Numerical Simulation of Turbulent Flow Through A Tube With Triple Helical Tape Inserts

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Abstract- *Thermal performance of heat transfer devices can be improved by heat transfer enhancement techniques. Turbulent convective heat transfer is the major heat transfer process in industry. For turbulent convective heat transfer enhancement internal inserts in tubes are found to be more efficient; therefore, important role in commercial applicationsis played by internally inserted tubes.*

More economical design of heat exchanger can be achieved by increasing heat exchangers performance which can help to make savings of energy, Material &cost related to a heat exchange process. The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings. This lead to the development of many techniques termed as ―Augmentation of Heat transfer. Convective heat transfer can be increased by Augmentation techniques by reducing the thermal resistance in heat exchangers.

In this project Influence of triple helical tapes inserted for turbulent flow through a tube on heat transfer enhancement will be studied numerically using ANSYS Fluent. The helix angle of Triple helical tapes are, α=9°, 13°, 17°,and 21° will be examined for Reynolds number ranging from 22,000 to 51,000. The Nusselt number, effectiveness and friction factor for the inserts will be found.

I. INTRODUCTION

In various industrial, commercial & domestic applications Heat exchangers are used in different processes ranging from conversion, utilization & recovery of thermal energy. Some common examples include steam generation & condensation in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchanger's performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to a heat exchange process.

The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings have led to development & use of many techniques termed as ―Heat transfer Augmentation‖. These techniques are also referred as ―Heat transfer Enhancement‖ or ―Intensification‖. Convective heat transfer can be increased by Augmentation techniques by reducing the thermal resistance in heat exchangers. Use of Heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, while designing a heat exchanger using any of these techniques, analysis of heat transfer rate & pressure drop has to be done.. To achieve high heat transfer rate in an existing or new heat exchanger while taking care of the increased pumping power, several techniques have been proposed in recent years and are discussed in the following sections.

Nowadays, twisted-tape inserts have widely been applied for enhancing the convective heat transfer in various industries, due to their effectiveness, low cost and easy setting up. Energy and material saving consideration, as well as economical, have led to the efforts to produce more efficient heat-exchanger equipment. Therefore, if the thermal energy is conserved, the economical handling of thermal energy through heat-exchanger will be possible.

The development of high performance thermal systems has stimulated interest in methods to improve heat transfer. The goal of enhanced heat transfer is to encourage or accommodate high heat fluxes. The heat transfer techniques enables heat exchanger to operate at smaller velocity, but still achieve the same or even higher heat transfer coefficient. This means that a reduction of pressure drop, corresponding to less operating cost. Heat transfer augmentation techniques refer to different methods used to increase rate of heat transfer without affecting much the overall performance of the system. These techniques are used in heat exchangers. Some of the applications of heat exchangers are-in process industries, thermal Power plants, air-conditioning equipment's, refrigerators, radiators for space vehicles, automobiles etc. These techniques broadly are of three types viz. passive, active and compound techniques

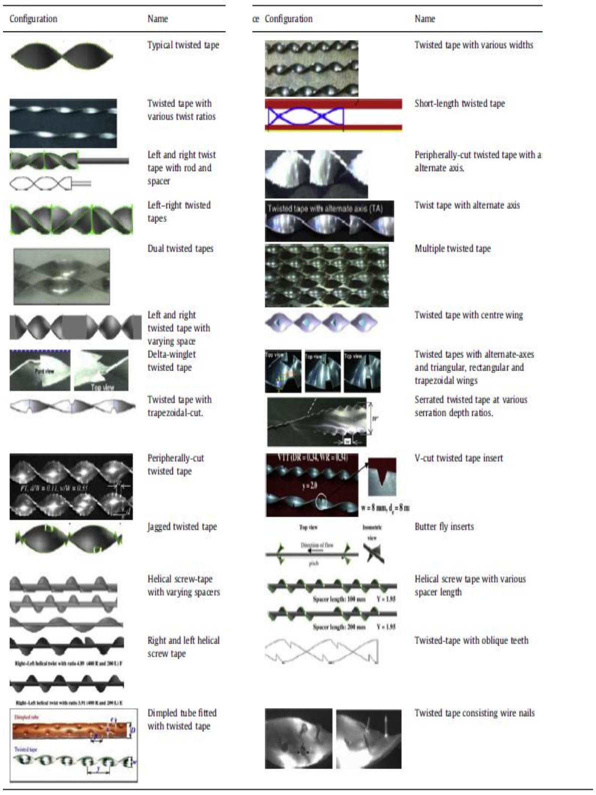


Fig.1. Configuration sketches of various twisted tapes.

