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Numerical Analysis of square Notched Twisted Tape Inserts in A Tube

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Abstract: *The present work represents numerical analysis of square notched twisted tape insert in a tube by varying pitch with air as a working fluid. The results for simple twisted tape insert, square notched with double slot twisted tape insert at different twist ratio (4, 5, and 6) determined. Reynolds number varied from 35000-45000.Both pressure drop, heat transfer coefficient, Nusselt number are calculated and compared with plane tube. It is found that heat transfer enhancement of square notched twisted tape double slot is about and 19.57%, 44.31%, & 75.79% using square notched twisted tape insert for 150mm, 125mm and 100 mm pitch as compared with plane tube.*

Keywords: *Heat transfer enhancement, Air, square notched twisted tape double slot, CFD simulation*.

I. INTRODUCTION

Heat transfer enhancement techniques are used in areas like heat recovery process, air conditioning, refrigeration systems (Satyajit et al 2015) [1], chemical reactors, process industries, heating, cooling in evaporators, thermal power plants, radiators for space vehicles, automobiles (Gawandare et al 2014) [2].Different Enhancement techniques are.

a) Passive technique:

The technique does not need any external power input is called Passive technique.

These techniques generally use surface to the flow channel by incorporating inserts. They provide higher heat transfer coefficient by disturbing the flow behavior expect for extended surfaces. Heat transfer enhancement by this technique can be achieved by using treated surface, rough surface, extended surface, swirl flow devices.

(b) Active technique:

The technique need any external power input is called active technique.

(c) Compound technique

The combination of passive and active technique may be employed simultaneously to enhance heat transfer of any device, which is greater than that of produce by any of that technique separately, then that technique is known as compound technique. The performance evaluation of heat transfer and friction factor in a tube with different twisted tape inserts are analysed by using computational fluid dynamics (CFD), (Eisma et al 2014)[6]. The correlations for Nusselt number, heat transfer coefficient, friction factor were proposed. In the present work presents the computational fluid dynamics (CFD) simulation i.e. flow analysis determination of heat transfer coefficient, Nusselt number, friction factor, performance evaluation criteria in a tube with square notched twisted tape with double slot for twist ratio 4, 5, 6, Reynolds number between 35,000 -45,000.Then this result obtained for tube fitted with square notched twisted tape, twisted tape, plane tube compared with experimental results. The main objectives of the present work is to estimate the flow structure (pressure drop, temperature plots, velocity flow plots) and heat transfer (fluid temperature along the tube and in each cross section) behaviors in a tube with twisted tape with square notched.

II. LITERATURE SURVEY DETAILS

(Satyajit et al 2015) [1] investigated the characteristics of heat transfer and pressure drop at a place of horizontal and double pipe with square jagged twisted tape inserts with working fluid is as water. As a result of insertion of square jagged twisted tape in concentric double tube heat exchanger gives better effectiveness on a flow friction characteristics and heat transfer rate those are experimentally investigated and shows that combination of twisted tape inserts with square jagged performs significantly better than individual enhancement technique. (Gawandare et al 2014) [2] Concluded that the heat transfer increased up to 154% for 51%increase in friction factor, for less pumping power heat transfer rate can increase 9

(Krishna et al 2015) [3] Determined of friction factor and heat transfer coefficient for various twisted tape inserts with varying twists and CuO Nano fluid. The 3mm thick with 4.2 twist copper insert and Nano fluid shows increase in Nusselt number values by 81% however there is increase in friction factor by only 21.5% as compared to the smooth tube values. (Murugesan et al 2011) [4] Experimental investigated of heat transfer and friction in a tube fitted with plain twisted tape (PPT) and U – cut twisted tapes with twist ratios 2,4.4,6. Geometries of twisted tape with twist ratios width (W) and depth (de) is 8and 8mm. (Amol et al 2014) [5] Under turbulent condition, the increase in heat transfer rate is more than that under laminar flow condition. In this paper this literature is used for comparison with different pitch like 100,120,160 and twist ratio 4.insertion of such geometry may lead to enhance the fiction factor and pressure drop which increases the heat transfer characteristics. (Eisma et al 2014) [6] The Navier-stokes equation with energy equation was solved using the k-result show that turbulence model. The experimental result show that heat transfer and friction factor increased with decreasing twist ratio. (Sushama Garad et al 2016) [7] Represented numerical analysis of square notched twisted tape insert in a tube by varying pitch with air as a working fluid. The results for simple twisted tape insert, square notched with single and double slot twisted tape insert at different twist ratio (4, 5, and 6) determined. Reynolds number varied from 35000-45000.Both pressure drop, heat transfer coefficient, Nusselt number are calculated and compared with plane tube. (K.G.kulkarni et al 2015) [8] investigated the heat transfer performance in a circular pipe by employing corrugated twisted tapes& also results are to be compared with plain twisted tape. These tapes will be tested for different configurations of twist ratios & wave angles. It is to be verified whether corrugated nature of twisted tape assists the heat transfer by turbulence enhancement or if it increases the pressure drop. Also the use of „CFD" software is proposed for analysis work & developing correlations.

