CFD Analysis for the Enhancement of Heat Transfer in a Heat Exchanger with Cut Twisted Tape Inserts

K.P.V. Krishna varma[#1], P.S. Kishore[*2], TulasiTirupathi[#3]

Assistant Professor, Mechanical Engineering, CMRCET, Hyderabad, Telangana, India

Professor, Mechanical Engineering, A.U. College of Engineering, Visakhapatnam, A.P, India

Associate Professor, Mechanical Engineering, CMRTC, Hyderabad, Telangana, India

Abstract

Insertion of twisted tapes into the tubes of the heat exchangers is a stature for enhancement of heat transfer to increase the performance of heat exchangers. In the present Research work, computational analysis has been carried out to analyze the enhancement of rate of heat transfer using varying cross sectional cut twisted tape (VCSCTT) inserts in a double pipe U bend heat exchanger (counter flow). Geometrical model of a double pipe U bend heat exchanger has been generated and computational mesh is created using ICEM CFD, an advanced meshing software. The analysis has been carried out for plain tube and with varying cross sectional cut twisted tape (VCSCTT) inserts with a twist ratio of 3 to analyze the temperature distribution, velocity distribution and pressure distribution along the tubes and shell using ICEM CFD. The contours has been plotted for the flow rate of the hot fluid at 6LPM in the annulus and flow rate of the working fluid in the tube side at 6LPM under turbulent flow conditions. From the temperature contours and velocity vector plots, the heat transfer characteristics like Nusselt number, heat transfer coefficients and pressure variation for VCSCTT inserts have been compared with that of the plain tube data. From the obtained velocity contours it has been found that the varying cross sectional cut provided in the twisted tapes enhance the eddy flow and create vortex which leads to the formation of more turbulent flow. This increases the rate of heat transfer in the tubes .Thus there is an considerable increase in Nusselt number and heat transfer coefficient with varying cross sectional cut inserts when compared with that of the plain tube.

Keywords : Varying cross sectional cut twisted tapes, Nusselt number, heat transfer coefficient, twist ratio