Twisted tapes-a type of passive heat transfer augmentation techniques have shown significantly good results in past studies. For experimental work, Reduced width twisted tapes, having width less than ID of inside tube (W/di=0.727)) are used as shown in Fig.1. Configuration sketches of various twisted tapes.

1.3 TWISTED TAPE

Twisted tapes are the metallic strips twisted with some suitable techniques with desired shape and dimension, inserted in the flow. Following are the main categories of twisted tape which are analyzed.

i. Full length twisted tape: These tapes have length equal to length of test section.
ii. Varying length twisted tape: These are distinguished from first category with regards that they are not having the length equal to length of test section, but half length, ¾ th length, ¼ th length of section etc.
iii. Regularly spaced twisted tapes: These are short length tapes of different pitches spaced by connecting together.
iv. Tape with attached baffles: Baffles are attached to the twisted tape at some intervals so as to achieve more augmentation.
v. Slotted tapes and tapes with holes: Slots and holes of suitable dimensions made in the twisted tape so as to create more turbulence.
vi. Tapes with different surface modifications: Some insulating material is provided to tapes so that fin effect can be avoided. In some cases dimpled surfaced material used for tape fabrication.

1.3.1 COMMON ATTRIBUTES OF TAPE:

i. Width: Small width tapes are preferred to minimize pressure drop.
ii. Thickness: Thickness of the tape plays important role in its fabrication and also has contribution in fin effect
iii. Pitch:It is the distance between two consecutive twists measured axially.
iv Twist ratio: It is the ratio of pitch of tape to tape width. So, if width of the tape considered as a constant (as found generally) twist ratio depends on pitch only. Under this condition if pitch is more it means less number of turns.
v. Fin effect: If the tape material is conductive then during the flow some heat will be absorbed by the tape material itself till its saturation. This is simply the loss of available heat energy.

1.3.2 IMPORTANT TERMS USED IN TWISTED TAPE

Thermo Hydraulic Performance- 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.

Overall Enhancement Ratio- The overall enhancement ratio is defined as the ratio of the heat transfer enhancement ratio to the friction factor ratio.

2.3 Nusselt Number- 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- The Prandtl number is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of heat.

Twisted tape- Twisted tapes are the metallic strips twisted with some suitable techniques with desired shape and dimension, inserted in the flow. Following are the main categories of twisted tape which are analyses earlier.

Pitch- 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.

Twist Ratio- The twist ratio is defined as the ratio of pitch length to inside diameter of the tube.

II. AIM OF THE PROJECT

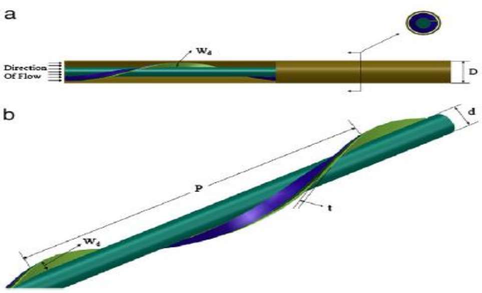


Fig2.1 (a) Geometry of test section fitted with triple helical tape insert with a core-rod, and (b) geometric parameters of the triple helical tape insert.

To study the modeling and simulating thermal–hydraulic characteristics of air flow inside a circular tube with tube inserts have been numerically investigated. In this project Influence of triple helical tapes inserted for turbulent flow through a tube on heat transfer enhancement will be studied numerically using ANSYS Fluent. The triple helical tapes made of mild steel with different helix angles, α=9°, 13°, 17°,and 21° will be examined for Reynolds number ranging from 22,000 to 51,000. The Nusselt number, effectiveness and friction factor for the inserts will be found.

