EFFECT OF DIFFERENT TYPES OF TURBULATOR USED IN HEAT EXCHANGER TO INCREASE HEAT TRANSFER

Tarun Kumar Upadhyay[1], Rajneesh Gedam[2]

[1]Research Scholar, [2]Assistant Professor
[1,2]RKDF college of Technology, Bhopal

***Abstract*: A heat exchanger is a device that exchanges the heat between two or more flowing fluids. In simper words one flowing fluid is at the lower temperature, called the cold fluid, and the other fluid is at the higher temperature, called the hot fluid, from which heat has to be extracted. The fluid with the lower temperature flows inside the geometry of the heat exchanger to extract heat from the hot fluid flowing with the higher temperature. Different types of turbulators with different pitch ratio were used to increase heat transfer rate inside the heat exchanger. Turbulators were used to increase turbulence and contact time which helps in increasing heat transfer rate. Here in this work it calculated the effect of different diameter circular helical turbulator to increase heat transfer, for analyzing the effect of different diameter of circular turbulator here it considered three different diameters that are 0.5, 1 and 2 mm. In this work it also calculates the effect of different shape of helical turbulator, for analyzing the effect of different shapes of helical turbulator here it considered three different shapes of turbulator with same cross sectional area that is circular, Square and rectangular shape turbulator. Through analysis it is found that heat exchanger with rectangular helical turbulator shows maximum value of heat transfer as compared to other.**

***Keywords:* heat exchanger, Turbulator shape, heat transfer, temperature distribution and Nusselt number**

1. Introduction

Heat exchangers are moreover that comforts the heat altercation among two solutions which are at diverse temperature though having them since intercourse with another. heat exchanger are normally utilized in practice in a wide variety of application, from heating as well as air conditioning systems in a domestic, to chemical processing as well as power production in large plant. A heat exchanger in which two fluids exchange heat by coming into straight interaction called direct contact heat exchanger. The wall may be an easy level wall or tube or a complex arrangement comprising fins, baffles and tubes multiple passes. These units, also called surface heat exchanger, are ordinary utilized as they can be created with huge heat transfer area in somewhat lesser volume and are fit for heating, cooling, evaporating or condensing applications. A periodic flow type heat exchanger called a regenerator. In this type of heat exchanger, the identical space of it consecutively engaged by hot and cold gases between which heats exchanged. Regenerator may discover its assertion in preheaters for condensation influence firm, blast furnaces, oxygen manufacturers, and many more.

Here in this work it performs the numerical analysis of tube in tube heat exchanger having turbulator inside the inner tube. Here in this work turbulator having 39 mm pitch were introduced inside the inner tube and measure the value of heat transfer. In order to measure the effectiveness of turbulator here it performs numerical analysis on both kind of geometries that is heat exchanger with helical turbulator and heat exchanger without turbulator. The heat exchanger used by Akyurek et.al [23] for the experimental analysis were considered to perform numerical analysis.

2. Development of solid model

The geometrical parameters used to develop solid model of heat exchanger is shown in the below table.

Table.1 Value of different geometric parameters of heat exchanger

Parameters	Values
Tube length	1.3 m
Inner tube diameter	12 mm
Tube wall thickness	2 mm
Outer tube diameter	33 mm
Pitch of turbulator	39 mm

Based on the above geometric parameters it developed the solid model of nano fluid heat exchanger. The solid model of heat exchanger is shown in the below fig.

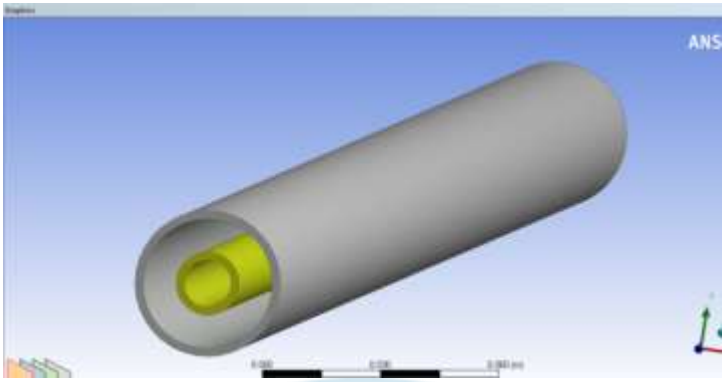

Fig.1 solid model of heat exchanger without helical turbulator

After analyzing the heat exchanger without turbulator, it analyzed the effect of use of turbulator in heat exchanger to increase the heat transfer rate. The solid model of heat exchanger having helical turbulator inside the inner tube is shown in the below fig.

