

Experimental Investigations on Double Pipe Heat Exchanger using Water/EG based Hybrid Nanofluids for Enhancement of Heat Transfer

¹ Ravi Kumar Mande, ² Sita Rama Raju. A. V

¹Department of Mechanical Engineering, JNTUH College of Engineering, Hyderabad, Telangana, India.

¹Department of Mechanical Engineering, Geethanjali College of Engineering and Technology, Hyderabad, Telangana, India. ²Department of Mechanical Engineering, Anurag University, Hyderabad, India.

Abstract: Heat transfer, Nu. number, friction factor, pressure drop, overall heat transfer coefficient is analyzed for different vol. concentrations of TiO₂/CuO water/EG (20:80) based hybrid NFs flowing through a double pipe heat exchanger or DPHE with low vol. concentrations viz. 0.01%, 0.03% and 0.05% at Re. number range of 2300 to 12000 respectively. In a validation study, the experimental results showed a good agreement with the data available in the literature. Based on experimental analysis, the enhancement of Nu. number with 0.05%, 0.03% and 0.01% of TiO₂/CuO hybrid NFs (20:80) water/EG was 45.30%, 37.15 % and 23.53% higher than water due to attribute more thermal conductivity with moderate increase in pressure drops. In addition, that, the improvement of overall heat transfer coefficient was found to be 12.72%, 11.37% and 9.64% than water with friction factor penalty was 53.55%, 49.47% and 25.45% higher than carrier fluids.

Keywords: Thermal conductivity, Nusselt's number, friction factor, hybrid nanofluids, heat transfer coefficient.

1. INTRODUCTION

Recently, an interest of research on hybrid nanofluids for enhancement of heat transfer is increased significantly. The hybrid nanofluids is a well dispersion of nanoparticles in a base fluid. Water, oils, ethylene glycol, lubricants, and other polymers are the most often used as base fluids. Different kinds of nanoparticles are being used as additive like metal matrix, ceramic matrix and polymer matrix. The thermo physical properties of combined nano sized particles along with base fluid have significant influence on the convective heat transfer performance. In addition, size, shape of the particle, volume or weight fraction of nano fluids, pH value are also having considerable influence on the heat transfer.

The creation of hybrid nanofluids based on ethylene glycol and their thermal characteristics have been only the subject of limited number of investigations. Paul et al. who worked on Al-Zn nano composite and prepared hybrid nanofluids based on ethylene glycol. Additionally, ethylene glycol-based hybrid nanofluids were created by Sundar et al., Baby and Rama Prabhu, and Ara3vind and Rama Prabhu etc.

2. LITERATURE REVIEW

Yongferg et.al [1] aims to studied the optimum heat transfer with low friction factor by using Al₂O₃. It was noticed that the average enhancement of Nu. number increase from 15.13 to 28.42 and friction factor from 0.022 to 0.052 by using semi-twisted tape at Re. number at 1000. Mawj et al [2] explored the heat transfer through a DPHE by using Al₂O₃-Fe₂O₃ nano particles at 0.005%, 0.1%, 0.15%, 0.2%, 0.25%, and 0.3%. The maximum enhancement of heat transfer of Al₂O₃-Fe₂O₃ at 6%. Gaurav Bhardwaj et al [3] focused on synthesis of 0.025% vol. concentration of Al & Cu based nanofluids by two-step method and studied characterization by XRD, SEM and Zeta analyzer and compared the results with data available in the literature. Mukesh Kumar et al [4] conducted CFD studied on a double helically coiled tube heat exchanger using MWCNT/water-based NFs, focused on heat transfer and flow characteristics under laminar flow conditions at 0.2%, 0.4% and 0.5% respectively. The simulation data compared with experimental results showed a good agreement and validating CFD analysis, especially at higher vol. concentrations, improved the heat transfer rate. Bhattad et al [5] studied the heat transfer and pressure drop characteristics using hybrid NFs in a plate type heat exchanger. It was

