NUMERICAL STUDY OF HEAT TRANSFER PERFORMANCE AND FLOW CHARACTERISITCS OF TWISTED TUBE, HELICAL TUBE AND PLAIN TUBE.

Mr. Thota Pavan Sai Narasimha[1], Mr. Varun N Shenoy[2], Ms. Rakshitha V[3], Mr. Rakesh Mohan Kumar[4], Mr. Naveen H E[5]

[1]Mr. Thota Pavan Sai Narasimha: Student, Dept. of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.
[2]Mr. Varun N Shenoy: Student, Dept. of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.
[3]Miss. Rakshitha V: Student, Department of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.
[4]Ms. Rakesh Mohan Kumar: Student, Department of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.
[5]Mr. Naveen H E: Assistant Professor, Dept. of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.

Abstract - *The thermal performance and compactness of the heat exchanger plays a supreme role in designing them because of their enormous number of applications. In majority of the application plain tubes are used. So in the view of this many active and passive techniques are used. The main aim of the study is to analyze thermal performance and flow characteristics of two passive types twisted tube and helical tube and compare them with the conventional plain tubes. Also in this study the effect of geometric parameters of twisted oval tube on its thermal performance is analyzed. The hydraulic diameter, length of the heated zone, boundary conditions and type of material used is kept the same for all the tubes. The Nusselt's number, pressure drop and friction factor of all tubes are compared for the same set of Reynolds number varying from 500-10000. In addition to this the feasibility of twisted tube having twisted and non-twisted connecting ends for multipass applications are analyzed computationally.*

Key Words: Twisted oval tube, Heat transfer enhancement, Multipass heat exchanger, twist ratio.

1.INTRODUCTION

Heat exchanger is a device which is used to exchange heat between two fluids. Heat exchangers have various industrial and engineering applications. exchangers is intricate, as it needs inception and analysis of heat transfer rate and pressure drop calculations. The utmost issue in designing a heat exchanger is to make the apparatus close packed and to attain a high heat transfer rate using least pumping power. The high cost of energy and material has resulted in an increased endeavor at producing more efficient heat exchange apparatus. In the view of this the heat transfer rate can be improved by either active or passive methods. The active method requires outer power, for example, electric field or surface vibration for improvement in heat transfer and it has not shown much improvement due to complexity in design and also external power is not easy to provide in several applications. Passive method does not need any external power input and the extra power required to enhance the heat transfer is obtained from the available power in the system, which eventually leads to pressure drop.

The thermal performance of the tubes is analyzed based on Nusselt's number.

The flow characteristics which are analyzed in this study are pressure drop and friction factor. The pressure drop is the difference between the total pressure at inlet and outlet of the tube. The friction factor is a dimensionless number which represents the resistance of the flow due the interaction in between the fluid and the pipe.

The twisted tube is one of the passive heat transfer improvement methods. Compared with the common plain tube, twisted tubes change the linear flow into a spiral flow, resulting in a secondary flow perpendicular to the main flow direction. The geometrical features of a twisted tube are twist pitch (S), major dimension of the cross section (a) and minor dimension of the cross section(b). The intensity of twisting is described by the twist ratio (twist pitch / hydraulic diameter). The intensity of tube flattening is described by aspect ratio (a/b). The twist and aspect ratio of the twisted oval tube which is analyzed is equal to 10 and 2 respectively. Helical tubes are generally used in applications such as food processing, refrigeration, heat recovery systems. The geometrical features of helical tube are curvature ratio (mean coil diameter / tube diameter), and pitch (p). The curvature ratio of the helical tube which is analyzed 9.

2. LITERATURE SURVEY

This section of the report addresses research work carried out by various researchers in the fields of forced internal convection, computational fluid dynamics. This forms the basis for future work to be carried out, and acts as motivation for future research work.

Tang et al.[1] Analyzed the "effect of the geometrical parameters on the flow characteristics and heat transfer performance of twisted oval tube and twisted tri lobed tube for Reynolds number in the range of 8000 to 21000, using water as the working fluid. Result showed that friction factor and heat transfer performance increased with the reduction of twisted pitch".

Bhadouriya et al.[2] Investigated "friction factor and heat transfer characteristics inside twisted squared duct with air flow and results showed that the maximum value for the product of Reynolds number and friction factor was observed for twisted ratio of 2.5 and Reynolds number 3000. It was also found that performance of twisted duct was enhanced in laminar and to some extent in turbulent flow region due to strong presence of secondary flow".

X.H. Tan et al.[3] Studied "fluid flow and heat transfer in twisted oval tubes for Reynolds number in a range of 10000 to 60000 and found out that the heat transfer coefficient and friction factor both were enhanced with the increase of axis ratio, while both decreased with the increase of twisted pitch length. It was also observed that the synergy angle between the velocity vector and temperature gradient was reduced and heat transfer process enhanced".

