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Numerical Heat Transfer Analysis of Flowing Fluid through a Circular Tube with Helical Twisted Strip Inserts

Sachin S. Surywanshi[1*], Sanjay V. Kadam[2], Suhas S. Mohite[3]

[1,2]Department of Mechanical Engineering, Rajarambapu Institute of Technology, Sakharale, India.

[3]Department of Mechanical Engineering, Govt. College of Engineering Karad, India

Abstract – Heat exchanger application in industrial as well as application in engineering is quite popular. The need is to improve heat transfer rate, reduce pressure drop with respect to long term performance aspect of equipment. The present work will be focused on heat transfer enhancement of heat exchanger using helical strip in circular pipe with working fluid as water. Circular pipe helical strip geometry is not reported yet in the open literature. This geometry helps to generates swirl motion of fluid flow and disturbs the boundary layer to increase the effective surface area, residence time, reduce pressure drop and increase heat transfer coefficient.

Keywords – Computational Fluid Dynamic, Heat Transfer Enhancement, Helical Strip Geometry, Turbulent Flow, Thermo Hydraulic Performance.

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INTRODUCTION

The design of heat exchanger efficiency has always been important for designers of equipment. Helical strip inside the circular pipe disturbs fluid which helps to swirl motion of water. Due to its compact structure and high coefficient of heat transfer as one of the serpentine coil technique, improved passive heat transfer is widely used in various industrial applications. Numerous studies have been conducted by researchers to investigate the characteristics of flow and heat transfer fluid in the pipe.

Sadeghi, et al. [1] worked on heat transfer and nanofluid flow characteristics through a circular tube fitted with helical tape inserts. In this four different twist ratios of 1.95–4.89, two different types of nanoparticles, Al_2O_3 and SiO_2 and 0.5–2.0% volume fraction in base fluid (water) and nanoparticle diameter in the range of 20–50 nm were used to identify their effect on the heat transfer and fluid flow characteristics through a circular tube fitted with helical tape insert geometries. The results indicate that the four types of nanofluids have achieved higher Nusselt number than pure water. Nanofluid with Al_2O_3 particle achieved the highest Nusselt number. **Suresh, et al. [2]** explained a comparison of thermal characteristics of Al_2O_3/water and CuO/water nanofluids in transition flow through a straight circular duct fitted with helical screw tape inserts. He concluded that helical screw tape inserts give better thermal performance when used with CuO/water nanofluid than with Al_2O_3/water nanofluid. **Bhattacharyya, et al. [3]** presented experimental friction factor and Nusselt number data for laminar flow through a circular duct having integral helical rib roughness and fitted with centre-cleared twisted-tape. He concluded that the centre cleared twisted tapes in combination with integral helical rib roughness perform significantly better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain amount of twisted-tape centre-clearance. **Sivashanmugam, et al. [5]** investigated heat transfer and friction factor characteristics of circular tube fitted with full-length helical screw inserts of different twist ratio. He concluded heat transfer coefficient and friction factor increases with the increases twist ratio. He developed empirical correlations relating twist ratio and Reynolds number, are fitting the experimental data within ±15% and ±13% for Nusselt number and friction factor, respectively. **Ibrahim. [6]** Investigated heat transfer characteristics and friction factor in the horizontal double pipes of flat tubes with full length helical screw element of different twist ratio and helical screw inserts with different spacer length.

His result shows that, the Nussle number (Nu) and friction factor (f) decrease with the increase of S or Y for flat tube. For a fixed Reynolds number, the friction factor (f) increases with the decrease in twist ratio and spacer length for the flat tubes. **Nagarajan, et al. [7]** investigated heat transfer and friction factor

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characteristics of circular tube fitted with 300 right-left helical screw inserts with 100 mm spacer of different twist ratio for laminar and turbulent flow. He found that the performance ratio increases with increasing Reynolds number and decreasing twist ratio with the maximum for the twist ratio of 2.93. Also the performance ratio of more than one indicates that the type of twist inserts can be used effectively for heat transfer augmentation. **Sarada, et al. [8]**

c_p	**specific heat, J/kg K**	η	**thermal performance factor**
k	thermal conductivity, W/m K	**Subscripts**	
L	tube length, m	bf	base fluid
Nu	Nusselt number	nf	nanofluid
Pr	Prandtl number	i	inlet
Re	Reynolds number	o	outlet
T	temperature, K	m	mean
V	mean velocity, m/s	b	bulk
m	mass flow rate, kg/s	w	water
D	tube diameter, m		
h	heat transfer coefficient, W/m^2 K		
Q	Heat transfer rate, w		
f	friction factor		
Greek			
ΔP	pressure drop, Pa		
μ	viscosity, Pa s		
ρ	density, kg/m^3		

