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Investigation of Heat Transfer Enhancement in Tube Heat Exchanger by using Outer Helical Fins and Helical Inserts

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***Abstract*—In this paper, the performance of a double pipe heat exchanger with helical fins and Helical inserts are investigated analytically.The study is to investigate the heat transfer coefficient and pressure drop for fins and insets configuration.The analysis is conducted for set values of diameters of pipes which gives the optimum Reynolds number for the flow to be in turbulent nature.The model was first validated for a simple double pipe heat exchanger by comparison with empirical correlations and was then used to investigate the helical fins and inserts effects having pitch (300-500mm).The results obtained provide enhanced heat transfer performance and high-pressure drop compared to large pitch of insert.Also empirical correlations expressing the results were developed based on curve fitting.**

Keywords: Double Pipe Heat exchanger, Heat transfer enhancement, Double pipe HX ,Helical fins, Helical Inserts.

1. INTRODUCTION

In todays world, the heat exchanger are one of the most widely used heat transfer equipment used varying its usability from automobile industry to chemical plants to power generation and many more. A simple double pipe exchanger consists of Two pairs of concentric pipes,the two fluids that are transferring heat flow in the inner and outer pipes ,respectively. Tubular heating is mainly used in applications such as plastic injection and rubber molding, packaging, plastic welding, plate heating.Heat Exchanger must have lower costs and higher energy efficiency.

Recently various studies have been done on heat transfer enhancement in heat exchangers, M C Wang et al[1] used helical baffles in shell and tube heat exchanger having parameter as folded helical baffle with electric heater with long u-tube.They have used the helical baffle with No perforation and none of the insert was used.The Helical baffle technique was quite effective and with helix angle being 25, it was most effective.Flow resistance was lesser than ordinary baffles and there is scope of improvement in results by using various inserts. Recently in 2017 Maakoul et al [2] investigated Helical baffles in double pipe HX having Baffle spacing of (100,50,25) on annulus side.The results were 5%, 17%, 30% and 45% on average with an increase in pressure drop equal on average to 2, 5, 11 and 20 time the pressure drop in a conventional HX.The scope of work was by increasing the length of the tubes , it’s effect on the pressure drop and heat transfer can be studied.In 2012 Thianpong et al [3] studied Perforated Twisted Tape insert in tube HX and tested for Perforated Twisted Tape with diff. Twist ratio, Pitch ratio and Dia ratios.The results proved that TPF decreases with increase in the tape twist ratio and pitch ratio.But at high Re TPF was observed to be less than unity which is not good. The length of the perforated insert was kept constant, so there is a scope of varying the length of the insert and getting the results at different ratios.In 2016 Chang et al[4] studied the thermal performances of turbulent tubular flows enhanced by ribbed and grooved wire coils.In this they used R-90; G-90 ,G-45, RG-90 augment for experiment.Due to separated flow which is generated by rib flowed through groove resulting in enhancement of thermal performance.The result was that TPF of R-90,R-45,RG-45 was more than unity and G-45 had the best performance in increasing TPF.The length of the insert was kept small.So the length variation can be obtained and also use of the software can justify the results.In 2013 Nanan et al[5] studied the Co and Counter Helical Twisted Tapes in tube HX where Twist ratio was 3-5 and angle was 30 to 90.It was found that at constant Re counter-swirl gets better than co-swirl. Counter-swirl consistently leads to significantly higher friction factor than the use of Co-swirl, as counter-swirl generates higher flow hindrance.The TPF obtained by Co-swirl insert are slightly good than those given by counter-swirl insert (up to 4.7%).As the result, they suggested that combined enhancement of TPF and all the factors was much more than the individual enhancement. Saha and Dutta[6] studied a circular tube having short length and smooth pitch and observed that friction factor and Nu increases with using augment. In 2018 Bhumina [7] investigated for twisted tape and found out that uniform twisted pitch performs better than varying pitch augment. Wang and suden [8] tested for circular pipe HX with twisted tape regularly spaced and found out that larger number of turns may yield improved thermohydraulic performance compared with single turn.Seigel[9] investigated that for tube HX horizontal insert in tube HX increases heat transfer rate more than vertical inserts.Bolla et al[10] found in this studies that while experimenting with ribs and tapes, the ribs performed better than tapes.Burfoot et al[11] He investigated that twisted tape for roughness in tube HX and found that surface roughness of inserts affects the thermophysical. Haruki [12]He tested wire coil in Tube HX and results were that pipe friction and heat transfer coefficients varies by values of velocity,pitch and length.Olvister and sahoji[13] investigated non-newtonian fluid in tube HX and found a drop in TPF by margin of 12%.
From literature study, it is seen that researchers have used various method to increase the heat transfer efficiency of tube heat exchager.But in order to improve the Thermal performance of the HX we can to evaluate the effect of two