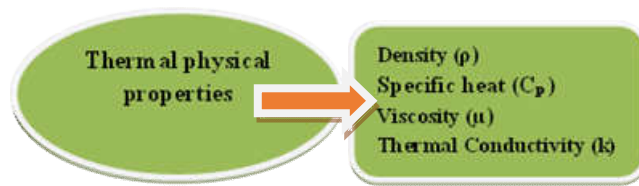
observed that while using hybrid NFs in a plate type heat exchanger can enhance heat transfer efficiency than conventional fluids. Vishal Bhalla et al [6] conducted the experimental study on photo-thermal analysis with surface absorption and blended nanofluids absorption-based systems. It was noticed that 40 mg/L Al_2O_3 + 40 mg/L CO_3O_4 is the optimum mass fraction at 5.4°C temperature of blended nanofluids absorption-based systems. Wang et al [7] focused on developed correlation for nanofluids' flow boiling heat transfer on $\text{AlN}/\text{H}_2\text{O}$ and Al_2O_3 and also predict the heat transfer behaviors. It was noticed that variation of pressure and flow rate of nanofluid's significantly impact on heat transfers phenomenon. Krishna Varma et al [8] studied and optimize the independent parameters of stability for Fe_2O_3 by NTU approach. A regression equation to evaluate the NTU was developed, the results obtained showed a good agreement with the experimental. Langeroudi et al [9] focused on performance of heat transfer by twisted tape and V-cut TT were inserted in corrugated tube. It was noticed that especially, V-cut TT, are expect to increase heat transfer rate compared to plain corrugated due to enhanced turbulence and fluid mixing. Liu Yang et al [10] explored the potential and challenges associated with TiO_2 nanoparticles in heat transfer applications. It can be concluded that has exhibited a positive with thermal conductivity and effects on other factors such as nano particle shape, size, base fluid, temperature, surfactant and sonication. Ravi Kumar Mande et al [11] conducted experiment through a double pipe heat exchanger with bowl cut TT inserts by TiO_2/CuO hybrid NFs. It was observed that while increase of scale ratios of bowl cut TT ($H/D=3$) inserts will enhance the heat transfer rate. Durga Prasad et al [12] investigated the heat transfer and friction factor using Al_2O_3 nanofluids in U-bent tube heat exchanger with helical tape inserts. It was observed that, Nu. number has increased by 32.91% at 0.03% vol. concentration with twist ratio ($p/d=5$) when compared to water. Further, suggested that thermal conductivity of nanofluids plays a significant role in the heat transfer applications. Mohammed Illbeigiel et al [13] investigated the heat transfer and pressure drop characteristics of Al_2O_3 flowing in a channel under non-Newtonian fluid in experimental and CFD. Both the experimental and computational results show an increase in the heat transfer coefficient and pressure drop with an increase in the nanofluid concentration. By using the experimental data, a correlation for the average Nusselt number estimation based on the dimensionless number (Re and (Pr) and nanoparticles concentration (ϕ) is obtained. The results of this correlation introduce a 1.162 % average absolute deviation. V. Rao et al [14] studied the heat transfer and friction factor by using CuO nanofluids in a U-bent DPHE with different mass flow rate and various vol. concentrations viz. 0.01%, 0.03% and 0.06%. It was noticed that the Nu. number enhancement is about 18.6% at 0.06% vol. concentration with the friction factor penalty of 1.09 times when compared to water. Syam Sunder et al [15] studied an experimental analysis of Fe_3O_4 nanofluids with 0.0% to 2.0% vol. concentrations at 20°C to 60°C . The thermal conductivity and viscosity of the nanofluid were increased with an increase in the particle volume concentration. Viscosity enhancement was greater compared to thermal conductivity enhancement under at same volume concentration and temperature.

3. MATERIALS AND METHODOLOGY

The preparation of hybrid NFs is an conceptual approach by dispersing synthesized NPs in to the water/ EG base fluids at predefined proportions with low vol. concentrations viz. 0.01%, 0.03% and 0.05% of TiO_2/CuO hybrid NFs. The TiO_2/CuO NPs were blended 1:1 at 0.01%, 0.03% and 0.05% low vol. concentrations in 20: 80 (water/EG) as base fluid and followed by two-step method for the preparation of hybrid NFs. The TiO_2/CuO NPs are purchased from Sisco research laboratory, Mumbai, Maharashtra. The TiO_2/CuO hybrid NFs are obtained while the immersion of NPs in the base fluids (water/EG). The thermal properties of hybrid NFs are very important to analyze the heat transfer performance.