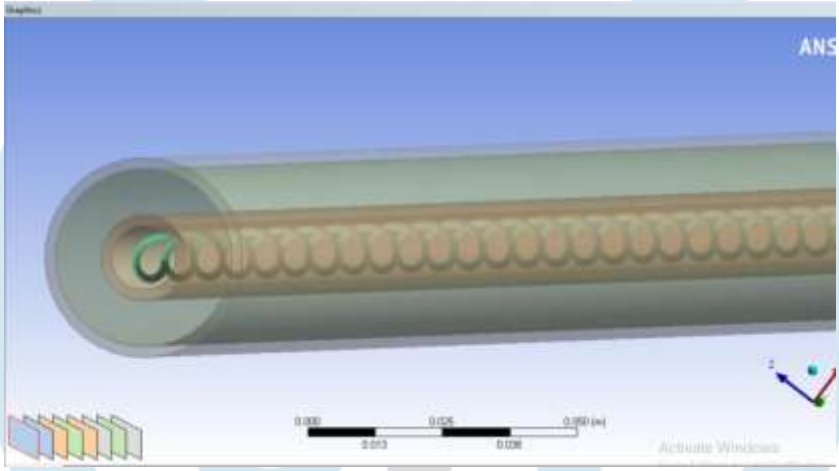

Fig.2 solid model of heat exchanger with helical turbulator

3. Meshing

To perform the numerical analysis of heat exchanger with or without turbulator it is necessary to discretize heat exchanger in to number of body and element. During numerical analysis, it calculates the result on element and nodes. In order to test the independency of number of nodes and elements, here we have discretized the body with different number of nodes and element and found that, result does not depends on number of elements and nodes. In order to improve the mesh different tools were used to refine the mesh. Mesh of the heat exchanger with and without turbulator is shown in the below fig.

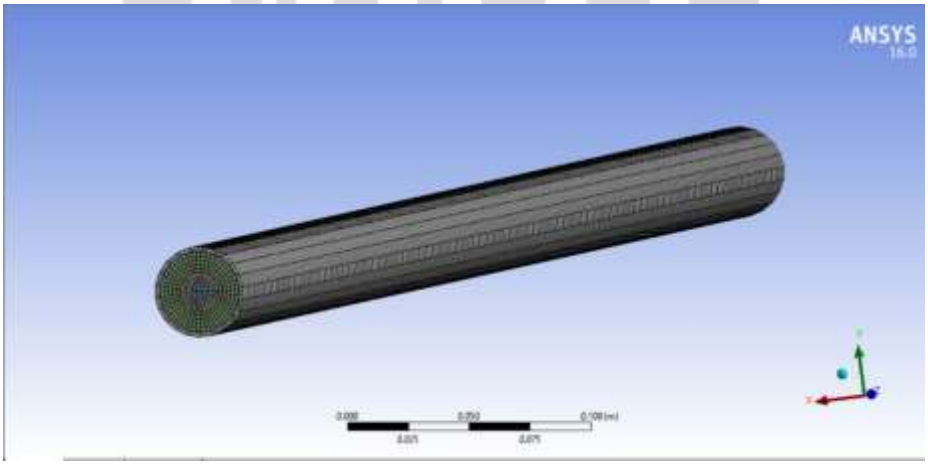

Fig.3 mesh of heat exchanger without helical turbulator

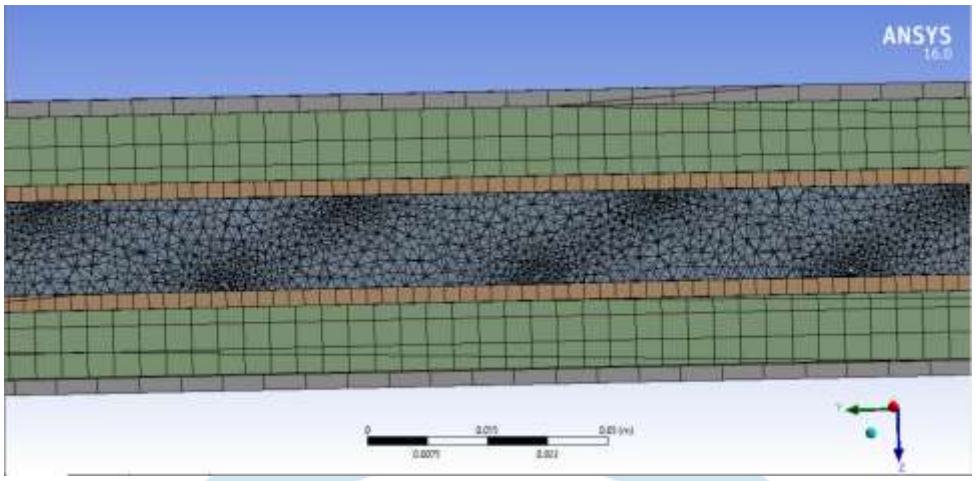

Fig.4 Cross sectional view of heat exchanger mesh

4. Material Used

Here in this work water is used as a hot fluid as well as cold fluid, whereas the inner tube of heat exchanger is made of aluminium and outer tube is made of polyethylene the properties of these materials are shown in the below section. Here in this work hot water is flowing in the outer tube and cold fluid is flowing in the inner tube. Turbulator is placed in inner tube to increase turbulence.

4.1 Water

Here in this work water is used as a working fluid which is flowing inside the heat exchanger. The properties of water used during the analysis is mention in the below table.

Table.2 Properties of water

Parameters	values
Density (ρ) kg/m^3	998
Specific heat (C_p) J/kg-K	4182
Thermal Conductivity (K) W/m-K	0.6

4.2 Aluminium

Here in this analysis aluminium is used to manufacture inside tube of heat exchanger.

Table.3 Properties of Aluminium

Properties	**Value**
Thermal conductivity(Wm^{-1}K^{-1})	202.4
Density (Kg/m^3)	2719
Specific heat (J/kg K)	871

4.3 Polyethylene

Here in this work outer tube of the heat exchanger is made of polyethylene. The properties of the material is shown in the below table.

