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Effect of CeO_2 nanofluids on heat transfer in tube in tube heat exchanger- An experimental study

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ABSTRACT

Heat exchangers are widely used in different industrial applications. Among all categories of heat exchangers, tube in tube heat exchanger is most effective in specific applications. The performance of heat exchange has depended on the properties of the working fluid. The present experimental study shows the performance enhancement of tube in tube heat exchanger using CeO_2/ H_2O nanofluid as compared to water. CeO_2/ H_2O nanofluids of different volume concentrations (1.0%, 2.0 % & 3.0%) of the various mass flow rate (1.5 lpm, 2.0 lpm, 2.5 lpm, 3.0 lpm and 3.5 lpm) used in the heat exchanger. Nanofluid application enhanced the overall heat transfer coefficient by 15-20%. It also reduced the required pumping power by 10-15% for the same heat transfer rate. Therefore, the authors claimed that nanofluids are an efficient working fluid and it shows its superior heat transfer potential for tube in tube heat exchanger applications.

Keywords: Tube in tube heat exchanger; Nanofluid; Heat transfer coefficient; Friction factor.

INTRODUCTION

Heat exchangers are quite common equipment used in many industries such as power generation, refrigeration, air conditioning, chemical industry. The need for better energy conversion required efficient heat exchangers. Tube in tube heat exchanger is the simplest and widely used due to their low cost of design and maintenance. Tube in tube heat exchanger (TITHE) is suitable for applications where extended heat transfer surface is not possible due to space limitation. Due to rapid technological development in the field of nano materials, make possible the use of nano particles (size less than 100 nm) dispersed in the conventional base fluids, and they are termed as nanofluids. This kind of fluid was first introduced by Choi et al.[1], showing that it can be used as a promising way for enhancing the heat transfer capability of base fluids. In the recent, many researchers have done experimental studies to investigate the heat transfer performance of various nanofluids. Duangthongsuk and Wongwises [2] investigated experimentally the thermal performance of TiO_2/water nanofluids in double tube heat exchanger and conclude that the heat transfer coefficient was 26% greater at 1.0 vol. % of nanofluid than that of water, with little penalty in pressure drop. Suresh et al. [3] conduct experimental investigation to analyze affect of nanofluid on heat transfer when Al_2O_3/water nanofluids flowing in plain tube and observed 24% increase in Nusselt Number as compared with water when Al_2O_3/water nanofluid with 0.5% vol. concentration was used. Azmi et al.[4] reported a maximum heat transfer coefficient enhancement of 26% at 1.0% nanofluid (TiO_2/water) concentration in a plain tube and found enhancement of 33.0% at 3.0% volume concentration of SiO_2/water nanofluid. Reddy and Rao [5] study the performance of TiO_2 nanofluids in water/EG base fluid in double pipe heat exchanger, and resulted in the finding that the heat transfer coefficient gets enhanced by 10.7% at 0.02% concentration. Albadr et al. [6] investigated Al_2O_3/water nanofluid (0.3-2%) convective heat transfer characteristic in a horizontal shell and tube heat exchanger, and reported that at 2% volume concentration overall heat transfer coefficient is 57% greater than that of base fluid. Suresh et al. [7] performed experimental study to investigate heat transfer characteristic of CuO/water nanofluid in the plain and helically dimpled tube and found a maximum of 12.6% higher Nusselt number for 0.3% vol concentration than those of distilled water in plain tube. Sonawane et al. [8] have studied Al_2O_3/water nanofluids heat transfer, flowing in concentric heat exchanger and observed 39% enhancement of overall heat transfer coefficient with 2.0 vol% compared to base fluid. Tiwari et al.[9] investigated heat transfer and pressure drop characteristic of corrugated plate heat exchanger using CeO_2 /water nanofluid and found 39% higher heat transfer coefficient at concentration of 0.75 vol.%. Chandrasekar et al.[10] reviewed the various mechanisms which are responsible for enhancement of heat transfer characteristic of various nanofluids. Kong and Lee [11] found that the heat transfer coefficient is improved by 19% with the addition of Al_2O_3 nanoparticles to base fluid water whereas overall performance improved by 8%.Therefore, to make heat exchange processes more energy efficient in terms of heat energy transfer, the stability and the thermo physical properties of the working fluid used in heat exchange have become a vital importance[12-14]

EXPERIMENTAL INVESTIGATION

In the present experimental study, CeO_2/ H_2O nanoparticles (size in the range of 30-50nm) procured from Alfa-Essar (USA), were used to prepared nanofluid. The nanofluid was prepared by two step method. To prepare CeO_2/ H_2O nanofluid, the required weight of CeO_2 nanoparticles for volume concentration of 1.0%, 2.0%, 3.0% were dispersed in distilled water and sonicating the mixture using an ultrasonicator for 4 h. To ensure good stability of nanofluid, zeta potential test was done using Zetasizer Nano ZS-Malvern. The result of the test (zeta potential value –29.2mV) ensured a good stability[15] shown in figure 1.

