Shell and Tube Type Heat Exchanger with Twisted Tape Insert in Shell Side by Using Al_2O_3 with Water as Nanofluid

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Abstract - A well-planned heat exchanger works on enhancing the effectiveness of the heat exchanger. In this study, the shell and tube type heat exchanger has been considered under the CFD modelling and the twisted tape insert has been attached within its flowing channel for creating turbulence to improve the rate of heat transfer without using any external source of energy. In addition, the nanofluid has been added as a coolant for enhancing the coefficient of heat transfer with zero input. This passive method of heat transfer has resulted in improved heat transfer characteristics of the studied heat exchanger.

Keywords – Shell and Tube Heat Exchanger; Twisted Tape Insert; Nanofluid; Thermal analysis.

INTRODUCTION

Heat exchanger is a mechanical device that reuses the heat energy present in the working fluid. The shell and tube are a versatile heat exchanger due to its flexibility in design and is commonly used in many industries for cooling of turbine and compressor, oil industries, for refrigeration and air conditioner etc. It consists of many numbers of tubes enclosed inside a shell. The twisted tape inserts have been utilizing by the worldwide researchers for increasing the rate of heat transfer as a passive technique. These inserts could be of many shapes such as elliptical, square and triangular etc. There are some embossing operations also which are used to create discontinuities for producing more turbulence in the flowing fluid stream. Today, successive utilization of various metal nanoparticles in ventures is self-evident. One of the utilizations of these particles is in heat move science. The utilization of nanoparticles with high warm limit could bring about an addition of warm conductivity of the nanofluid.

The Aluminum Oxide (Al2O3) with water as a base fluid is used inside the shell side for improvement in rate of heat transfer due to its cumulative contribution in higher thermal conductivity. Double distilled water is used to prepare the nanofluid and Sodium Dodecyl Sulphate is used as surfactant to increase the stability of the nano fluid. The hot fluid flows inside the tube side and the cold fluid i.e., water with nano particles concentration, flows through shell side. The shell side flow rate has been varied from 1 lpm to 5 lpm and tube side flow rate has been kept constant as 1 lpm. The analysis has been done for all the cases to find the most effective one. The outlet temperature of the tube and shell side and effectiveness of heat exchanger has also been calculated and presented graphically in this research work.

Saha et al. [1] examined the intensity move of stream and strain drop qualities inside a round tube with wound tape components, tentatively. Chun et al. [2] concentrated on the impact of nanofluid on the intensity move inside a twofold line heat exchanger in laminar stream, tentatively. They sorted out that, the level of volume part of nanoparticles and calculation of particles is the major figure heat move improvement. Date and Saha [3] examined developed stream inside a cylinder with long wound tape and sorted out that, by diminishing contorted breadth and making more courses, huge thermohydraulic execution can be gotten. Wen et al. [4] researched the nanofluid inside a cylinder, tentatively. That's what they proclaimed, by expanding the volume part of nanoparticles, the hydrodynamics entrance length diminishes, and the warm entry length upgrades. Sharma et al. [5] concentrated on a round tube with wound tape and showed that water-Al2O3 nanofluid upgrades the intensity move with the expansion of Reynolds number and nanoparticle focus. Murugesan et al. [6] examined the contact variable of a twofold line heat exchanger with square bent tapes and straightforward turned tape with water as a functioning liquid, tentatively. They reasoned that the upsides of Nusselt number and erosion calculate tubes with square curved tapes are higher than the cylinder (without bent tapes) and cylinders with essentially contorted tapes. Jaisankar et al. [7] concentrated on the intensity move, grinding component, and warm execution of a sun powered water radiator with wound tapes with various turned proportions, tentatively. They sorted out that the intensity move coefficient in tubes with contorted tapes (from left to right) is superior to the cylinder (without turned tapes). Salman et al. [8] concentrated on heat move of rotational stream by utilizing CFD reproduction and showed that the increment of intensity move and grating variable in the cylinder with two-way thick tape has an immediate relationship with the decrease of curved proportion and shear profundity. The presence of a bent tape tube causes the improvement of intensity move and Nusselt number, which is because of the making of vortices destructing the limit layer. Salman et al. [9] explored the intensity move and grating element of nanofluid stream inside a round tube with curved tapes by utilizing CFD technique. They showed that intensity move and contact factor upgrade with the expansion of turns and decrease of shear profundity of tapes. Jafaryar et al. [10] concentrated on the intensity move upgrade inside a contorted tape tube with an elective pivot and uncovered that, by expanding the turned point, temperature slope (because of the improvement of optional stream) upgrades, however pressure diminishes. They additionally sorted out that, by expanding the curved point, the Nusselt number improves. Tusar et al. [11] researched the stream and intensity move characteristics through a cylinder with curved tape embeds, mathematically. Liang et al. [12] analyzed the impact of the middle tightened wavy-tape embed on the warm execution of laminar stream in a line. Abolarin et al. [13] researched the intensity move qualities in a roundabout cylinder with wound tape. Wang et al. [14] played out a mathematical reproduction to examine the intensity move performance in the round tube with the vortex generator. Yang et al. [15] completed a mathematical recreation on the shell side of a shell and cylinder heat exchanger. They proposed the ideal calculation of bent taps to accomplish the most elevated warm water driven execution.