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augment on a single setup.so that we can compare the results with the previous work to see the actual margin we have achieved.

2. NUMERICAL MODEL

2.1 Physical Model

The aim of the research is to study the effect of Helical inserts of different pitch and outer helical fins in tube heat exchanger. As there is change in dimensions of HX so, the pressure and velocity along the tube heat exchanger changes and thus the amounts of heat transfer rate and pressure drop changes. The configuration of helical insert in double-pipe

heat exchanger are shown in fig 2, the insert pitch B varies from 25 to 100 mm (top to bottom order).It is seen that geometry of HX is simple but its numerical thermo-hydraulic study is complex due to the complexity of flow regime in the annulus and inner tube side.

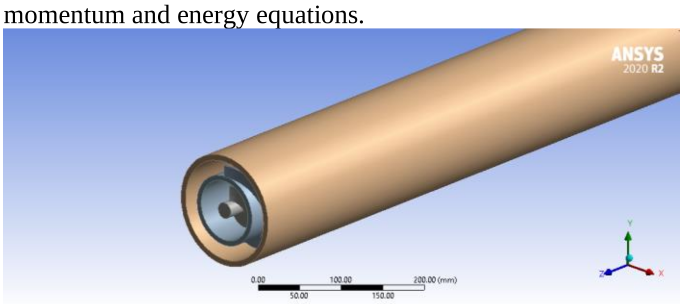
The cold water flows on the tube side, while the hot water flows in the annulus side in a counter-current configuration.

The length and diameters of the modeled heat exchangers are kept the same with each other, which is to ensure all of the values of geometry parameters are consistent except the pitch of helical insert. The material of the heat exchangers parts is stainless steel considering all the factors.The fig 1 shows the geometric representation of the flow arrangement and gives the idea about the placing of outer helical fins and helical inserts.The diameter is calculated by considering the turbulent flow condition in picture, which will help in increasing the chances of heat transfer rates.The CFD software Fluent and design modeller were adopted to establish the models and analyze the flow and heat transfer properties.

2.2 Governing Equation

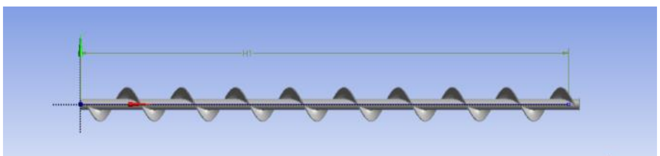
Water is used as it is a incompressible fluid with constant properties. Furthermore, the fluid flow and heat transfer processes are considered in the turbulent regime and steady-state case, within the calculation range, all RE are greater than 5000 for inner pipe and greater than 3000 for annulus region. The leak in between helical wall and the annulus pipe is very small and can be neglected.

This model was based on the numerical solution of continuity, momentum and energy equations.



(a)