			Mean (mV)	Area (%)	St Dev (mV)
Zeta Potential (mV):	-29.2	Peak 1:	-29.2	100.0	8.02
Zeta Deviation (mV):	8.02	Peak 2:	0.00	0.0	0.00
Conductivity (mS/cm):	0.0757	Peak 3:	0.00	0.0	0.00
Result quality :	Good				

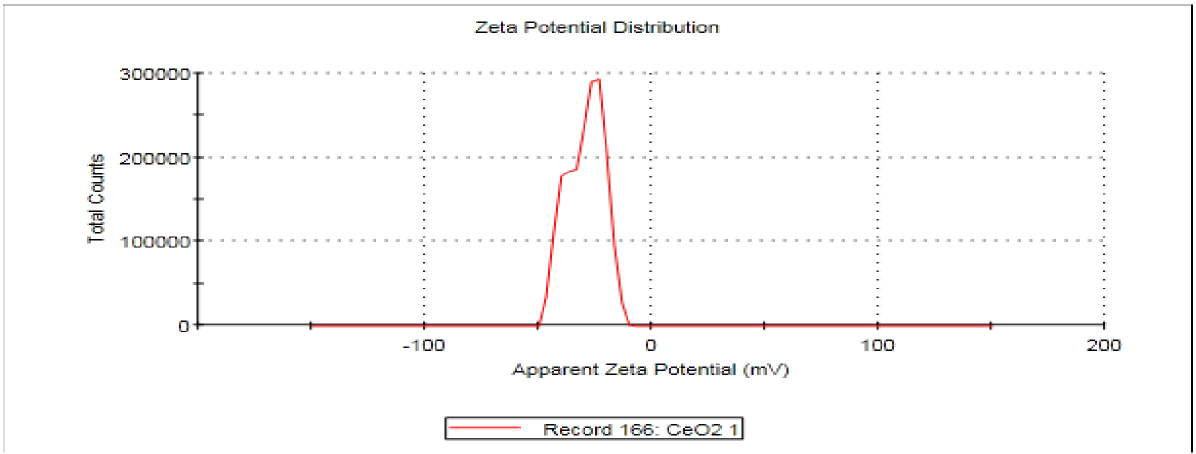

Figure1 Zeta potential test result image of nanofluid sample with volume concentration (3.0%).

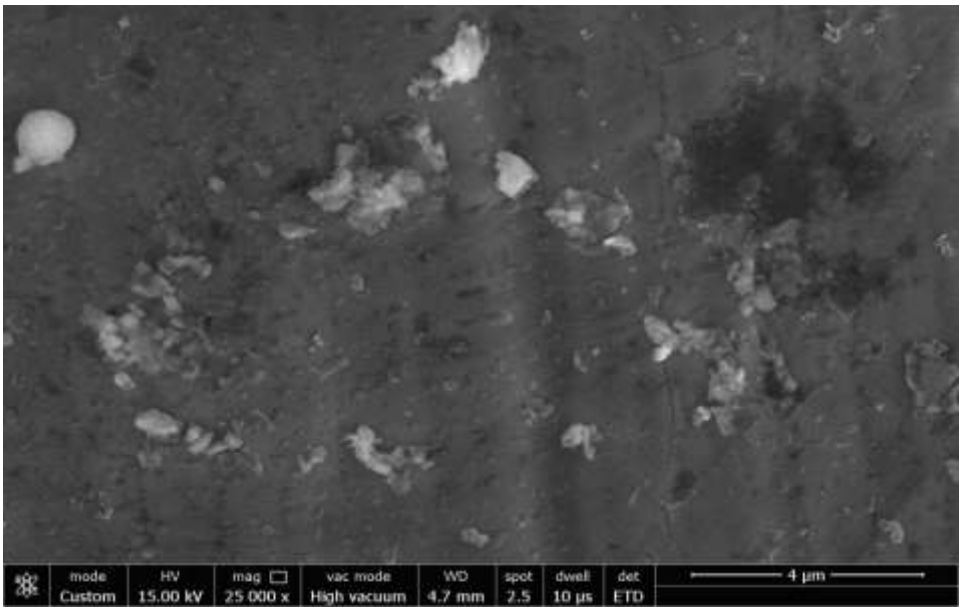

Figure 2 FESEM image of nanofluid sample.

THERMOPHYSICAL PROPERTIES

The thermo-physical properties (thermal conductivity, viscosity) of nanofluid were measured experimentally. A KD2 pro thermal analyzer (Decagon Devices, Inc; USA) was used to measure thermal conductivity of nanofluid. Brookfeild viscometer was used to measure the dynamic viscosity of nanofluid. A significant increase in thermal conductivity and dynamic viscosity was observed with the rise in volume concentration of nanofluid.

EXPERIMENTAL SETUP

The present investigation on heat transfer and pressure drop characteristic of a TITHE is conducted to study the effect of using CeO_2 /water. The figure 3 shows the schematic representation of experimental setup. The outer tube of heat exchanger is made with Galvanised Iron (G.I.) material having inner diameter and outer diameter 28.5 mm, 32.5 mm respectively. The inner tube is made up of copper having inner diameter and outer diameter 9.5 mm, 12.5 mm respectively. The outer tube is insulated with cladding of glass wool to minimize the heat loss. Two separate tanks are provided for cold water and hot nanofluid. The flow rate of cooling water and hot nanofluid is measured by using two calibrated float type rotameters (each of 0.2 – 10.0 lpm range). The inlet and outlet bulk temperatures of cooling water and hot nanofluid were measured using four thermocouples. A 2kW electric heater with thermostat is used to heat and, to keep the nanofluid temperature constant. Two centrifugal pumps are used to circulate water and nanofluid in the cool water loop and hot nanofluid loop, respectively. The pressure drop of nanofluid was measured along the test section, by using a U-tube manometer with mercury as manometric fluid.