(Aditi Desai et al 2016) [9] Represented numerical and experimental study of heat transfer characteristics with centrally cleared two twisted tapes. Results obtained for single twisted tape insert and two twisted tape inserts are compared analytically as well as numerically. Air is used as a working fluid. Results were compared at Reynolds number 45000 for no twisted tape, one twisted tape, two tapes. Results for two twisted tapes with twist ratios 3, 4, 5 are compared at Reynolds number 45,000. Heat transfer coefficient is improved as compared to plain tube and single tape by 2.2%, to 10.1%. Optimum results are obtained at twist ratio 5. (AI Amin et al 2013) [10] Used a rotating twisted tape insert to observe the effect on heat transfer coefficient, heat transfer rate and heat enhancement efficiency. Higher heat transfer rate can be obtained at high 600 RPM and flow rate that governs the heat transfer characteristics. (Versteeg et al 1995) [i], the basic numerical techniques have been developed around series of worked examples. The use of computational fluid dynamics (CFD) to predict internal and external flows has risen dramatically.

From above literature review, it is observed that the heat transfer and friction factor characteristics using various twisted tape inserts experimentally investigated. The notched twisted tape with air is used as working fluid is not reported yet. Creation of notched at different location may enhance the heat transfer rate by reduction in pressure drop. To study this possibility square notched twisted tape with single and double slot at different twist ratio, and Reynolds Number are analysed. The geometry with best possible results is finalized for further experimental analysis.

III. NUMERICAL SIMULATION

3.1. Problem Definition

The numerical simulations were carried out using the CFD code FLUENT-14.0 that uses the finite volume method to solve the governing equations. The Geometry of the twisted tape, square notched twisted tape insert was created using ICEM-14.0 software, faithfully reproducing the geometric characteristics of the problem. The result of heat transfer enhancement in term of Nusselt number, with the use of square notched twisted tape, square notched twisted tape with single slot, square notched twisted tape with double slot in comparison with Plain tube and twisted tape insert.

3.2 Boundary conditions

Air is used as the working fluid. The numerical studies are carried out with velocity profile at the inlet of the horizontal tube. Studies are carried out with uniform velocity profile at inlet of the horizontal tube. The direction of the flow defined normal to the boundary. Inlet velocity and temperature are specified. Outflow boundary condition is used at pressure-out let boundary. The wall of the tube line was assumed to be perfectly smooth with zero roughness height and stationary wall and no slip condition. A constant heat flux condition of 1360.29 W/m2 is used at the wall boundary. Velocity - inlet boundary: inlet is taken for the tube inlet section and velocity values are varying as 16-20 m/s. initial gauge pressure is taken as zero Pascal. Temperature is taken as 310-309.46K. Wall thickness is 1.5mm. Tube outside (do) and inside diameter (di): 38.1 and 35.1mm. The heater input (Q) is 120W.

3.3 Objectives of the present study

1. The simulation and computational fluid dynamics modelling when fitted with twisted tape and added with square notch with different twist ratio 4, 5 and 6 provide the maximum heat transfer enhancement when compared with plan tube fitted with twisted tape only.
2. Simulation of square notched horizontal tube and computational fluid dynamics modelling fitted with twisted tape and added with square notched twisted tape inserts of different twist ratio between 4 to 6 and square notch dimensions (10, 10) identify the geometry of square notched twisted tape insert which provides the maximum heat transfer enhancement when compared with horizontal plane tube with twisted tape.

Specification of inserts:
Working fluid: Air
Material: Aluminium
Width of twisted tape (W): 25mm
Pitch (Y): 100,125and150mm
Twist ratio (Y/W): 4, 5, and 6.
Length of insert (L): 1000mm
Thickness of insert (: 2mm

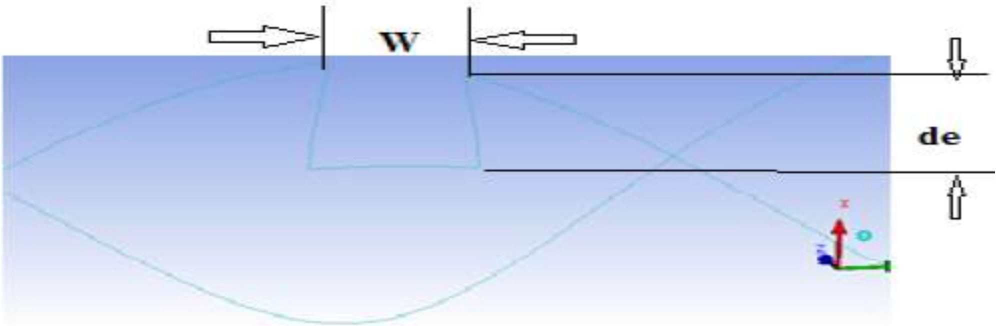

Fig.1. Geometry of square notched twisted tape slot [7].

w= 10mm
de = 10mm
fig1. Shows the geometry of square notch twisted tape slot. The dimensions are shown in above.