Furthermore, Geete et al. [16] worked on a shell-spiral heat exchanger, the performance of constructed heat exchanger at different flow rates and inlet temperatures of hot and cold fluids, shows the highest achievable effectiveness of 0.988. Gupta et al. [17] reviewed the forced convection heat transfer characteristics with different nanofluids based on experimental investigations with constant heat flux, constant wall temperature boundary conditions and in heat exchangers is presented. Nanofluids demonstrate an improved heat transfer coefficient compared to its base fluid. Further it increases significantly with increasing concentration of nanoparticles as well as Reynolds number. Gupta et al. [18] observed that energy saving is the major challenge for people now these days because of the depleting fossils fuels day by day. Shell & tube heat exchanger is used in many industrial applications such as renewable energy, aviation industry, automobile industry, oil, and gas industry and many more for energy conversion at reduced cost without any environmental effects. Liu et al. [19] experimental investigation results shows that nanofluids with low concentration of Cu, CuO, or carbon nanotube (CNT) have considerably higher thermal conductivity than identical base liquids. Moorthy & Srinivas [20] findings of the anticorrosive properties and enhanced heat transfer properties of carboxylated water-based nanofluids. The stability of nanofluid is greater with carboxylated water rather than normal water. Qi et al. [21] analyzes flow and heat transfer characteristics of TiO2-water nanofluids with different nanoparticle mass fractions in a spirally fluted tube and a smooth tube are experimentally investigated at different Reynolds numbers. The effects of pH values and doses of dispersant agent on the stability of TiO2-water nanofluids are discussed. It is found that there is a larger increase in heat transfer and a smaller increase in frictional resistance coefficients for turbulent flow than that for laminar flow of TiO2-water nanofluids in the spirally fluted tube. Teng et al. [22] analyze the characteristics of alumina (Al2O3)/water nanofluid to determine the feasibility of its application in an air-cooled heat exchanger for heat dissipation for PEMFC or electronic chip cooling. Experimental results show that the nanofluid has a higher heat exchange capacity than water, and a higher concentration of nanoparticles provides an even better ratio of the heat exchanger. W. He et al. [23] investigated the effects of the nanofluid and twisted tape on the heat transfer characteristics of the heat exchanger and suggested to use variations in the concentration of the nanofluids and nano particles.

Objective of Present Study

This article is focused on CFD analysis of the double pipe heat exchanger with twisted tape insert by using Al_2O_3 as nanofluid particle with water as a base fluid. In [22], the researcher has analyzed the characteristics of (Al2O3)/water nanofluid for its feasibility to use in heat exchanger. It has been observed that very few work has been done by using the (Al2O3)/water nanofluid with twisted tape insert. There can be variation of nanofluid concentration along with the use of twisted tape insert. Under the CFD analysis the meshing creates the complexity due to finite element analysis and it becomes difficult to compute the results and while doing variation on meshing can also alter the results. Here this research work can be carried out to do the CFD experimentation for twisted tape insert. Furthermore, the shell and tube heat exchanger can be considered for this research and can check either its versatility is useful for the nanofluid with twisted tape insert or not. And also, the pressure drop needs to be examined so that it can be found that in what cost of pressure drop, the supposed methodology gives better performance without using any external source of energy input.

Design and CFD analysis

The geometry of the heat exchanger modeled on ANSYS Workbench 2020 with the dimensions as below.

