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Heat Transfer Performance of EG-Water Based Fe_3O_4 and its Hybrid Nanofluids in a Double Pipe Heat Exchanger

T. Kanthimathi, P. Bhramara, Ayub Shaik

Abstract*: Nanofluids have good potential in enhancing the heat transfer performance of conventional fluids. In the present paper, the heat transfer performance of Fe_3O_4 and its Hybrid mixture with Fe_3O_4 and SiC nanoparticles in the volume ratio of 50:50 in 20:80 Ethylene Glycol (EG) –Water as base fluid are determined experimentally and the results are compared with that of the base fluid. The volume concentration range of nanoparticles considered in the analysis is 0.01% to 0.08%. The experiment is carried under turbulent flow conditions with Reynolds number ranging from 5000 to 20000 in a Double Pipe Heat Exchanger (DPHE) with U-bend. Results indicate that the thermal conductivity of hybrid nanofluid is higher by 16.19% and its viscosity is lower by 11.6% compared to Fe_3O_4/20:80 EG-Water nanofluid at an operating temperature of 45°C. The heat transfer coefficient and overall performance of hybrid nanofluid are better than Fe_3O_4/20:80 EG-Water nanofluid. The overall performance of Hybrid nanofluid is 27.75% better than that of Fe_3O_4/20:80 EG-Water nanofluid.

***Keywords*: Heat transfer coefficient Hybrid nanofluid, Thermal performance, Turbulent flow, Volume concentration.**

I. INTRODUCTION

In order to improve the performance of the conventional heat transfer fluids, a new class of fluids was introduced by Choi [1] called nanofluids. Nanofluids consists of the suspensions of nanometer-sized metallic/non-metallic/metal oxide particles in the conventional fluids like water, Ethylene Glycol or Propylene Glycol.

Azmi [3] investigated experimentally 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% at an operating temperatures range 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. Selvan et al., [4] conducted 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 an 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 an 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., [5] conducted 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. Jospin Zupan et al. [6] investigated thermal conductivity and viscosity of Iron (II, III) oxide nanoparticles with water as the 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. Aghayari et al. [7] 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.

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Azmi et al. [8] 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.

Murshed et al. [9] conducted a review on thermal conductivity and convective heat transfer characteristics of EG & EG-Water based nanofluids. He pointed out that most of the researchers used EG-Water as base fluid instead of EG in order to reduce the viscosity and thereby enhance the heat transfer performance.

Based on the literature survey it is understood that the stability of nanofluid is better in EG-Water based nanofluids compared to that of EG- based nanofluids.

Suresh et al. [10] studied heat transfer and pressure drop characteristics of Al_2O_3-Cu hybrid nanocomposite dispersed in water nanofluid experimentally in a uniformly heated circular tube for 0.1% volume concentration, with Reynolds number ranging from 3000 to 12000. The study revealed that the average increase in Nusselt number for Al_2O_3-Cu/Water nanofluid was 8.02% when compared to pure water, whereas the enhancement obtained for Al_2O_3/water nanofluid was 5.16% when compared to pure water. The average increase in the friction factor of Al_2O_3-Cu/Water nanofluid at 0.1% concentration is 10.48% while it is 5% for Al_2O_3/water nanofluid. Sundar et al. [11]., conducted an experimental investigation to study the heat transfer and friction factor of MWCNT-Fe_3O_4/ water hybrid nanofluid in a circular tube under turbulent conditions for a volume concentration of 0.1% and 0.3%. Results indicated that there was a maximum enhancement of 31.1% and 21.1% in Nusselt number for MWCNT-Fe_3O_4/ water hybrid nanofluid and for Fe_3O_4/ water nanofluid respectively, at a volume concentration of 0.3% for the Reynolds number of 22000. The friction factor of MWCNT-Fe_3O_4/ water hybrid nanofluid is reported to be 1.18 times the base fluid while it is 1.14 times for Fe_3O_4/water nanofluid at 0.3% at a Reynolds number of 22000 when compared with that of base fluid. Madesh et al. [12] experimentally investigated the heat transfer enhancement of Cu-TiO_2 hybrid nanocomposite with water as the base fluid for a volume concentration range of 0.1 to 2%, with the Re varying between 3500 to 7500, using DPHE. Results indicate that a maximum enhancement of 49% was observed in Nusselt number at 1% volume concentration, but at 2% it is only 19% higher than the base fluid. This decrease is explained due to higher dynamic viscosity and increased thermal boundary layer thickness, with the increase of particle concentration. The friction factor and pressure drop of hybrid nanofluid were reported to be 1.7% and 14.9% respectively for be 2.0% volume concentration. These results show the benefits of hybrid nanofluid compared to that of single-component nanofluid.