Fig 1. (a) Geometry of Double pipe HX with Helical fins and Helical inserts



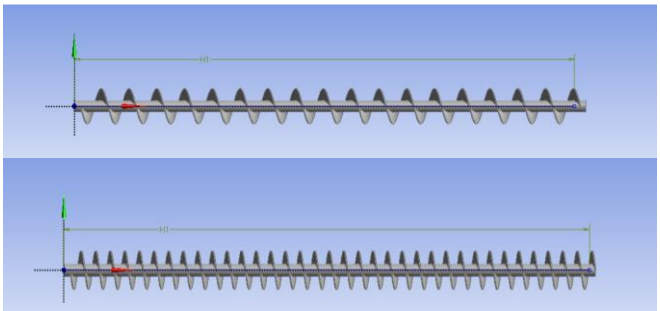


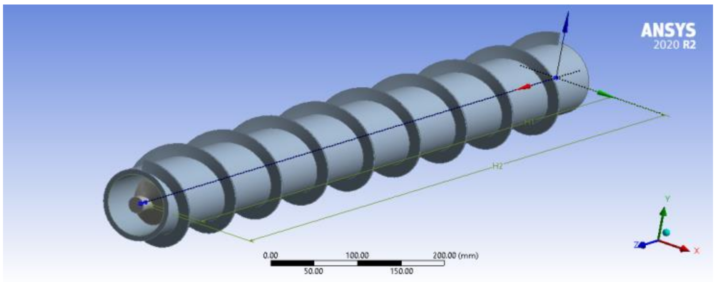
Fig 2. Helical inserts of varying pitch (100-25mm)

Table 1. Operational parameters

Sr. No	Dimensional parameter	Dimension
1	Heat exchanger's capacity	25kw
2	Temperature range	20-90 ℃
3	Length of Heat exchanger	1000mm
4	Working fluid	water
5	Flow type	Counter clock flow
6	Flow condition	Cold water inside

Continuity Equation:

$$\frac{du_i}{dx_i} = 0$$



(b)

(b) Design of Helical fins on outer tube and inserts in inner tube

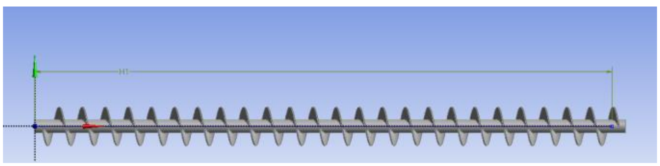
Momentum Equation:

$$\frac{\partial u_i u_j}{\partial x_i} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}((v + v_{turb})(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}))$$

Energy Equation:

$$\frac{\partial u_i T}{\partial x_i} = \rho \frac{\partial}{\partial x_i}((\frac{v}{Pr} + \frac{v_t}{Pr_{turb}})\frac{\partial T}{\partial x_i})$$

where u; T and p represent the fluid velocity, temperature and



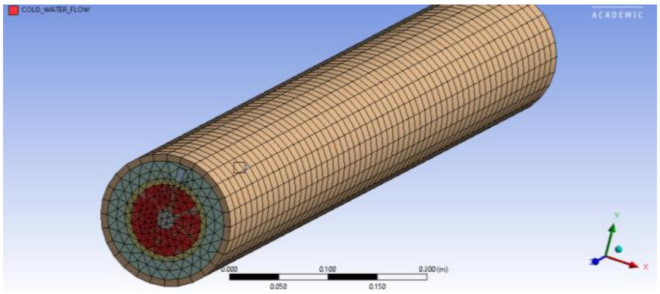
pressure, respectively. q is the fluid density, m and Pr are the fluid kinematic viscosity and Prandtl number, subscript turb refers to turbulent flow.

2.3 Domain definition, Mesh sensitivity, Boundary condition.
In paper 5 double-pipe heat exchangers are studied consisting One simple double-pipe exchanger and the others have helical inserts with different pitch(25-100mm) on the inner side of the pipe.For each of the 5 studied heat exchangers, three domains are defined, two fluid domains (water in the inner tube and water in the annulus side) and one solid domain (walls, baffles).The mesh used is a mix of unstructured tetrahedral and wedge (Prism) grid .So due to wedge elements results in use of inflation layers and are located near the walls.
In order to ensure the accuracy of the numerical results, the mesh sensitivity test was conducted for B= 50 mm. A series of grid sensitivity tests were carried out to ensure that optimized computational mesh was obtained.