Wang et al.[4] "The turbulent heat transfer in twisted square duct were investigated and results showed that the twisted divergent duct always enhanced heat transfer, the twisted convergent duct always decreased heat transfer and the twisted constant cross section duct was somewhat in between".

Guo et al.[5] "Numerically studied that the friction factor and heat transfer characteristics in a circular tube with laminar flow, fitted with centre cleared twisted tape. The result showed that the thermal performance of the tube with centre cleared twisted improved by 7% to 20% and the flow resistance could be reduced compare with the conventional twisted tape".

X.N. Gao et al.[6] "Experimental investigation was carried out for the flow resistance and the heat transfer characteristics flow of water inside the twisted tube which have large twist ration in turbulent flow and transition flow regime. The friction factor and Nusselt number for twisted tube are comparatively higher than smooth tube. It was also seen that friction factor and Nusselt number increased with the decrease of twist pitch or with the increase of aspect ratio".

Joseph Adler et al.[7] "The effect of laminar flow inside a helical coil tube was studied and result showed that the secondary flow pattern depends on the relative strength of wall velocity and velocity of flow through the tube".

Dravid et al.[8] "Numerical research was carried out to understand the effect of secondary flow on the heat transfer in helical tube. A secondary flow which is normal to the primary direction of flow with circulatory effects was generating by centrifugal forces, that increases both the rate of heat transfer and friction factor. The intensity of secondary flow developed in the tube is the function of coil diameter and tube diameter".

K.S. Bharuka et al.[9] "Investigated the characteristics of heat transfer in helical tube and found that the heat transfer coefficient increases with dean number".

3. OBJECTIVES

The objectives of the study are:

- To numerically investigate and compare heat transfer performance and flow characteristics of twisted tube, helical tube and plain tube for Reynolds number ranging from 500 to 10000.
- To find out the effect of twist ratio of a twisted tube on Nusselt's number and pressure drop.
- To investigate the effect of twisted and non-twisted connecting ends on performance of twisted tubes.
- To determine the feasibility of twisted tube in different application like radiators, air conditioner etc. based on pressure drop, ease of fabrication and thermal performance.

4. METHODOLOGY

This chapter gives a description about the methodology incorporated and also explains about the parameters considered for the work. The following flow chart represents the methodology process.

A. Problem Definition:

Majority of the heat exchangers consists of plain tube for transportation of the fluid. So, our research is mainly focused on finding out the thermal performance, flow characteristics and feasibility of twisted tube and helical tube in thermal engineering applications.

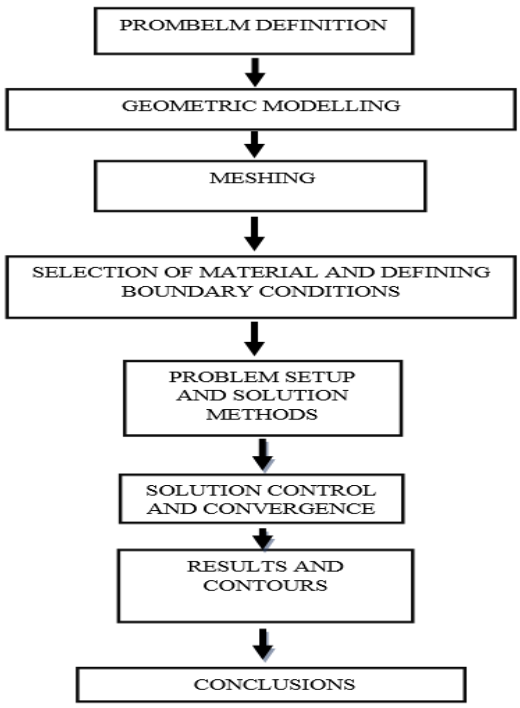

Fig -2: Methodology Flowchart

B. Geometric modelling:

- The geometry of straight tube and the helical tube was created in Ansys workbench design modeler.
- AutoCAD software is used for creating geometries of twisted tube, twisted tube with connecting and non-connecting ends and later these models were imported to Ansys workbench.
- All the geometries were divided into 4 parts and named accordingly such as inlet, entry region, heated zone and outlet.
- diameter, length of inlet zone, length of heated zone and length of outlet zone for all the tubes are 5×10^{-3}m ,0.075m,0.3m and 0.025m respectively.
- For Helical tube: curvature ratio=9, pitch=50.1403 mm, number of turns = 2.
- For Twisted tube: aspect ratio = 2, twist ratio considered are: 5,10 and 15.
- For twisted tube with twisted and non-twisted connecting ends the curvature ratio considered is 6.36.