2.1OBJECTIVE AND SCOPE OF THE WORK OBJECTIVE OF THE PRESENT STUDY IS TO:

Perform CFD Simulation of simple smooth pipe with different Reynolds number ranging from 22,000 to 51,000 compares the effects in terms Pressure drop, Nusselt number and HTC values

Perform CFD Simulation of the typical tube insert with different Reynolds number ranging from 22,000 to 51,000 compares the effects in terms Pressure drop, Nusselt number and HTC values for various helix angles, α=9°, 13°, 17°,and 21°.

SCOPE:

Literature review on tube insert has been carried out by referring through the reviewed journals and technical papers

The Experimental and Numerical models on tube insert has been studied from the reviewed journals

Geometric Model of the circular pipe with will be created using ANSYS Design –Modeler

Computational domain has been discretized using ANSYS Meshing

The CFD analysis will be out for the circular helical tapes insert to predict pressure drop, HTC and temperature and velocity distribution of the flow.

Comparison of pressure drop, and HTC for different helix angles, α=9°, 13°, 17°,and 21°.

III. CFD ANALYSIS OF SMOOTH AND HELICAL TUBE

3.1 SMOOTH TUBE RESULTS

Prior to the experiments using the dimpled tube combined with the twisted tape, the Nusselt number and the friction factor in a plain tube were calculated. The CFD data were, and then compared with the results given by the well-known correlations under a similar condition, in order to evaluate the validity of the plain tube.

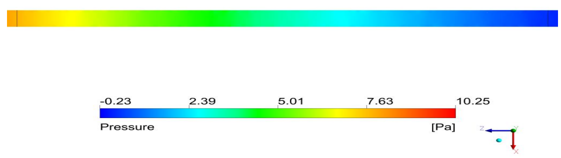


Fig.3.1 Pressure contours smooth tube velocity Re=22000

Fig.3.1 shows the Pressure contours smooth tube velocity 5.3m/s. In these contours shows helical tube pressure drop 10.25Pa.

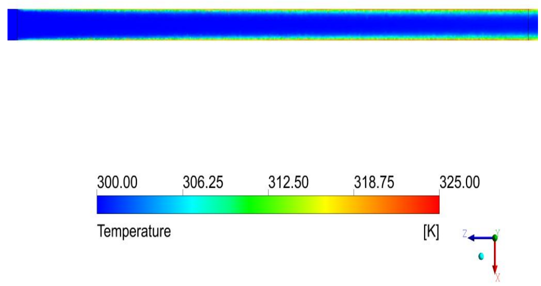


Fig.3.2 Temperature contours smooth tube Re=22000

Fig.3.2 Temperature contours smooth tube with velocity 2m/s. In this contour shows the temperature increased from 300K to 304.

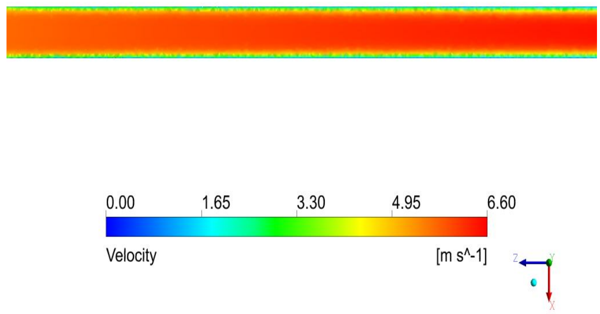


Fig.3.3 Velocity contours smooth tube velocity Re=22000

Fig.3.3 shows the Velocity contours smooth tube velocity Re=22000, it shows the higher velocity in tube region due to air.