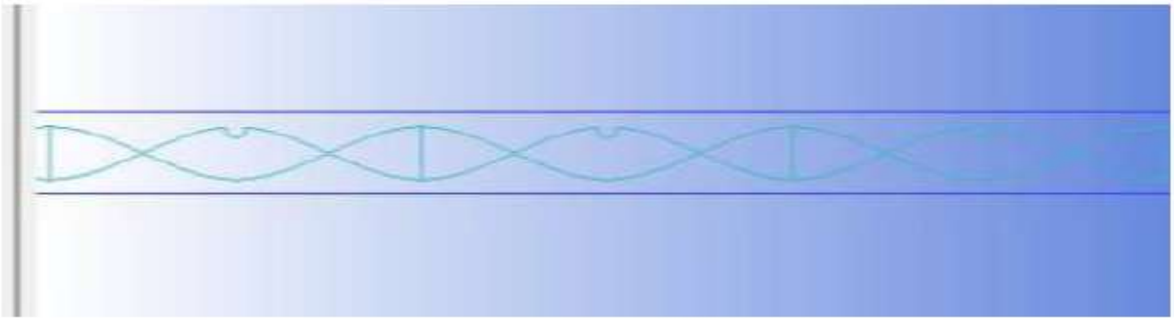

Fig.2. Geometry of square notched single slot twisted tape

Fig.3. Geometry of square notched double slot twisted tape

For single and double square notch the dimensions are,
w= 10mm and de = 10m

Fig.4.Plane tube

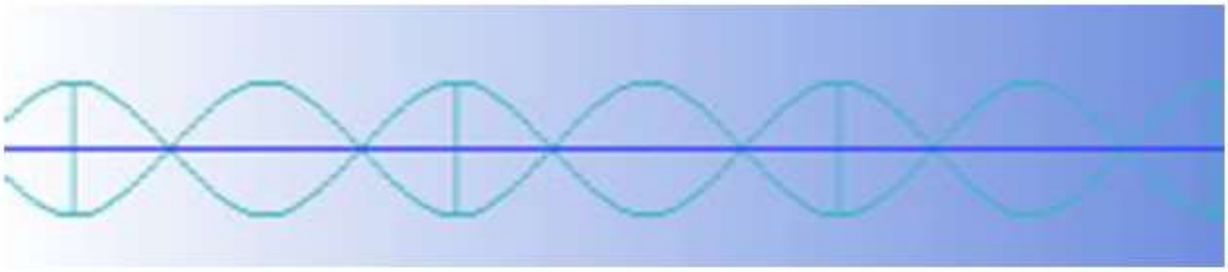

Fig.5. Geometry twisted tape

Heat transfer coefficient in case of double square notch twisted tape is higher than square notch single slot twisted tape for all pitch ratios with reduction in pressure drop because of development of secondary flow. Therefore double square notch geometry is considered for further study.

3.4 Methodology adopted

Computational Fluid dynamics (CFD) is the use of computer based simulation to analyze systems involving fluid flow, heat transfer. A numerical model is first constructed using a set of mathematical equations that describe the flow.

The mathematical modelling of a flow problem is achieved through three steps:

1. Governing equation which describe the flow

The simplified form of continuity, momentum, and energy equation are shown below:

Continuity equation

$$\frac{\partial(\rho \overline{u_i})}{\partial x_i} = 0$$

Momentum equation

$$\frac{\partial(\rho \overline{u_i}}{\delta t} + \frac{\partial(\rho \overline{u_i\, u_j}}{\partial x_j} = -\frac{\partial \overline{P}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial(\overline{u_i})}{\partial x_j} - \rho \overline{u_i' u_j'}\right)$$

Energy Equation

$$\frac{\partial}{\partial x_i}(\rho \overline{T}) + \frac{\partial}{\partial x_i}(\rho \overline{u_i} \overline{T}) = \frac{\partial}{\partial x_i}\left(\frac{\lambda}{c_p} \frac{\partial \overline{T}}{\partial x_i}\right)$$

2. Discretization of the governing equations.
3. Solving the resulting numerical equations.
4. ANYSIS based simulation model is prepared.
5. The available model is checked by simulation method within different parameters and on the basis of which graph is generated.
6. Results and post processing.

3.5 Meshing

The grid generations and numerical simulations are performed using commercial Ansys 14.0 software package like ICEM, Fluent, and CFD post respectively. Fig. 6, 7, 8 presents the mesh generation of the computation domain using hybrid method of size function and boundary layer technique. Medium grids are employed to generate mesh in the interior of tube and boundary layers, respectively. In all cases, the grid is finer close to the wall and the vicinity of the square notched twisted tapes where the temperature and velocity gradients are large.
Total Nodes: 156465
Total Elements: 912385