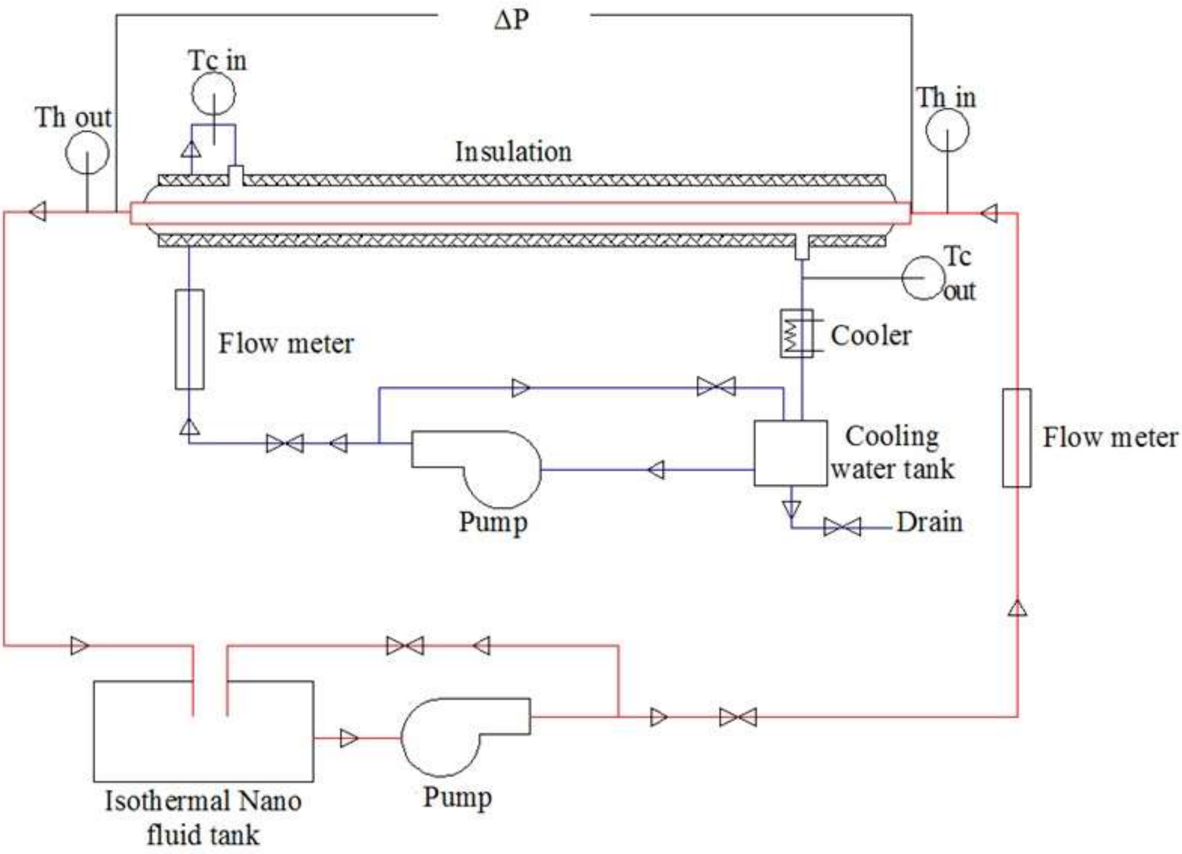

Figure 3 Schematic diagram of experimental setup

DATA REDUCTION AND VALIDATION

In the present experimental study, the performance of heat exchanger was evaluated based on convective heat transfer coefficient and pressure drop, using following equations.

Heat transfer rate of the base fluid (water) and nanofluid:

$$Q_w = m_w C_w (T_{c,in} - T_{c,out})_w \quad (1)$$

$$Q_{n=} m_n C_n (T_{h,in} - T_{h,out})_n \quad (2)$$

Where, $T_{c,in}$ is the inlet temperature of base fluid, $T_{c,out}$ is outlet temperatures of base fluid .$T_{h,in}$ and $T_{h,out}$ are the inlet and outlet temperatures of nanofluid, respectively.