Length of test section – 1000 mm

Shell side – 84 mm

ID and OD of cold and hot fluid – 40 mm

Tube OD – 42 mm

Tube ID – 40 mm

Number of turns of twisted tape insert – 4

Nanofluid used - Al_2O_3

The materials used are aluminum and graphene. The shell and tube are made up of aluminum. The tube side is filled with hot fluid and the shell side is filled with cold fluid.

Numerical Solution Procedure

Essential overseeing conditions like force condition, energy condition, and the progression condition are utilized in the CFD examination of shell and cylinder type heat exchangers. PRESTO plan is utilized in the coupling of tension and speed under SIMPLEC calculation. For mathematical discretization of the relative multitude of conditions, the upwind plan of second-request is being used in light of more precision than the first-request upwind plan. Assembly rules for the various boundaries are unique. For congruity condition, 1.0e-05 is utilized, for speeds this way and that 1.0e-05 is utilized, for energy condition 1.0e-08 is utilized and for k and e 1.0e-05 is utilized. To arrive at the combination esteem quick, the unwinding esteem allotted to pressure is 0.3 while k and ∈ are 0.7 and temperature is 0.9. Mass stream channel is utilized for delta of the cold and hot liquid and tension outlet is utilized for the power source of the two liquids.

Boundary Conditions

The hot liquid's mass stream rate is 1 lpm, 2 lpm, 3 lpm, 4 lpm and 5 lpm yet the mass stream rate is saved steady for the chilly liquid, which is 1 lpm. The temperature of cold liquid delta is 300 k while hot liquid channel is 353 k.

Grid Formation

After model development of the intensity exchanger, fitting is to be finished on the model. Fitting is the method involved with disseminating surfaces into little regions. These little regions are dissected independently to track down the last arrangement. Cross section ought to be fine, and the nature of the lattice is checked by perspective proportion and skewness. Viewpoint proportion ought to be under 600 and skewness ought to be under 0.9.

The calculation has coincided with a component size of 10 mm. Expansion is given on both internal and external liquid independently to think about of no-slip condition and laminar sub-layer in the limit layer. Coincided math and the expansion are displayed in Fig.1. The primary layer thickness is determined from the wall y+ adding machine. The naming of both channel and outlet of cold and hot liquid is finished for the counter progression of liquid. Limit conditions are applied on the arrangement page of Ansys 2020. Energy conditions are kept on and stream is thought to be fierce. A violent model of k-epsilon is utilized. Materials properties are added for graphene and Al2O3 nanofluid. The hot liquid is water, and the chilly liquid is nanofluid. The material of the shell and cylinder is aluminum, and the layer of the cylinder side is graphene. The mass stream pace of cold liquid is kept fixed i.e., 1 lpm, and the mass progression of hot liquid is fluctuated from 1 to 5 lpm. Emphasis is finished till the union is reached. Every one of the information has been determined from post-examination. Heat motion, the temperature of the wall and liquid, pressure drop, skin grinding coefficient, surface Nusselt number, and powerful Prandtl number are determined. Convective intensity move coefficient is determined from the standard condition of intensity move i.e., q = hdT. The liquid temperature, wall temperature and intensity transition are taken at 10 distinct areas each at 0.1 m. Then, at that point, a normal of the multitude of information to work out the convective intensity move coefficient is taken.