I INTRODUCTION

Double pipe heat exchangers are widely used in industrial and engineering applications like HVAC, heat recovery, refrigeration, chemical reactors etc because of the maximum temperature difference that can be established by them between the shell side and tube side fluids. Enhancement of heat transfer in double pipe heat exchangers using CFD has been reported in the literature. [1] **Kanade Rahul H.et.al** illustrated that the internal aluminum baffles of semicircular and quarter circular geometries arranged on outer surface of inner pipe of DPHE enhanced the rate of heat transfer using CFD.[2] **D.Bhanuchandrarao et.al** analyzed the temperature drops as a function of both inlet velocity and inlet temperature for both parallel and counter flow heat exchangers experimentally and numerically with fouled piping and concluded that the fouled piping provides lesser rate of heat transfer. [3]**Agniprobho Mazumder et.al**. Proposed a linear model of a double pipe heat exchanger considering it as a black box and carried out analysis to determine the outlet temperatures to justify a linear approximation by varying the inlet temperatures, mass flow rates of hot and cold fluids. Use of twisted tape inserts is a passive technique for enhancement of heat transfer characteristics in a heat exchanger without affecting the overall performance of the system. Heat transfer enhancement has been achieved using various types of twisted tapes like full length, half length, varying length, twisted tape with baffles, surface modified twisted tapes etc. Rate of heat transfer has been enhanced by using different twist geometries and with different twist, width ratios. [4] **C Rajesh Babu et.al.** inserted helical inserts in a double pipe heat exchanger and carried CFD analysis with different boundary conditions of hot and cold fluids and concluded that with helical twisted tapes 10-15% of enhancement of heat transfer has been achieved with an allowable pressure drop .[5] **Patnala Sankara Rao et.al.** Carried out CFD analysis with helical insert in annulus and twisted tape insert in the tubes and determined the enhancement in heat transfer and corresponding friction factors. The results obtained are compared with that of the experimental values and concluded that there is a considerable enhancement in rate of heat transfer with helical and twisted tape inserts with an allowable pressure drop.[6] **Bharat Bhushan Verma et.al.** Developed a 3-D analytical model and analyzed the characteristics of heat transfer in a heat exchanger with helical tape inserts with different pitch length. It is concluded that with decrease in pitch length, the rate of heat transfer has been increased. [7] **J.Kalil Basha et.al**. Studied the effect of wire coiled coil matrix turbulator, taper wire coiled turbulator, and pin wire coiled turbulator on the heat transfer for a fully developed turbulent flow for different pitches of the wire coils. The rate of heat transfer increased with the decrease of the pitch of the wire coils. [8] **Deepali Gaikwad et.al.** used twisted wire brush inserts to enhance the rate of heat transfer in a double pipe heat exchanger.[9] **M. Sandeep et.al.** Developed a numerical model and investigated the effect of twist ratio in a double pipe heat exchanger. The results depicted that with the decrease in twist ratio, there is an increase in the rate of heat transferred. Cut provided on the surface of the twisted tapes also provide a considerable augmentation of heat transfer in heat exchangers as the cut provided increase the turbulence intensity near the tube walls.. [10] **Pratik P. Ganorkar et.al**.Carried out experimental investigation for enhancement of heat transfer using an elliptical cut twisted tape insert of different major and minor axis ratios. The obtained results shows that the mean Nusselt number and the mean friction factor in the tube with elliptical-cut twisted tape increase with decreasing major to minor axis ratio(Z).[11] **Bodius Salam et.al** used rectangular cut twisted tape insert to augment the heat transfer when compared to plain tube. It is found that there is a considerable increase in Nusselt number and heat flux 2.3 to 2.9 times and 68% than the smooth tube respectively. [12] **Pawan A. Sawarkar et.al.** Investigated the effect of semi circular cut twisted tapes in a horizontal tube. The results showed that the use of semi circular cut inserts generate turbulence and superimposed vortex motion causing a thinner boundary layer and resulting in increase of heat transfer coefficient and less flow resistance. [13] **Sami D. Salman et.al.**Carried out numerical investigation to determine heat transfer coefficient and friction factor using CFD. For the analysis they considered classical and quadrant cut twisted tapes with three twist ratios and various depth of cuts. It was found that with decrease in twist ratio and depth of cut, there is an enhancement in heat transfer and friction factor.

II OBJECTIVE OF THE WORK:

From the literature, various cut inserts of regular geometry like rectangular cut, semi circular cut, elliptical cut, trapezoidal cut have been used in the heat exchangers for the enhancement of heat transfer. In the present work, the focus is to study the effect of the varying cross sectional cut provided on the twisted tape insert. For this two varying cross sectional cut twisted tape inserts have been placed in the inner tubes of a Double pipe U- tube heat exchanger. One at the entry of the inner tube and the other at the exit of the outer tube respectively. Temperature, pressure and velocity distribution has to be analysed for plain tube and for plain tube with varying cross sectional cut twisted tape inserts.

III: MODEL OF THE HEAT EXCHANGER

A Double pipe U bend heat exchanger with two tubes is modelled and meshed using ICEM CFD software. The geometric model as shown in fig.1The heat exchanger has two shells and two inner tubes. The inner diameter of the tubes is 0.017m and the outer diameter of the inner tubes is 0.019m. The tubes are made up of copper and the shell mild steel. The length of the shell is 2.8m (2*1.4m) and the length of the tubes 5.6 m (4*1.4m). The model of the heat exchanger is as shown in the figure below:

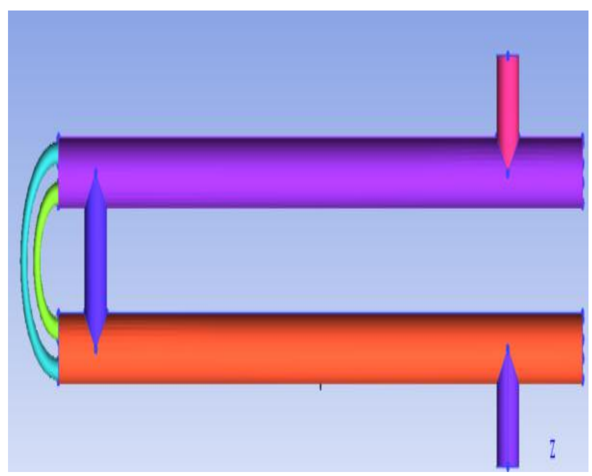

Fig.1Geometric model of a Double pipe Heat Exchanger

IV GEOMETRY OF TWISTED TAPE:

Varying cross sectional cut is provided on the regions of the periphery of the alternative surfaces of plain twisted tape insert. The modelling is done in CATIA and is imported into ICEM CFD software. The varying cross sectional cut twisted tape insert is of 1mm thick, one meter length and has a h/d ratio of 3.The width being 15mm and pitch being 45mm.

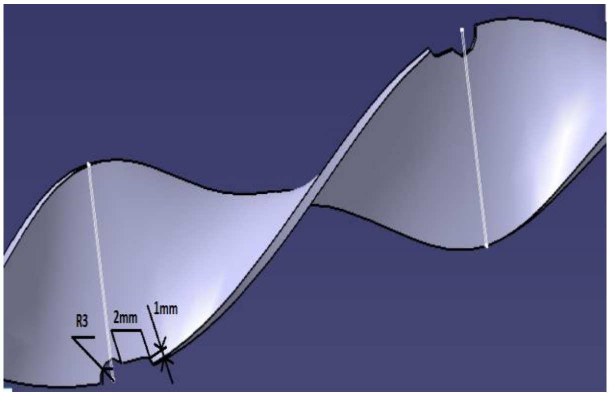

Fig.2 Model of varying cross sectional cut twisted tape insert.

V MESHING

The heat exchanger model is meshed using mesh and grid independence test was conducted for 6Lpm of hot water and 6lpm of cold water by increasing and decreasing the size of the elements. The meshed model of the Double pipe U- tube heat exchanger is as shown in the fig.3:

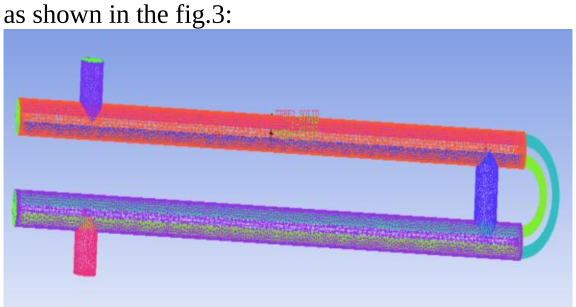

Fig.3.Meshed model of a plain U-tube Double pipe heat exchanger

VI Boundary conditions:

No slip condition is considered at the wall surfaces and the temperatures and mass flow rates are given at the inlets of the shell and tubes. The boundary conditions given are as shown in the tableI below:

A. Mass flow rate of hot fluid(LPM)	***6***
B. Mass flow rate of cold fluid(LPM)	*6*
C. Temp of hot fluid(K)	*303*
D. Temp of cold fluid(K)	*333*

Table I : Boundary conditions

VII PHYSICAL MODEL:

Since the Reynolds number used in the analysis is >2000, Turbulence model has to be used. In the current analysis, **SST K-** ϵ model is used for the analysis as the SST **K-** ϵ Model has low Reynolds number correction factor.

Results and Discussions:

For plain tube:

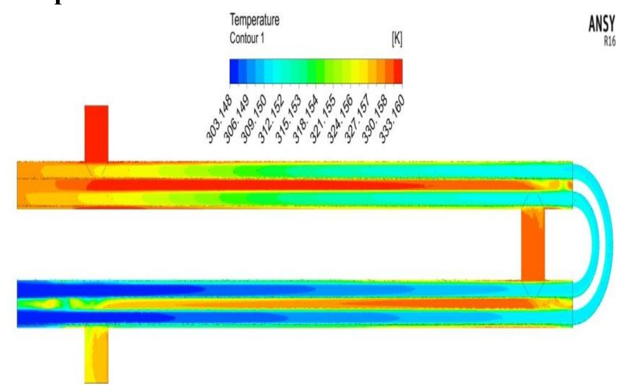

Fig.4. Temperature distribution in the shell and tube along centre plane

Fig.4. shows the temperature distribution in the shell and in the tubes. It is evident from the figure that there is a drop of 26.5deg centigrade in the shell and a rise of 12 deg centigrade is observed in the tubes. It has been found that in the upper shell, the velocity of hot fluid will be low. The hot fluid comes in contact with the cold fluid after some time. So the rate of heat transfer is found to be less. The hot fluid when it comes in contact with the cold fluid, i.e., in the region where the two shell are connected, the temperature began to drop drastically. In the tubes, the gain in temperature is found to be almost equal in the two tubes with a slight variation.