Table 1: Thermal properties of base fluid water, EG, TiO₂ and CuO

Parameter	Water	EG	TiO ₂	CuO
Density(ρ) Kg/m ³	998	1110	3900	6300
Specific heat (C_p) J/kg C	4182	2.42	697	550.5
Thermal Conductivity (k) (Wm/K)	0.6024	0.251	11.8	37.0
Viscosity (μ) N-s/m ²	0.001003	0.0041	0.5	0.0161

**Figure 1:** Thermophysical properties**Figure 2: a.** TiO₂ powder**b.** CuO powder

The weight of NPs required for 0.01%, 0.03% and 0.05% low vol. concentrations of TiO₂/CuO hybrid NFs was estimated by using below Eq. (1), when water/EG is used as based fluids under consideration

$$\% \text{ of Volume Concentration} = \frac{(Wt/\rho)CuO + (Wt/\rho)TiO_2}{(Wt/\rho)CuO + (Wt/\rho)TiO_2 + (Wt/\rho)bf} \quad (1)$$

Where

Wt = Weight of nanoparticle,

ρ_{bf} = density of base fluid

TiO₂ = Titanium oxide nanoparticle,

CuO = Copper oxide nanoparticle

The thermal properties are assessed to analyze the Nusselt's number, friction factor, pressure drop, heat transfer coefficient, average heat transfer rate and thermal performance factor. By adding the nano sized particles to the carrier fluids (water/EG), the thermal properties of hybrid NFs will be improved. This is to fact that the solid possess more thermal conductivity than liquids while, adding nano sized particles to the base fluids may enhance thermal conductivity of hybrid NFs. The thermal properties viz.

density, thermal conductivity, viscosity and specific heat can be determined experimentally by using low vol. concentrations viz. 0.01%, 0.03% and 0.05% of TiO₂/CuO hybrid NFs when water/EG used as base fluids.

Where

ρ_{hnf} = density of hybrid NFs

k_{hnf} = thermal conductivity of hybrid NFs

μ_{hnf} = viscosity of hybrid NFs

Cp_{hnf} = specific heat of hybrid NFs



Figure 3: TiO₂/CuO - EG/water hybrid nanofluids sample along with surfactant

4. DATA REDUCTION

The Nusselt's number, friction factor, heat transfer coefficient, heat transfer rate and thermal performance have been carried out through a DPHE by using TiO₂/CuO hybrid NFs having low vol. concentrations viz. 0.01%, 0.03% and 0.05% in the ranging of Re. number 2300 to 12000 respectively. To validate the experimental results, the Nusselt's number values for water/EG are compared with Notter Rouse Eq. (13) and Gnielinski Eq. (11) similarly experimental values of friction factor for water/EG are compared with Blasius Eq. (14) and Petukhov Eq. (15)

The following are the mathematical expressions used in the experimental analysis.

Heat transfer rate (inside) is obtained by using Eq. (2)

$$Q_c = m_c C_{p_c} (T_{co} - T_{ci}) \quad (2)$$

Heat transfer rate (annulus side fluid) is obtained by using Eq.(3)

$$Q_h = m_h C_{p_h} (T_{hi} - T_{ho}) \quad (3)$$

Average heat transfer is obtained by using Eq. (4)

$$Q_{avg} = (Q_c + Q_h) / 2 \quad (4)$$

Overall heat transfer coefficient (tube side) is obtained by using Eq. (5)

$$U_i = Q_{avg} / A_i (\Delta T)_{LMTD} \quad (5)$$

Logarithmic mean temperature difference is obtained by using Eq. (6)

$$(\Delta T)_{LMTD} = (\theta_1 - \theta_2) / \ln (\theta_1 / \theta_2) \quad (6)$$

Where

$$\theta_1 = T_{hi} - T_{co}$$

$$\theta_2 = T_{ho} - T_{ci}$$

Overall heat transfer coefficient can be obtained using Eq. (7)

$$U_i = Q_{avg} / A_i (\Delta T)_{LMTD} \quad (7)$$

The heat transfer coefficient was computed using the Eq. (8)

$$\frac{1}{U_i} = \frac{1}{h_i} + B \quad (8)$$

Where the constant B is evaluated using the Wilson chart drawn between

$$\left(\frac{1}{U_i} \text{ versus } \frac{1}{Re} \right) \text{ as the intercept on the Y axis}$$

