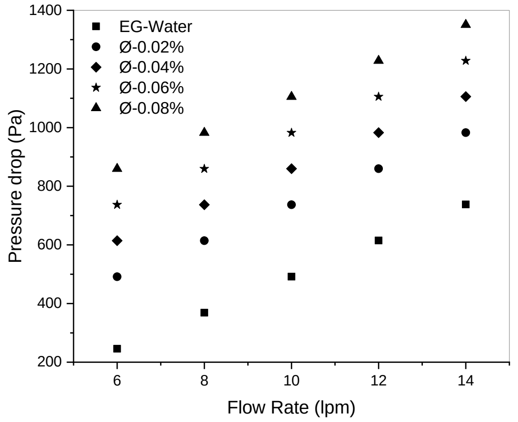

Fig.9 Pressure Drop of Fe3O4/EG-Water Nanofluid

Fig. 9 shows the variation of pressure drop of nanofluid with flow rate. The graph indicates that the pressure drop of the nanofluid is greater than that of base fluid at all volume concentrations considered in the analysis. The average increase in the pressure drop is 35.31% at 0.02% and 56.92% at 0.08% of the nanofluid, compared to that of the base fluid. Figs. 8 and 9 clearly show that the enhancement in friction factor and pressure drop respectively is higher at 0.08% compared to that at lower volume concentrations of Fe_3O_4/ 20:80 EG-water nanofluid, unlike in case of Nu or heat transfer coefficient as shown in Figs. 6 and 7. To observe the combined effect of enhancement in heat transfer coefficient and increase in pressure drop, thermal performance factor (η) [4] is calculated using Eq. (15).

$$\eta = \frac{(\frac{Nu_{nf}}{Nu_{bf}})}{(\frac{f_{nf}}{f_{bf}})^{1/3}} \qquad (15)$$

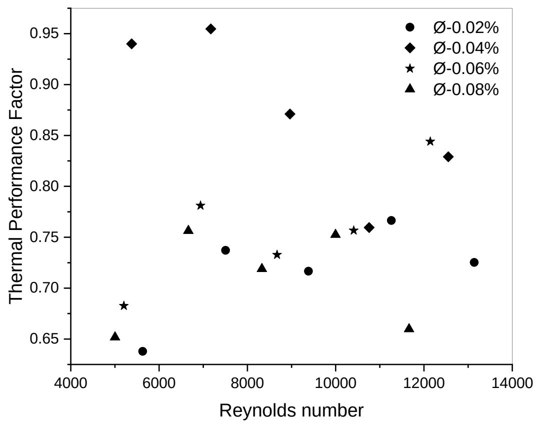

Fig.10. Thermal Performance Factor of Fe3O4/EG-Water Nanofluid

Fig.10 indicates the thermal performance factor of Fe_3O_4/20:80 EG-Water nanofluid at various concentrations of the nanoparticles. The value of η varies from 0.63 to 0.76 for 0.02%, 0.75 to 0.95 for 0.04%, 0.68 to 0.84 for 0.06% and 0.65 to 0.75 for 0.08% concentration. The thermal performance factor is less than 1 for all the volume concentrations considered in the analysis as the increase in viscosity for the volume concentrations considered in the analysis vary from 30.42% to 38.6%, while the enhancement in thermal conductivity is 19.35 % to 21.2% as the volume concentration of Fe_3O_4/ 20:80 EG-water nanofluid varies from 0.02% to 0.08%. A higher value of η is observed for 0.04% concentration nanofluid compared to that of other volume concentrations considered in the analysis. The results clearly show that the relative increase in viscosity and thermal conductivity of nanofluids plays a major role in determining the overall performance of nanofluids.

The enhancement in the heat transfer coefficient, friction factor and thermal performance factor with respect to the volume concentration is tabulated in Table I.

Table I. Enhancement in the Performance Factors

Volume Concentration (%)	Heat transfer Enhancement (%)	Percentage Increase in Friction Factor	Average Thermal Performance Factor
0.02	3.08	21.96	0.71
0.04	34.28	32.21	0.87
0.06	22.32	32.63	0.76
0.08	19.48	47.33	0.70

VII. CONCLUSION

The heat transfer coefficient, friction factor and overall thermal performance of Fe_3O_4/ 20:80 EG-Water nanofluid are determined in a DPHE with U bend at a volume concentration range of 0.02 to 0.08% of nanoparticles. The following are the conclusions obtained from the present work.

- The increase in viscosity is observed to be significantly higher than that of the thermal conductivity of Fe_3O_4/ 20:80 EG-Water nanofluid at the volume concentrations considered in the analysis. At 0.08% volume concentration, the maximum increase in viscosity is 38.6%, while the enhancement of thermal conductivity is 21.22% compared to that of base fluid at an operating temperature of 47.5°C.
- The heat transfer enhancement compared to that of base fluid increased from 0.02% to0.04% of Fe_3O_4/ 20:80 EG-Water nanofluid and then decreased further.
- Due to the conflicting effects of the increase of thermal conductivity and increase in viscosity of the Fe_3O_4/ 20:80 EG-Water nanofluid, which is more prominent at higher volume concentrations, the higher enhancement in heat transfer coefficient is not observed at a higher volume concentration of 0.08% of nanofluid.
- The friction factor of the Fe_3O_4 / 20:80 EG-Water nanofluid increases with an increase in volume concentration, unlike in the case of Nusselt Number. The Maximum increase in the average friction factor and pressure drop are 25.58% and 56.92% respectively, at 0.08% volume concentration.
- For the volume concentrations considered in the analysis, the thermal performance factor is observed to be less than 1. The highest value of TPF is observed to be for a volume concentration of 0.04% Fe_3O_4 / 20:80 EG-Water nanofluid at comparatively low Reynolds number considered in the analysis.
- The results clearly show that the relative increase in viscosity and thermal conductivity of nanofluids plays a major role in determining the overall performance of nanofluids.

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