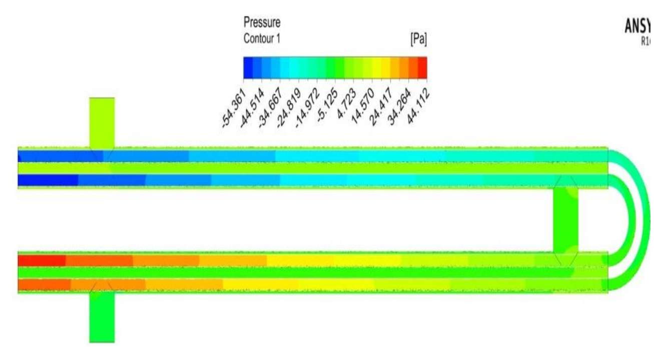

Fig.5. Pressure Distribution

The above figure shows the variation in pressure in the tubes and shell. There is not much variation found in the shell. But due to the bends in the tubes there is a drop in pressure in the two tubes.

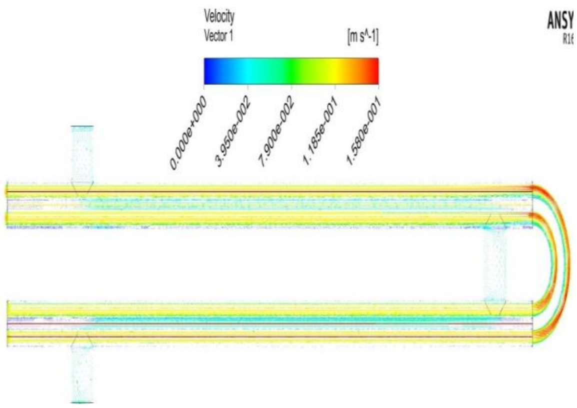

Fig.6. Velocity vectors along a central plane

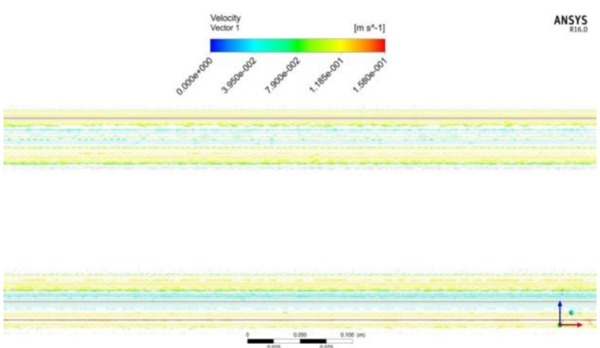

Fig.7. Closure view of Velocity variation along the center plane

Fig.6 and Fig7 represent the velocity variation along the center plane passing through the heat exchanger. The velocity contours show that the flow is parallel to the tubes of the heat exchanger and thus limiting the heat transfer to take place to the walls. Thus the rate of heat transfer is not uniform along the walls of the tubes. The values of heat transfer coefficient and Nusselt numbers for the shell side and tubes are as shown in the table II below:

S.NO	***Part***	***HeatTransfer coefficient***	***Nusselt Number***
1	*Tube1*	*9.407e+02*	*1.162e+02*
2	*Tube2*	*9.693e+02*	*1.198e+02*
3	*Shell*	*5.922e+02*	*7.318e+01*