The Nusselt's number (Nu) is analyzed using the Eq. (9)

$$Nu = \frac{h_i d_i}{k_{mf}} \quad (9)$$

The friction factor is computed using the Eq. (10)

$$f = \frac{\Delta p}{L} \cdot \left(\frac{D V^2}{2} \right) \quad (10)$$

The Nusselt's number is computed using Eq. (11)

$$Nu = \frac{\frac{L}{d} (Re - 1000) Pr}{1.07 + 12.7 \left(\frac{L}{d} \right)^{0.5} (Pr^{0.5} - 1)} \quad (11)$$

Where f is the friction factor, which is determined from the Eq. (12)

$$f = (1.58 \ln(Re))^{-3.82} - 2 \quad (12)$$

This correlation is valid within the range of $2300 < Re < 5 \times 10^6$ and $0.5 < Pr < 2000$.

The correlation proposed by Notter- Rouse is shown in Eq. (13)

$$Nu = 5 + 0.015(Re)^{0.856} (Pr)^{0.347} \quad (13)$$

This correlation is valid within the range of $2300 < Re < 5 \times 10^6$ and $0.5 < Pr < 2000$.

Correlation of Blasius is shown in Eq. (14) while the correlation of Petukhov is shown in Eq. (15)

$$f = 0.31649(Re)^{-0.25} \quad (14)$$

This correlation is valid in the range of $3000 < Re < 10^5$

$$f = (0.790 \ln(Re))^{-(1.64)} - 2 \quad (15)$$

This correlation is valid in the range of $2300 < Re < 5 \times 10^6$

The thermal performance factor (TPF) using the Eq. (16)

Thermal performance factor (TPF)

$$PF = \frac{\left(\frac{Nu_i}{Nu_{mf}} \right)}{\left(\frac{f_i}{f_{mf}} \right)^{1/3}} \quad (16)$$

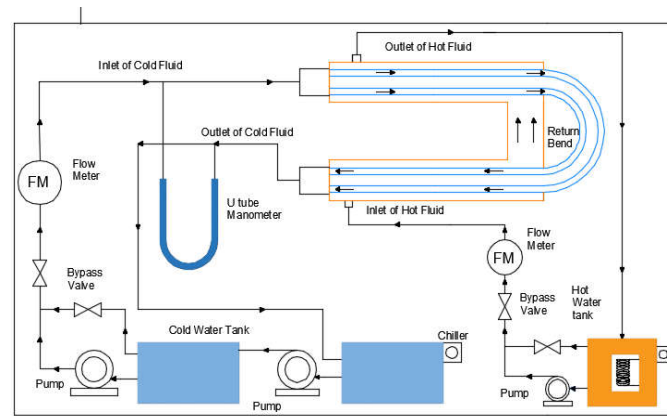


Figure:4 Schematic view of experimental set-up

4.1 Uncertainty

It is a conceptual approach used to identify the errors associated with name of the device or experiment and to identify the maximum possible error. It was observed that the uncertainty values for thermal conductivity apparatus in the range of $\pm 2.5\%$, viscosity measurement $\pm 1\%$, density $\pm 0.001\%$ and specific heat apparatus $\pm 1.5\%$ respectively.

Table:2 Uncertainty values computed for experimental work

Device Name	Uncertainty ($\pm$ in %)
Flow meter	$\pm 1.2\%$
Manometer	$\pm 1.5\%$
Temperature K	$\pm 1.2\%$
Voltage (V)	$\pm 0.6\%$
Velocity (m/s)	$\pm 1.25\%$

5. RESULTS AND DISCUSSIONS

5.1 Validation study

The experimental Nu. number of plain walls was validated with data available in the literature under forced convective turbulent flow conditions. The outcome results under turbulent conditions showed good agreement the Notter (1972) and Gnielinshi (1976) in the range of Re of 2300 to 12000. The Fig.5 shows the validation of experimental have been compared with standard correlations such as Gnielinshi [11] and Notter Rouse [13] equations. The experimental values showed a similar kind of tendency with standard correlations. It was noticed that the percentage deviation of Nu. number with correlations in between 12 to 20% respectively.