explained turbulent flow heat transfer in a horizontal tube by varying width of twisted tape inserts with air as the working fluid. He found that the enhancement of heat transfer with twisted tape inserts as compared to plain tube varied from 36 to 48% for full width (26mm) and 33 to 39% for reduced width (22 mm) inserts. Correlations are developed for friction factors and Nusselt numbers for a fully developed turbulent swirl flow, which are applicable to full width as well as reduced width twisted tapes, using a modified twist ratio as pitch to width ratio of the tape. **Rios-Iribe, et al. [10]** investigated the effect of different twist ratios of the tape on the convective heat transfer and the pressure drop over the Reynolds number range of 0.2-600. It was found that a twisted tape induces a swirling flow, which increases the velocity gradient at the tube wall and consequently generates an enhancement in heat transfer.

PROBLEM DEFINITION:

Plain pipe heat exchanger gives less heat transfer performance. It needs to improve heat transfer rate. For this purpose modified geometry that is circular pipe with helical holed strip is considered to enhance heat transfer rate.

CFD THEORIES AND EQUATION:

The flow field is governed by the three-dimensional Reynolds-averaged Navier-Stokes (RANS) equations. Turbulence model k-ε was used because it can model adverse change in flow distribution and pressure distributions. In the present work the temperature and pressure distribution through internally corrugated tubes were simulated by using FLUENT software. All the simulations were performed by using single phase model under steady state condition based on the assumption that the heat transfer and fluid flow processes are turbulent and heat loss to the environment is neglected.

The governing equations are as follows:

-Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho U)=0 \qquad (1)$$

-Momentum equation:

$$\frac{\partial}{\partial t}(\rho U) + \nabla\cdot(\rho U U)= -\nabla P+\nabla\tau+B \qquad (2)$$

-Energy equation:

$$\frac{\partial}{\partial t}(\rho h) + \nabla\cdot(\rho U C p T)= \nabla\cdot(k\nabla T) \qquad (3)$$

All the governing equations were solved using the ANSYS Fluent software. The SIMPLE algorithm was used for the velocity-pressure coupling, and the second-order upwind scheme was applied for the discretization of the convection terms. The minimum

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convergence criterion was 10-4 for the continuity equation, velocity and turbulence quantities and 10-8 for the energy equation.

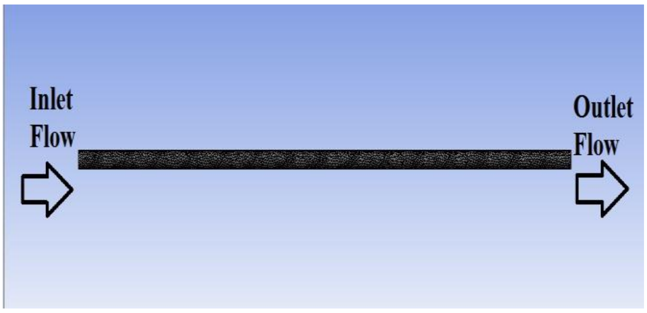

Fig.1 Computational Domain with Boundary condition

TERMINOLOGY USED IN TWISTED TAPE:

Twist ratio (s): the twist ratio is defined as the ratio of pitch length to inside diameter of the tube.

Thermo Hydraulic Performance (η): For a particular Reynolds number, the thermo hydraulic performance of an insert is said to be good if the heat transfer coefficient increases significantly with a minimum increase in friction factor Thermo hydraulic performance estimation is generally used to compare the performance of different inserts under a particular fluid flow condition.

Nusselt Number (Nu): The Nusselt number is a measure of the convective heat transfer occurring at the surface and is defined as hd/k, where h is the convective heat transfer coefficient, d is the diameter of the tube and k is the thermal conductivity.

Prandtl Number (Pr) : The Prandtl number is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of heat.

Pitch (P): The Pitch is defined as the distance between two points that are on the same plane, measured parallel to the axis of a Twisted Tape.

