

Effect of Different Shapes of Perforation in Discontinuous Helical Turbulator on Heat Transfer Enhancement

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Abstract— Heat exchangers are used to transfer heat from one medium to another. Heat transfer depends on different process parameters of heat exchanger in which different types of turbulators were used inside the heat exchanger to increase the turbulence. Turbulators are used to increase the performance of heat exchanger, here in this work it uses discontinuous helical perforated turbulators at different Reynolds number to increase the performance of heat exchanger. For analysing the effect of different perforated turbulator here it considered three different types of perforated discontinuous helical turbulator that is rectangular, triangular and circular at 25 degree inclination angle. Here it calculate the value of Nusselt number, friction factor and thermal performance at different Reynolds number. Through analysis it is found that the discontinuous helical turbulator with triangular perforation shows maximum heat transfer.

Key words: Turbulator, Heat Transfer Enhancement

I. INTRODUCTION

A heat exchanger is equipment utilized to exchanging heat amongst the solid body and a fluid, or among two or more liquids. The liquid might be unglued by a solid wall to avert intercourse or they might be in straight interaction. They are extensively utilized in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The definitive illustration of a heat exchanger is originated in an internal combustion engine in which a mingling liquid recognized as engine coolant flows through radiator coils and air flows earlier the coils, which cools the coolant with heats the incoming air. One more instance is the heat sink, which is an inert heat exchanger that posted the heat produced by an electronic or a motorized expedient to a liquid medium, always air or a liquid coolant. The foremost attentions regarding the effectiveness of shell tube heat exchanger are comes in a region of turbulence, drop in pressure, coefficient of heat exchanger, fouling, as well as percentage or aggregate of stream rates on tube to shell side, length of heat exchanger as well as baffle types. By increasing the turbulence power level, conflict to the flow also extended, which advanced the heat exchanger effectively. Heat exchanger rate may be developed with huge loss of pressure though it stimulates to increase in power consumption, which is its real downside. Consequently, assessment of reorganized drop in pressure for ideal rate of heat exchanger as well as power consumption is used. More projecting heat exchanger coefficient upsurges the heat exchanger rate. Heat exchanger coefficient improved by increasing the rate of flow at shell and tube side, coil diameter as well as pitch are also in consideration by mentioning counter stream design.

On the basis of different applications, water to air heat exchanger can be selected. It can be utilized for

residential heating and dehumidification. Swirl flow device are one of the similar way for heat transfer enhancement which becomes popular due to low price. To enhance the heat transfer from water to air different types of discontinuous helical turbulators were placed in the outer surface of inner tube. Due to this helical turbulator, turbulence and contact time were increased which helps in increasing the heat transfer. In this work through analysis it is found that heat transfer also depends on the inclination of helical turbulators and through analysis it is also found that at 25° inclination angle of discontinuous helical circular perforation shows maximum heat transfer. So here in this work we have considered three different shapes of perforated discontinuous helical turbulator at 25° inclination that are triangular, rectangular and circular perforated helical baffles to enhance heat transfer rate. To find out the effect of different Reynolds number (Re) on heat transfer hear it considered four different Re of cold fluid that is 6000, 8000, 10000, 12000. Here it calculate the value of nusselt number for different Re and also calculate the value of friction factor for different nusselt number. To measure the heat transfer increment due to use of different discontinuous perforated helical turbulator here it also calculate the value of thermal performance.

II. DEVELOPMENT OF SOLID MODEL OF HEAT EXCHANGER

For the validation of the numerical analysis here first it considered heat exchanger having circular perforation helical turbulator as considered in base paper. The solid model of heat exchanger is develop on the basis of geometry considered by Sheikholeslami et.al considered during the experimental analysis the geometric specification of solid model of heat exchanger is given in the below table

Geometric specification	Values	
Inner pipe diameter (mm)	Inner diameter D_i	28
	Outer diameter D_o	30
Outer pipe diameter (mm)	Inner diameter d_i	50
	Outer diameter d_o	60
Turbulator Thickness (mm)	2	
Turbulator width (mm)	7	

Table 3.5: Value of Geometric Specification

The solid model of the heat exchanger is shown in the below fig.