Table.4 Properties of polyethylene

Properties	**Value**
Thermal conductivity(Wm^{-1}K^{-1})	0.33
Density (Kg/m^3)	970
Specific heat (J/kg K)	1900

5. Mathematical model

In order to calculate the performance of heat exchanger nusselt number and overall heat transfer coefficient. With the help of CFD analysis temperature of hot and cold fluid at inlet and outlet where measured. After measuring the temperature of hot and cold fluid value of nusselt number and overall heat transfer coefficient where calculated with the help of following mathematical model

5.1 Heat transfer from hot water fluid

$$Q_h = C_{pw} \times m_w(T_{inh} - T_{outh}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where Q_h is the heat transfer from water, C_{pw} is the specific heat of water, m_w mass flow rate of water, T_{outw} is the temperature of water at exit and T_{inw} is the temperature of water at inlet.

5.2 Heat transfer to cold fluid

$$Q_c = C_{pc} \times m_c(T_{outc} - T_{inc}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where Q_c is the heat transfer to cold fluid, C_{pc} is the specific heat of cold fluid, m_c mass flow rate of cold fluid, T_{outc} is the temperature of cold fluid at exit and T_{inc} is the temperature of cold fluid at inlet.

In order to calculate the properties of nano fluid following mathematical model formulas were used

5.3 The average heat transfer rate

$$Q_{avg} = \frac{Q_h + Q_c}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The overall heat transfer coefficient

$$Q_{avg} = UA_i\Delta T_{lm} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where U is the overall heat transfer coefficient, A_i is the surface are of inner pipe, ΔT_{lm} is the logarithmic mean temperature difference.

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where,

$$\Delta T_1 = T_{hi} - T_{co} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$\Delta T_2 = T_{ho} - T_{ci} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Heat transfer coefficient for cold fluid

$$h_c = \frac{Q_{avg}}{\pi DL(\Delta T_{lm})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where, h_c is the heat transfer coefficient of cold fluid

Calculation of nusselt number for cold fluid

$$Nu_c = \frac{h_c D}{K_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

6. Boundary condition

Here in this work hot water is flowing in the outer tube, whereas the cold fluid is flowing in inner tube. The inlet temperature of hot water is 343 K whereas the inlet temperature of cold fluid is 293 K. the velocity of hot fluid is considered as 0.0084 m/s as considered in base paper. The velocity of cold fluid changes as the Re number of cold fluid changes.

7. Result

Here in this work the performance of heat exchanger depends on the turbulator used inside the heat exchanger. In order to increase the performance of heat exchanger different types of turbulators can be used inside the heat exchange. Here in this work it considered three different wire coil diameter that is 0.5, 1 and 2 mm circular turbulators. It also analyzed the effect of different turbulator wire coil shape, to analyzed the effect of different shape of turbulator here it considered three different shapes of wire used as a circular helical turbulator inside the inner tube that is circular, square and rectangular which is having same cross sectional area.

7.1 Without helical turbulator

- **For Re = 4000**

Here in this section cold fluid is flowing at a Re 4000. Whereas the hot fluid is flowing at a speed of 0.0084 m/s. the temperature contour of heat exchanger for this Re number is shown in the below fig.

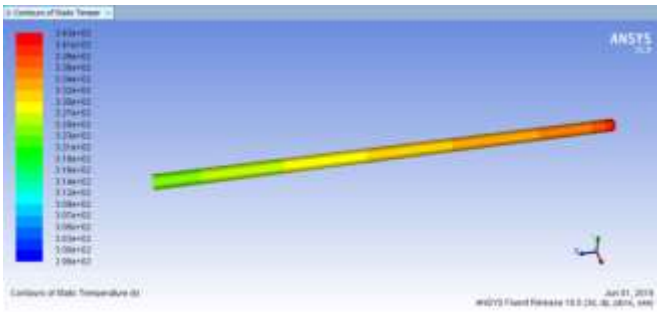

Fig.5 shows the temperature contours of heat exchanger for Re = 4000

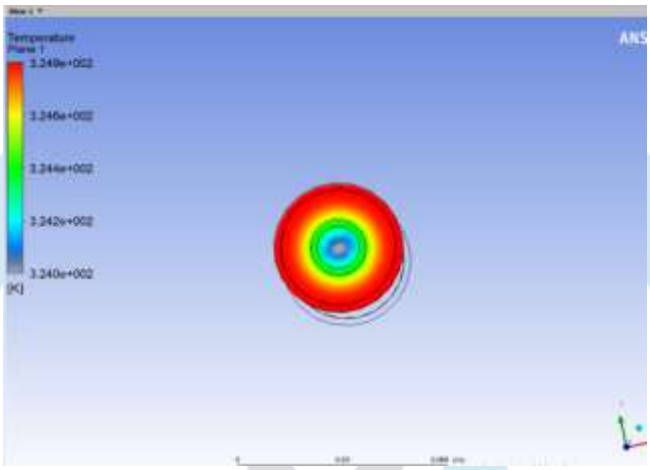

Fig.6 shows the temperature at the exit of heat exchanger

Through CFD analysis we have calculated the value of temperature of hot and cold fluid at inlet and outlet for Re =4000. The temperature of hot and cold fluid at inlet and exit where mention in the below section. On the basis on temperature at the exit and inlet, here we have calculate the value of nusselt number and overall heat transfer coefficient using eq. 1, 2, 3, 4, 5, 6, 7, 8 and 9 as mention in chapter 3.