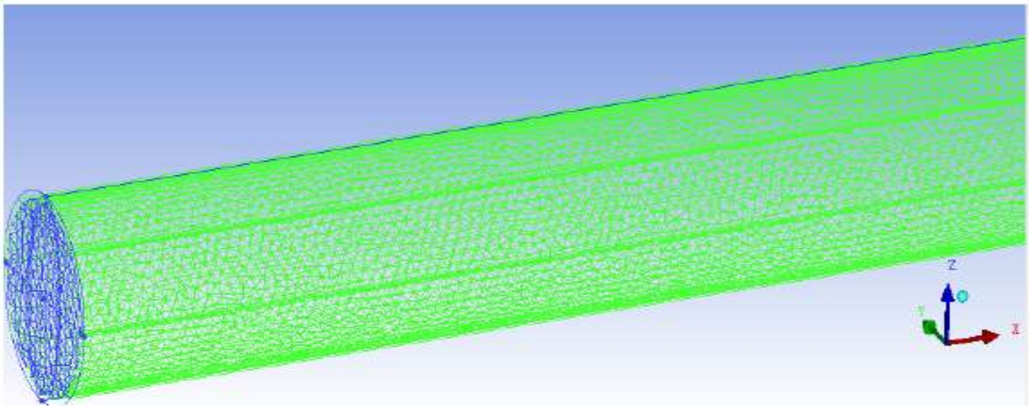

Fig.6. Meshing for plane tube

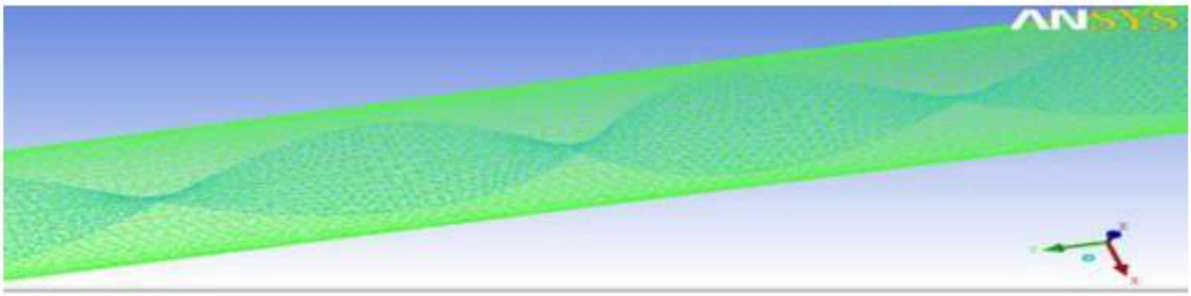

Fig.7. Meshing for twisted tape in a tube

Total Nodes: 157057
Total Elements: 928628

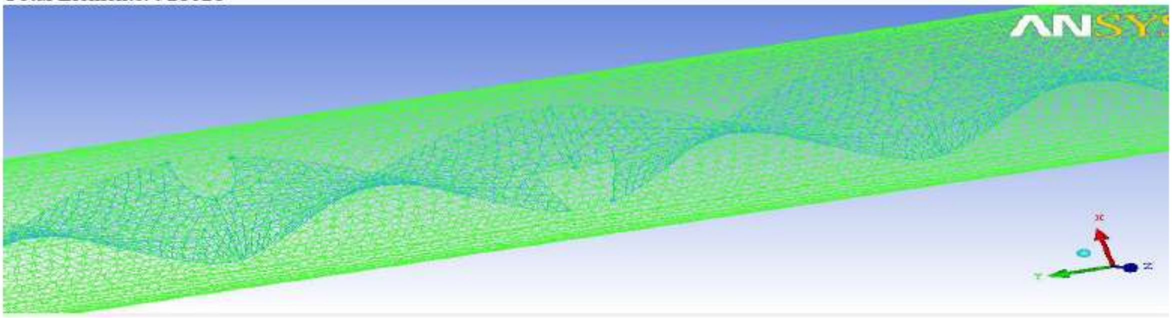

Fig.8. Meshing for square notched double slot twisted tape in a tube

Total Nodes: 159866
Total Elements: 922570
After the completion of meshing the design is opened in ANSYS Fluent. In fluent boundary conditions are given as per requirement and the solution is initialized and calculations are iterated. After the calculation is converged the contours are to be plotted.

3.6 Fluid flow characteristics:

Velocity contours are shown in fig.9, 10 and 11 next for all types of configurations under consideration. These velocity contours are plotted at X-Y plane at Z = 0. These sections correspond to plane exactly at middle section on inlet to outlet path of flow domain. Fig.12 shows velocity contour of plane tube V=16 m/s. The velocity contours in the computational domain of the double slot square notched twisted tape insert in a tube at different Twist ratios are presented in Fig. 9 (4 twist ratio). These squares carry the heated fluid in the channel toward the outside and the external cold fluid toward the channel, enhancing heat transfer. By provision of squares, velocity near the squares increases slightly and thereby increases heat transfer occurring through it. Velocity near square notched twisted tapes are very much less compared to corresponding values near the top of square notched twisted tapes. This indicates the developing or developed nature of flow in flow domain.