The heat transfer, as well as flow characteristics Fe3O4 and its hybrid with SiC in 20:80 EG-Water nanofluid, has scope for research and the results of the same are presented in this paper.

II. PREPARATION OF NANOFLUIDS

The Nanoparticles Fe_3O_4 and SiC of less than 50 nm size (99% purity) are procured from Nanoamor Texas.

The percentage volume concentration of nanofluid is calculated using Eq. (1).

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

The percentage volume concentration of Fe_3O_4-SiC hybrid nanofluid is calculated using Eq. (2) by considering 50% Fe_3O_4 and 50% SiC by volume

$$\phi = \frac{\text{Volume of SiC} + \text{Volume of } Fe_3O_4}{\left(\text{Volume of SiC} + \text{Volume of } Fe_3O_4 + \text{Volume of EG-Water}\right)} \times 100 \quad (2)$$

'ϕ' is the volume concentration of the nanofluid. Nanofluid at various volume concentrations in the range of 0.01- 0.08% is prepared using a two-step method. In order to avoid the sedimentation of the nanoparticles, mechanical stirrer is used continuously for 24-36 hours.

III. ESTIMATION OF PROPERTIES

A. Measurement of Viscosity of Nanofluid

The viscosity of the nanofluids at various concentrations is measured using the DV3T Rheometer as shown in Fig. 1. The viscosity of the Fe_3O_4 and Hybrid in /20:80 EG-Water nanofluid is measured for volume concentrations ranging from 0.01-0.08% at an operating temperature of 45°C.

Fig.1. DV3T Rheometer

Fig.2 shows that the viscosity of Fe_3O_4/20:80 EG-Water nanofluid is higher than that of hybrid nanofluid at all volume concentrations considered in the analysis. The enhancement in the viscosity of Fe_3O_4/20:80 EG-Water and Hybrid nanofluid at a volume concentration of 0.08% is 38.62% and 33.58% respectively compared to that of base fluid at the temperature of 45^{0}C.

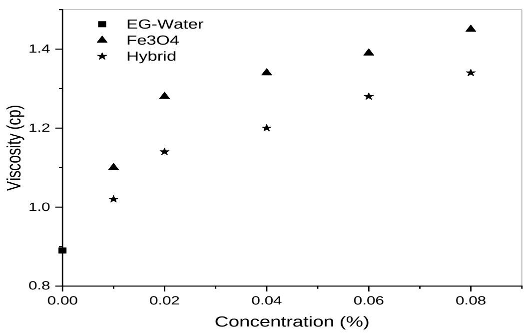

Fig.2. The viscosity of Fe_3O_4 and Hybrid in 20:80 EG-Water Nanofluid

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B. Measurement of Thermal conductivity of Nanofluid

The ultrasonic interferometer as shown in Fig.3 is used to measure the velocity of an ultrasonic wave in nanofluids and to study the effect of temperature on velocity in nanofluids of different concentrations. The 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

The thermal conductivity of nanofluid using ultrasonic rheometer is calculated using Eq.(3)

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

Where N is the Avogadro number, V_m is the molar volume of nanofluid, K is the Boltzmann constant and V is the velocity of the wave. Fig. 4 shows the variation of thermal conductivity of two different nanofluids considered in the analysis at the operating temperature of 45°C with the volume concentration. The thermal conductivity of Hybrid nanofluid is observed to be higher than that of Fe_3O_4/20:80 EG-Water nanofluid at all volume concentrations and the with the increase of volume concentration, the enhancement is observed to increase for hybrid nanofluid compared to that of Fe_3O_4/20:80 EG-Water nanofluid within the range of volume concentrations considered in the analysis. At 0.08% volume concentration, the enhancement in thermal conductivity is observed to be 21.22% and 38.97% for Fe_3O_4/20:80 EG-Water and Hybrid nanofluid respectively, compared to that of the base fluid.