Average heat transfer rate:

$$Q_{ave} = \frac{Q_w + Q_n}{2} \quad (3)$$

Overall Heat transfer coefficient (OHTC)

$$U_{exp} = \frac{Q_{average}}{A(\Delta T)_{LMTD}} \quad (4)$$

The logarithmic temperature difference:

$$(\Delta T)_{LMTD} = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln\left(\frac{T_{h,in} - T_{c,out}}{T_{h,out} - T_{c,in}}\right)} \quad (5)$$

The Nusselt number

$$Nu_{exp} = \frac{h_{exp} \times D}{k} \quad (6)$$

The Reynold number

$$Re_{nf} = \left(\frac{\rho v d_i}{\mu}\right)_{nf} \quad (7)$$

The effectiveness

$$\varepsilon = \frac{1-\exp[-NTU(1-Z)]}{1-Z\exp[-NTU(1-Z)]} \quad (8)$$

The pressure drop is measured and the friction factor calculated based on the diameter of the inner tube

$$f_{exp} = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho v^2}{2}\right)} \quad (9)$$

The performance index of the heat exchanger [16] is given by

$$\eta = \frac{Q_{ave}}{P_p} \quad (10)$$

UNCERTAINTY ANALYSIS

The result of the experiment depends on uncertainties due to the errors in measurement of all the parameters that are measured to determine the dimensionless numbers (Reynolds number, Nusselt number etc.).In the present experimental study, the probable error associated with each measured data is calculated and the uncertainty in result is estimated using the equation of Moffat [17]. The estimated uncertainty of OHTC and friction factor found 6.8% and 5.1% respectively.

RESULT AND DISCUSSION

The baseline verification of the experimental apparatus is carried out by performing experiments using base fluid water and compares the experimental data with the correlation for turbulent flow and friction factor provided by Kakac [18] and Zayed [16] with Reynolds number ranging from 5000 to 15000.

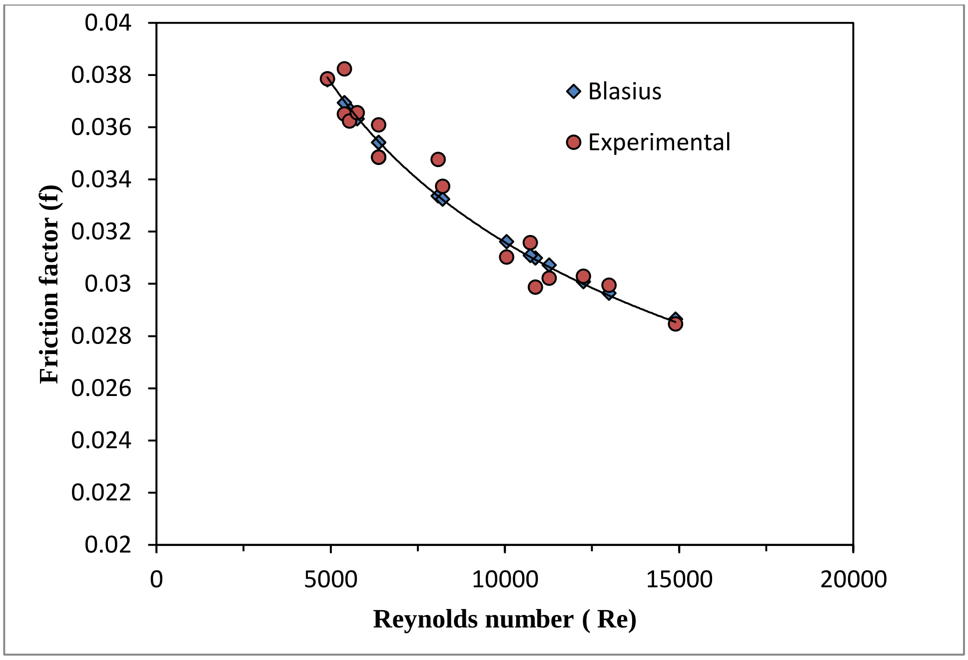

Figure 4 Comparison of experimental friction factor with Blasius relation for water (base fluid)

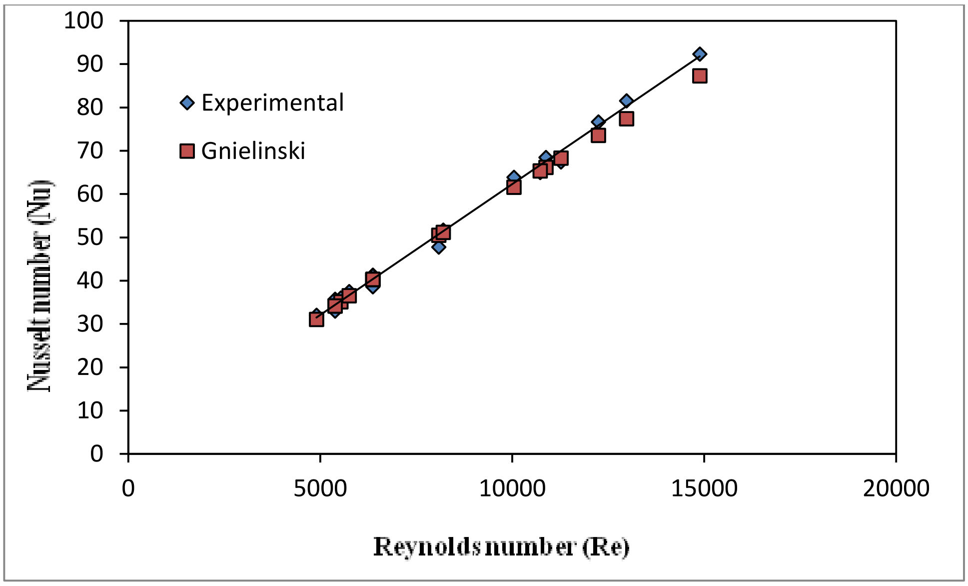

Figure 5 Comparison of experimental Nu with Gnielinski relation for water

The comparison of experimental data shows a good agreement of experimental values of Nusselt number and Darcy friction factor with the classical correlation as shown in figure 4 and figure 5.