From CFD T_{hi} (temperature of hot fluid inlet) = 343 K, T_{ho} (Temperature of hot fluid outlet) = 312.5 k, T_{ci} (Temperature of cold fluid inlet) = 293 k, T_{co} (Temperature of cold fluid outlet) = 336 k

Heat transfer from hot fluid

$$Q = \dot{m}C_p\Delta T$$

Where, $\dot{m}$ is the mass flow rate, C_p is the specific heat of water and ΔT is the change in temperature of hot fluid

$$Re = \frac{\rho VD}{\mu} \quad \text{.....} (10)$$

Where ρ is the density of water, V is the velocity of cold fluid, D is the diameter of inner tube and μ is the viscosity of water. After calculating the value velocity of cold fluid at Re = 4000 is 0.033 m/s. whereas the mass flow rate is calculate on the basis of below formula

$$\dot{m} = \rho AV \quad \text{.....} (11)$$

Where A is the cross sectional area of inner pipe and v is the velocity of cold fluid. On the basis of above eq. we have calculated the value of mass flow rate of hot and cold fluid.

Likewise the above calculation for Re = 4000, we have calculated the value of overall heat transfer coefficient and Nusselt number for different Re numbers. The value of overall heat transfer coefficient for heat exchanger without turbulator at different Reynolds number is shown in the below table.

Comparison of value of overall heat transfer coefficient values calculated with the help of numerical analysis with the value of overall heat transfer coefficient obtained from the experimental analysis performed by Akyürek et.al [23].

Table.5 Comparison of value of overall heat transfer coefficient

S.No	Reynolds Number	Overall heat transfer coefficient (U) W/m^{2}K calculated through numerical analysis	Overall heat transfer coefficient (U) W/m^{2}K from base paper	Percentage error (%)
1	4000	1007	980	2.7
2	8000	1225	1170	4.7
3	12000	1316	1260	4.4
4	16000	1408	1340	5
5	20000	1426	1360	4.8

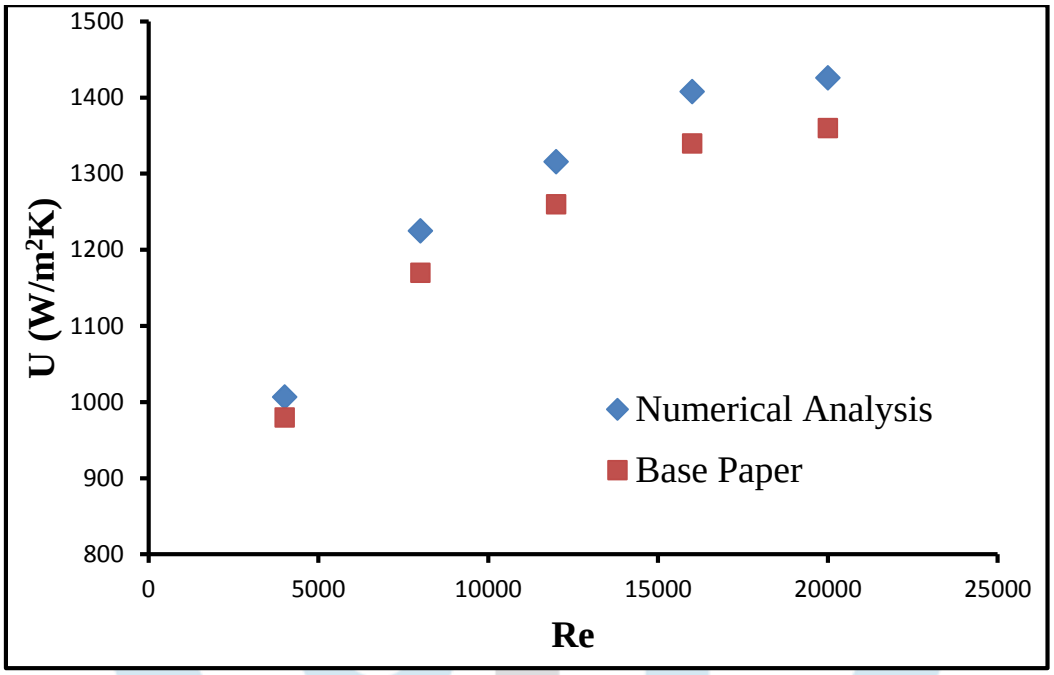

Fig.7 Comparison of value of overall heat transfer coefficient

7.2 For Heat exchanger having different circular helical turbulator

After validating the CFD model of heat exchanger, hear we have used solid model of heat exchanger having different helical turbulator inside the inner tube of heat exchanger. The helical turbulator is made on the basis of geometrical pitch that is 39 mm as mention in the base paper; turbulator is mainly used to increase the turbulence inside the heat exchanger. Here in this case water is flowing in both tubes that are in outer tube and inner tube. The velocity of water flowing in the outer tube is same as considered during without turbulator case that is 0.0084 m/s. for analyzing the effect of different core diameter of circular turbulator on heat transfer here we have considered three different coli diameter that is 0.5, 1 and 1.5 mm.

7.3 Comparison of different coil diameter of circular helical turbulators

Here we have compare the value of overall heat transfer coefficient and Nu number at different Reynolds for coil diameter circular helical turbulators. The comparison of different performance parameters of heat exchanger shown in the below fig.