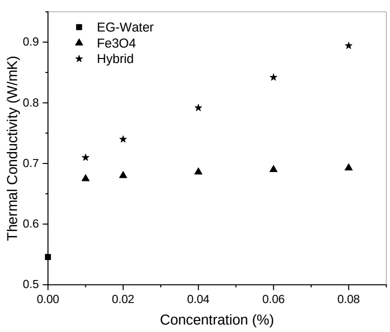

Fig. 4. Thermal conductivity of Fe_3O_4 and Hybrid in 20:80 EG-Water Nanofluid

C. Measurement of Density and Specific Heat of Nanofluid

The density and specific heat [1] of Fe_3O_4 in 20:80 EG-Water is estimated using Eqs. (4) and (6) respectively, while that of hybrid nanofluid using Eqs. (5) and (7) respectively.

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi\rho_p \qquad (4)$$

$$\rho_{hnf} = \phi_{np1}\rho_{np1} + \phi_{np2}\rho_{np2} + (1-\phi_{np1}-\phi_{np2})\rho_{bf} \qquad (5)$$

$$c_p = \frac{(1-\phi)\rho c_p + \phi\rho_p c_{p_p}}{\rho_{nf}} \qquad (6)$$

$$(\rho C_p)_{hnf} = \varnothing_{p1}(\rho C_p)_{np1} + \varnothing_{p2}(\rho C_p)_{np2} + (1-\varnothing_{p1}-\varnothing_{p2})\rho_{bf} \qquad (7).$$

IV. EXPERIMENTAL SETUP AND PROCEDURE

The experimental setup consists of DPHE with U bend as shown in Figs. 5a and 5b.

Fig. 5a. Experimental Setup

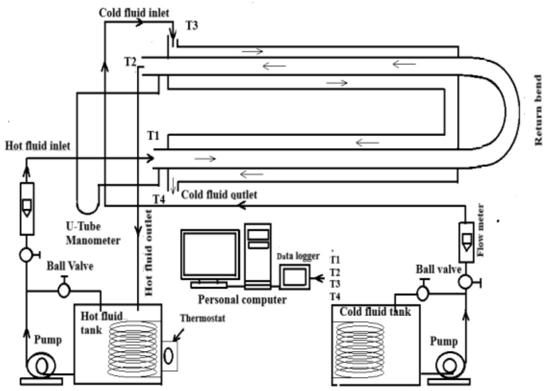

Fig 5b Schematic Diagram of the Experimental Setup

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. Hot fluid flows through the inner tube and cold water flows through the annulus.

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All the instrumentation, viz., temperature sensors, flow meters, and pressure sensors are connected to the datalogger The experimental setup is initially validated by comparing the experimental heat transfer coefficient and friction factor of water with that of Dittus Boelter [3, 13] and Gnielinski [3] correlations for heat transfer coefficient and Colebrook correlation [14] for friction factor. After, the validation, the experiments are repeated with 20:80 EG-Water, Fe_3O_4/20:80 EG-Water and Hybrid nanofluids. The flow rate of cold fluid is kept constant and the hot fluid is allowed to vary in the turbulent range.

V. DATA ANALYSIS

A. Estimation of Heat Transfer Coefficient

The experimental setup is calibrated initially with pure water. The heat lost by the hot fluid and heat gained by the cold fluid is calculated using the Eqs. (8) and (9). Eq. (10) gives the average heat duty of the heat exchanger.

$$Q_h = m_h c_{\text{nf}} \left(T_{hi} - T_{ho}\right) \quad (8)$$

$$Q_c = m_c c_{pc} \left(T_{co} - T_{ci}\right) \quad (9)$$

$$Q_{\text{avg}} = \frac{Q_h + Q_c}{2} \text{ (average heat)} \quad (10)$$

Based on the recorded temperature readings, Logarithmic Mean Temperature Difference (LMTD) is calculated using Eq. (11).