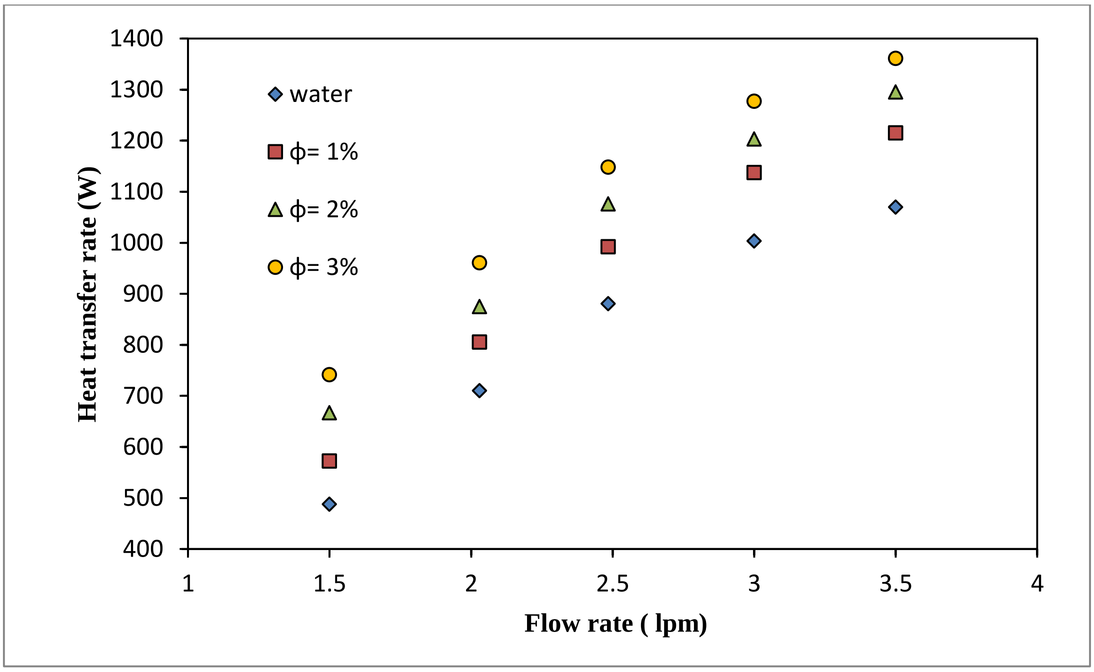

Figure 6 Heat transfer rate verses Flow rate of nanofluid.

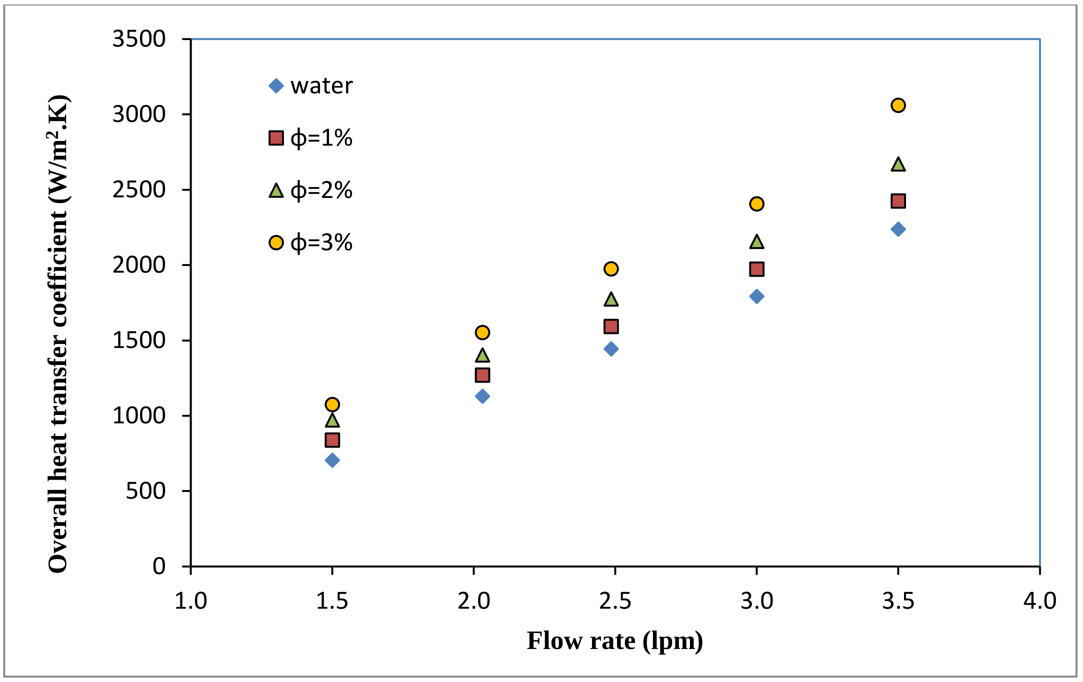

Figure 7 Overall heat transfer coefficient verses flow rate

The effect of variation in nanofluid flow on the heat transfer rate and the overall heat transfer rate are shown in figure 6 and figure 7. It is observed that the inclusion of nanoparticles in base fluid result in increase in heat transfer rate and in terms of nanofluid flow also. The maximum improvement in heat transfer rate observed with 3.0% volume concentration of nanofluid at 3.5 lpm volume flow rate (at 50^{o}C temperature) whereas enhancement observed in overall heat transfer coefficient.