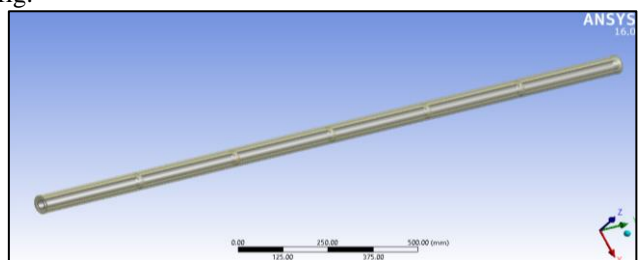


Fig. 3.1: Solid Model of the Heat Exchanger with Perforated Helical Baffles

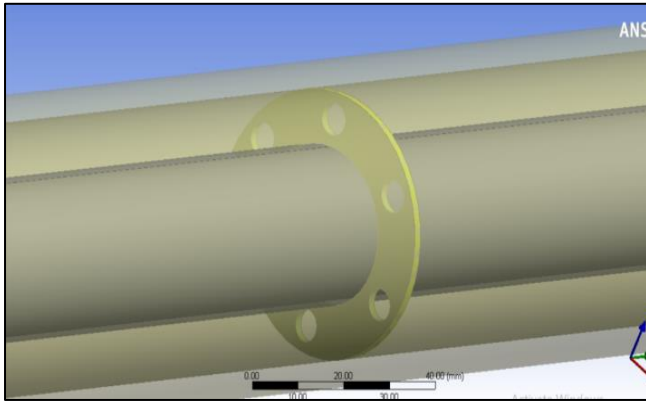


Fig. 3.2: Shows the Circular Perforation Helical Baffles

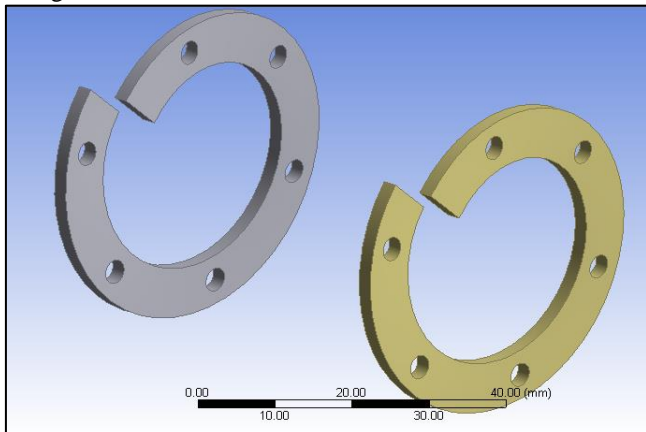


Fig. 3.3: Discontinuous Helical Baffles Used For the Analysis

A. Meshing

To perform the numerical analysis here it has to discretize the solid model in to number of elements and nodes. To perform proper mesh different meshing tool where use for the refinement of mesh. Mesh of the helical baffles heat exchanger is shown in the below fig. In order to perform the mesh independent test, here in this work it has done meshing with different number of elements and calculate the value of temperature of hot fluid at the exit of heat exchanger. The value of temperature of water at the exit for different number of element of mesh is shown in the below table

constant	Density (ρ) (kg/m ³)	Specific heat (Cp) (J/kg-K)	Dynamic viscosity (μ) (kg/m-s)	Thermal conductivity (K) (W/m-k)
A ₁	4.54	1.05E03	9.46E-05	1.80E-02
A ₂	-2.32E-02	-3.51E-01	-1.02E-06	-1.68E-04
A ₃	5.64E-05	5.84E-04	4.71E-09	1.38E-06
A ₄	-6.28E-08	3.03E-07	-9.11E-12	-3.26E-09
A ₅	2.36E-11	-5.2E-10	6.54E-15	2.75E-12

Table 3.1: Value of Coefficient for Different Properties of Air

$$A_1 + A_2 \times T + A_3 \times T^2 + A_4 \times T^3 + A_5 \times T^4 \dots \dots \dots (1)$$

D. For Outer Tube

For outer tube it used plexiglas as a manufacturing material which act as thermal insulator. It prevents heat to go inside the tube.