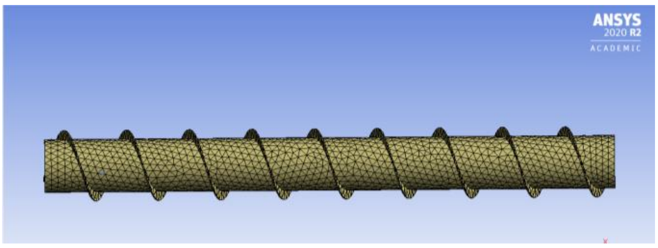
Table 2. Mesh metrics

Nodes	Elements	Avg. Skewness	Orthogonal
24805	131209	0.209	0.867

The Boundary is set having zero slip and zero edging. The walls represent the solid-fluid interaction between the two fluid domains and the solid domain two interfaces with coupled wall.
The outlets are kept to zero pressure so the inlet pressure is equal to the pressure drop on both sidesThe algorithm of simulation is kept simple to avoid any calculation glitch and further error addition as if we increase the complexity, the error also multiply and the results obtained are not upto the mark which is not acceptable in CFD analysis .



(a)



(b)

3 DATA REDUCTION

[1] The Heat transfer for tube side(cold fluid) is given by

$$Q = m_c \cdot c_{pc} \cdot \Delta T_c$$

Where m_c is the mass flow rate of cold water, c_{pc} is specific heat of cold water and ΔT_c is Temperature difference between cold water inlet and outlet.

[2] Heat transfer for annulus side (hot fluid) is given by

$$Q = m_h \cdot c_{ph} \cdot \Delta T_h$$

Where m_h is the mass flow rate of hot water, c_{ph} is specific heat of hot water and ΔT_h is Temperature difference between hot water inlet and outlet.

[3] Flow Velocity is calculated as

$$v = \frac{m}{\rho * A_c}$$

Where m is the mass flow rate,ρ is density of water and Area of flow section is given by A_c.

[4] Reynolds number (Re) is calculated as

$$Re = \rho v d / \mu$$

Where μ is dynamic viscosity.

[5] Hydraulic Diameter is calculated by

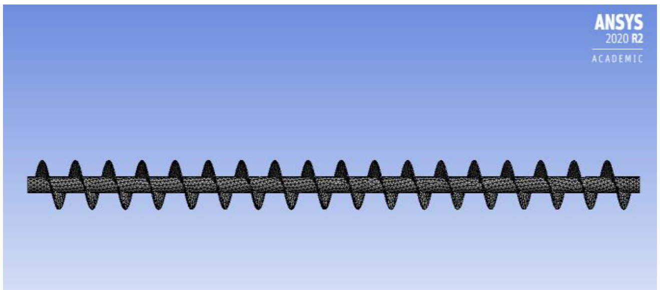
$$D_h = \frac{4 * A_c}{P}$$

Where A_c is contact area of flow and P is the wetted perimeter.

[6] For helical fins annulus side area is given by

$$A_{cross} = 0.5B(D_i - d_o)$$

Where B is the pitch of the outer helical fins, D_i is internal diameter of annulus side and $d_o$is outer diameter of inner tube.



(c)

Fig 4. Mesh, (a) Body . (b) Helical fins . (c) Helical insert

[7] Nusselt number(Nu) is given by

$$Nu = \frac{h * d}{k}$$

Where h is the heat transfer coefficient, d is the diameter and k is thermal conductivity.

4 RESULT AND DISCUSSION

In this study thermal and performance of heat exchanger is analyzed using CFD simulation and numerical analysis. The study takes into account the temperature range of 22-27°C for cold fluid and range of 85-90°C for hot fluid.Flow rate was varied from 0.1 kg/s $\leq m_a \leq$ 0.3kg/s for bot hot and cold pipes.Nusselt number validation for both inner tube and annulus side was done using the following correlation:

$$Nu = 0.023Re^{0.8}Pr^{1/3} \qquad [8]$$

4.1 Reynolds no.(Re) Variation with cold water inlet(T_{ci}):

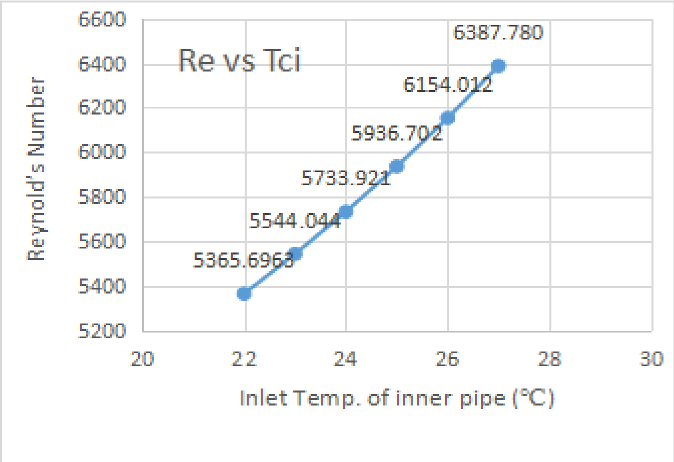


Fig 5. Re vs T_{ci}

Reynold's number is important parameter while studying the heat exchangers.From the above result it is observed that as we increase the inlet temperature of cold fluid, the reynolds number increase non linearly.This is because as we increase the inlet temperature, ΔT_c decreases and it results in increase in m_c,as heat exchager's capacity is fixed.so due to increase in m_c, reynolds number increase.

4.2 Reynolds no.(Re) Variation with hot water inlet(T_{hi}):
The hot water inlet T_{hi} is important inputs which use in heat exchangers.After analyzing the graph it is clear that as we increase the hot water inlet T_{hi} , the reynolds no. Decreases.This is because as we increase the T_{hi} from 85 to 90°C, the ΔT_h increases which results in decrease of m_h as capacity is fixed.so this results in decrease of reynolds number.

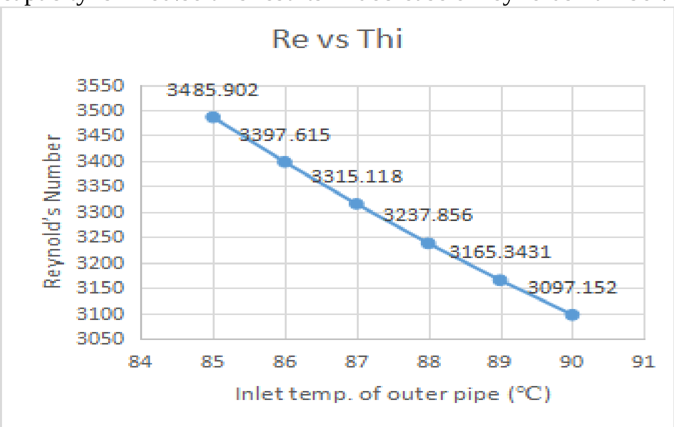


Fig 6. Re vs T_{hi}

5.3 Cold pipe pipe Dia variation with cold water inlet(T_{ci}):

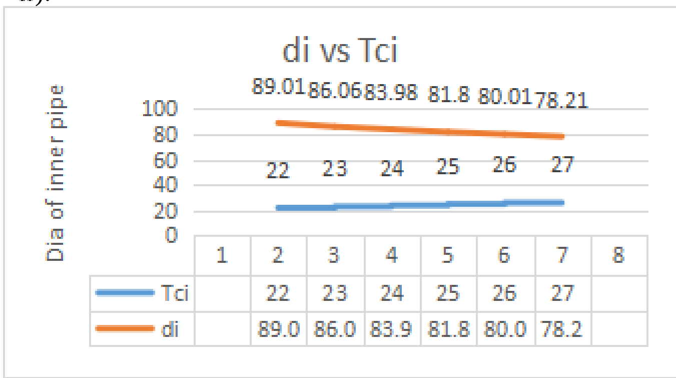


Fig 6. di vs T_{ci}

The diameter selection of pipes is important factor while designing the heat exchangers. The diameters are selected such that it will enhance the chance of improvement. From the above fig. It is clear that the temperature range which we used for cold inlet(22-27°C), the favourable diameters for inside pipe's inner diameter is ranging from 78.2 to 89mm.So from this the diameter was selected to be 88.9mm considering the standard size availability in market.

4.3 Hot pipe pipe Dia variation with hot water inlet(T_{hi}):
The diameter selection of pipes is important while deciding the geometry of the heat exchangers. The diameters must be selected such that it will enhance the chance of improvement. From the below fig.,It is clear that the temperature range which we used for hot inlet(85-90°C), the favorable diameters for outside pipe's inner diameter is from 125 to 131mm.So thus, 127mm is taken as per availability in market.