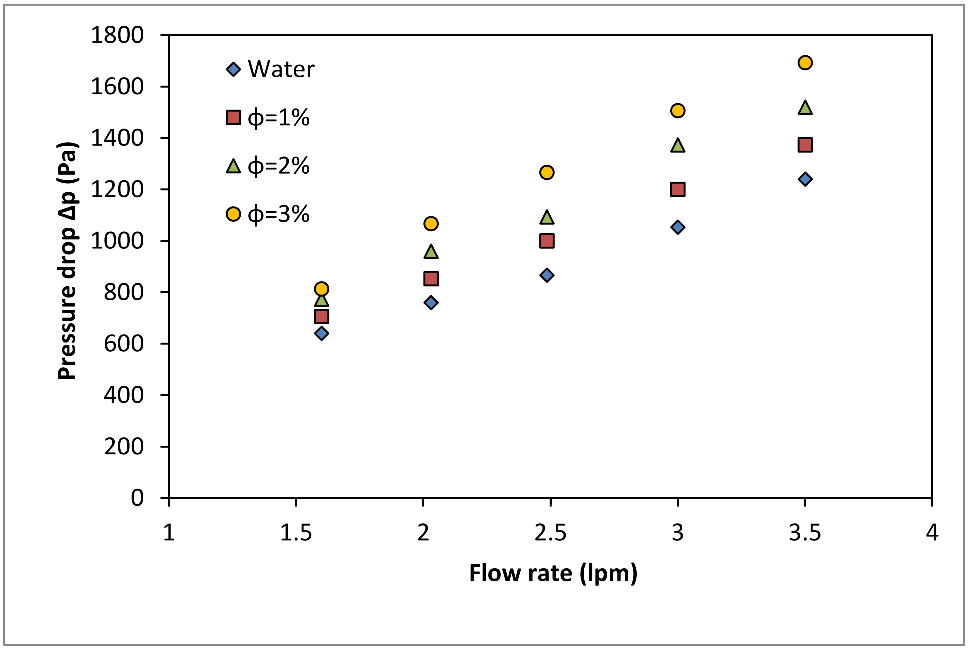

Figure 8 Pressure drop verses flow rate

The observed values of the pressure drop in the experiments as shown in figure 8 demonstrate that the pressure drop rises with increase in flow rate of nanofluid and increase in volume concentration of nanoparticles also. This is due to enhancement in dynamic viscosity with increase in VC of nanoparticles in the water and turbulence in flow. The same trend was observed in increase of pumping power as presented in figure 9.

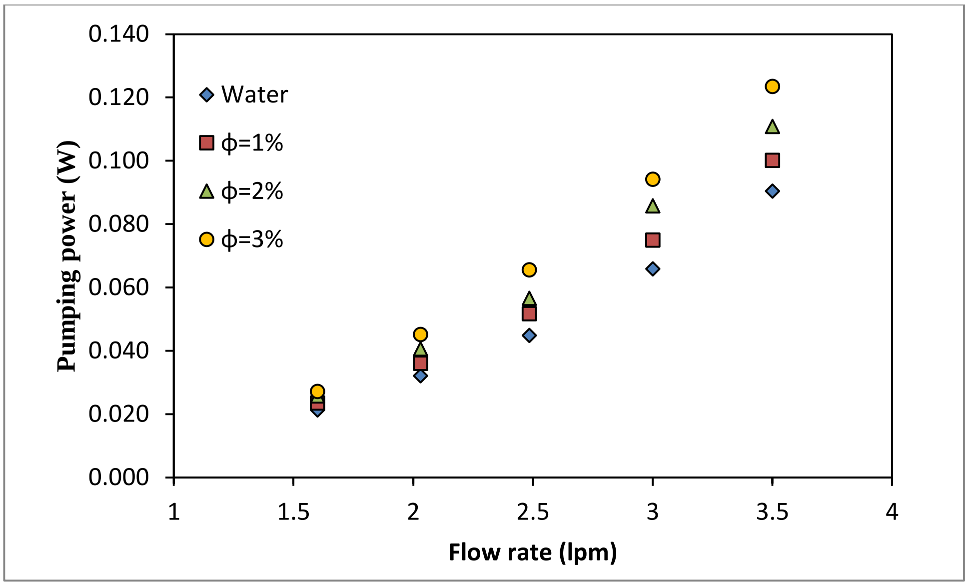

Figure 9 Pumping power verses flow rate.

The figure 10 demonstrates the result of experiments for variation in effectiveness verses flow rate at different VC. The results show that, at higher flow rate, the effectiveness increases and observed a maximum enhancement of 28.7% in effectiveness with 3.0% VC compared to water (base fluid).