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (11)$$

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

Using Eqs. (10) and (11), the overall heat transfer coefficient based on the inner surface area of the inner pipe is calculated using Eq. (12).

$$U_i = \frac{Q_{\text{avg}}}{A_{si}\left(LMTD\right)} \quad (12)$$

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

Gnielinski[3] correlation given by Eq. (13) is used to evaluate the Nusselt number for the annulus pipe.

$$Nu_o = \frac{\left(\frac{f}{8}\right)\left(\text{Re} - 1000\right)\Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(\Pr^{\frac{2}{3}} - 1\right)} \quad (13)$$

Where Reynolds number $\text{Re} = \frac{\rho_c V_c d_h}{\mu_c}$, Hydraulic diameter $d_h = d_o - d_i$, and Pr is the Prandtl number

Friction factor f is calculated using Petukhov's [15] correlation, given by Eq. (14)

$$f = \left(0.79 \ln \text{Re} - 1.64\right)^{-2} \quad (14)$$

Using Eq. (12), the annulus heat transfer coefficient is calculated by Eq. (15)

$$h_o = \frac{Nu_o \times k_o}{d_h} \quad (15)$$

Eq. (16) shows the calculation of Heat transfer coefficient of the hot fluid flowing inside the inner pipe of the DPHE, using Eqs. (12) and (15).

$$\frac{1}{h_i} = \frac{1}{U_i} - \frac{r_i}{k}\ln\left(\frac{r_o}{r_i}\right) - \frac{1}{h_o} \quad (16)$$

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. (17)

$$f = \frac{2\Delta P d}{\rho l v^2} \quad (17)$$

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

A. Nusselt Number of Fe_3O_4 Nanofluid in 20:80 EG-Water

Fig. 6 shows the variation of Nusselt number of Fe_3O_4 in 20:80 EG-water nanofluid, with Reynolds Number at the operating temperature of 45°C.

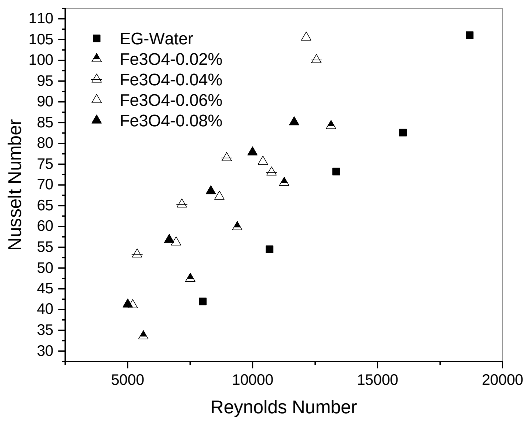

Fig 6. Experimental Nusselt number of Fe_3O_4 /20:80 EG-Water

The higher viscosity of Fe_3O_4 in 20:80 EG-water nanofluid has resulted in a significant variation in the Reynolds Number compared to that of base fluid at the same flowrate. The enhancement in Nusselt number is observed to be higher for a volume concentration of 0.04% of Fe_3O_4 in 20:80 EG-water nanofluid compared to that with other concentrations. These results are in coordination with the corresponding variation of viscosity and thermal conductivity as shown in Figs. 3 and 4 respectively.

Within the Re range of 7500 to 12500, the average increase in the Nu is 12.63% at 0.02%, 44.25% at 0.04%, 38.91% at 0.06% and 40.8 at 0.08% of the nanofluid, compared to that of the base fluid, at an operating temperature of 45°C.

B. Nusselt Number of Hybrid Nanofluid in 20:80 EG-Water

Fig. 7 shows the variation of Nusselt number of Hybrid nanofluid with Reynolds Number.