BOUNDARY CONDITIONS AND DATA REDUCTION:

Mass flow inlet boundary condition was applied at the inlet and the fluid temperature of the inlet is fixed at 304 K, while a pressure-outlet condition is applied at the outlet. Non slip velocity conditions on the walls were assumed. A constant and uniform temperature of 325 K was applied on tube surface. Water was selected as the working fluid, and all results were obtained under steady-flow conditions with Reynolds numbers ranging from 3500 to 6000. The velocity and temperature fields data obtained from simulation were used to determine the dimensionless parameters to represent flow conditions, convective heat transfer and frictional losses in the form of Reynolds number, Nusselt number and friction factor respectively. After computing the velocity and temperature fields, the average heat transfer coefficient can be calculated as follows:

The Reynolds number is defined as follows:

$$Re = \frac{\rho v D}{\mu} \qquad (4)$$

The average Nusselt number and friction factor are defined as follows:

$$Nu = \frac{hD}{k} \qquad (5)$$

$$f = \frac{2\Delta PD}{\rho v2L} \qquad (6)$$

Thermo hydraulic performance parameter (η) proposed by Webb and Eckert for assessment of thermal and hydraulic benefits of the corrugated tube is defined as,

$$\eta = \frac{\frac{Nuc}{Nu}}{\sqrt[1/3]{\frac{fc}{f}}} \qquad (7)$$

Where, Nus and fs are the Nusselt number and the friction factor in the smooth tube, respectively.

Table 1 PROPERTY OF WATER AND ALUMINUM TUBE

Type	Twist ratio	No of revolution of strip per unit 1 m	Inside Diameter of pipe	Outside Diameter of pipe
	Units	mm	mm	mm
1	2.4691	15	27	28
2	2.0576	18	27	28
3	1.7636	21	27	28

Table 2 MODEL DIMENSIONS

Description	water	Al	Value	Units
Density	1000	2719	2719	kg/m^3

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Specific Heat	4182	871	871	J/kgK
Thermal Conductivity	0.6	202.4	202.4	W/mK

VALIDATIONS

Calculating Nusselt number by using theoretical equation with the help of numerical simulation result and comparing it with Dittus bolter equation, for this we use following co relations.

Bulk mean temperature = (Ti +To)/2

Theoretical heat transfer (Q_{th}) =m Cp (To – Ti)

According to Newton low of cooling,

$$Q_{th} = h\,A\,(T_{surf} - T_{bm}) \quad (8)$$

$$h = \frac{Qth}{A(Tsurf - Tbm)} \quad (9)$$

$$Nu = \frac{hD}{k} \quad (10)$$

Calculation of Nusselt number by Dittus bolter equation

Nu (Dittus Bolter) = $0.023(Re)^{4/5}(Pr)^{2/5}$

$$Pr = \frac{\mu * Cp}{k} \quad (11)$$

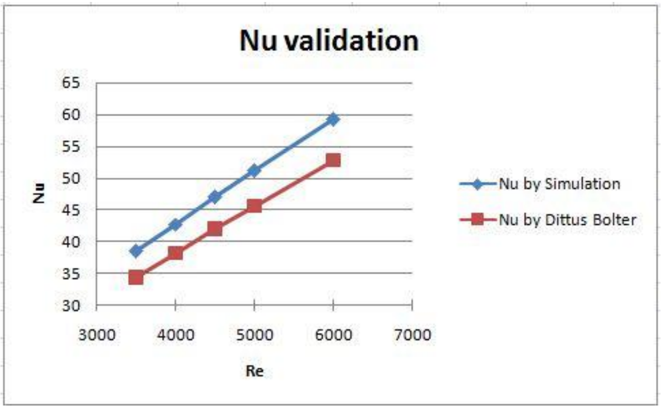

Fig.2 Nu validation of plain pipe

RESULTS AND DISCUSSION

A. Analysis of helical strip tube:

Numerical analysis is carried out to obtain the heat transfer and pressure drop data for a flow flowing through circular pipes with helical strip. The Reynolds number the flow is varied from 3500 to 6000. The Nusselt number and Pressure drop plots are discussed for different twist ratio. The heat transfer enhancement brought out by strip is determined by the ratio of Nusselt number for helical strip to that of a smooth tube. The thermo-hydraulic performance factor is examined for different twist ratio.

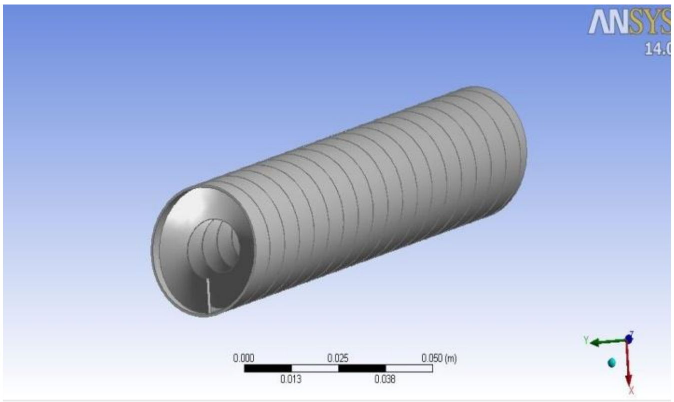

Fig.3 Geometric model of helical strip circular pipe

B. Effect of Reynolds Number:

Fig.5 shows the effect of Reynolds number on pressure drop for smooth tube and circular pipe with helical strip. From the Figure, it can be seen that pressure drop increases with increase in Reynolds number for smooth pipe as well as circular pipe with helical strip.