Property	Values
Density (kg/m ³)	1180
Specific heat (J/kg-k)	1466

No. of elements	Temperature (K)
385563	318
404586	318.5
432486	319

Table 3.6: Value of Temperature for Different Number of Elements

From the above table it is found that the value of temperature of water at the exit is not depending on the number of mesh elements. So to minimize the computational time here it considered minimum number of elements to perform the numerical analysis. Mesh with minimum optimum number of element is shown in the below fig.

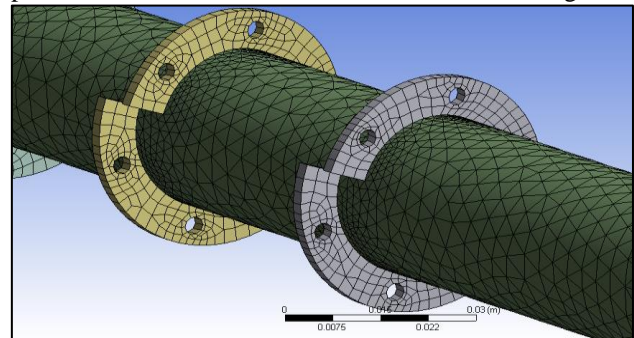


Fig. 3.5: Showing the Mesh of Discontinuous Helical Baffles

B. Material Selection

Here in this work warm fluid water is flowing in the inner tube whereas cold fluid that is air is flowing in the outer pipe. The inner pipe of heat exchanger is made of copper material whereas outer tube is made of Plexiglas which acts as a thermal insulating material. The properties of all material is mention in above section, the selection of different material for different components is shown in the below section.

C. For Cold Fluid

Air is used as a cold fluid which is flowing in the outer tube of heat exchanger; here the property of air is also varying with respect to temperature. Properties of air vary with respect to the equation (1) as mention in the below section. The value of coefficient for different properties are mention in the below table

Thermal conductivity (W/m-k)	0.000581
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Table 3.3: Properties of plexiglas material

1) For Inner Tube

Here in this work copper is used for inner tube manufacturing, the properties of copper material is shown in the below table.

Property	Value
Density (kg/m ³)	8978
Specific heat (J/kg-k)	381
Thermal conductivity (W/m-k)	387.6

Table 3.4: Properties of Copper Material

E. Solution Method

To examine the heat exchanger, here in this work it uses the K-epsilon (turbulent kinetic energy rate of dissipation) model with standard wall function. The procedure of solution method where shown in the block diagram. Due to standard wall function, the velocity of air or water particles which come in contact with the wall is zero that is no slip (zero velocity of fluid relative to the boundary) condition is applicable at the wall of inner and outer pipe.