3.6.1. Velocity contours

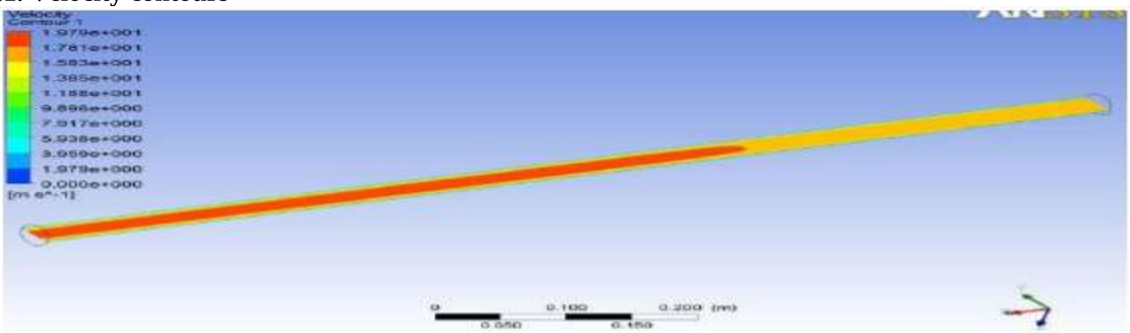

Fig.9. velocity contour of plane tube V=16 m/s

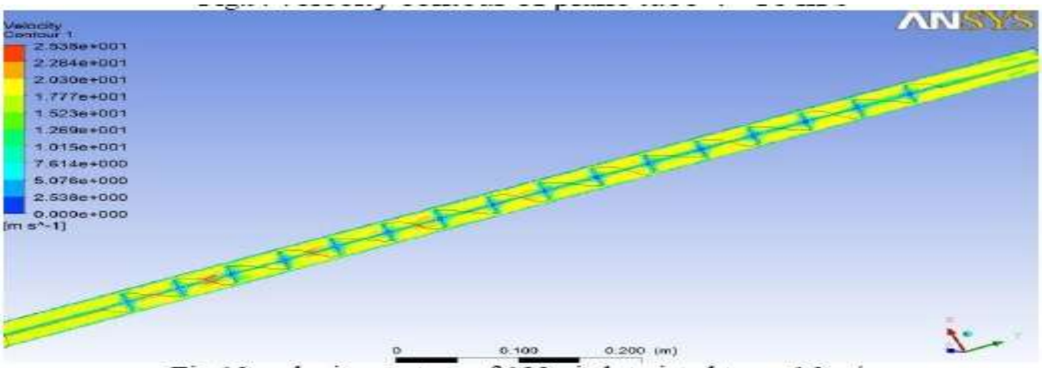

Fig.10. velocity contour of 100 pitch twisted tape=16 m/s

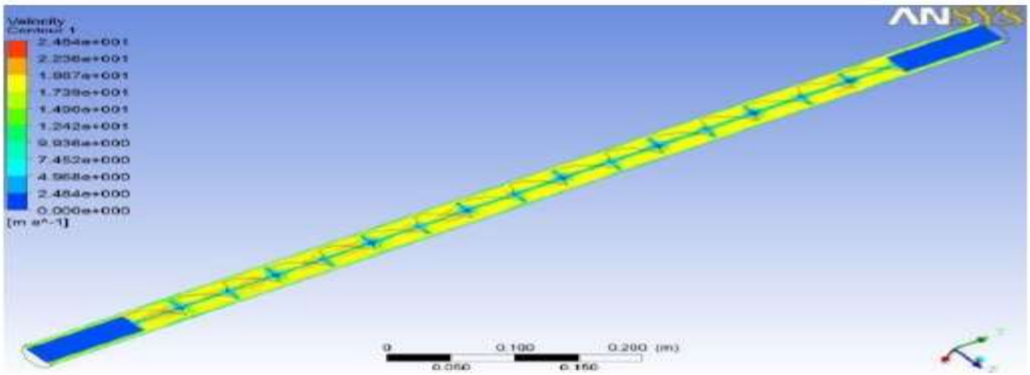

Fig.11. velocity contour of 100 pitch square notch twisted tape=16 m/s

3.6.2 Temperature contours

Figures 12, 13, 14 represent the temperature contours on X-Y plane for four different configurations at various Reynolds numbers. In case of smooth pipe, temperature pattern is uniform with not much change from inlet to outlet region. But when corresponding temperature contour is plotted for inline configuration, variation in flow pattern can be easily observed. Fig.17 show that due to formation of square in tube, the corresponding heat transfer associated with it increases.