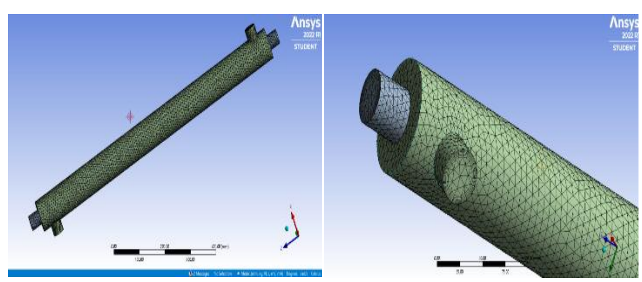


Figure 1. Inflation at the tube side of the heat exchanger

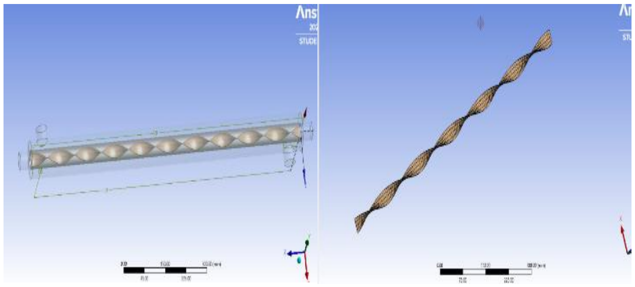
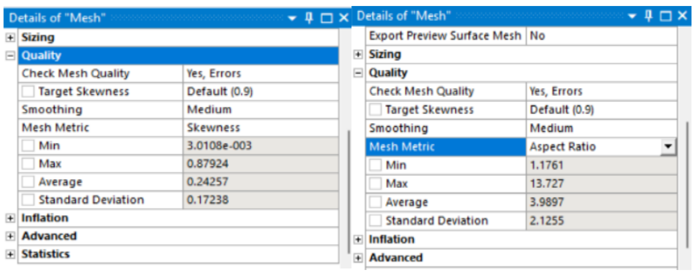


Figure 2. Model of heat exchanger with twisted tape and its meshing



Details of "Mesh"	
Sizing	
Quality	
Check Mesh Quality	Yes, Errors
Target Skewness	Default (0.9)
Smoothing	Medium
Mesh Metric	Skewness
Min	3.0108e-003
Max	0.87924
Average	0.24257
Standard Deviation	0.17238
Inflation	
Advanced	
Statistics	

Details of "Mesh"	
Export Preview Surface Mesh	No
Sizing	
Quality	
Check Mesh Quality	Yes, Errors
Target Skewness	Default (0.9)
Smoothing	Medium
Mesh Metric	Aspect Ratio
Min	1.1761
Max	13.727
Average	3.9897
Standard Deviation	2.1255
Inflation	
Advanced	

Figure 3. Quality of the mesh

Terminology used
At volume fraction = 0.6

Nano fluid density (ρ_{nf}):
ρ_{nf} = 2727.28 kg/m^3

Nano fluid specific heat ($C_{p\ nf}$):
$C_{p\ nf}$ = 1389.02 J/kg-K

Nano fluid viscosity (μ_{nf}):
μ_{nf} = 0.0025075 kg/m-s

Nano fluid thermal conductivity (K_{nf}):
K_{nf} = 5.13 W/m-K

Result and conclusion

Performance analysis of the designed shell and tube type heat exchanger with twisted tape insert along with Al_2O_3 nanofluid is as follows:

Heat Flux

Heat flux is showing improvement for both nanofluid and nanofluid with twisted tape insert. Heat flux for the coolant on shell side that is, nanofluid with twisted tape insert increases from 5994.98 to 10,361.31 W/m², which is very close to the values of hot fluid on tube side which is showing the effectiveness of the developed model and strategy. And, also for nanofluid without twisted tape insert, the heat flux increases from 3596.57 to 5852.59 W/m².

Convective Heat Transfer Coefficient

As shown in the figure 5, we can observe that the convective heat transfer coefficient for cold fluid that is nanofluid with twisted tape is higher for STHX followed by nanofluid and water only. The twisted tape creates turbulence in cold fluid causing to increase the convective heat transfer coefficient of nanofluid. The convective heat transfer coefficient increases from 1070.16 to 1533.01 W/m²K, and 531.67 to 1412.48 W/m²K and 379.72 to 700.04 W/m²K for water without nanofluid.