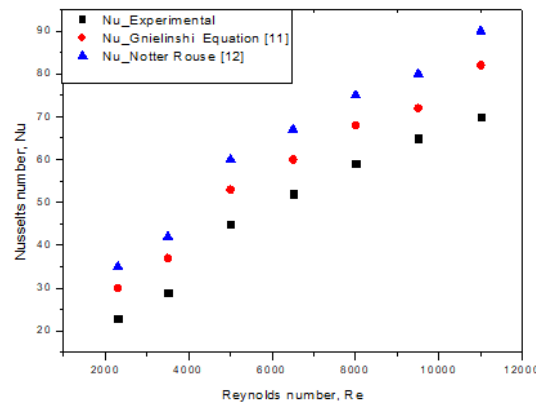


Figure: 5 Validation of test results

5.2 Nusselt's number

The experimental was conducted through a double pipe heat exchanger (DPHE) with base fluids water/EG (20:80) along with low vol. concentrations such as 0.01%, 0.03% and 0.05% of TiO_2/CuO hybrid NFs having different mass flow rate in the range of Re of 2300 to 12000 respectively. It is noticed that the Nu. number values increase with rise of vol. concentrations of TiO_2/CuO hybrid NFs due to attracted more thermal conductivity. The enhancement of Nusselt's number for 0.05%, 0.03% and 0.01% (20:80) water/EG vol. concentrations of TiO_2/CuO hybrid NFs was 45.30%, 37.15% and 23.53% higher than water.

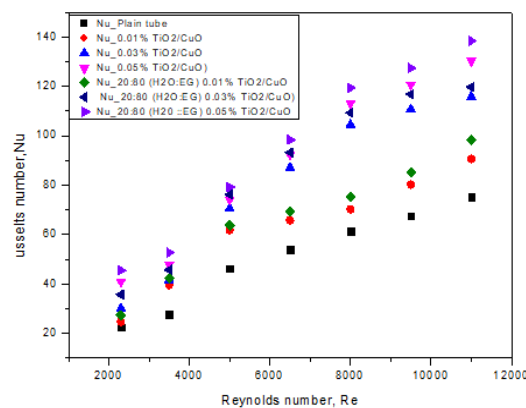


Figure :6 Experimental Nu. number

5.3 Pressure drop

The experimental analysis of pressure drops through a U-bent DPHE for water and different vol. concentrations viz. 0.01%, 0.03% and 0.05% of (20:80) water/EG based TiO_2/CuO hybrid NFs in the range of Re. number from 2300 to 12000. It was observed that the pressure drops increases with rise of mass flow rate as well as vol. concentrations of TiO_2/CuO hybrid NFs. In addition to that the increase in pressure drop is much lower with higher vol. concentrations of water/EG based TiO_2/CuO hybrid nanofluids when compared with base fluid water.

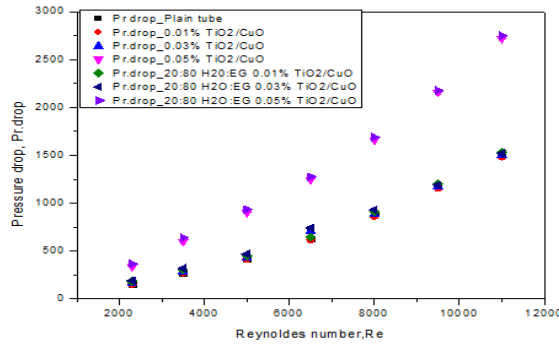


Figure :7 Experimental Pressure drop

5.4 Friction factor

The experimental analysis of friction factor through a DPHE for water and water / EG based various vol. concentrations of TiO_2/CuO hybrid NFs viz. 0.01%, 0.03% and 0.05% with mass flow rate having range of Re 2300 to 12000 respectively. It was observed that friction factor values increase with increasing vol. concentrations of hybrid NFs, but it was reduced while increasing of mass flow due to rising of viscosity in the TiO_2/CuO hybrid NFs