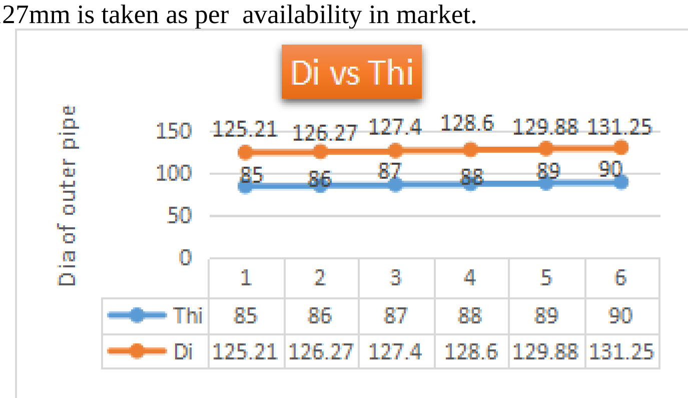


Fig 7. Di vs T_{hi}

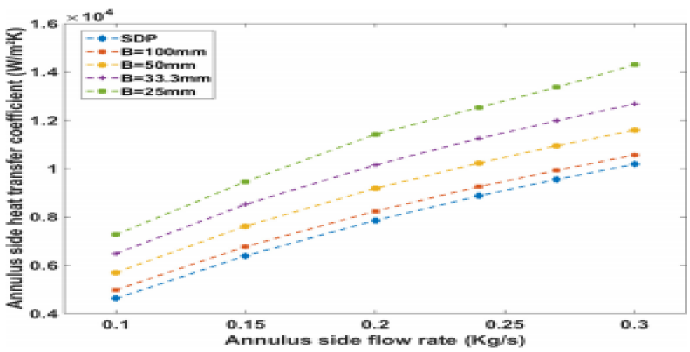


Fig 8

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4.4 Heat Transfer Performance:

Fig 8 represents the comparison of heat transfer coefficient for all four conditions of helical inserts having pitch from 25-100mm.It is observed that the heat transfer coefficient h_a increases with the increase in the mass flow rate inside pipe.The heat transfer coefficient h_a also varies inversly with pitch of helical insert. As we decrease the pitch of helical insert from 100mm to 25mm , the heat transfer coefficient h_a increase.This is due to higher fluid average and maximum velocities when using helical inserts of smaller pitch.Thus use of helical geometry improves H.T in this condition.