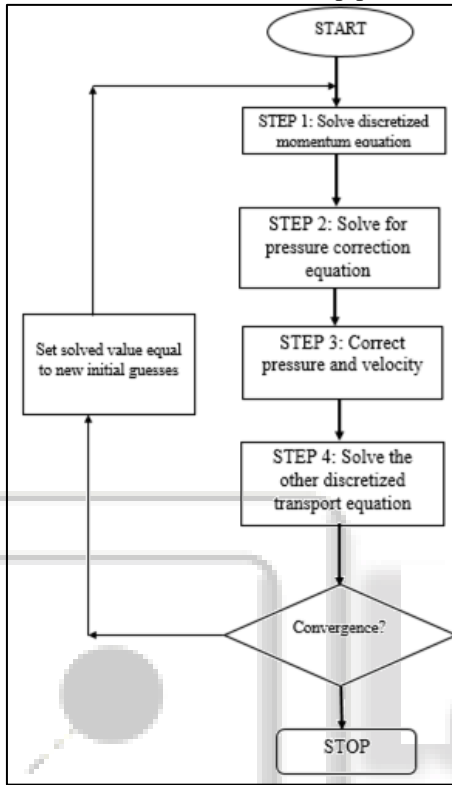


Fig. 3.14: Block Diagram of Solution Method used During the Analysis

III. BOUNDARY CONDITION

The temperature of warm fluid at inlet is 346.11 K and flowing at a velocity of 0.063 m/s. whereas cold fluid is flowing at a velocity of 6.82 and temperature of cold fluid at inlet 301.16 K as considered during the experimental analysis performed by Sheikholeslami et.al [21]. For validating the CFD model of heat exchanger having discontinuous helical turbulator, here it examine the heat exchanger having helical discontinuous turbulator with circular perforation as consider during the experimental analysis performed by Sheikholeslami et.al. The inlet and outlet conditions of hot fluid and cold fluid were same as considered during the experimental analysis and calculating the value of nusselt number, Darcy friction factor. The contour of temperature and velocity for different Re numbers are shown in the below section

A. For Re 6000

The temperature contours for 6000 Re number is shown below

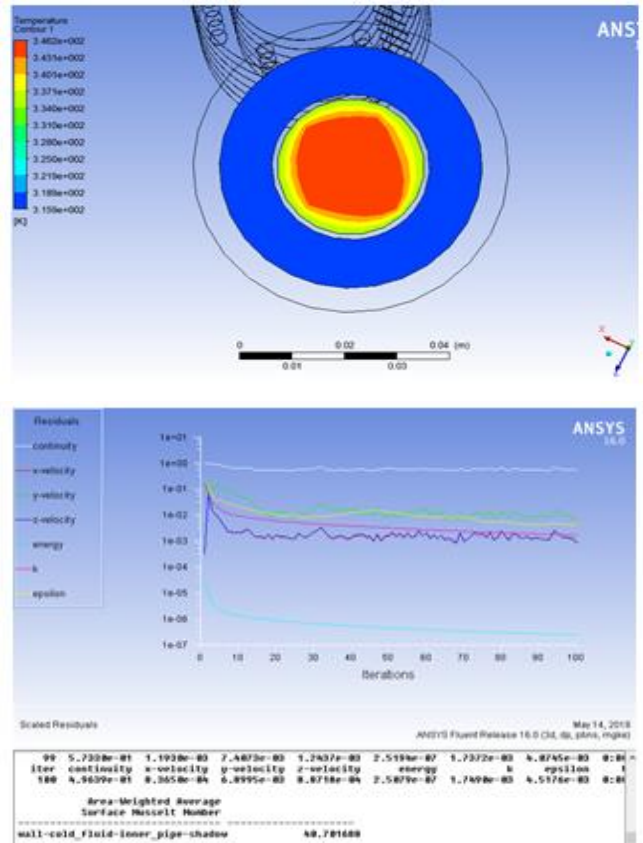


Fig. 3.17: Temperature Contour of Cold Fluid Outlet for Re 6000 For Re 8000 The contours of temperature for Re 8000 at the exit of heat exchanger is shown in the below fig.