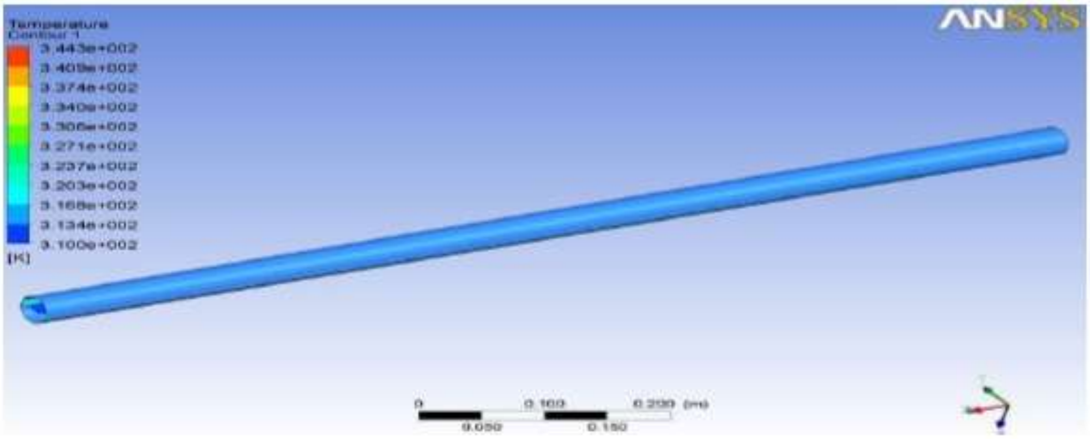

Fig.12.Temperature contour of plane tube v=16 m/s

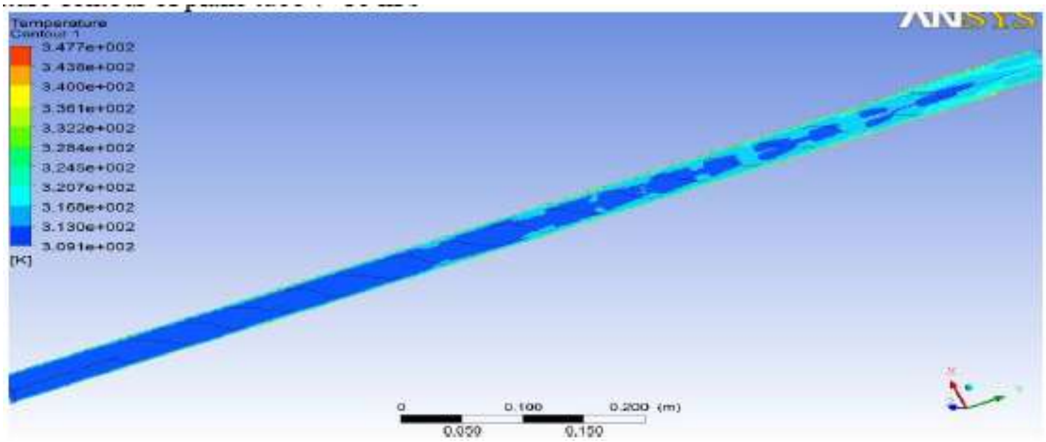

Fig.13.Temperature contour of 100pitch twisted tape v=16 m/s

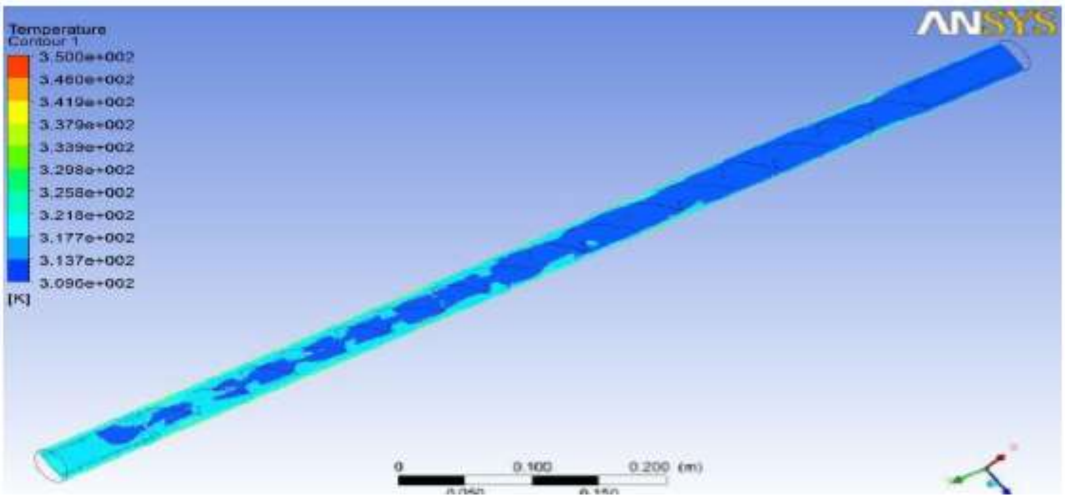

Fig.14. Temperature contour of 100 pitch square notch twisted tape v=16 m/s

3.6.3 Pressure contours

Figures 15, 16, 17 Represents the pressure contours on X-Y plane for four different configurations at various Reynolds numbers. Pressure contours display the drop of pressure along the flow direction in all cases. Compare to smooth pipe, it is found that the presences of square notched twisted tape increases the pressure drop nearly independent of its configurations.

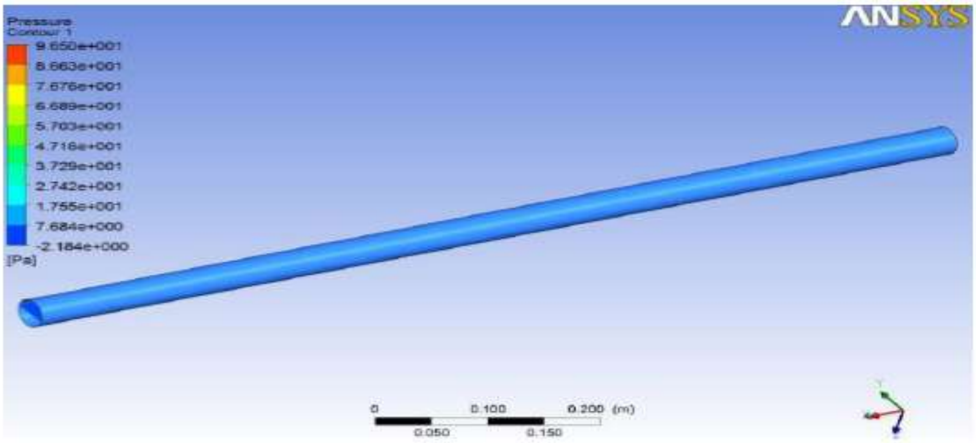

Fig.15. Pressure contours of the plane tube, V=16m/s.