3.2 VALIDATION

The comparisons for Nusselt number and friction factor are shown in Fig. 3(a) and (b), respectively. Obviously, the experimental data are in good agreement with existing correlations, which are Dittus–Boelter correlation. It is noted that the Nusselt number differs by up 5% from the Dittus–Boelter correlation. In addition, the experimental results of the present study are correlated with Nusselt number and friction factor as follows,

$$f = 0.718\mathrm{Re}^{-0.309}$$

$$\mathrm{Nu_o} = \frac{h_o D_H}{k} = 0.023\mathrm{Re}^{0.8}\mathrm{Pr}^{0.3}$$

The Nusselt number (Nu) was calculated as follows: with the Bulk fluid properties are taken as an average between the inlet and outlet of the tube. First Eq(2) is used to Calculate Q, the duty of the tube (W), ṁ is mass flow (kg/s), A is tube surface area (m^2), Cp is specific heat capacity (J/kg C) and ΔT (C) is the temperature difference between the inlet and outlet of the tube.

$$Q = \dot{m} * C_p * \Delta T \qquad (1)$$

Next hi, the overall heat transfer coefficient (W/m^2 K) of the tube is calculated using Eq(2). With ΔTLMTD, the log mean temperature difference given by Eq(3). For the wall temperatures the measured annulus inlet and outlet temperatures were used, this was possible since the annulus flow rates were very high with hardly any temperature change

$$hi = Q/A * \Delta T_{LMTD} \qquad (2)$$

$$\Delta T_{LMTD} = \left(\left(T_{WALL} - T_{OUT}\right) - \left(T_{WALL} - T_{IN}\right)\right) \Big/ LN\left(\frac{\left(T_{WALL} - T_{OUT}\right)}{\left(T_{WALL} - T_{IN}\right)}\right) \qquad (3)$$

Finally Nu is calculated using Eq(4), D is tube diameter (m) and k is thermal conductivity (W/m K).

$$Nu = \left(hi * D\right)/k \qquad (4)$$

Analytical and Experimental Results for different Reynolds number

Reynolds number	V m/s	Analytical Nu	CFD NU
22000	5.306905	5.04E+01	46.8222
27000	6.51302	5.99E+01	53.8975
32000	7.719135	6.91E+01	60.7493
37000	8.92525	7.81E+01	67.4996
42000	10.13136	8.68E+01	74.074
47000	11.33748	9.54E+01	80.5376
51000	12.30237	1.02E+02	85.5787

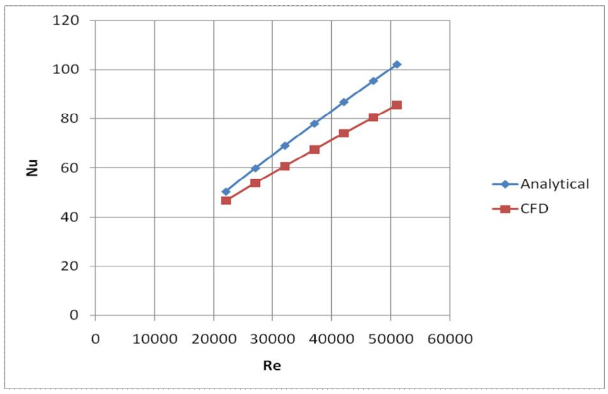


Fig.3.4 Comparisons of CFD and empirical correlations of the plain tube for Nu

Fig.3.4 shows comparison between the present experimental and analytical work. In the figures, the present work agrees well with the available correlations with ±10% in comparison Dittus–Boelter for the friction factor.