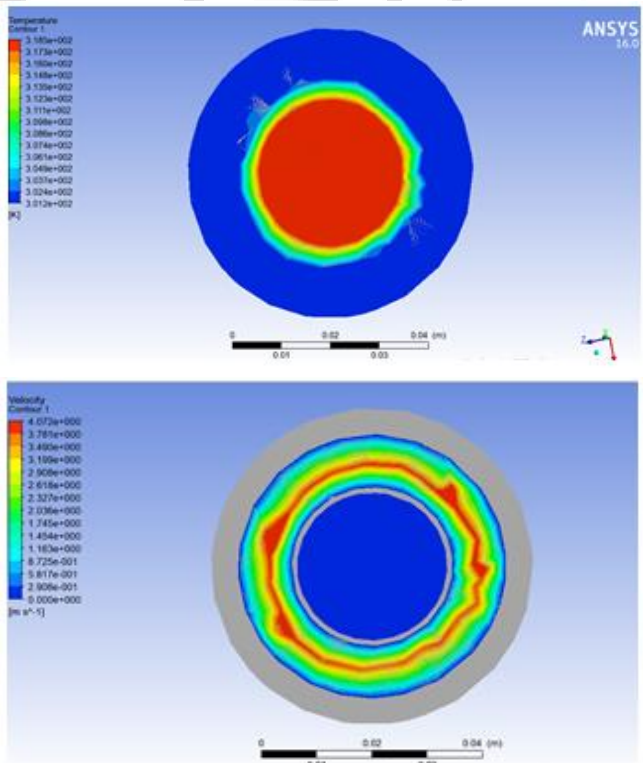


Fig. 3.19 Contour of Temperature at the Hot Fluid Exit of Heat Exchanger

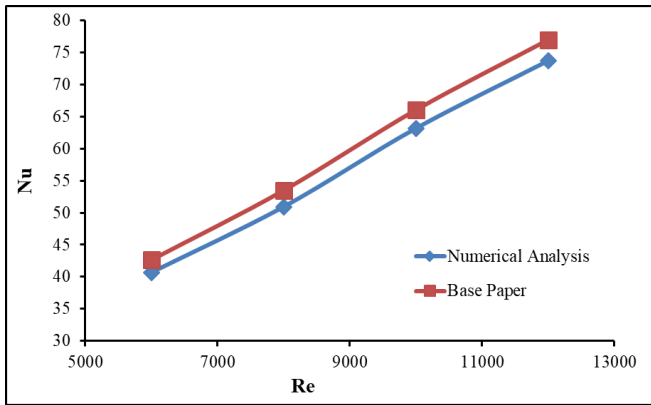


Fig. 3.23: Comparison of Value of Nu for Different Re Numbers

From the above comparison graph it is found that the value of Nu for different Re number calculated through Numerical analysis is near to the value of Nu obtained from the base paper. So the numerical model of discontinuous helical turbulators heat exchanger is correct.

For examine the value of Darcy friction factor (f) following mathematical calculation where used. The mathematical equation used for calculating friction factor

$$f = \frac{2 \Delta P D_H}{L \rho u^2} \dots\dots\dots (2)$$

Where ΔP is the pressure difference at the inlet and outlet, D_H is the hydraulic mean diameter, L is the length of heat exchanger, ρ density of air and u is the velocity of air at inlet. With the support of eq.2 we can calculate the value of friction factor for different Re numbers. The value of friction factor for different Re number is shown in the below table.

Reynolds number	Friction factor from base paper	Friction factor for numerical analysis	Error in %
6000	0.055	0.054	1.81
8000	0.0475	0.0468	1.05
10000	0.041	0.040	1.21
12000	0.037	0.0360	1.08

Table 3.8 Value of Friction Factor for different Re number

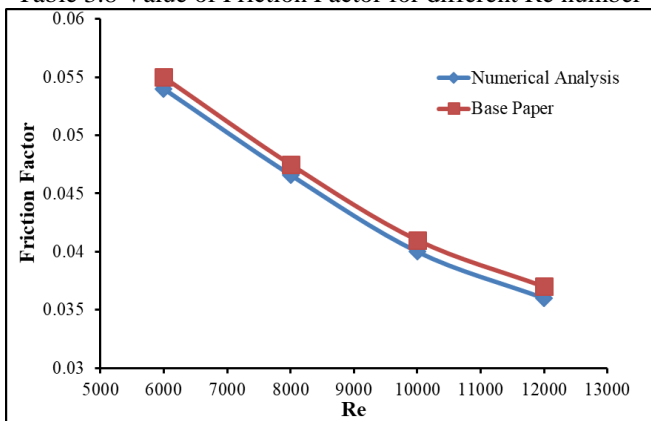


Fig. 3.24: Comparison of Value of Friction Factor for Different Reynolds Number

From the above fig. it is found that the value of friction factor decreases as the Re number increases. The value of friction factor calculated from numerical analysis is near to the value of friction factor give in the base paper, so the numerical model develop for discontinuous helical turbulator is correct. After validation of the numerical model

of discontinuous helical baffle heat exchanger, here in this work we have calculated the effect of continuous helical turbulator and also calculated the effect of inclination of turbulator on heat transfer enhancement. Here we have also optimized the inclination angle of turbulator for maximum heat transfer.