Fig.1. Straight tube

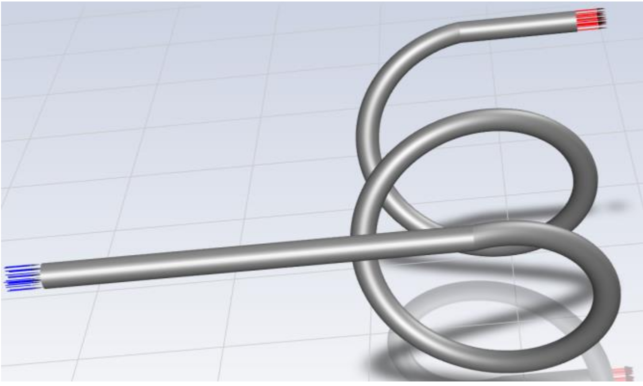

Fig.2. Helical tube

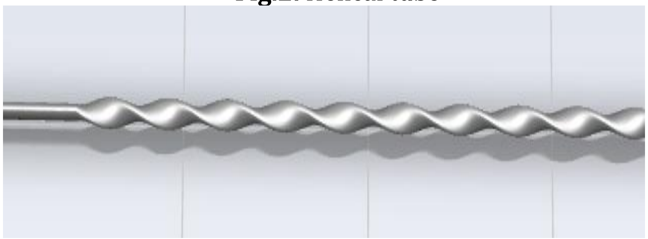

Fig.3. Twisted tube

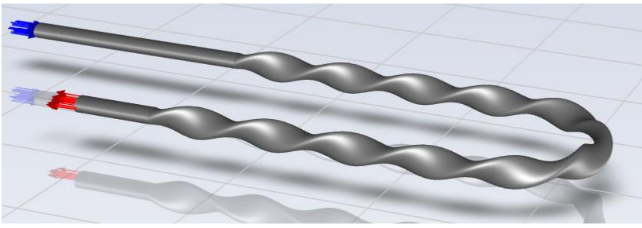

Fig.4. Twisted tube with twisted connecting ends

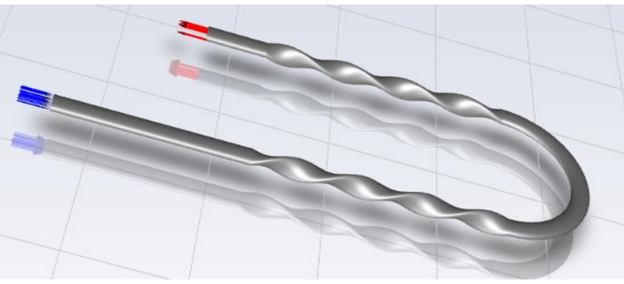

Fig.5. Twisted tube with non-twisted connecting ends

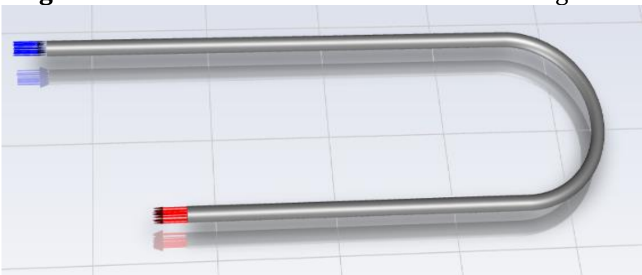

Fig.6. Plain tube with non-twisted connecting ends

C. Meshing:

- For all the models the mesh was created using the meshing module of the Ansys workbench.
- For straight and helical tube, the mesh contained mixed cells of (tetra and hexahedral cells) having quadrilateral faces at the boundaries.
- For twisted tube, twisted tube with twisted and non-twisted connecting ends, the mesh contained mixed cells of (tetra and hexahedral cells) having both quadrilateral and triangular faces at the boundaries.
- Structured hexahedral cells are considered as much as possible to reduce errors caused by numerical diffusion.
- The face size and number of the meshing elements to be considered is determined by performing grid independent test.

D. Selection of material and defining boundary conditions:

- Inlet and outlet zone are covered with an adiabatic wall.
- The heated zone is maintained at constant surface temperature 350.15K and inlet temperature of water is 300.15K.
- The turbulent intensity is considered to be 5% for all the cases (except for laminar Straight tube and helical tube).

- The outlet was defined as the pressure outlets and the pressure is kept at default atmospheric pressure.
- Properties of water employed in the simulation are:

ρ	μ	C_p	λ
$998.25\frac{Kg}{m^3}$	$0.0008845\frac{N\,s}{m^2}$	$4.17\frac{KJ}{Kg-K}$	$0.6\frac{W}{m-K}$

E. Problem setup and solution methods:

- The model is solved using Fluent solver from the Ansys workbench. Initially the meshing is checked and steady state pressure-based solver is selected.
- For helical tube the continuity, momentum and energy equations were used.
- For straight tube the continuity, momentum, energy and Realizable K- $\mathcal{E}$ models were used. The Realizable K- $\mathcal{E}$ model is used only for Reynolds number varying from 3000 to 10000.
- For twisted tube, twisted tube with twisted and non- twisted connecting ends the continuity, momentum, energy equations and Realizable K- $\mathcal{E}$ models were used.
- The Semi-implicit method for pressure linked equation (SIMPLE) is used for pressure velocity coupling.
- Second order upwind scheme is used for discretization of the Turbulent kinetic energy, turbulent dissipation rate, energy and for momentum equations.
- Least squares cell-based technique is used for gradient.