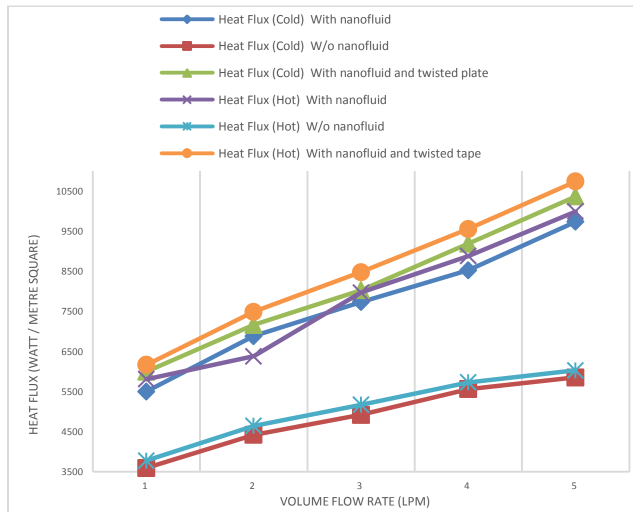


Figure 4. Heat flux of hot and cold fluid

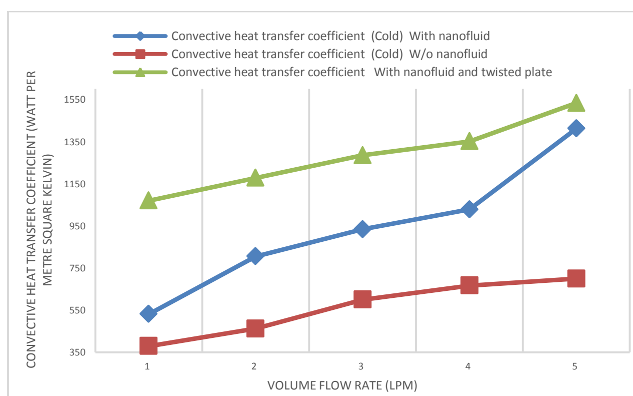


Figure 5. Growth in convective heat transfer coefficient of coolant i.e., nanofluid with and without twisted tape insert and hot water.

Pressure Drop

Pressure drop variation has been presented graphically in the figure 6, from which, it can be observed that the pressure drop is increasing with flow rate and also it is higher for the case of nanofluid than the water (without nanofluid) and again it becomes higher in the case of nanofluid with twisted tape. That means there is strong increase in rate of heat transfer by using twisted tape insert along with nanofluid and increasing the thermal efficiency but with the cost of pressure drop. But, if we observe, it clearly showed that the rate of heat transfer is increasing with the much bigger margin than the increase in pressure drop rate. So, it can be said that the overall efficiency of the heat exchanger has been improved with greater margin by using the twisted tape insert along with the nanofluid.

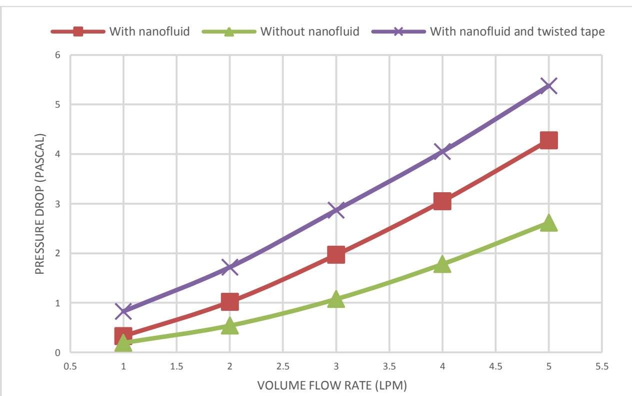


Figure 6. Pressure drops for hot and cold fluid

The Nusselt number (Nu) obtained through the calculations has been presented in the figure 7. It is to be noticed that the Nusselt number is highest in case when cold fluid is nanofluid with the twisted tape insert followed by nanofluid and simple water for all the flow rates. Whereas with increasing the flow rate, the Nusselt number is also increasing continuously for all the flow rates. This is showing that our developed strategy is successful for improvement of the rate of heat transfer of the heat exchanger by using this passive method.

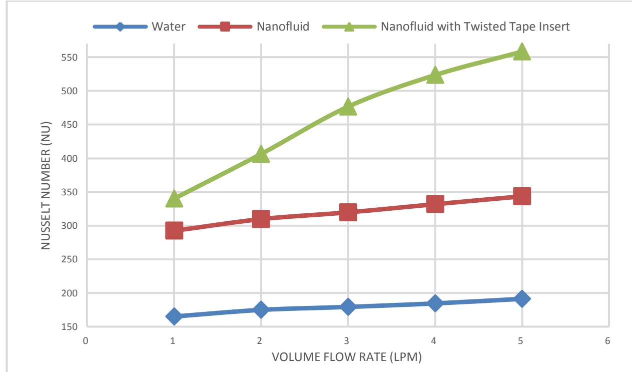


Figure 7. Growth of the Nusselt number

Conclusion

Convective heat transfer coefficient for cold fluid using nanofluid with twisted tape insert at flow rate of 5 lpm gives the highest value of 1533.01 W/m^{2}K, while ranging from 1070.16 W/m^{2}K.