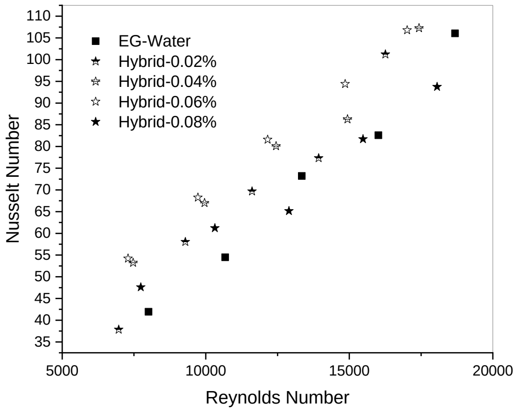

Fig 7. Experimental Nusselt Number of Hybrid Nanofluid

Figs. 6 and 7 show that the variation in Reynold's number of hybrid nanofluid compared to that of base fluid which is not as significant as that of Fe_3O_4 nanofluid in 20:80 EG-water. Unlike in the case of Fe_3O_4 in 20:80 EG-water nanofluid, the enhancement in Nusselt number of hybrid nanofluid from that of base fluid is comparatively less. In addition, at higher volume concentration of 0.08%, the enhancement is clearly less than that of 0.04% and 0.06%. Within the Re range of 7000 to 17000, the average Nusselt number increases by 6.22% at 0.02%, 8.33% at 0.04%, 9.02% at 0.06% and 4.93% at 0.08% volume concentration compared with that of the base fluid, at an operating temperature of 45°C.

This does not mean, the heat transfer enhancement of hybrid nanofluid is less than that of Fe_3O_4 in 20:80 EG-water nanofluid, as the value of Nu for all volume concentrations of hybrid nanofluid is observed to be greater than that of Fe_3O_4 in 20:80 EG-water nanofluid as shown in Figs. 6 and 7. However, compared to the base fluid the enhancement is marginal, which shows that the combination of high and low-density nanoparticles of Fe_3O_4 and SiC in hybrid nanofluid distributed the high thermal conductivity particles in boundary layer and bulk fluid respectively, leading to the enhancement of heat transfer by conduction as well as convection.

C. Comparison of heat transfer coefficient of Fe_3O_4 and Hybrid nanofluids in 20:80 EG-Water

The comparison of the heat transfer coefficient of Fe_3O_4 and Hybrid nanofluids in 20:80 EG-Water with respect to hot fluid flow rate is shown in Fig.8.

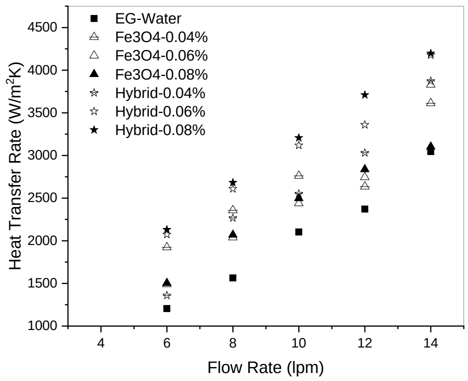

Fig. 8. Comparison of Heat Transfer Coefficient of Fe_3O_4 and Hybrid Nanofluids in 20:80 EG-Water

The figure clearly shows that at a given flow rate, the heat transfer coefficient of hybrid nanofluid is higher than that of Fe_3O_4 nanofluid in 20:80 EG-Water at all concentrations considered. The average enhancement in the heat transfer coefficient of Hybrid nanofluid in 20:80 EG-Water at 0.08% volume concentration is 64.57% whereas that of Fe_3O_4 nanofluid in 20:80 EG-Water is 19.48% at 0.08% volume concentration compared to that of the base fluid. Thus the results clearly indicate the effect of thermophysical properties on the heat transfer enhancements of the nanofluids considered.

D. Friction Factor of Fe_3O_4 nanofluid in 20:80 EG-Water

Fig. 9 shows the variation of the friction factor of Fe_3O_4 nanofluid in 20:80 EG-water with Re. The friction factor is observed to increase with the increase of volume concentration of nanofluid.