F. Solution control and convergence:

- Hybrid initialization method was used for initializing the flow variables because it had faster convergence compared to standard initialization.
- The convergence criteria were set to 10^{-5} for the three velocity components, $10^{-4}$for continuity, turbulent kinetic energy and for turbulent dissipation rate, 10^{-6} for energy.
- The number of iterations was set to 1000 with step size 1. The calculation is continued till the results are converged.

G. Results and contours:

CFD post results module from the Ansys workbench is used for obtaining the velocity, pressure and temperature distribution across the profile. Along with these, parameters like pressure drop and Nusselt's number is also obtained.

5. NUMERICAL SIMULATION

In this section the governing equations and the validation of the numerical results are discussed. To get the velocity and temperature distribution of straight tube, helical tube, twisted tube, twisted tube with twisted and non- twisted connecting ends are comparatively analyzed with Ansys 2021 R1(academic) software.

A. Mathematical model:

In the simulation of fluid flow, the continuity equation, energy equation, momentum equations are used for getting velocity and temperature distribution. The Realizable K-ε[13] model is used as turbulence model.
The governing equation in cartesian coordinate for a fully developed flow is shown below:
The continuity equation:

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}=0$$

The momentum equation:

$$\rho\frac{\partial u}{\partial t}+\rho v\frac{\partial u}{\partial x}=-\frac{\partial p}{\partial x}+\mu\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)$$

The energy equation:

$$\rho\frac{\partial T}{\partial t}+\rho\frac{\partial(uT)}{\partial x}=-p\frac{\partial u}{\partial x}+\lambda\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)$$

The k equation:

$$\rho\frac{\partial k}{\partial t}+\rho\frac{\partial(vk)}{\partial y}=\frac{\partial}{\partial y}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial y}\right]+\eta_t\frac{\partial u}{\partial v}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)-\rho\varepsilon$$

The $\mathcal{E}$ equation:

$$\rho\frac{\partial\varepsilon}{\partial t}+\rho\frac{\partial(v\varepsilon)}{\partial y}=\frac{\partial}{\partial y}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial\varepsilon}{\partial y}\right]+C_1\rho S\varepsilon-C_2\rho\frac{\varepsilon^2}{k+\sqrt{\vartheta\varepsilon}}$$

Where:

$$C_1=\max\left[0.43,\frac{\eta}{\eta+5}\right],\eta=\frac{Sk}{\varepsilon},S=\sqrt{2S_{ij}S_{ij}S_{ij}}=\frac{1}{2}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)$$

$$C_2=1.9,\sigma_\varepsilon=1.2,\sigma_k=1.0,\mu_t=c_\mu\rho k^2/\varepsilon$$

Here: μ_t is a function of mean strain and rotation rates.

B. Validation of numerical results:

- For turbulent flow Realizable K- $\mathcal{E}$ model is chosen, as suggested in the studies done by X.H. Tan[3]. Investigation done by X.H. Tan[3] showed that the Realizable K- $\mathcal{E}$ model had close tolerance with experimental results and predicted the characteristics better than standard K-ε model, K-ω model and RNG model.

C. Grid independence test:

- To verify the accuracy of our simulation the grid independence test has been performed.
- Grid independence test is carried out to find out the optimum size of the grid at which the parameters don't change with varying grid size of the mesh.
- In this method the same simulation is carried out on different types of grids. When the grid is good enough the solution does not change, so that the solution is grid independent.

- So, from this test the discretization error inherent in CFD is reduced.

Results of grid independence test for different geometries are shown blow:

a. Straight tube:

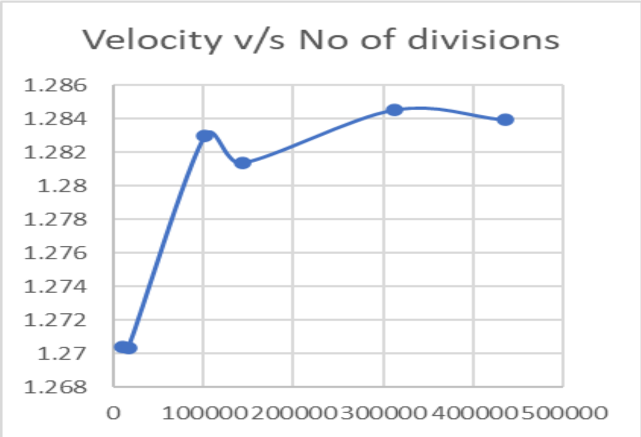

Fig.7. variation of outlet velocity with no.of divisions

b. Helical tube:

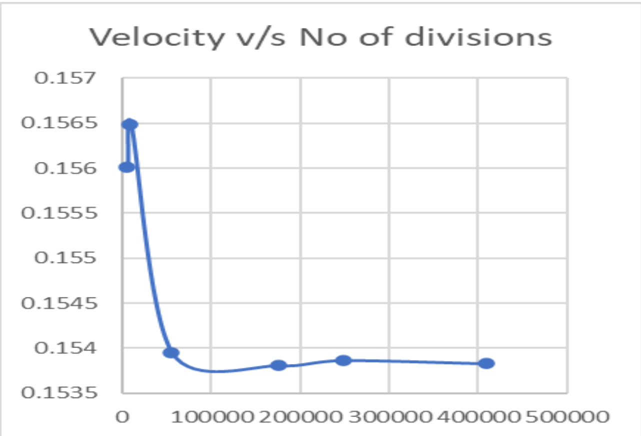

Fig.8. variation of outlet velocity with no.of divisions

c. Twisted tube:

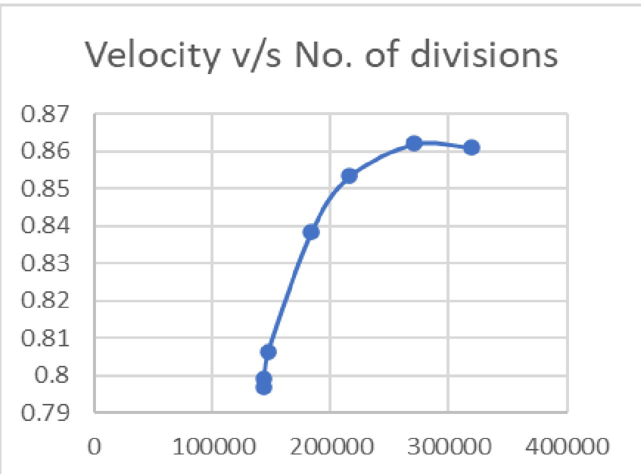

Fig.9. variation of outlet velocity with no.of divisions

6. RESULT AND DISCUSSION

In this chapter the results of numerical simulations of all the computational models are shown in graphical form.

A. Comparison of straight tube, helical tube and twisted tube:

Variation of Nusselt's number, friction factor and pressure drop for straight tube, helical tube and twisted tube are shown below:

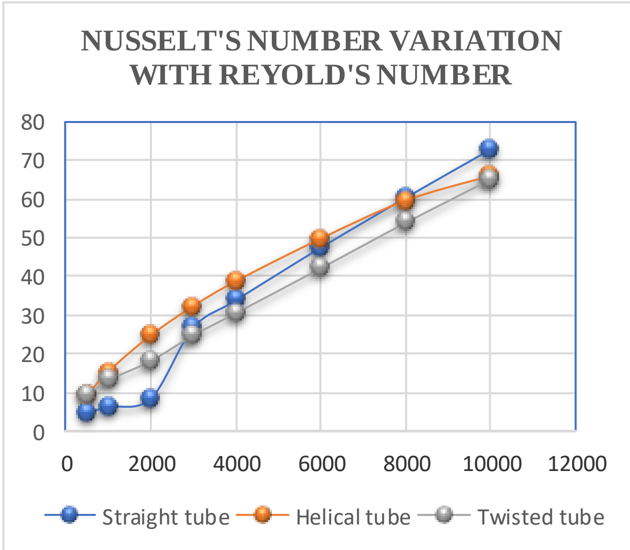

Fig.10. Nu v/s Re (Straight tube, helical tube and twisted tube)

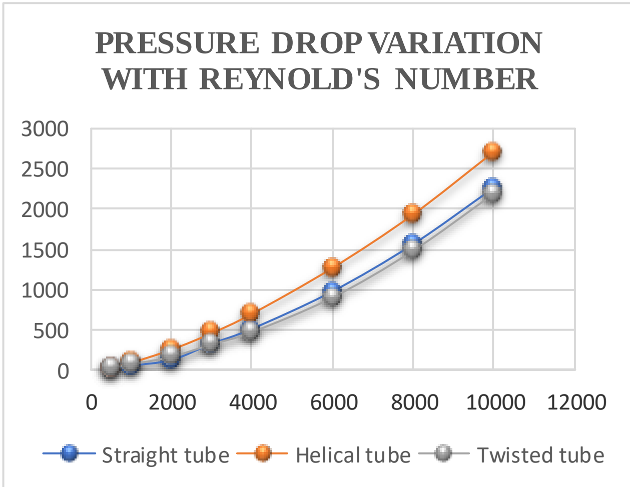

Fig.11. Pressure drop v/s Re (Straight, helical and twisted tube)