TABLE:II: Heat transfer coefficient and Nusselt Numbers

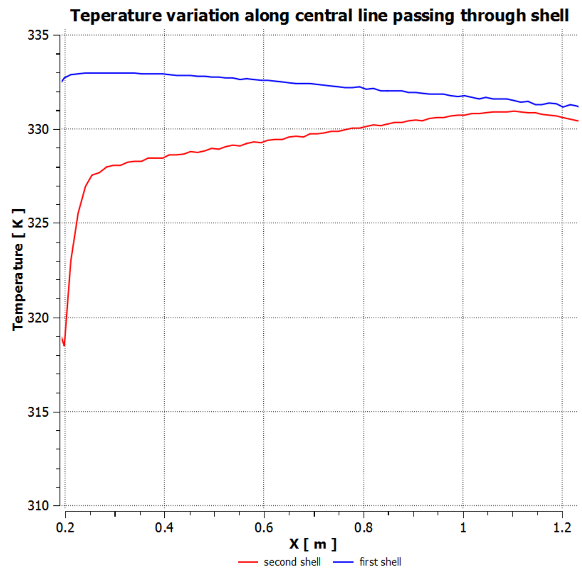

Fig.8. Temperature plot along the center line passing through the shell

The temperature profile along the central line passing through the shell of the heat exchanger is as shown in above fig. The temperature variation in the first shell is found to be very less compared to the variation in temperature in the second shell. Fig.8 shows that the variation in temperature in the first shell is very less .i.e., from 333deg to 331 deg centigrade. But the temperature drop in the second shell is found to be from 331 to 319 deg centigrade.

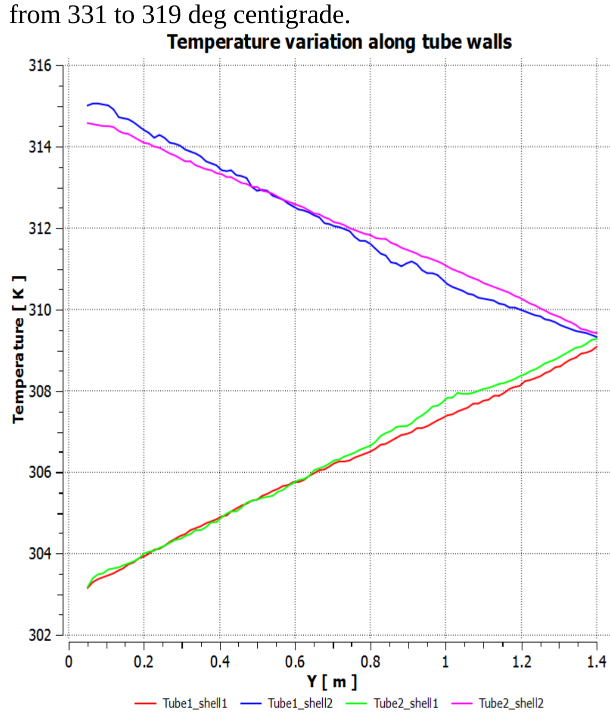

Fig.9. Temperature plot along the centre line passing through the tubes

The above figure shows the variation in temperature in the tubes along the length of the tubes. It can be clearly seen that in the tubes, there is an increase in temperature from 303 deg centigrade to 309 degree centigrade in one tube and in the other tube there is an increase of 310 to 315 degree centigrade.

For Plain tube with Varying cross sectional cut Insert

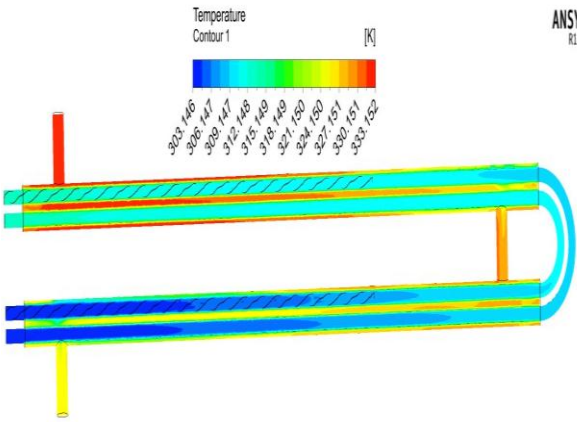

Fig.10.Temperature distribution along the centre plane

In the above figure it clearly depicts that due to the insertion of varying cross sectional cut twisted tape inserts, there is more contact of the cold fluid with hot fluid at the walls due to the decrease in the cross section of the tube at the insert and tube interface. This leads to an increase in surface area of contact at the walls and thus an increase in heat transfer rate. Thus there is an increase in temperature drop in the shell. Thus it can be seen that there is an increase in heat gained by the cold fluid inside the tubes also.