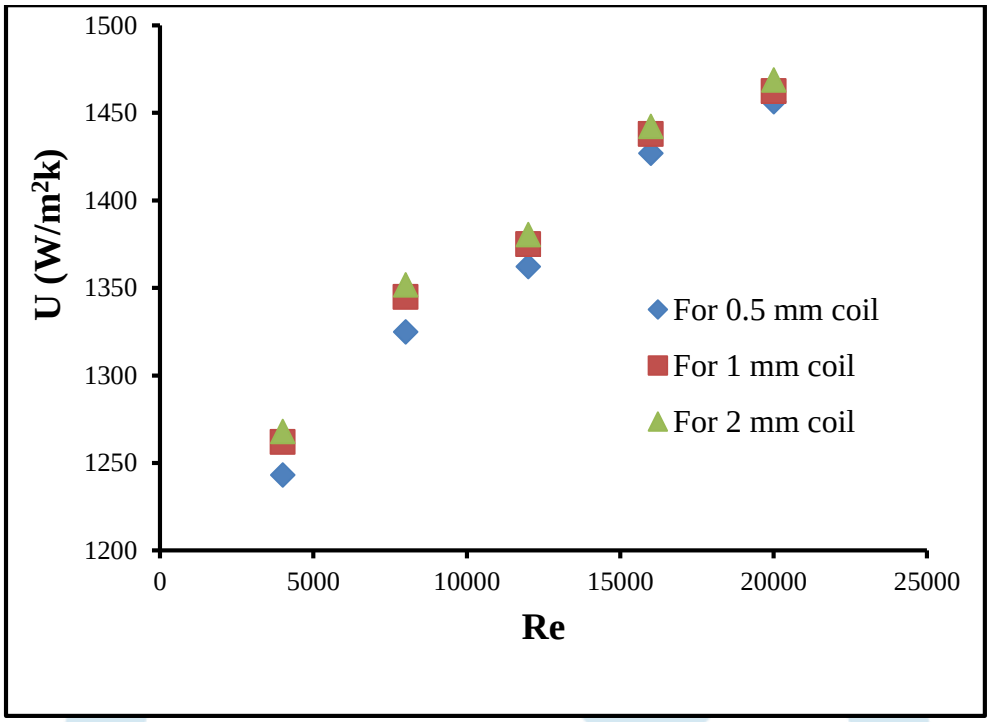

Fig.8 value of overall heat transfer coefficient

Form the above fig. it is conclude that the value of overall heat transfer coefficient is higher in case of 2 mm coil diameter as compared to 0.5 and 1 mm coil diameter. Above fig. also shows that the variation of overall heat transfer coefficient for different coil diameters at particular Re number start decreasing as the Re number increases and minimum for Re number 20000.

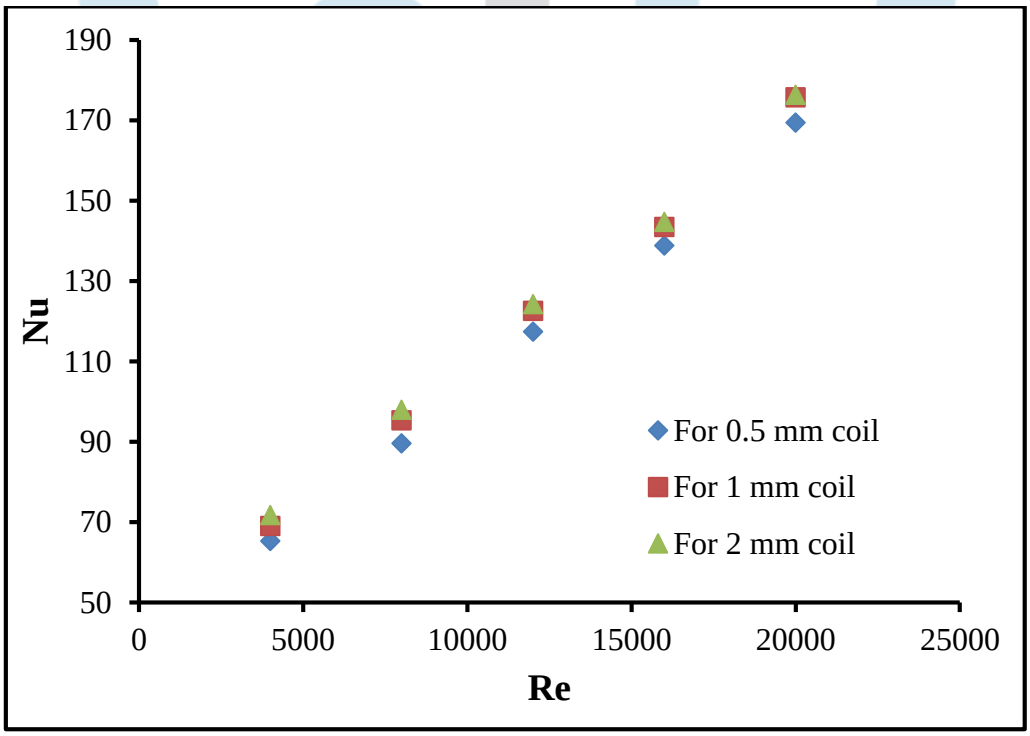

Fig.9 comparison of Nu number for different circular coil diameter helical turbulator

From above graph it is found that the value of Nu number increases with increase in Re number and it is higher for 2 mm coil diameter. After analyzing the circular coil turbulators of different diameter, here we have also analyzed the effect of different shapes of coil used for helical turbulators. In order to analyze the effect of different shapes of helical turbulator here we have considered circular, square and rectangular turbulaotrs inside the inner tube of heat exchanger and calculate the value of overall heat transfer coefficient and nusselt number. Here cross sectional area of all three turbulators are same, during circular shape coil analysis 2 mm diameter coil shows maximum overall all heat transfer coefficient so here we have considered the cross section area same as cross sectional area of 2 mm circular coil that is 3.141 mm^2.