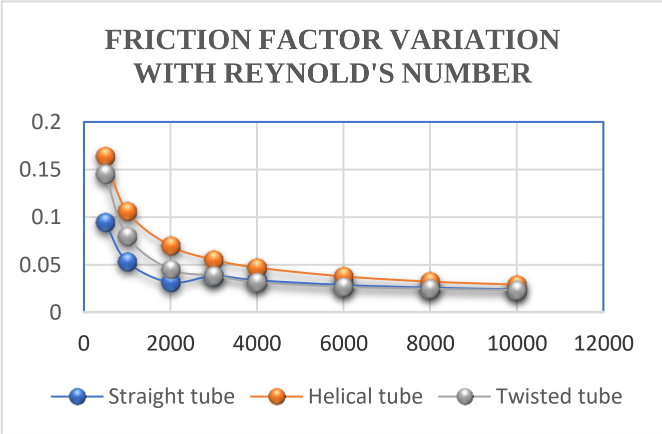

Fig.12. Friction factor v/s Re (Straight, helical, twisted tube)

B. Effect of twist ratio:

Variation of Nusselt's number, friction factor and pressure drop for twisted tube with various twist

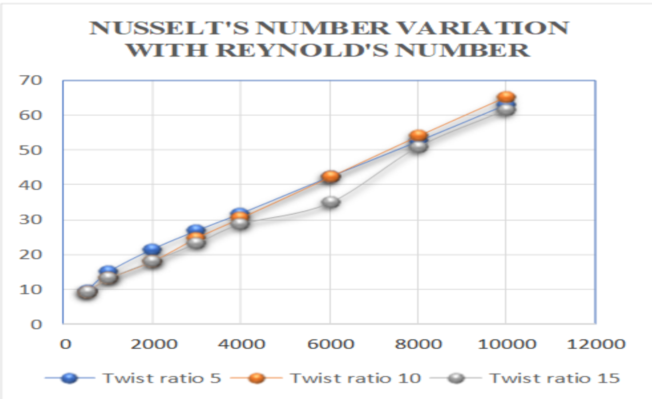

Fig.13. Nu V/S Re (Twisted tube with twist ratios 5,10,15)

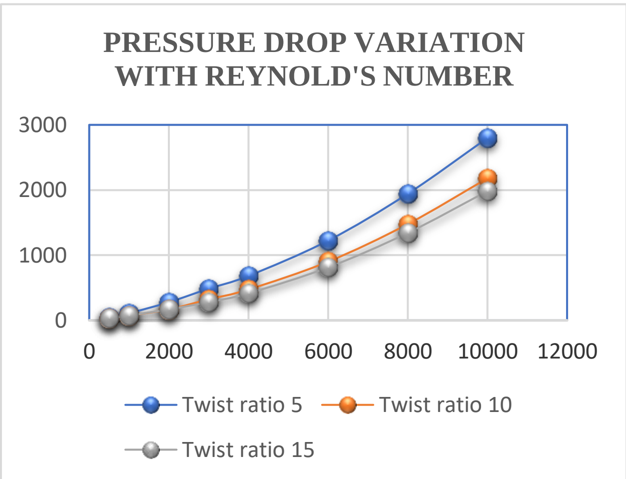

Fig.14. Pressure drop V/S Re (Twisted tube with twist ratios 5,10,15)

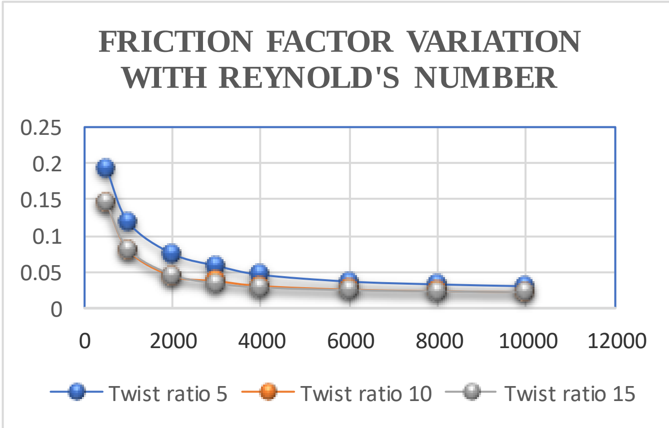

Fig.15. Friction factor V/S Re (Twisted tube with twist ratios 5,10,15)

C. Feasibility of twisted tube in multipass heat exchanger applications:

Variation of Nu, friction factor and ΔP with Reynolds number for straight tube with non-twisted connecting ends, twisted tube with twisted and non-twisted connecting ends.