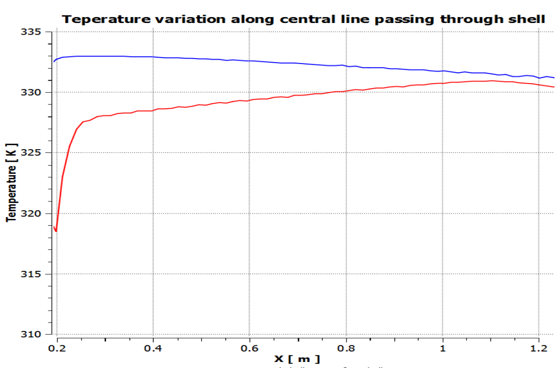

Fig.11. Temperature plot along the center line of shell

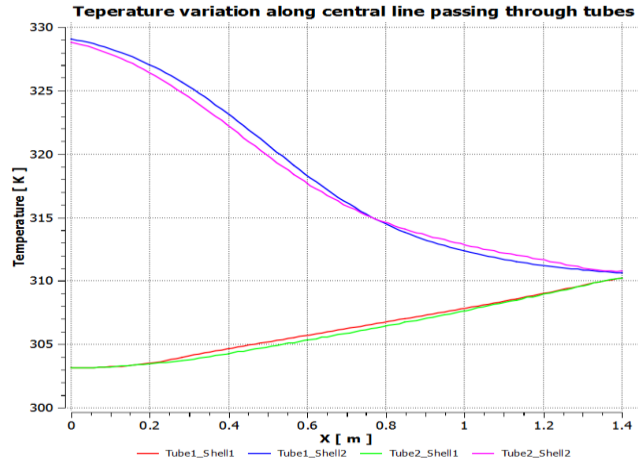

Fig.12. Temperature plot along the center plane

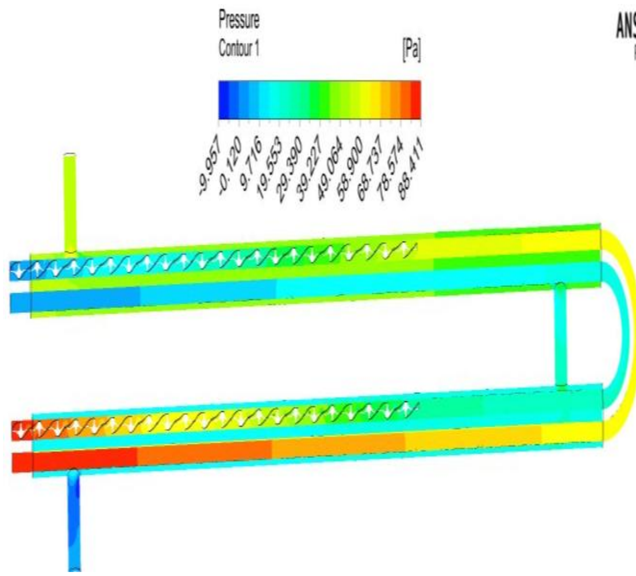

Fig.13. Pressure distribution along the center plane of heat exchanger

Due to the inserts provided inside the tubes of the heat exchanger, there is a considerable increase in pressure drop inside the tubes of the double pipe heat exchanger.