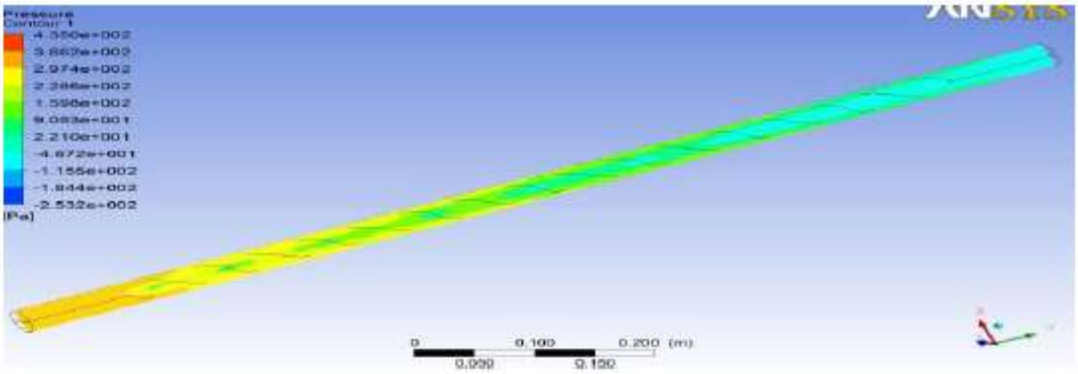

Fig.16 Pressure contours of the twisted tape V=16m/s

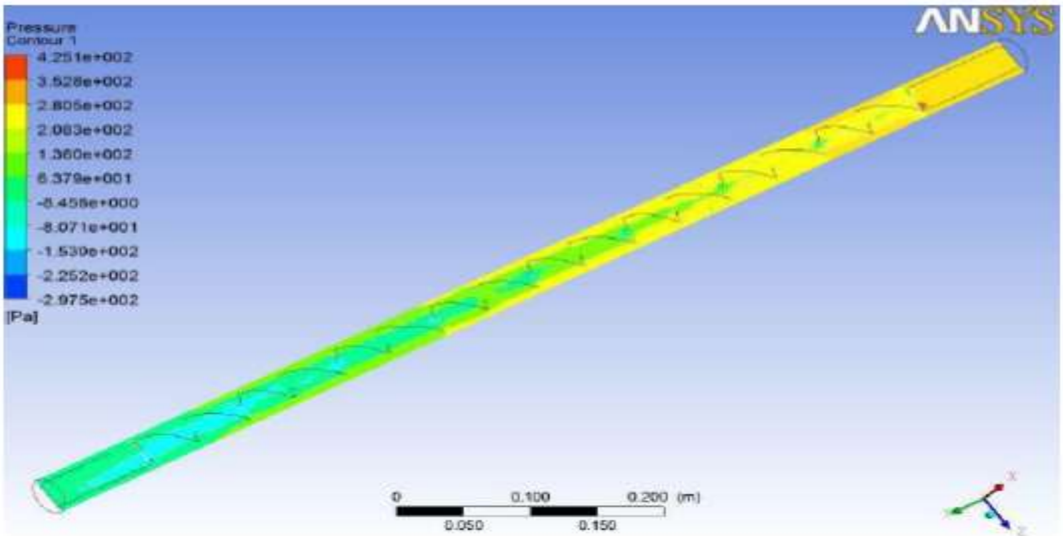

Fig. 17 Pressure contours of the 100 square notched double slot twisted tape V=16m/s.

From above graph it is clear that the pressure drop decreases with increasing pitch. But heat transfer coefficient increases. For double slot the heat transfer coefficient is greater compared to plane tube and twisted tape inserts.

Mathematical correlations for CFD simulation results:

Heat transfer coefficient and pressure drop values are compared for plane tube, twisted tape, and square notched twisted tape with double slot. To calculated heat transfer coefficient, temperatures measured by thermocouples are used. Surface temperature and mean temperature is calculated based on thermocouples temperatures.

Heat transfer coefficient is calculated using following,

$$h = \frac{Q}{A\Delta T} \quad (1)$$

Nusselt number is calculated using following,

$$Nu = \frac{h\,D_h}{k} \quad (2)$$

Friction factor is calculated using following,

$$f = \frac{\Delta P}{\left[\frac{L}{d_o}\right]\left[\frac{\rho U^2}{2}\right]} \quad (3)$$

Nusselt number, friction factor calculated using mathematical correlation and from numerical analysis are compared. Air is considered at room temperature.Air properties used for calculations at room temperature.

Air properties used for calculations are as follows:

ρ = 1.177

μ = 1.845 × kg/ms

k= 0.0261 W/mk

Cp = 1.005 KJ/Kgk

IV. RESULTS AND DISCUSSION

Using the data obtained from the CFD simulations, heat transfer, friction factor and Performance evaluation criteria of square notched twisted tape inserts are discussed below:

4.1. Effect of square notch twisted tape on Heat Transfer

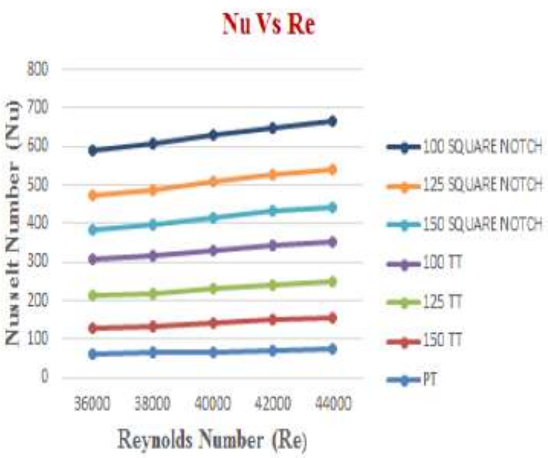

Fig.18 Nusselt Number Vs Reynolds Number

Fig. 18 shows the Nusselt number for plane tube, twisted tape, and square notched twisted tape at different pitches. Reynolds number for given values like 36000-44000 of pitches p = 150mm, 125mm and 100mm. Value of Nusselt number found to increase with increasing Reynolds number in all cases as expected. Square notch twisted tape can be seen to yield Maximum Nusselt number at relative pitch p= 100mm as compared to that of twisted tapes, plane tube and other twisted tape pitches , also other square notch pitches like 150mm and 125mm. Nusselt number increases with decreasing relative pitch values.