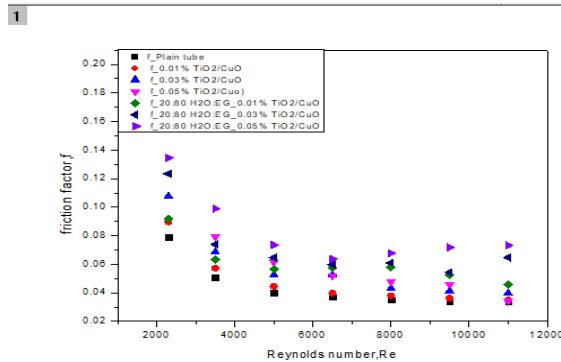


Figure: 8 Experimental friction factors

5.5 Overall heat transfer coefficient

The experimental analysis of Overall heat transfer coefficient (U) was conducted through a DPHE for water and various vol. concentrations of TiO_2/CuO hybrid NFs viz. 0.01%, 0.03% and 0.05% (20:80) water/EG having mass flow rate in the Re. number range 2300 to 12000 respectively. It was observed that the enhancement of Overall heat transfer coefficient was 12.76%, 11.37% and 9.94% higher, when compared to water.

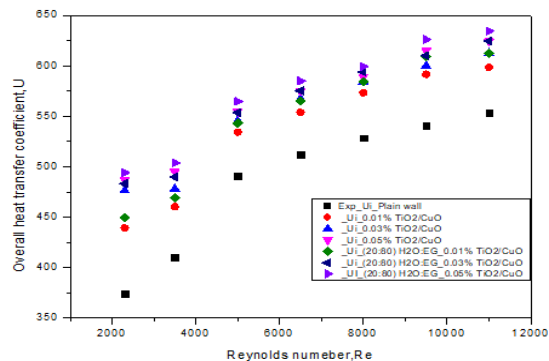


Figure:9 Experimental Overall heat transfer coefficient

CONCLUSION

The experimental investigations were carried out through a DPHE using TiO₂/CuO hybrid NFs of volume loading (0.01% to 0.05%) with water/EG (20:80) to analyze the heat transfer and friction factor. The following conclusions have identified and highlighted in the below

- The enhancement of Nu. number having 0.05%, 0.03% and 0.01% of TiO₂/CuO hybrid nanofluids with plain wall and water/EG (20:80) by 45.30%, 37.13% and 23.53% higher than water
- The friction factor (f) was enhanced by 53.55%, 49.47%, 25.45% in the above criteria than base fluid water.
- While compared to base fluid, the TiO₂/CuO water/EG (20:80) hybrid nanofluids exhibit an average increase in pressure drops are 6.3%, 12.5% and 44.32% at 0.01%, 0.03% and 0.05% vol. concentrations.
- At the vol. concentration of 0.05%, 0.03% and 0.01% of TiO₂/CuO with (20:80) water/EG hybrid NFs the Overall heat transfer coefficient (h) was increased by 12.77%, 11.37% and 9.64% higher, when compared to water.

Acknowledgement

The authors thank to managements of Geethanjali College of Engineering and Technology and JNTU College for their unwavering support and providing the necessary research facilities for this research work.

Conflict of Interest

The authors declared no conflict of interest between the contents of work and any reported studies

Orcid ID : Ravi Kumar Mande <https://orcid.org/0000-0003-0728-8281>

REFERENCES

- [1] Yongfeng Ju, Tiezhu Zhu, Ramin Mashayekhi, Hayder Mohammed, Afrasyab Khan, Pouyan Talebizadehsardari and Wahiba Yaïci "Evaluation of Multiple Semi-Twisted Tape Inserts in a Heat Exchanger Pipe Using Al₂O₃ Nanofluids -Nano materials-(2021).
- [2] Mawj K. Qasim¹, Hadi O. Basher² Mohammed D. Salman³, The Iraqi Journal for Mechanical and Material Engineering-(2021). Vol. 21, pp no 2
- [3] Gaurav Bhardwaj "Synthesis and characterization of AL and Cu base nano fluids, Materials Today Proceeding-2020.
- [4] P.C. Mukesh Kumar, M. Chandrasekhar CFD analysis on heat and flow characteristics of double helically coiled tube heat exchanger handling MWCNT/water nanofluids, Heliyon - (2019), Vol 5.