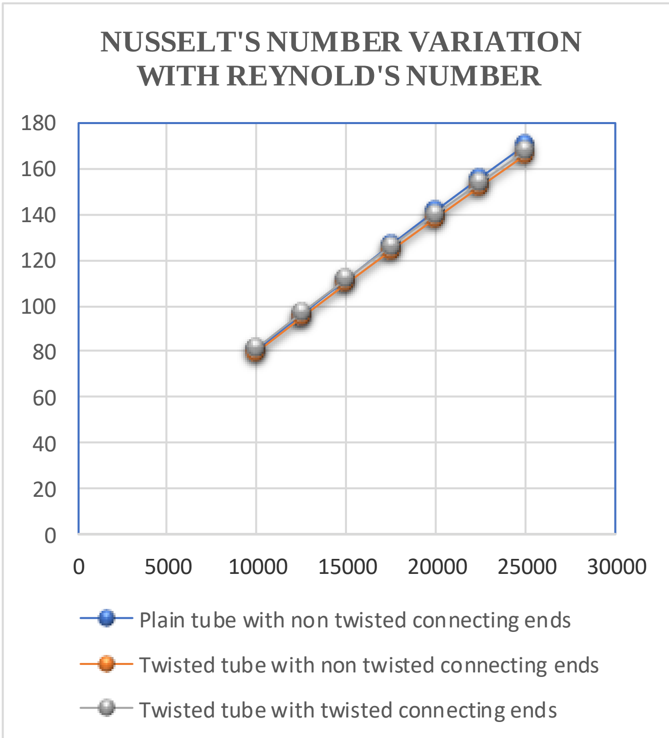

Fig.16. Nu V/S Re (Twisted tube with twisted connecting ends, plain tube and twisted tube with non-twisted connecting ends)

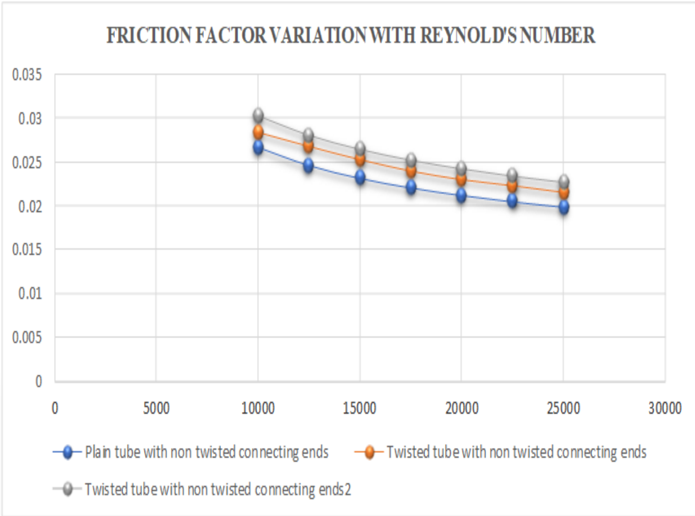

Fig.17. Friction factor V/S Re (Twisted tube with twisted connecting ends, plain tube and twisted tube with non-twisted connecting ends).

7. CONCLUSION AND FUTURE SCOPE

CONCLUSION:

The main purpose of the project is to study the thermal performance and flow characteristics of passive heat transfer enhancement techniques (twisted tube and helical tube) and their feasibility in heat transfer applications.
In this study we analysed:

1. The effect of twist ratio on heat transfer performance and flow characteristics of a twisted tube.
2. The effect of twisted and non-twisted connecting on heat transfer performance and their feasibility in multi pass heat transfer applications is also studied.
3. Flow characteristics and thermal performance of Twisted tube, Helical tube and straight and analysed and compared.

Some of the main findings from our project are listed below:

- On comparing the results of twisted tube, straight tube and helical tube the helical tube and twisted tube had better thermal performance in low Reynolds number region than the straight tube. So, by this we can conclude that for applications involving high viscous fluids helical and twisted tubes can be used instead of straight tube.

- The pressure drop in helical tube is found to be the highest of all the three tubes. So, due this the helical tube is only preferable when space is limited and pumping power is not an issue.
- In higher Reynolds number region straight tube showed slightly better thermal performance than the other two tubes. By this, for high Reynolds number application and for low viscous fluids straight tube is preferable.
- In this study twisted tube (aspect ratio-2) with 3 different twist ratio (5,10 and15) are analysed to find out the effect of twist ratio on thermal performance and on flow characteristics.
- The numerical results showed that the Nusselt's number increased with decreasing in twist ratio because as the twist ratio is decreasing the number of turns or twists for a fixed length of the tube will increase. So, due to this more no of turns or twists better mixture of flow is taking place or the secondary flow is having a more impact on heat transfer. Along with increase in heat transfer the pressure drop is also increasing with decrease in twist ratio. Based on these conclusions depending upon the required application suitable twist ratio should be chosen.
- On comparing the results of twisted tube with twisted connecting ends, twisted tube with non-twisted connecting ends and straight tube with non – twisted connecting ends, the plain tube with non-twisted connecting ends had best thermal performance and also had the least pressure among the other two. So, by this study we conclude that the plain with non- twisted connecting should be preferred in multipass heat transfer application over the other two.