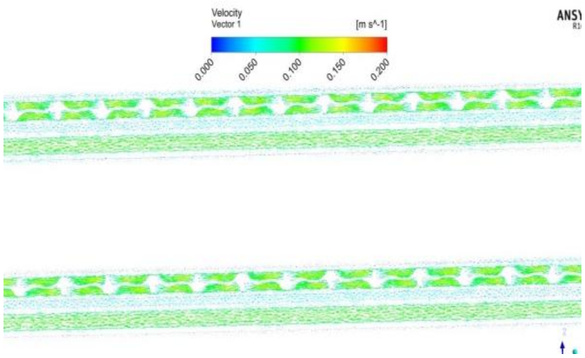

Fig.14. Velocity profile at the location of the inserts

The above figure depicts that as the water flows through the inserts, flow becomes more and more turbulent because of the curvature provided on the surface of the twisted tape inserts. The varying cross section increases the turbulence near the walls of the tubes. This results in thinning of the boundary layer. The swirl generated produces a vortex motion and thus enhances the turbulence. Because of this an additional turbulence is generated and thus an increase in heat transfer. Fig.14. shows the velocity profile generated inside the tube due to the presence of varying cross sectional cut twisted tape inserts. The curvature provided produce rotation of the fluid. So the flow will not be parallel to the tube but tends to move in tangential direction. This leads to more disturbance in the fluid which creates a whirling motion.

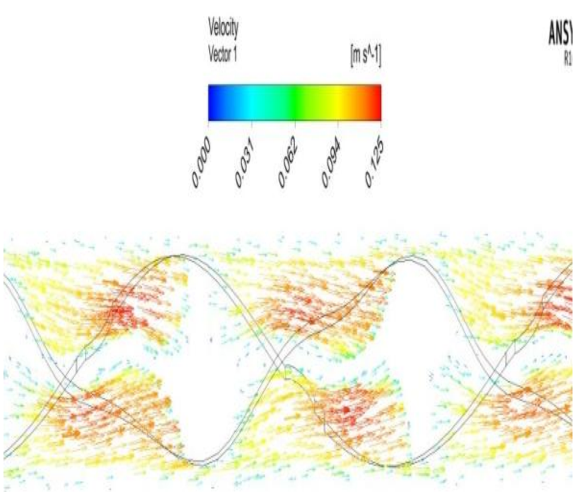

Fig.15. Turbulence created in the tubes due to the presence of inserts

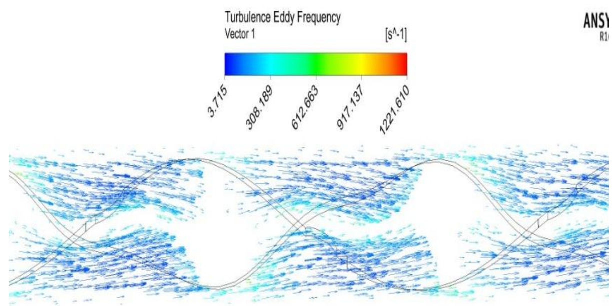

Fig.16. Turbulence eddy frequency vectors at the insert tube interface

The table III below shows the values of heat transfer coefficient and Nusselt numbers along the tube and shells when the varying cross sectional cut twisted tapes are inserted into the tubes of the double pipe heat exchanger. Due to the additional turbulence created, more heat transfer takes place in the tubes of the heat exchanger. This causes an increase in heat transfer coefficient and Nusselt number.

S.NO	***Part***	***Heat Transfer coefficient***	***Nusselt Number***
1	*Tube1*	*1.145e+03*	*3.207e+01*
2	*Tube2*	*1.286e+03*	*3.604e+01*
3	*Shell 1*	*6.106e+02*	*6.037e+01*
4	*Shell 2*	*6.543e+02*	*6.469e+01*

TABLE III: Heat transfer coefficient and Nusselt Numbers

Conclusions:

In the plain tube the flow is found to be parallel to the tubes in the inner tubes. This results in the lower heat transfer coefficient and lower rate of heat transfer. This is evident from the low Nusselt number and heat transfer coefficient values for plain tube. The velocity variation in the tubes if found to be very less. There is very less turbulence along the length of the pipe. Considerable turbulence is found at the return bend of the u-tube of the heat exchanger. But this is not found to be sufficient enough to increase the rate of heat transfer in the heat exchanger. Varying cross sectional cut twisted tapes are inserted into the tubes of the heat exchanger so that the additional turbulence is created by the twisted tape inserts at the tube walls. Two things are to be taken into account. One is the decrease in the velocity of the water along the length of the tubes and at the tube walls the velocity should be high to create more turbulence.