The change in velocities at the inlet and outlet for both the fluid is negligible. There is a maximum increase of 1.2 percentage in velocities. This shows the losses in the pipe are considerable.

The nanofluid gives higher heat flux with the increase in the difference in mass flow rate of hot and cold fluid, whereas the combine effect of twisted tape insert and nanofluid gives a higher convective heat transfer coefficient for cold fluid.

The combined effect of twisted tape insert and nanofluid increases the pressure drop on the cold side with increase in mass flow rate but the Nusselt number has been improved by greater margin with a little cost of pressure drop which can be minimized by using the suitable percentage of concentration of the nanofluid with cold fluid that is water. Above results indicates that with low-pressure drop-in shell side nanofluid gives higher heat flux.

References

[1] S. K. Saha, U. N. Gaitonde, and A. W. Date, “Heat transfer and pressure drop characteristics of laminar flow in a circular tube fitted with regularly spaced twisted-tape elements,” Exp. Therm. Fluid Sci., vol. 2, no. 3, pp. 310–322, 1989, doi: https://doi.org/10.1016/0894-1777(89)90020-4.

[2] B.-H. Chun, H. U. Kang, and S. H. Kim, “Effect of alumina nanoparticles in the fluid on heat transfer in double-

pipe heat exchanger system," Korean J. Chem. Eng., vol. 25, no. 5, pp. 966–971, 2008, doi: 10.1007/s11814-008-0156-5.

[3] A. W. Date and S. K. Saha, "Numerical prediction of laminar flow and heat transfer characteristics in a tube fitted with regularly spaced twisted-tape elements," Int. J. Heat Fluid Flow, vol. 11, no. 4, pp. 346–354, 1990, doi: https://doi.org/10.1016/0142-727X(90)90058-J.

[4] D. Wen and Y. Ding, "Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions," Int. J. Heat Mass Transf., vol. 47, no. 24, pp. 5181–5188, 2004, doi: https://doi.org/10.1016/j.ijheatmasstransfer.2004.07.012.

[5] K. V Sharma, L. S. Sundar, and P. K. Sarma, "Estimation of heat transfer coefficient and friction factor in the transition flow with low volume concentration of Al2O3 nanofluid flowing in a circular tube and with twisted tape insert," Int. Commun. Heat Mass Transf., vol. 36, no. 5, pp. 503–507, 2009, doi: https://doi.org/10.1016/j.icheatmasstransfer.2009.02.011.

[6] P. Murugesan, K. Mayilsamy, and S. Suresh, "Turbulent Heat Transfer and Pressure Drop in Tube Fitted with Square-cut Twisted Tape," Chinese J. Chem. Eng., vol. 18, no. 4, pp. 609–617, 2010, doi: https://doi.org/10.1016/S1004-9541(10)60264-9.

[7] S. Jaisankar, T. K. Radhakrishnan, K. N. Sheeba, and S. Suresh, "Experimental investigation of heat transfer and friction factor characteristics of thermosyphon solar water heater system fitted with spacer at the trailing edge of Left–Right twisted tapes," Energy Convers. Manag., vol. 50, no. 10, pp. 2638–2649, 2009, doi: https://doi.org/10.1016/j.enconman.2009.06.019.

[8] S. D. Salman, A. A. H. Kadhum, M. S. Takriff, and A. B. Mohamad, "CFD Analysis of Heat Transfer and Friction Factor Characteristics in a Circular Tube Fitted with Quadrant-Cut Twisted Tape Inserts," Math. Probl. Eng., vol. 2013, p. 273764, 2013, doi: 10.1155/2013/273764.

[9] S. D. Salman, A. A. H. Kadhum, M. S. Takriff, and A. B. Mohamad, "Heat Transfer Enhancement of Laminar Nanofluids Flow in a Circular Tube Fitted with Parabolic-Cut Twisted Tape Inserts," Sci. World J., vol. 2014, p. 543231, 2014, doi: 10.1155/2014/543231.

[10] M. Jafaryar, M. Sheikholeslami, and Z. Li, "CuO-water nanofluid flow and heat transfer in a heat exchanger tube with twisted tape turbulator," Powder Technol., vol. 336, pp. 131–143, 2018, doi: https://doi.org/10.1016/j.powtec.2018.05.057.