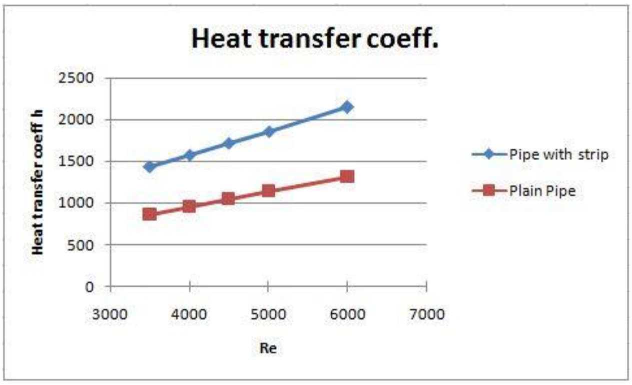

Fig.4 Comparison of heat transfer coefficient of with strip and without strip pipe.

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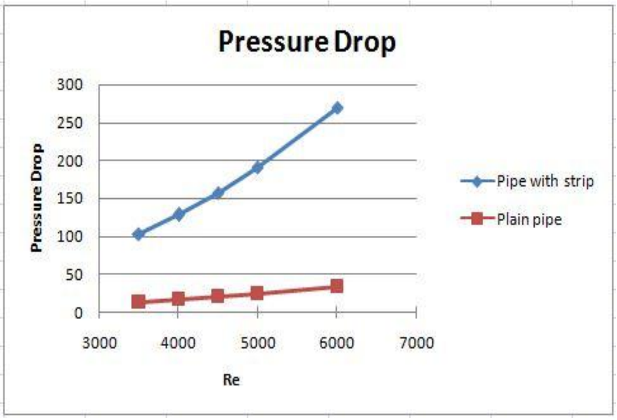

Fig.5 Comparisons of pressure drop of with strip and without strip pipe.

Fig.6 shows the effect similarly in case of heat transfer coefficient that heat transfer coefficient of different strip increases as Reynolds number increases.

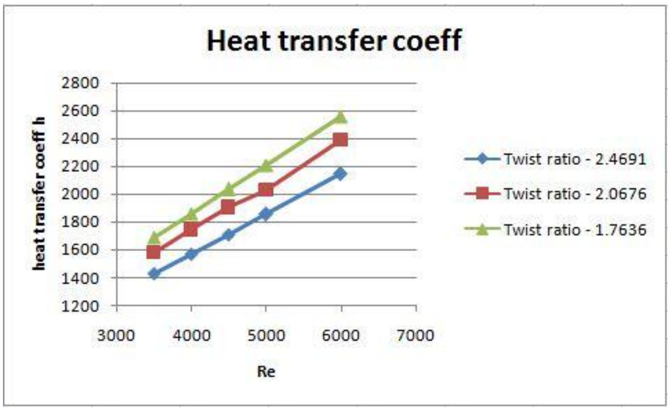

Fig.6 Comparison of heat transfer coefficient of different twist ratios

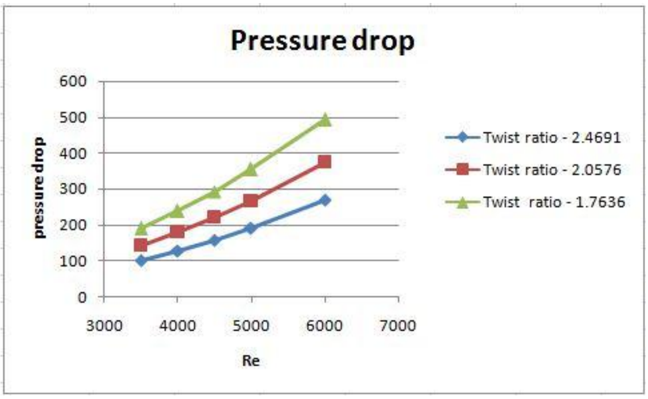

Fig.7 Comparisons of pressure drop of different twist ratios

C. Thermo-hydraulic performance:

It can be seen that the increase in heat transfer enhancements are accompanied with the increase in turbulence due to the disturbance of the boundary layer by the helical strip. To find the net benefit of placing the helical strip in pipe, the thermo-hydraulic performance factor (η) is determined for all helical twist ratios and at all the Reynolds number. Fig. shows the variation of thermo hydraulic performance parameter as a function of Reynolds number. It can be observed that the thermo hydraulic parameter decreases with increase in Reynolds number. It is seen that the thermo-hydraulic parameter remains highest at the low Reynolds number for all different twist ratio.