- [5] *Bhattad, J. Sarkar, P. Ghosh, Discrete phase numerical model and experimental study of hybrid Nanofluids heat transfer and pressure drop in plate heat exchanger, Int. Commun. Heat Mass Transf. 91 (2018) 262–273.*
- [6] *V. Bhalla, V. Khullar, H. Tyagi, Experimental investigation of photo-thermal analysis of blended Nanoparticles (Al_2O_3/CO_3O_4) for direct absorption solar thermal collector, Renew. Energy 123 (2018) 616–626.*
- [7] *Y. Wang, K.H. Deng, B. Liu, J.M. Wu, G.H. Su, A correlation of Nanofluids flow boiling heat transfer based on the experimental results of AlN/H_2O and Al_2O_3/H_2O nanofluids, Exp. Thermal Fluid Sci. 80 (2017) 376–383.*
- [8] *KPV Krishna Varma, Kavati Venkateswarlu, PV Durga Prasad, Uday Kumar Nutakki, Prediction of stability parameters of ferric oxide nanofluids using response surface methodology based on desirability approach, Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering 2023, pp no 1-12.*
- [9] *H.G. Langeroudi and K. Javaherdeh, Investigation friction factor and heat transfer characteristics of turbulent flow inside the corrugated tube inserted with typical and V-cut twisted tapes, Springer Nature-(2018).*
- [10] *Liu Yang and Yuhua Hu, Toward TiO_2 Nanofluids—Part 2: Applications and Challenges, Nano scale Research letter-2017, Vol 12, pp no 446*
- [11] *Ravi Kumar Mande, Sita Rama Raju, K.V.P. Krishna Varma, "Augmentation of heat transfer in a DPHE with bowl cut twisted tape inserts and TiO_2/CuO hybrid nano fluids" <https://doi.org/10.1080/00986445.2024.2406026>. Pages 219-234, 25th- Sep (2024).*
- [12] *P.V. Durga Prasad, A.V.S.S.K.S. Gupta, M. Sreeramulu, L. Sundar, M.K. Singh, Antonio C.M. Sousa, Experimental study of heat transfer and friction factor of Al_2O_3 nanofluids in U tube heat exchanger with helical tape- Experimental Thermal and Fluid Science-(2014).*
- [13] *Mohammad Illbeigi lireza Solaimany Nazar "Numerical Simulation of Laminar Convective Heat Transfer and Pressure Drop of Water Based- Al_2O_3 Nanofluids as A non - Newtonian Fluid by Computational Fluid Dynamic (CFD)" Trans. Phenom. Nano Micro Scales-(2017). Vol 5(2) pp no 130-138.*
- [14] *M.C.S. Reddy, V.V. Rao, Experimental investigation of heat transfer coefficient and friction factor of ethylene glycol water based TiO_2 nanofluid in double pipe heat exchanger with and without helical coil inserts, Int. Commun. Heat Mass Transfer 50(2014) 68–76*
- [15] *L.S. Sundar, M.K. Singh, A.C.M. Sousa, Investigation of thermal conductivity and viscosity of Fe_3O_4 nanofluid for heat transfer applications, Int. Commun. Heat Mass Transfer 44 (2013) 7–14*
- [16] *Petukhov B S (1970) Heat Transfer and Friction in Turbulent Pipe Flow with Variable Physical Properties, in J P Hartnett and T F Irvine, (eds), Advances in Heat transfer, Academic Press, New York, pp. 504-564*

- [17] *H. Yarmand, S. Gharehkhani, S.F.S. Shiraz, M. Goodarzi, A. Amiri, W.S. Saras, M.S. Alehashem, M. Dahari, S.N. Kazi, Study of synthesis, stability and thermo-physical properties of graphene Nano platelets/platinum hybrid Nanofluids, Int. Commun. Heat Mass Transf.77(2016) 15–21*
- [18] *K. P. V. Krishna Varma , B. Srinivasa Varma, K. Ratna Kumari, CFD Analysis of a Heat Exchanger Using Enhanced Wall Treatment Function to Capture the Laminar Sub-Layer Close to the wall, International Journal of Mechanical and Production Engineering Research and Development, Vol.9, Issue 6, Dec (2019), 263–278.*