[11] M. Tusar, A. Noman, M. Islam, P. Yarlagadda, and B. Salam, "CFD study of heat transfer enhancement and fluid flow characteristics of turbulent flow through tube with twisted tape inserts," Energy Procedia, vol. 160, pp. 715–722, 2019,doi: https://doi.org/10.1016/j.egypro.2019.02.188.

[12] Y. Liang, P. Liu, N. Zheng, F. Shan, Z. Liu, and W. Liu, "Numerical investigation of heat transfer and flow characteristics of laminar flow in a tube with center-tapered wavy-tape insert," Appl. Therm. Eng., vol. 148, pp. 557–567, 2019, doi: https://doi.org/10.1016/j.applthermaleng.2018.11.090.

[13] S. M. Abolarin, M. Everts, and J. P. Meyer, "Heat transfer and pressure drop characteristics of alternating clockwise and counter clockwise twisted tape inserts in the transitional flow regime," Int. J. Heat Mass Transf., vol. 133, pp. 203–217, 2019, doi: https://doi.org/10.1016/j.ijheatmasstransfer.2018.12.107.

[14] Y. Wang, P. Liu, F. Shan, Z. Liu, and W. Liu, "Effect of longitudinal vortex generator on the heat transfer enhancement of a circular tube," Appl. Therm. Eng., vol. 148, pp. 1018–1028, 2019, doi: https://doi.org/10.1016/j.applthermaleng.2018.11.080.

[15] D. Yang, T. S. Khan, E. Al-Hajri, Z. H. Ayub, and A. H. Ayub, "Geometric optimization of shell and tube heat exchanger with interstitial twisted tapes outside the tubes applying CFD techniques," Appl. Therm. Eng., vol. 152, pp. 559–572, 2019, doi: https://doi.org/10.1016/j.applthermaleng.2019.01.113.

[16] A. Geete, A. Bhattacharjee, A. Patwa, and K. Pandey, "Entropy, exergy and entransy analyses on fabricated shell and spiral tube heat exchanger," J. Inst. Eng. Ser. C, vol. 102, no. 4, pp. 897–908, 2021.

[17] M. Gupta, N. Arora, R. Kumar, S. Kumar, and N. Dilbaghi, "A comprehensive review of experimental investigations of forced convective heat transfer characteristics for various nanofluids," Int. J. Mech. Mater. Eng., vol. 9, no. 1, pp. 1–21, 2014.

[18] S. K. Gupta, S. Gupta, and R. Singh, "A comprehensive review of energy saving in shell & tube heat exchanger by utilization of nanofluids," Mater. Today Proc., vol. 50, pp. 1818–1826, 2022, doi: https://doi.org/10.1016/j.matpr.2021.09.212.

[19] M. Liu, M. C. Lin, and C. Wang, "Enhancements of thermal conductivities with Cu, CuO, and carbon nanotube nanofluids and application of MWNT/water nanofluid on a water chiller system," Nanoscale Res. Lett., vol. 6, no. 1, pp. 1–13, 2011.

[20] C. V. Moorthy and V. Srinivas, "Corrosion and heat transfer characteristics of water dispersed with carboxylate additives and multi walled carbon nano tubes," J. Inst. Eng. Ser. C, vol. 97, no. 4, pp. 569–577, 2016.

[21] C. Qi, C. Li, and G. Wang, "Experimental Study on the Flow and Heat Transfer Characteristics of TiO2-Water Nanofluids in a Spirally Fluted Tube," Nanoscale Res. Lett., vol. 12, no. 1, p. 516, 2017, doi: 10.1186/s11671-017-2284-5.

[22] T.-P. Teng, Y.-H. Hung, T.-C. Teng, and J.-H. Chen, "Performance evaluation on an air-cooled heat exchanger for alumina nanofluid under laminar flow," Nanoscale Res. Lett., vol. 6, no. 1, pp. 1–11, 2011.

[23] W. He, D. Toghraie, A. Lotfipour, F. Pourfattah, A. Karimipour, and M. Afrand, "Effect of twisted-tape inserts and nanofluid on flow field and heat transfer characteristics in a tube," Int. Commun. Heat Mass Transf., vol. 110, p. 104440, 2020, doi: https://doi.org/10.1016/j.icheatmasstransfer.2019.104440.