From the Graph, it is observed that the rate of change of Nusselt number for square notch twisted tape at pitch 100mm is maximum. At higher pitch variation in Nusselt number is appreciable as Compared to twisted tape and plane tube.

4.2. Effect of square notch twisted tape on Friction Factor

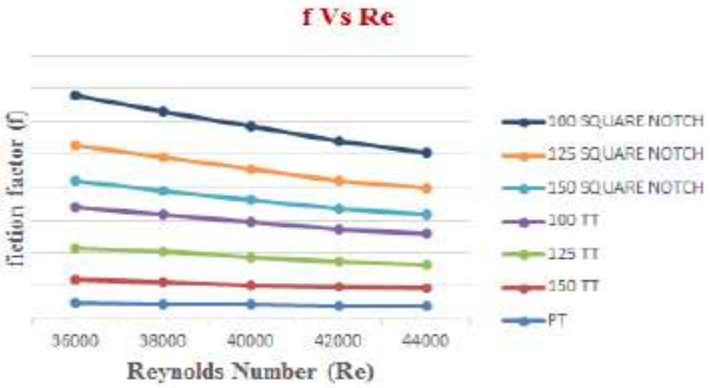

Fig.19 Friction Factor Vs Reynolds Number

The effect of relative pitch and Reynolds number on friction factor of plane tube, twisted tapes and the square notched twisted tape for various ranges of pitches like 150mm, 125mm, and 100 mm is shown in fig 19. It is seen that the value of friction factor decreases with increasing Reynolds number in all cases as expected due to the suppression of viscous sub-layer with increasing Reynolds number. Also friction factor increases with decreases in relative pitch value. Friction is minimum when twisted is not inserted. Further, with the increase in twist, i.e. with decrease in twist ratio, the friction factor goes on increasing for a particular Reynolds number.
It is observed that relative pitch of 100 mm has maximum friction factor and 150 mm has minimum friction factor value. But compare to twisted tapes and plane tube both of values are higher.
It shows continuous rise in Nusselt number and friction factor with reducing the pitch.

4.3. Effect of square notch twisted tape on performance evaluation criteria

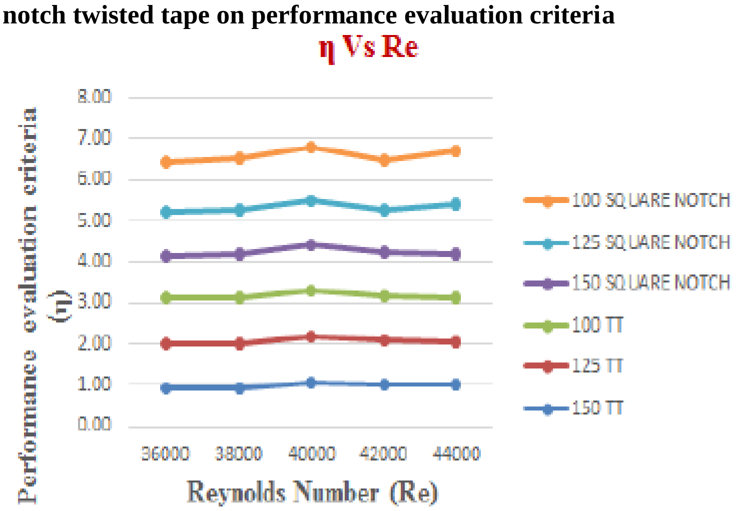

Fig.20 Performance evaluation criteria (η) Vs Reynolds Number (Re)

From the fig.20, it is observed that the Performance evaluation criteria for pitch 100mm is maximum as compared to twisted tapes (pitches 150,125 and 100mm) and plane tube. At higher pitch variation in Performance evaluation criteria is appreciable as Compared to twisted tapes and plane tube. The Performance evaluation criteria increased with decreasing pitch (also twist ratio). Throughout the results of the experimentation, it appears that use of the small twist ratio (Y) i.e. 4 leads to higher Performance evaluation criteria than the larger twist ratio (Y) i.e. 6 as shown in below fig 30. it can be seen that the Performance evaluation criteria increases as twisted ratio (Y) decreases which is generally higher at high Reynolds numbers for all twist ratios.

V. CONCLUSION

1) For 100 pitch (125,150 pitch also) double square notch twisted tape the heat transfer coefficient is higher than single slot square notch ,twisted tape and plane tube.
2) For 100 pitch (125,150 pitch also) double square notch twisted tape the friction factor increases as compared to 100 pitch single square notch twisted tape. Therefore this geometry is finalized.
3) Heat transfer coefficient enhanced about 19.57%, 44.31% and 75.79% using square notched twisted tape insert for 150,125 and 100mm pitch as compared to plane tube.
4) As Reynolds Number increases the Nusselt Number also increase.
5) Also heat transfer coefficient increases with decreasing twist ratio or pitch.

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