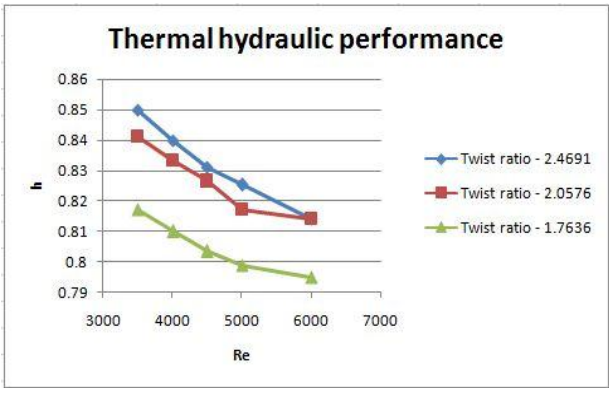

Fig.8 Thermal Hydraulic Performance factor for different twist ratio

The value of the thermo-hydraulic parameter is minimum for twist ratio of 1.7636. For the twist ratio of 1.7636, 2.0576 and 2.4691 the values of thermo-hydraulic parameters lie between 0.8171-0.7947, 0.8409-0.8139 and 0.8497-0.8141 respectively. Therefore on the basis of thermo-hydraulic factor it can be seen that the tube having twist ratio 2.4691 gives good performance for all velocity range.

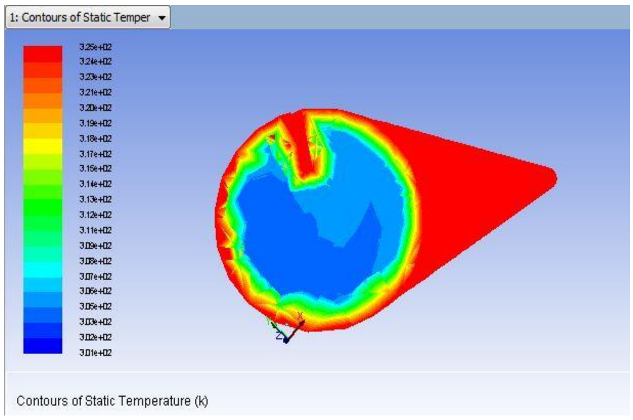

Fig.9 Temperature contour plot for outlet

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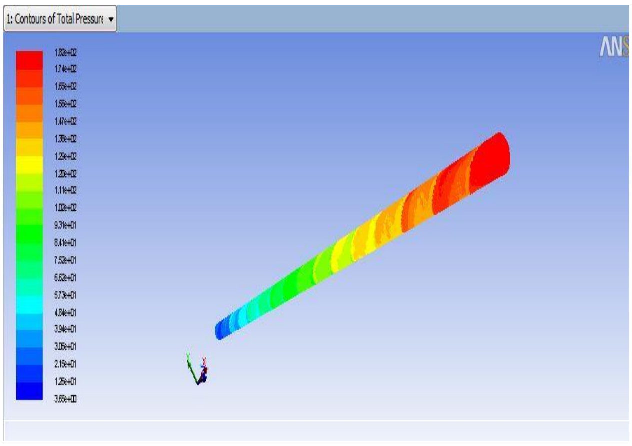

Fig.10 Total Pressure Contour plot for helical strip pipe

CONCLUSIONS

During the study of CFD analysis performed on helical strip in circular pipe heat exchanger geometry for various twist ratios and keeping constant wall temperature it is concluded that-

- As compared with plain pipe and twisted pipe, heat transfer rate increases up to 50% to 70%. But in other side pressure drop also increases up to 90 % drastically due to huge turbulence flow.
- In case of different twist ratio, heat transfer coefficient rate increases as twist ratio increases, also pressure drop increases simultaneously.
- In case of thermo hydraulic performance for different twist ratio gives different result. As twist ratio increases, performance factor decreases so from the graph, twist ratio 2.4691 gives higher value of performance than other twist ratio strip pipe.
- It is concluded that keeping same operating parameters for both heat exchangers, helical strip in circular pipe geometry gives more heat transfer rate.

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Corresponding Author

Sachin S. Surywanshi*

Department of Mechanical Engineering, Rajarambapu Institute of Technology, Sakharale, India

E-Mail – sachinsurywanshi111@gmail.com