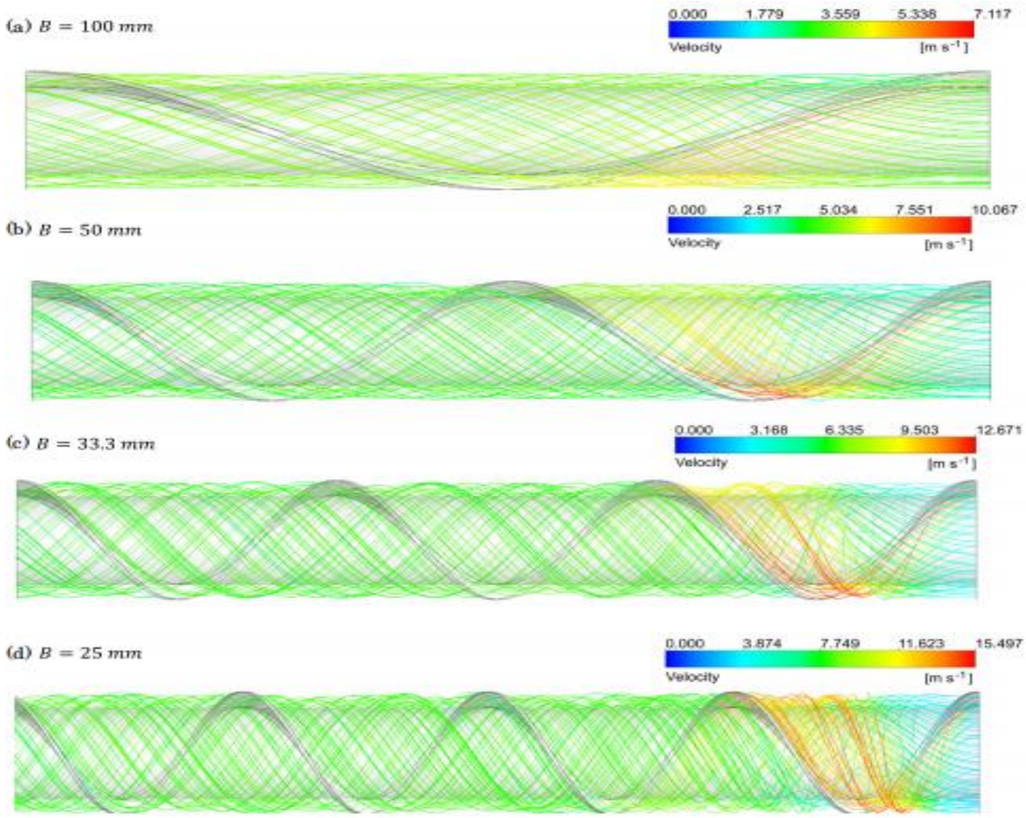

Fig 9.Velocity streamlines for different pitch of insert.

5.6 Pressure Drops:

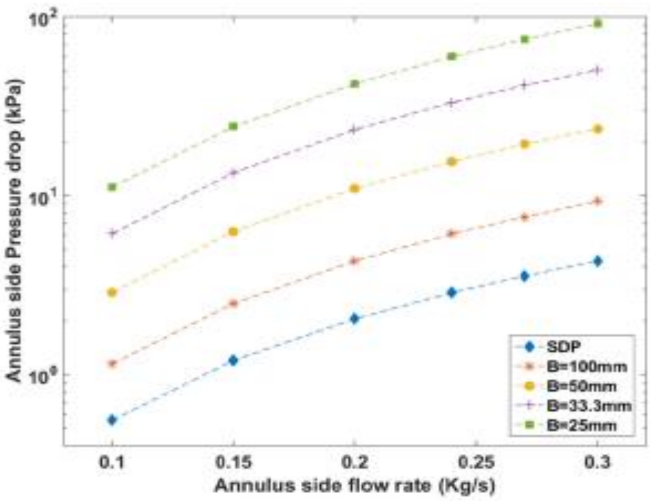

Fig 10. Pressure drop variation

The pressure drop is of great importance in the design of heat exchanger and also pumping cost is highly correlated to pressure drop,
and therefore lower pressure drop results in lower operating costs.Fig 10 depicts the variation of the pressure drop ΔP versus the mass flow rate for the studied cases.As expected previously, the use of helical inserts results in a higher pressure drop, which is equal to on average of 2, 5, 11
and 21 time the pressure drop for a conventional flow, for B equal to 100 mm, 50 mm, 33.3 mm and 25 mm respectively.This high pressure drop is caused by: (1) The decrease in annulus fluid path, notably for lower B values (2) high average velocity in the annulus side as a result of the reduced flow area (3) the sudden change in flow area at the inlet side (5) higher maximal velocity at entrance region (4) a larger contact surface between the fluid and the solid walls due to the addition of the helical geometry. The fluid which is in the layer is in contact with the solid walls (tubes and insert walls) will come to a complete stop. This results in slowing down of particles, thus, increasing the pressure drop.

5 CONCLUSION

In the present study, a tube heat exchanger with helical insert and fins was studied analytically and CFD analysis was performed to evaluate the performance of the HX. It was found out that using the insert on smaller pitch increases the heat transfer efficiency by 5% than the conventional one. But also with the inserts of smaller pitch, the pressure drop is high.The turbulent regime was considered thought the study for making it closer to real situations.
Further points which must be studied are (1) The optimum combination of outer fins and inserts for enhancement.(2) Length variation can be studied keeping same condition.(3)Effect of change in helical insets and fins geometry such as thickness and inclination angle.

NOMENCLATURE:

d_i Inside diameter of inner pipe
d_o Outside diameter of inner pipe
D_i Inside diameter of outer pipe
D_o Outside diameter of outer pipe
B Pitch of insert
h Average heat transfer coefficient
Re Reynolds number
Nu Nusselt number
ΔP Pressure drop
k Thermal conductivity

Subscript:

In Inlet
Out Outlet
turb Turbulent

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