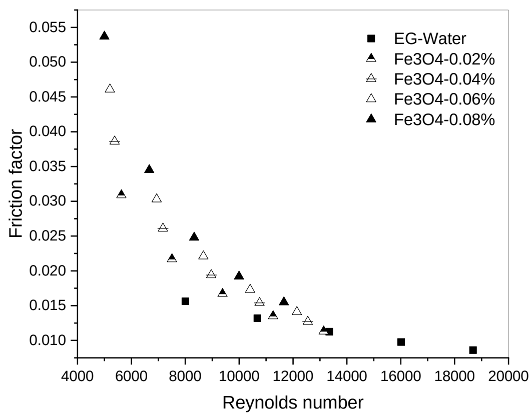

Fig.9. Friction Factor of Fe_3O_4 / 20:80 EG-Water Nanofluid

The average increase in the friction factor is 20.09% at 0.02%, 30.91% at 0.04%, 24.41% at 0.06% and 31.8% at 0.08% of the nanofluid, compared to that of the base fluid.

E. Friction Factor of Hybrid Nanofluid in 20:80 EG-Water

Figs. 9 and 10 show that the average increase in friction factor of hybrid nanofluid is comparatively less than that of Fe_3O_4 in 20:80 EG-Water.

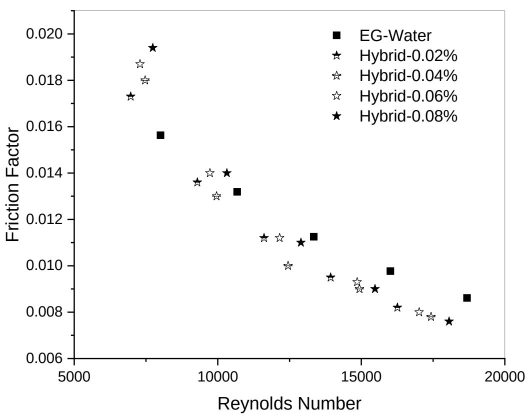

Fig 10. Friction Factor vs Reynolds Number of Hybrid Nanofluid in 20:80 EG-Water

The average friction factor of hybrid nanofluid is observed to be less than that of base fluid at a volume concentration of 0.02% volume concentration by 4.45%. For other volume concentrations considered in the analysis, the friction factor increased compared to that of the base fluid. At 0.04%, 0.06% and 0.08% volume concentrations of hybrid nanofluid, the average increase in friction factor is 0.73%, 5.13% and 9.34% respectively.

F. Comparison of Pressure Drop of nanofluids

The Pressure drop of the Fe_3O_4 and Hybrid nanofluid in 20:80 EG-Water are compared in Fig. 11.

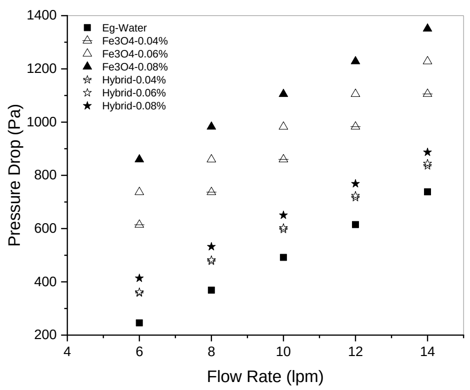

Fig. 11. Pressure Drop Vs Flow Rate

The pressure drop of Fe_3O_4/20:80 EG-Water nanofluid is higher than that of hybrid nanofluid as shown in Fig.11. The increase in pressure drop for 0.08% Fe_3O_4/20:80 EG-Water nanofluid is 144.65%, while that of hybrid nanofluid is 37.95%, compared to that of the base fluid, over the range of flow rates considered in the analysis.

G. Thermal Performance of Nanofluids

The results clearly indicate the effect of viscosity and thermal conductivity on the heat transfer coefficient of the nanofluids. In order to determine the combined effect of the viscosity and thermal conductivity on the heat transfer characteristics of nanofluids, the thermal performance index is calculated using the Eq.18.