Thus the fluid retains for more time in the heat exchanger and due to the turbulence created, more heat transfer takes place in the tubes of the heat exchanger.

References

1. Heat transfer enhancement in a double pipe heat exchanger using cfd, Kanade Rahul H, Kailash B A, Gowreesh , International Research Journal of Engineering and Technology (IRJET), Volume: 02 Issue: 09 | Dec-2015, pg No:419-430
2. Cfd analysis and performance of parallel and counter flow in concentric tube heat exchangers, D.Bhanuchandrarao, M.Ashok chakravarthy, Dr. Y. Krishna, Dr. V .V. Subba Rao, T.Hari Krishna, International Journal of Engineering Research & Technology (IJERT),Vol. 2 Issue 11, November – 2013, Pg:2782-2792
3. Numerical Modeling and Simulation of a Double Tube Heat Exchanger Adopting a Black Box Approach, Agniprobho Mazumder, Dr. Bijan Kumar Mandal, Int. Journal of Engineering Research and Applications, ISSN: 2248-9622, Vol. 6, Issue 4, (Part - 2) April 2016, pp.35-41
4. Cfd analysis of heat transfer enhancement by using passive technique in heat exchanger, C Rajesh Babu, Santhosh Kumar Gugulothu, International Journal of Recent advances in Mechanical Engineering (IJMECH) Vol.4, No.3, August 2015, Pg : 99-111.
5. Numerical and Experimental Investigation of Heat Transfer Augmentation in Double Pipe Heat Exchanger with Helical and Twisted Tape Inserts, Patnala Sankara Rao, K Kiran Kumar, International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 9, September 2014, Pg: 180-192
6. CFD Analysis and Optimization of Heat Transfer in Double Pipe Heat Exchanger with Helical-Tap Inserts at Annulus of Inner Pipe, Bharat Bhushan Verma, Saurabh Kumar, Iosr journal of Mechanical and civil Engineering (iosr-jmce)
7. Heat transfer enhancement on double pipe heat exchanger by wire coiled and pin wire coiled turbulator inserts , J. kalil basha,m.raja . narasimman, kumaravel, International Journal of Research in Aeronautical and Mechanical Engineering issn (online): 2321-3051 Vol.3 Issue.6, June 2015. Pgs: 1-11
8. Heat Transfer Enhancement for Double Pipe Heat Exchanger Using Twisted Wire Brush Inserts Deepali Gaikwad , Kundlik Mali, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 7, July 2014, ISSN: 2319-8753, Pgs: 14741-14748.
9. CFD Analysis on Performance of Double Pipe Two Pass Heat Exchanger, M. Sandeep B. Chandra Shekar, IJSRD - International Journal for Scientific Research & Development| Vol. 4, Issue 07, 2016 | ISSN (online): 2321-0613,Pg Nos:62-64
10. Heat Transfer Enhancement in a Tube Using Elliptical-Cut Twisted Tape Inserts, Pratik P. Ganorkar, R.M. Warkhedkar, SSRG International Journal of Mechanical Engineering (SSRG-IJME) – volume 2 Issue 5–May 2015, Pg No: 20-27
11. Heat transfer enhancement in a tube using rectangular-cut twisted tape insert, Bodius Salam, Sumana Biswas, Shuvra Saha, Muhammad Mostafa K Bhuiya, 5th BSME International Conference on Thermal Engineering,Pg Nos: 96-103
12. Experimental Analysis of Augmentation in Heat Transfer Coefficient Using Twisted Tape with SemiCircular Cut Insert, Pawan A. Sawarkar, Pramod R. Pachghare, International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064,Pg Nos:1174-1179
13. CFD Analysis of Heat Transfer and Friction Factor Characteristics in a Circular Tube Fitted with Quadrant-Cut Twisted Tape Inserts, Sami D. Salman, Abdul Amir H. Kadhum, Mohd S. Takriff, and Abu Bakar Mohamad, Mathematical Problems in Engineering Volume 2013 (2013), Article ID 273764, 8 pages