7.4. Square coil helical turbulators

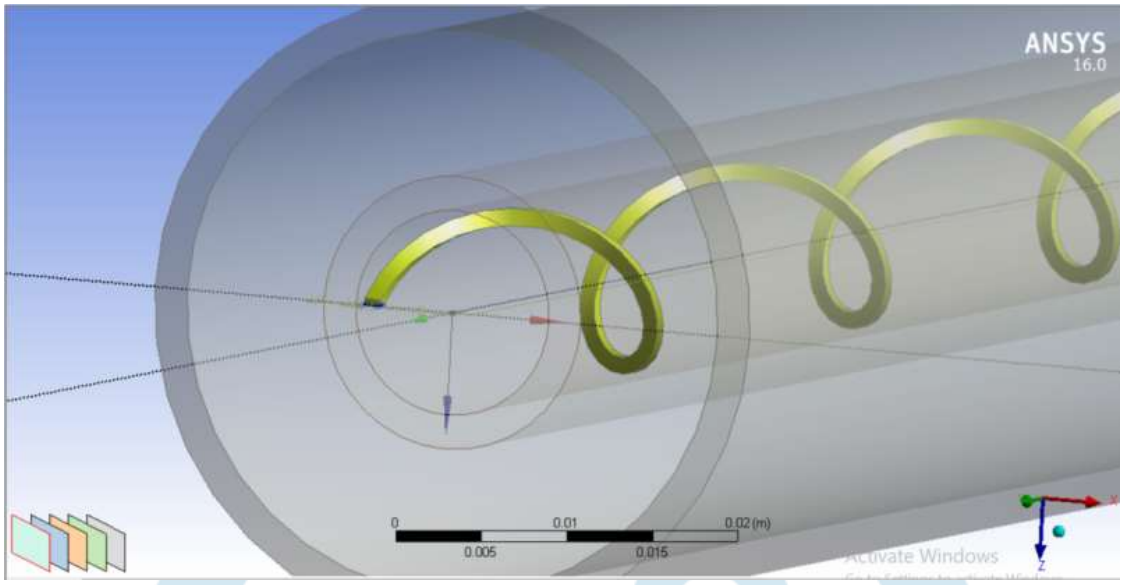

Fig.10 shows the square shape coil helical turbulator

7.5. Rectangular coil helical turbulators

Here in this section rectangular shape coil is used to make helical turbulator inside the heat exchanger. The solid model of rectangular shape helical coil is shown in the below fig.