IV. RESULT

For calculating the result of perforated helical turbulator shapes on heat transfer, here in this work we have considered three different shapes of perforated helical turbulators. The cross section area of the perforation remains same, triangular, rectangular and circular shape perforations were considered during the analysis. The dimension of the perforation were mention in the below section

Perforation shape	Dimension (mm)	
Circular	Diameter (d_s) = 3.2863	
Rectangular	Width	5.8248
	Height	1.4562
Triangular	Side (b) = 4.4258	

Table 4.1: Geometric Dimension of Different Perforations

Circular perforation helical turbulator were Analyzed in the above section, now CFD analysis of heat exchanger having Rectangular and triangular perforation were performed in the below section.

A. For Rectangular Shape Perforation

Here shape of the perforation on discontinuous baffles is of rectangular shape, during the analysis the boundary condition were same as considered during the analysis of heat exchanger having circular perforations. The velocity and temperature of hot and cold fluid will remain same as considered in circular perforation. The solid model of discontinuous helical baffles having rectangular shape perforation were shown in the below fig.

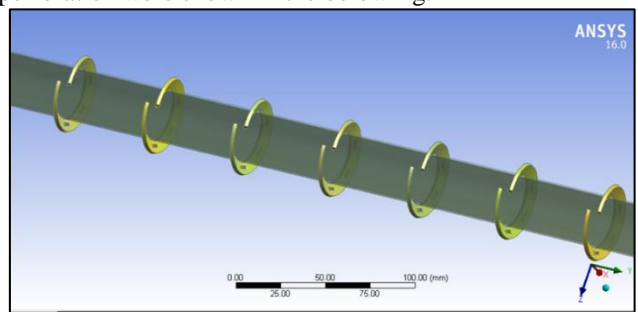


Fig. 4.1: Solid Model of Heat Exchanger with Square Perforation

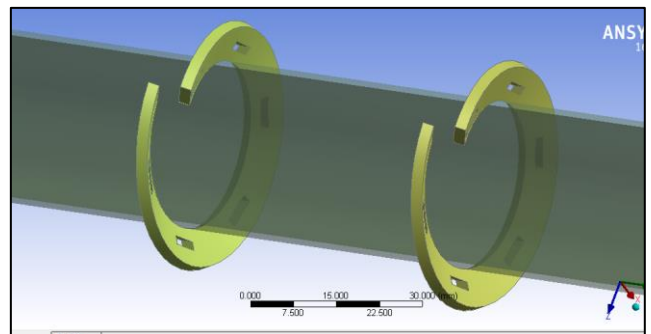


Fig. 4.2: Close View of Discontinuous Rectangular Perforated Helical Turbulator

B. For $Re = 6000$

Here the cold fluid is flowing with Re number 6000, whereas the hot fluid is flowing at a constant velocity. The temperature contours for Re is shown in below fig.