Thermal Performance index

$$\eta = \frac{\left(\frac{Nu_{nf}}{Nu_{bf}}\right)}{\left(\frac{f_{nf}}{f_{bf}}\right)^{1/3}} \quad (18)$$

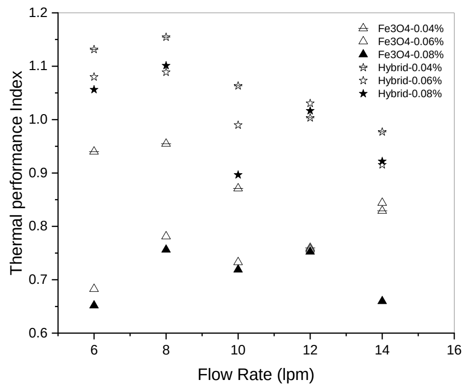

Figure 12. Comparison of Thermal Performance Index

Figure 12. shows the thermal performance index of Fe_3O_4 and hybrid nanofluid in 20:80 EG-Water at volume concentrations of 0.04%, 0.06%, and 0.08%. From the figure, it is evident that the thermal performance of Fe_3O_4 nanofluid is less than one at all concentrations considered. The maximum TPF is observed to be 1.0659 for volume concentration of 0.04% of hybrid nanofluid, while for Fe_3O_4/ 20:80 EG-Water, the maximum TPF is 0.8709 for 0.04% volume concentration. On an average, the thermal performance of hybrid nanofluid is 27.75% greater than Fe_3O_4 nanofluid in 20:80 EG-water, for the range of volume concentrations are flow rates considered in the analysis.

VII. CONCLUSIONS

The following are the inferences obtained from the comparative study of heat transfer coefficient, friction factor and overall thermal performance of Fe_3O_4 and hybrid nanofluids in 20:80 EG-Water

- Addition of Fe_3O_4 and hybrid nanoparticles in 20:80 EG-Water in the volume concentration range of 0.01% to 0.08% enhanced the thermal conductivity and viscosity of the base fluid The maximum enhancement of thermal conductivity for Fe_3O_4 and hybrid nanofluids in 20:80 EG-Water is observed to be 21.22% and 38.97% compared to the base fluid at 0.08% volume concentration at an operating temperature of 45°C . The maximum enhancement of viscosity for Fe_3O_4 and hybrid nanofluids is 38.62% and 33.58% at 0.08% volume concentration for Fe_3O_4/20:80 EG-Water and 33.58% compared to the base fluid at 0.08% volume concentration of hybrid nanofluid at an operating temperature of 45°C.
- Due to the increase in viscosity and decrease in the thermal conductivity values of Fe_3O_4 nanofluid in 20:80 EG-Water compared to hybrid nanofluid the enhancement in the average Nusselt number of Fe_3O_4 nanofluid in 20:80 EG-Water is observed to be greater than hybrid nanofluid for the range of Reynolds number considered in the analysis at an operating temperature of 45°C.

- The average increase in the heat transfer coefficient of Fe_3O_4 nanofluid in 20:80 EG-Water is 34.28% and 19.48%_ at a volume concentration of 0.04% and 0.08% and for hybrid nanofluid, the average enhancement of heat transfer coefficient is 64.57% at a volume concentration of 0.08% at an operating temperature of 45°C, when compared with the base fluid.
- The Friction factor and Pressure drop of Fe_3O_4 nanofluid in 20:80 EG-Water are higher than hybrid nanofluid at all volume concentrations considered. The average increase in the pressure drop of Fe_3O_4 nanofluid in 20:80 EG-Water is 144.65% and that of hybrid nanofluid is 37.95% at a volume concentration of 0.08% compared to base fluid.
- The thermal performance index for hybrid nanofluid is greater than one at all volume concentrations considered whereas that of Fe_3O_4 nanofluid in 20:80 EG-Water nanofluid is less than one for the same concentrations. The average thermal performance of hybrid nanofluid is 27.75% greater than Fe_3O_4 nanofluid in 20:80 EG-water.
- The results show that the thermal performance of Hybrid nanofluid is dominant over Fe_3O_4 nanofluid in 20:80 EG-Water at the low volume concentrations considered in the analysis for an operating temperature of 45°C.

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