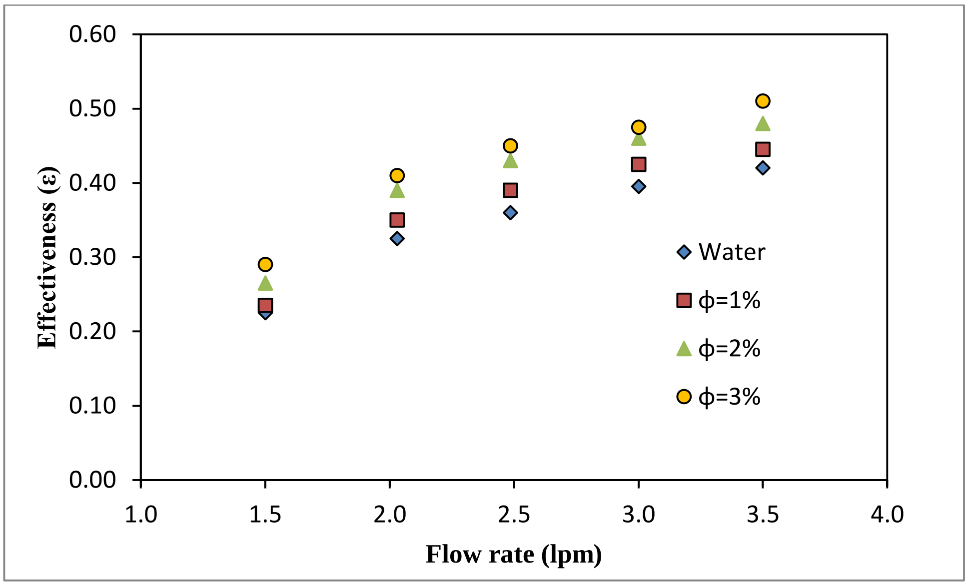

Figure 10 Variation of Effectiveness with flow rate

The performance of the TITHX at different concentration of nanofluids varying from 1.0 % to 3.0% for various volume flow rates (1.5 lpm, 2.0 lpm, 2.5 lpm, 3.0 lpm and 3.5 lpm) is evaluated on the basis of performance index (Ƞ). The value of Ƞ i.e. the ratio of heat transferred to the pumping power shows the tradeoff between the enhancement in heat transfer rate and corresponding increase in power consumption. The figure 11 represents the variation in the performance index verses volume flow rate at different volume concentration of nanofluid (at 50^{o}C temperature). The results demonstrate that at higher flow rate (above 2.5 lpm) of the nanofluid, the performance index was decreases with increase in volume flow rate. The maximum performance index obtained at 2% VC with 2.5 lpm flow rate of nanofluid. The maximum enhancement of 17.98 % in thermal performance factor was obtained at 2.0% volume concentration

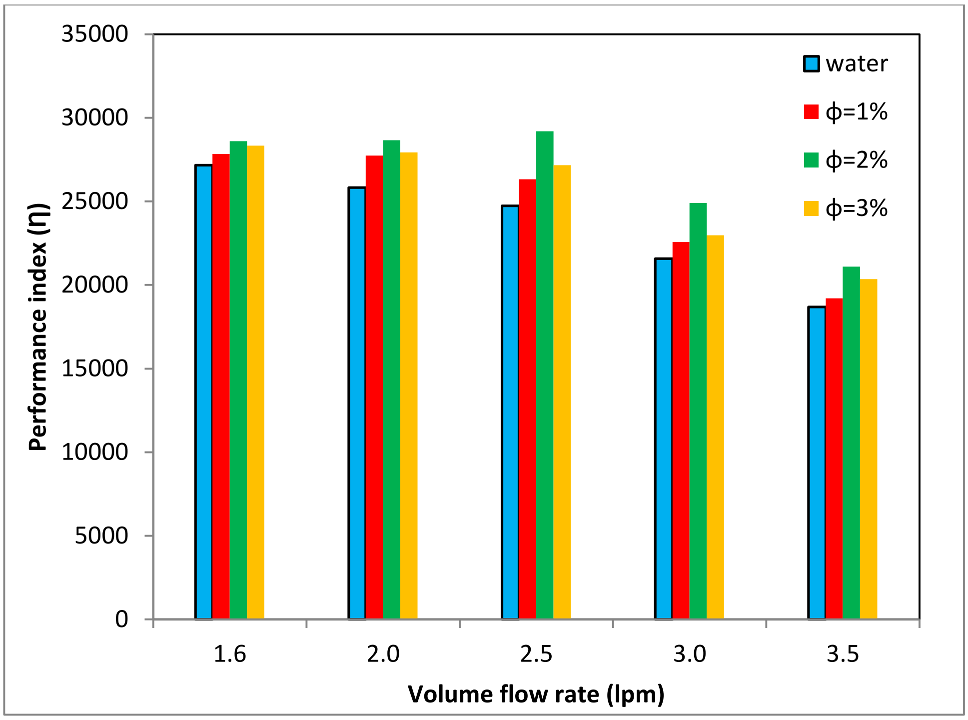

Figure 11 Variation of Performance index with volume flow rate

CONCLUSION

An experimental investigation was performed to study the effect of variation in volume flow rate of CeO_2/ H2O nanofluid of different volume concentration of nanoparticles. on the thermal performance of TITHX was investigated. The findings of the experimental study are as follows

-The viscosity of the nanofluids increases with increase in volume concentration of nanoparticles and found the maximum enhancement of in viscosity of the CeO_2/water at 3.0% volume concentration.