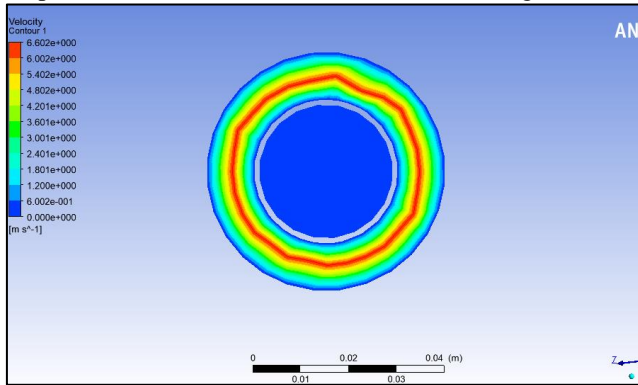


Fig. 4.4: Velocity Contours of Hot Fluid at the Exit of Heat Exchanger

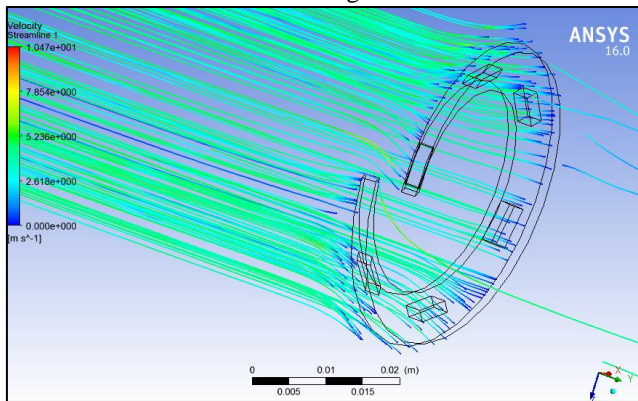


Fig. 4.5: Flow of Air through Square Perforation

Re	Nusselt (Nu)	Friction Factor
6000	110.1585	0.085
8000	157.3855	0.071
10000	202.1198	0.061
12000	251.4058	0.052

Table 4.2 Show the Value of different Parameters for Rectangular Perforations

C. For Triangular Shape Perforation

Here shape of the perforation on discontinuous baffles is of triangular shape, during the analysis the boundary condition were same as considered during the investigation of heat exchanger having circular perforations. The velocity and temperature of hot and cold fluid will remain same as considered in circular perforation. The solid model of discontinuous helical baffles having triangular shape perforation were shown in the below fig.

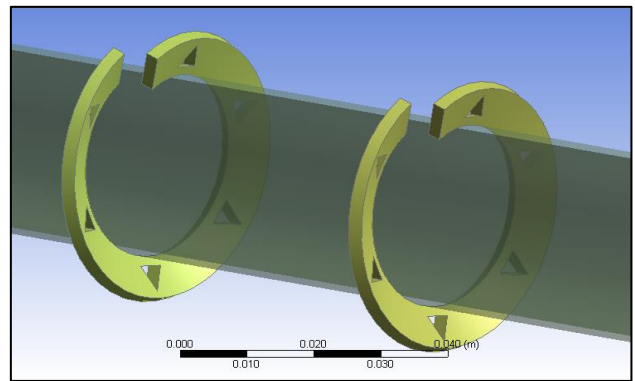


Fig. 4.9: Solid Model of Heat Exchanger Having Triangular Perforation

Mesh of the solid model of heat exchanger having discontinuous helical turbulator having triangular perforations is shown in the below fig.

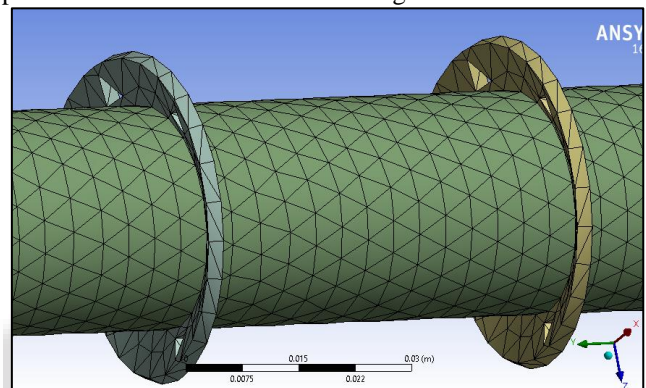


Fig. 4.10: Meshing of the Solid Model of Heat Exchanger with Triangular Perforations

The velocity and temperature contours of heat exchanger having triangular perforation for different Re numbers were shown in the below fig, through numerical analysis it find out the value of Nu number for different Re number and with the help of eq. 1 we can calculate the value of Darcy friction factor. The value of different parameters for different Re number were shown in the table below

Re	Nusselt (Nu)	Friction Factor
6000	115.624	0.088
8000	164.6863	0.0737
10000	210.397	0.0643
12000	259.048	0.0548

Table 4.3: Value of Different Parameters for Triangular Perforation

D. Comparison of Different Perforations

To calculate the effect of different shapes of perforation heat transfer, value of Nu and friction factor for different perforation at different Re number is compared in the below section.