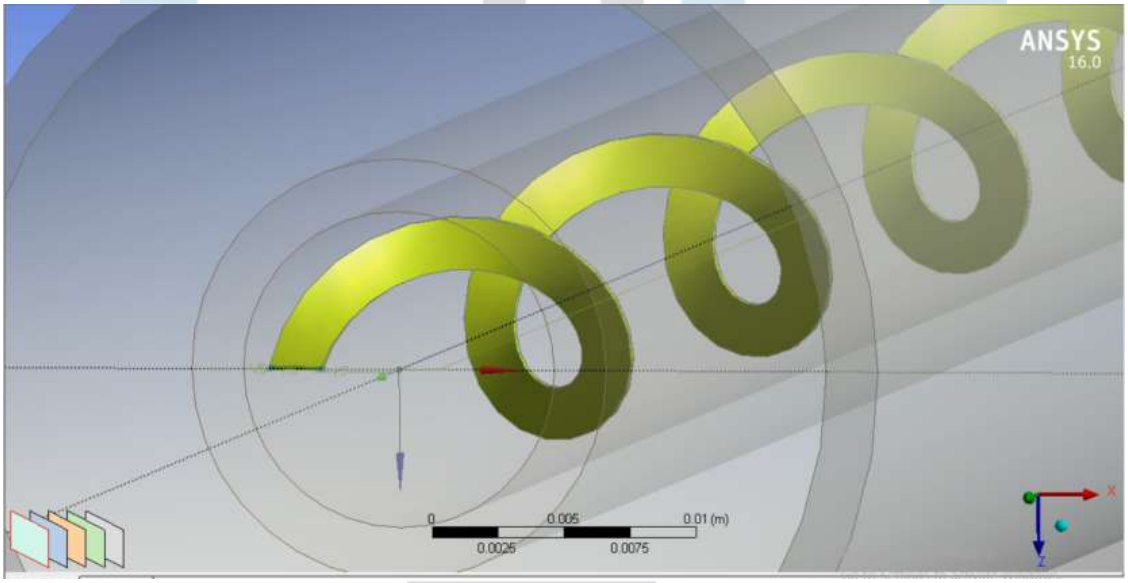

Fig.11 rectangular shape coil helical turbulator

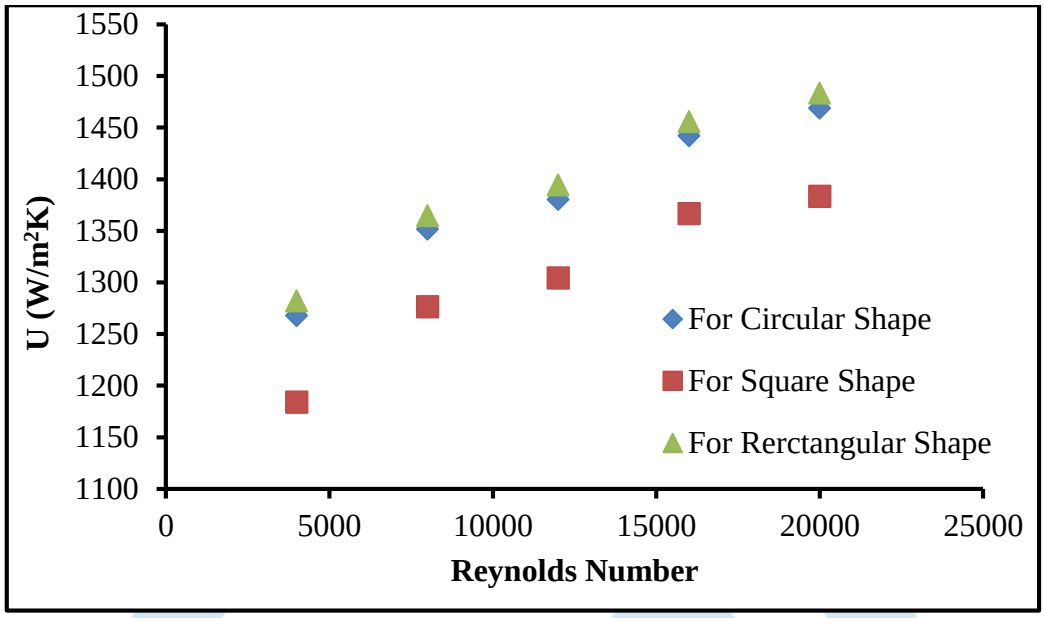

Fig.12 comparison of value of overall heat transfer coefficient for different shape of turbulators

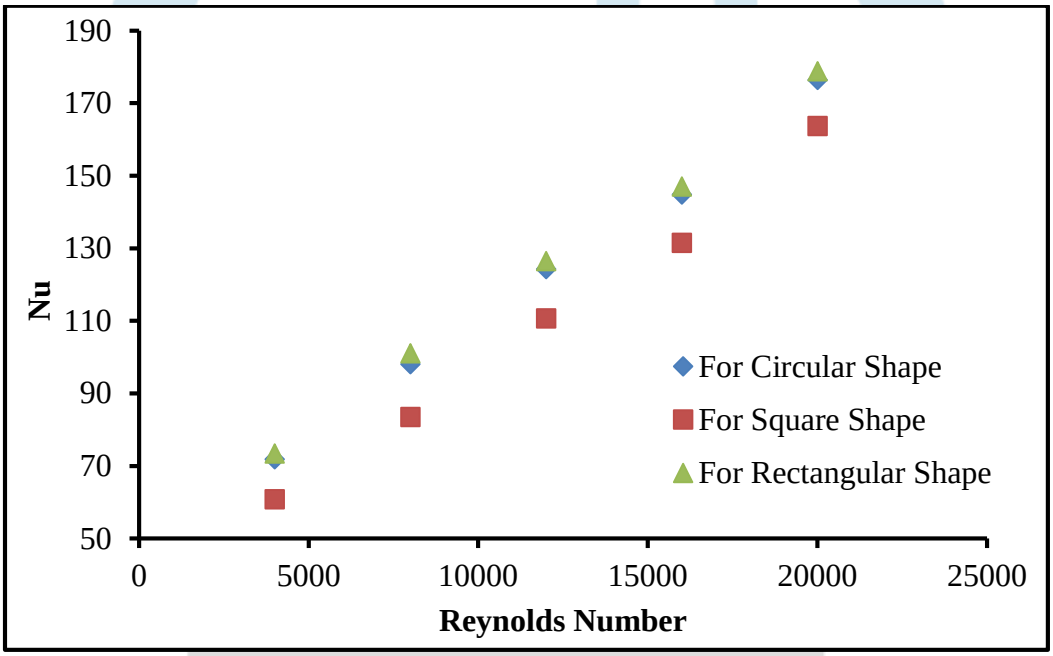

Fig.13 comparison of value of Nusselt number for different shape of turbulators

Form the above analysis it is found that the value of overall heat transfer coefficient for rectangular shape turbulator is high as compared to other shape of helical turbulator. Through analysis it is found that the value of Nusselt number for rectangular turbulator is high as compared to other.

8. Conclusion

- Develop the numerical analysis of heat exchanger with different shapes of helical turbulator.
- Through analysis it is found that the value of nusslet number and overall heat transfer coefficient increases with increase in Reynolds number.
- Heat exchanger with circular shape turbulator with 2 mm core diameter shows higher value of overall heat transfer coefficient and nusslet number.
- It means that heat exchanger with 2 mm core diameter shows maximum heat transfer as compared to other core diameter helical turbulator.
- After analyzing different shapes of helical turbulator it is found that the value of Nusslet number and overall heat transfer coefficient is high for heat exchanger having rectangular shape turbulator.
- Through analysis it is conclude that heat exchanger with rectangular shape helical turbulator shows maximum heat transfer as compared to other shapes of helical turbulators.