-Adding CeO_2 nanoparticles in base fluid increases thermal conductivity of the nanofluids. The enhancement observed with 3.0% volume concentration.

-The overall heat transfer coefficient increases with increase in volume concentration of nanofluids but at 3.5 lpm flow rate of nanofluid, the enhancement in heat transfer coefficient was less compared to that of observed at 1.5 lpm volume flow rate. The maximum enhancement of 55.5% in heat transfer coefficient was obtained at 1.5 lpm flow rate of nanofluid of 3.0% volume concentration. Whereas the effectiveness was enhance by 28.0%.

- At higher flow rate of the nanofluid the pressure drop increases result in increase in pumping power required to circulate the base fluid. This was also due to the fact that more viscous nanofluid available at 3.0% volume concentration.

The maximum enhancement of 17.98 % in thermal performance factor was obtained at 2.0% volume concentration compared to that of base fluid, while the flow rate of hot nanofluid was 2.5 lpm.

REFERENCES

1. Lee, Minjung & Shin, Yunchan & Cho, Honghyun. (2021). Theoretical study on performance comparison of various solar collectors using binary nanofluids. Journal of Mechanical Science and Technology. 35. 1267-1278. 10.1007/s12206-021-0238-4.
2. Chandra Sekhara Reddy, M. and V. Vasudeva Rao, *Experimental investigation of heat transfer coefficient and friction factor of ethylene glycol water based TiO2 nanofluid in double pipe heat exchanger with and without helical coil inserts.* International Communications in Heat and Mass Transfer, 2014. **50**: p. 68-76
3. Albadr, J., S. Tayal, and M. Alasadi, *Heat transfer through heat exchanger using Al2O3 nanofluid at different concentrations.* Case Studies in Thermal Engineering, 2013. **1**(1): p. 38-44.
4. Azmi, W.H., et al., *Heat transfer and friction factor of water based TiO2 and SiO2 nanofluids under turbulent flow in a tube.* International Communications in Heat and Mass Transfer, 2014. **59**: p. 30-38.
5. Performance comparison of innovative spiral shaped solar collector design with conventional flat plate solar collector, SK Verma, K Sharma, NK Gupta, P Soni, N Upadhyay, Energy 194, 116853

6. Sonawane, S.S., R.S. Khedkar, and K.L. Wasewar, *Study on concentric tube heat exchanger heat transfer performance using Al2O3 – water based nanofluids.* International Communications in Heat and Mass Transfer, 2013. **49**: p. 60-68
7. Suresh, S., M. Chandrasekar, and S. Chandra Sekhar, *Experimental studies on heat transfer and friction factor characteristics of CuO/water nanofluid under turbulent flow in a helically dimpled tube.* Experimental Thermal and Fluid Science, 2011. **35**(3): p. 542-549.
8. Investigating the effects of amine functionalized graphene on the mechanical properties of epoxy nanocomposites, A Yadav, A Kumar, K Sharma, MK Shukla, Materials Today: Proceedings 11, 837-842
9. Tiwari, A.K., P. Ghosh, and J. Sarkar, *Heat transfer and pressure drop characteristics of CeO2/water nanofluid in plate heat exchanger.* Applied Thermal Engineering, 2013. **57**(1): p. 24-32.
10. Sharma, A., An intelligent position control using priority based fitness scheme and optimal tuning of fuzzy logic controller parameters with binary bat algorithm for nonlinear gantry crane system. Journal of Green Engineering, 2020. 10(11): p. 11687-11700
11. Kong, M. and S. Lee, *Performance evaluation of Al2O3 nanofluid as an enhanced heat transfer fluid.* Advances in Mechanical Engineering, 2020. **12**(8): p. 1687814020952277.
12. Bharadwaj, G., K. Sharma, and A.K. Tiwari, *Performance analysis of hybrid PCM by doping Graphene.* Materials Today: Proceedings, 2020. **26**: p. 850-853.
13. R P Singh, K.S.a.A.K.T., *An Experimental Investigation of Thermal Conductivity of TiO_2 Nanofluid:Proposing a New Correlation.* Journal of Scientific & Industrial Research, 2019. **78**(9): p. 620-623.
14. Chaturvedi, R., P.K. Singh, and V.K. Sharma, Analysis and the impact of polypropylene fiber and steel on reinforced concrete. Materials Today: Proceedings, 2021..
15. Singh, R.P., K. Sharma, and K. Mausam, *Dispersion and stability of metal oxide nanoparticles in aqueous suspension: A review.* Materials Today: Proceedings, 2020. **26**: p. 2021-2025.
16. Zayed, Mohamed & Zhao, Jun & Du, Yanping & Kabeel, Abd Elnaby & Shalaby, S.. (2019). Factors affecting the thermal performance of the flat plate solar collector using nanofluids: A review. Solar Energy. 182. 10.1016/j.solener.2019.02.054..
17. Role of graphene in biosensor and protective textile against viruses, A Kumar, K Sharma, AR Dixit, Medical hypotheses 144, 110253
18. Kakac, S., H. Liu, and A. Pramuanjaroenkij, *Heat exchangers: selection, rating, and thermal design*. 2020: CRC press.