- The twisted tube with twisted and non- connecting ends did not perform well because the flow tries to generate swirl in the twisted part, but as the length was very short fully developed velocity profile is not produced. With the undeveloped velocity and temperature profile synergy is not established. Thus, heat transfer is not good.

FUTURE SCOPE:

Future works required to be carried out for further improvement are list below:

1. To find out the effect of the curvature ratio of helical tube on heat transfer performance and flow characteristics.
2. To find out the effect of aspect ratio of twisted tube on heat transfer performance and flow characteristics.
3. Further this work can be extended by carrying out the simulation on tubes with connecting ends for different curvature ratios.
4. Finding out the heat transfer and flow characteristics for a twisted tube with non-uniform pitch.

ACKNOWLEDGEMENT

We would like to mention a few people whose support was instrumental in completing our project.

We would like to thank Dr. Subhash S Kulkarni, Principal for providing excellent infrastructure and everlasting support to make this project a success.

We would like to extend our gratitude towards Dr. SV Satish, Head of Department, for his support and encouragement.

We express our sincere gratitude towards our guide Mr. Naveen H E, Assistant Professor, Department of Mechanical Engineering, for his vital support, guidance, and encouragement throughout the project.

Finally, we would like to extend our gratitude to all the department faculties and non-teaching staff for their insightful comments and encouragement.

REFERENCES

[1] X.Y. Tang, X.F. Dai, D.S. Zhu, Experimental and numerical investigation of convective heat transfer and fluid flow in twisted spiral tube, Int. J. Heat Mass Transf. 90 (2015) 523–541.
[2] R. Bhadouriya, A. Agrawal, S.V. Prabhu, Experimental and numerical study of fluid flow and heat transfer in a twisted square duct, Int. J. Heat Mass Transf. 82 (2015) 143–158.
[3] X.H. Tan, D.S. Zhu, G.Y. Zhou, Experimental and numerical study of convective heat transfer and fluid flow in twisted oval tubes, Int. J. Heat Mass Transf. 55 (17–18) (2012) 4701–4710.
[4] Wang LB, Tao WQ, Wang QW, He YL (2001) Experimental and numerical study of turbulent heat transfer in Twisted Square ducts. J Heat Transfer 123:868–877.
[5] Guo J, Fan AW, Liu W (2011) A numerical study on heat transfer and friction factor characteristics of laminar flow in a circular tube fitted with center-cleared twisted tape. Int J Therm Sci 50:1263– 1270.
[6] X.N. Gao, H.C. Zou, D.Y. Wang, Y.S. Lu, Heat transfer and flow resistance properties in twisted oblate tube with large twist ratio, Journal of South China University of Technology (Natural Science) 36 (11) (2008) 17e21 26(in Chinese).
[7] Joseph, B., Adler, R.J., 1975. Numerical treatment of laminar flow in helically coiled tubes of square cross section. Part II: Oscillating helically coiled tubes. AIChE Journal, 21(5):974-979.
[8] Dravid, A.N., Smith, K.A., Merril, E.W., Brian, P.L.T., 1971. Effect of secondary fluid motion on laminar flow heat transfer in helically coiled tubes. AIChE Journal, 17(5): 1114-1122.
[9] K.S. Bharuka, D.Y. Kasture, 1984, Flow through a helically coiled annulus, Applied Science Research, 41, 55–67.
[10] Yunus A. Çengel - Heat Transfer_ A Practical Approach-McGraw-Hill ,2nd edition (2002).
[11] Mehdi Gobadi - Experimental Measurement and Modelling of Heat Transfer in Spiral and Curved Channels
[12] Heat and mass transfer data hand book- Ninth Edition by C P Kothandaraman and S Subramanyam published by new age international publishers Pvt. Ltd.
[13] T.H. Shih, W.W. Liou, A. Shabbir, Z.G. Yang, J. Zhu, A new k-e eddy viscosity model for high Reynolds number turbulent flows, Comput. Fluids 24 (3) (1995).
[14] Ansys Fluent 12.0 User guide
[15] Launder BE, Sharma BI (1974) Application of the energy dissipation model of turbulence to the calculation of flow near a spinning disc. Lett Heat Mass Transf 1:131–138.
[16] Jones QP, Launder BE (1972) The prediction of laminarization with a two-equation model of turbulence. Int J Heat Mass Transf 15: 301–314.
[17] Jones QP, Launder BE (1973) The calculation of low-Reynolds number phenomena with a two-equation model of turbulence. Int J Heat Mass Transf 16:1119–1130.