REFERENCES

[1] S.U.S. Choi and J. A. Eastman, "Developments and applications of non-Newtonian flows", ASME FED, 66 (1995) 99–105
[2] M. Chandrasekar, S. Suresh, A. Chandra Bose, "Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/water nanofluid", Experimental Thermal and Fluid Science, 34 (2010) 210–216
[3] Narendra Singh, Gaurav Chand & S. Kanagaraj (2012) "Investigation of Thermal Conductivity and Viscosity of Carbon Nanotubes–Ethylene Glycol Nanofluids", Heat Transfer Engineering, 33:9, 821-827
[4] Celen, A., Çebi, A., Aktas, M., Mahian, O., Dalkilic, A.S., Wongwises, S., "A review of nanorefrigerants: Flow characteristics and Applications", International Journal of Refrigeration
(2014), doi: 10.1016/j.ijrefrig.2014.05.009
[5] R. Saidur, S.N. Kazi, M.S. Hossain, M.M. Rahman, H.A. Mohammed, "A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems", Renewable and Sustainable Energy Reviews 15 (2011) 310–323
[6] Muhammad Abbas, Rashmi G. Walvekar, Mohammad Taghi Hajibeigy, Farhood S. Javadi, "Efficient Air-Condition Unit By Using Nano-Refrigerant", EURECA 2013
[7] Halil Dogacan Kocaa, Serkan Doganayb, Alpaslan Turgutc, Ismail Hakki Tavmanc, R. Saidurd, Islam Mohammed Mahbubulf, "Effect of particle size on the viscosity of nanofluids: A review", Renewable and Sustainable Energy Reviews, j.rser.2017.07.016
[8] Mohamed R. Abdel Hady, M. Salem Ahmed, G. Abdallah, "Experimental investigation on the performance of chilled - water air conditioning unit using alumina nanofluids", Thermal Science and Engineering Progress S2451-9049(17)30123-3
[9] Ali Barati-Harooni, Adel Najafi-Marghmaleki, Armin Mohebbi, Amir H. Mohammadi, "On the prediction of viscosity of Newtonian nanofluids", Journal of Molecular Liquids (2017), doi: 10.1016/j.molliq.2017.06.088
[10] D. Han, W.F. He, F.Z. Asif, "Experimental study of heat transfer enhancement using nanofluid in double tube heat exchanger", Energy Procedia 142 (2017) 2547–2553
[11] S. Ferrouillat, André Bontemps, João-Paulo Ribeiro, Jean-Antoine Gruss, Olivier Soriano, "Hydraulic and heat transfer study of SiO2/water nanofluids in horizontal tubes with imposed wall temperature boundary conditions", International Journal of Heat and Fluid Flow 32 (2011) 424–439
[12] Fatou Toutie Ndoye, Patrick Schalbart, Denis Leducq, Graciela Alvarez, "Numerical study of energy performance of nanofluids used in secondary loops of refrigeration systems", International journal of refrigeration 52 (2015) 122-132
[13] E. Ebrahimnia-Bajestan, Mohammad Charjouei Moghadam, Hamid Niazmand, Weerapun Daungthongsuk, Somchai Wongwises, "Experimental and numerical investigation of nanofluids heat transfer characteristics for application in solar heat exchangers", International Journal of Heat and Mass Transfer 92 (2016) 1041–1052
[14] Adriano Akel Vasconcelos, Abdul Orlando Cárdenas Gómez, Enio Pedone Bandarra Filho, José Alberto Reis Parise, "Experimental evaluation of SWCNT-water nanofluid as a secondary fluid in a refrigeration system", Applied Thermal Engineering (2016), j.applthermaleng.2016.06.126
[15] Murat Unverdi and Yasar Islamoglu, "Effect of Al_2O_3 Nanomaterials on Convection heat transfer enhancement in a plate heat exchanger channel" Scientific Proceedings XIII International Congress, Machines Technologies Materials 2016 – Winter Session.
[16] Ramtin Barzegariana, Alireza Aloueyanb, Tooraj Yousefic, "Thermal performance augmentation using water based Al_2O_3-gamma nanofluid in a horizontal shell and tube heat exchanger under forced circulation", International Communications in Heat and Mass Transfer 86 (2017) 52–59
[17] Mahdi Daneshipour, Roohollah Rafee, "Nanofluids as the circuit fluids of the geothermal borehole heat exchangers", International Communications in Heat and Mass Transfer 81 (2017) 34–41
[18] Joanna Wilk, Robert Smusz, Sebastian Grosicki, "Thermophysical properties of water based Cu nanofluid used in special type of coil heat exchanger", Applied Thermal Engineering 127 (2017) 933–943
[19] A.E. Kabeel, T. Abou El Maaty, Y. El Samadony, "The effect of using nano-particles on corrugated plate heat exchanger performance", Applied Thermal Engineering 52 (2013) 221-229
[20] A.K. Tiwari, P. Ghosh, J. Sarkar, "Performance comparison of the plate heat exchanger using different nanofluids", Experimental Thermal Fluid Sci. 49 (2013) 141–51.
[21] Vikas Kumar, Arun Kumar Tiwari, Subrata Kumar Ghosh, "Characterization and performance of nanofluids in plate heat exchanger", 5th International Conference of Materials Processing and Characterization (ICMPC 2016)
[22] Mehdi Bahiraei, Reza Rahmani, Ali Yaghoobi, Erfan Khodabandeh, Ramin Mashayekhi, Mohammad Amani, "Recent research contributions concerning use of nanofluids in heat exchangers: A critical review", Applied Thermal Engineering (2018), doi: https://doi.org/10.1016/j.applthermaleng.2018.01.041
[23] Akyürek, E.F., Geliş, K., Şahin, B., Manay, E., Experimental Analysis for Heat Transfer of Nanofluid with Wire Coil Turbulators in a Concentric Tube Heat Exchanger, Results in Physics (2018), doi: https://doi.org/10.1016/j.rinp.2018.02.067
[24] Nilesh Purohit, Varun Anand Purohit, Kamlesh Purohit, Engineering Science and Technology, an International Journal 19 (2016) 574–586