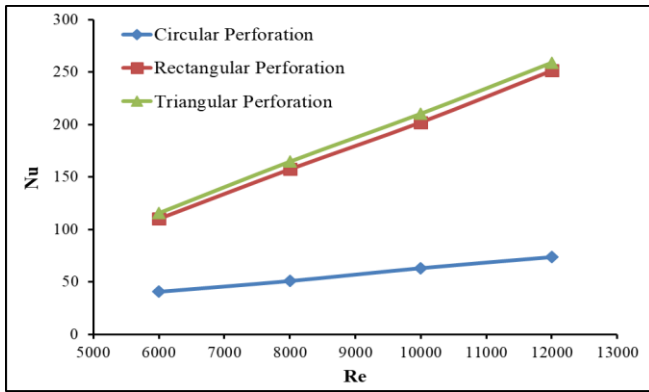


Fig. 4.16: Comparison of Nu Number for Different Perforation of Discontinuous Turbulator

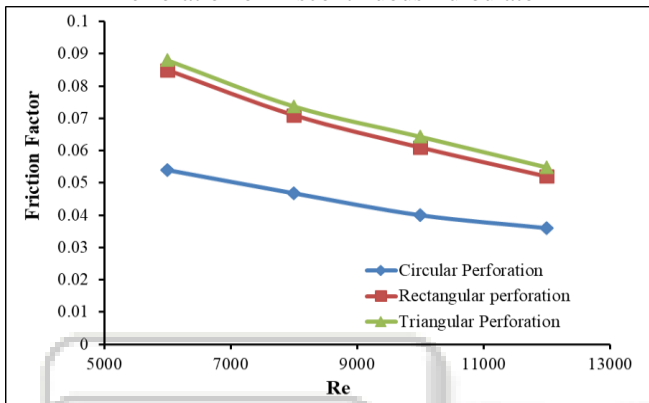


Fig. 4.17: Comparison of Friction Factor for Different Perforation of Discontinuous Helical Baffles

To calculate the effect of different perforation on the thermal enhance of heat exchanger, here it determine the value of thermal performance of heat exchanger having different categories of perforations. To calculate the value of thermal performance of heat exchanger following calculation were used.

$$\eta = \frac{Nu_{Num}/Nu_s}{(f_{Num}/f_s)^{\frac{1}{3}}} \dots\dots\dots (3)$$

Where

f_s = Darcy friction factor for smooth pipe (without perforation)

Nu_s = Nusselt number for smooth pipe (without perforation)

f_{Num} = Darcy friction factor calculate through Numerical analysis

Nu_{Num} = Nusselt number calculate through numerical analysis

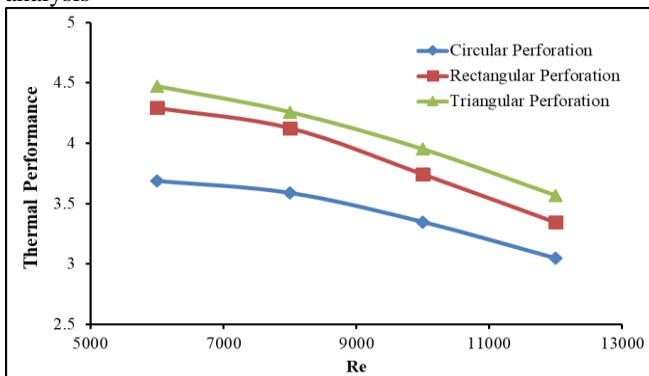


Fig. 4.18: Comparison of Thermal Performance for Different Perforated Heat Exchanger

V. CONCLUSION

The value of Nu number is greater for heat exchanger having discontinuous helical baffles with triangular perforation as compared to the heat exchanger with circular and rectangular perforation. Darcy friction factor is reducing with increase in Re Number. Whereas the value of Friction factor is supreme for triangular perforation as compared to the other perforation shapes. Which means pressure drop inside the heat exchanger having discontinuous helical turbulator is high as compared to other so it required higher pumping power. Though the pressure drop inside the heat exchanger having triangular perforation helical turbulator is high, but as compared to pressure increment heat transfer increment is more which will compensate the increase in friction factor. Through calculation it is found that the value of thermal performance of heat exchanger having discontinuous helical baffles with triangular perforation is maximum as compared to the circular and rectangular perforations at 25° inclinations.

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