IV. RESULTS AND DISCUSSIONS

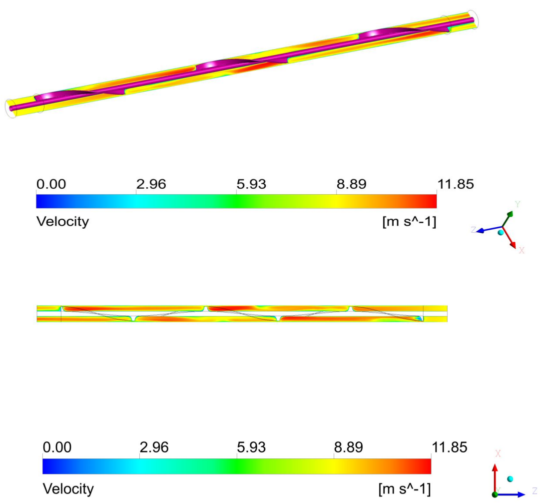


Fig.4.1 Velocity contours Helical insert with Re=37000 helix angles, α=9°

Fig.4.1 Velocity contours Helical Tape pitch length 600 mm velocity Re=37000. The twisted tube causes more turbulence intensity in the flow, because its sharp corner edge can produce more turbulence than the smooth surface, but, it causes more recirculation region inside the groove. So, it prevents good mixing of the fluid. Thus, it results in less increase of heat transfer compare with plain tubes.

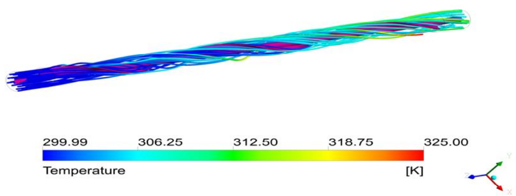
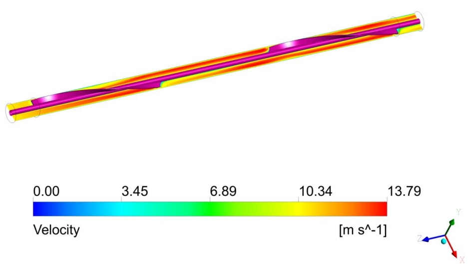


Fig.4.2 Velocity streamlines Helical insert without rod Re=37000 helix angles, α=9°



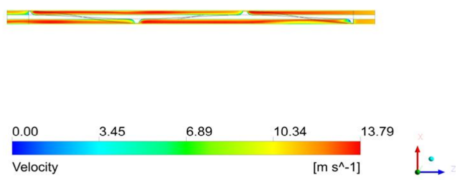


Fig.4.3 Velocity contours Helical insertwith Re=47000 helix angles, α=17°

Fig.4.3 Velocity contours Helical Tape pitch length 1000 mm velocity Re=47000. The twisted tube causes more turbulence intensity in the flow, because its sharp corner edge can produce more turbulence than the smooth surface, but, it causes more recirculation region inside the groove. So, it prevents good mixing of the fluid. Thus, it results in less increase of heat transfer compare with plain tubes.

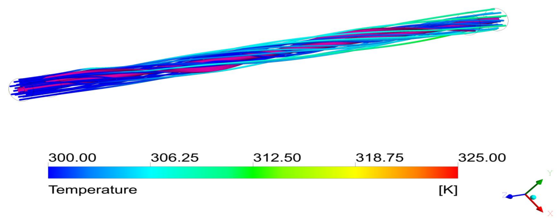


Fig.4.4 Velocity streamlines Helical insert without rod Re=47000 helix angles, α=17°

V. CONCLUSION

ACFD analysis has been conducted to investigate heat transfer enhancement by means of helical tape inserts in a double pipe heat exchanger using cold water and hot air as the test fluids. From the experimental results, it can be concluded as follows: found that enhancing heat transfer with passive method using different types of helical tape construction in the inner tube of a concentric double pipe heat exchanger can improve the heat transfer rate efficiently.

The maximum mean Nusselt number may be increased by 160% for the full-length helical tape with centered-rod, 150% for the full-length helical tape without rod and 145% for the regularly-spaced helical tape, s = 0.5, in comparison with the plain tube. The increase in heat transfer and pressure drop can be explained by the swirling flow as a result of the secondary flows of the fluid. Visualization streamlines show the flow pattern of the flow through the helical tape in the tube. It was observed that there are strong swirling flows in the tube fitted with the helical tape while the axial flow and the weak swirling flow were seen in the freespacing in the case of the regularly spaced helical tape without a rod.

Future work may be extended to:

Compound enhancement techniques maybe applied i.e., the tape inserts can be coupled with coil wire inserts for better enhancement

Other reduced width twisted tapes along with variation in Reynolds numbers; and

Develop further correlations by considering lower Reynolds numbers

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