EVALUATING THE PERFORMANCE OF HEAT EXCHANGER HAVING DIFFERENT SHAPES OF PERFORATED TURBULATORS

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Abstract
The performance of heat exchanger depends on many parameters, one of the parameters is flow behavior of flowing fluid. Many of the researchers have performed different work to increase the performance of heat exchanger. In order to further increase the performance of heat exchanger, in this work perforated turbulators was used. In this work, through CFD analysis effect of different shapes of perforation on heat exchanger performance was analyzed. The numerical analysis of heat exchanger was performed with the help of Ansys (Fluent) software. For evaluating the effect of different shapes of perforation, four different shapes of perforation was considered that is circular, elliptical, triangular and rectangular. Also calculate the effect of change in Reynolds number for different shapes of perforation and considered 6000, 8000, 10000 and 12000 Reynolds number during numerical analysis. It calculates the value of Nusselt number, friction factor and thermal performance of heat exchanger having different shapes with different Reynolds number. Through analysis it is found that heat exchanger having triangular perforation shows an average of 22.9% heat transfer enhancement as compared to circular perforation.

***Keywords:-** heat exchanger, perforation, turbulators, different shapes, heat transfer*

1. Introduction

Water to air heat exchanger can be selected on the basis of different application. 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 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 in this work we have calculated the effect of different shapes of perforation on discontinuous circular turbulators on heat transfer and optimized the perforation shapes of circular turbulator. For calculating the effect of different shapes of perforation on circular turbulator, it considered four different perforation shapes that are circular, triangular, elliptical and rectangular. For performing the numerical analysis, first we have developed the solid model of heat exchanger having different perforation shapes of circular turbulator. On the basis of geometrical condition as mention below we have develop the numerical model.

2. Development of solid model of heat exchanger

For the validation of the numerical analysis here first it considered heat exchanger having circular perforation circulator 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

Table.1 Value of geometric specification

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)	6	
Turbulator Width (mm)	7	

During the development of solid model of heat exchanger here it considered 5.83 pitch ratio in between the two turbulators. The solid model of the heat exchanger is shown in the below fig.

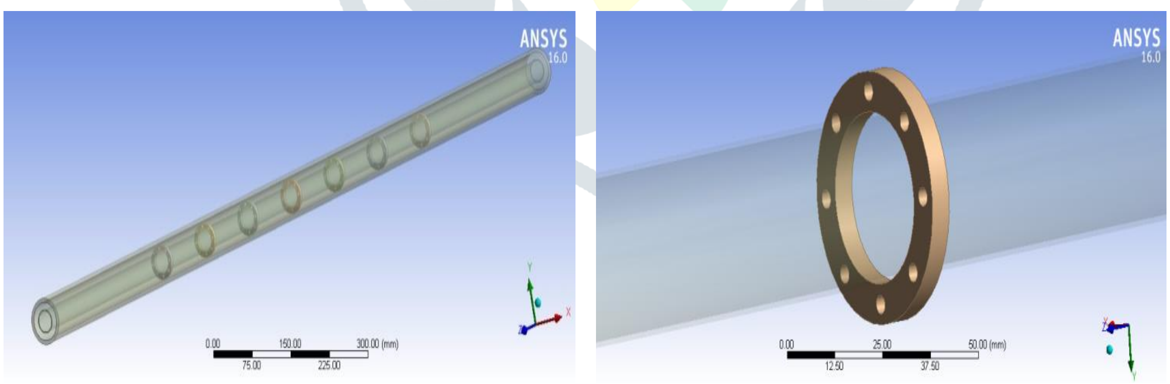

Fig.1 solid model of the heat exchanger with perforated circular baffles

3. 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 circular baffles heat exchanger is shown in the below fig.

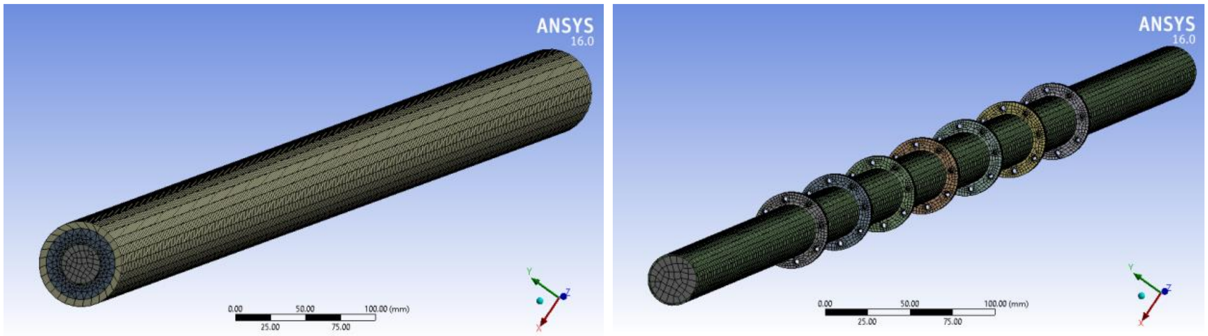

Fig.2 shows the mesh of the circular baffle heat exchanger

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

Table.2 Value of temperature for different number of elements

No. of elements	**Temperature (K)**
397563	317.5
457587	318.2
542483	318.8

4. 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 below section.

4.1 For Hot Fluid

The polynomial equation according to which properties of water varies is mention here

$$\text{Property} = A_1 + A_2 \times T + A_3 \times T^2 + A_4 \times T^3 + A_5 \times T^4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where A_1, A_2, A_3, A_4, A_5 are the coefficient, the value of coefficient for different property of water is shown in the below table.

Table.3 Value of coefficient for different properties of water

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	-1.66E02	1.22E04	4.55E-01	2.11E-01
A_2	1.22E01	-9.29E01	-5.26E-03	-4.06E-03
A_3	-4.65E-02	4.07E-01	2.29E-05	4.05E-05
A_4	7.71E-05	-8.03E-04	-4.45E-08	-9.56E-08
A_5	-5.03E-08	6.05E-07	3.24E-11	6.77E-11

4.2 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 above section.

Table.4 Value of coefficient for different properties of air

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

4.3 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.

Table.5 Properties of copper material

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

4.4 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.

Table.6 Properties of plexiglas material

Property	**Values**
Density (kg/m^3)	1180
Specific heat (J/kg-k)	1466
Thermal conductivity (W/m-k)	0.000581

5. 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 0.9669 and temperature of cold fluid at inlet 301.16 K as considered during the experimental analysis performed by Sheikholeslami et.al. For validating the CFD model of heat exchanger having discontinuous perforated circular turbulator, here it examine the heat exchanger having circular discontinuous turbulator with circular perforation as consider during the experimental analysis performed by Sheikholeslami et.al.

5.1 For Re 6000

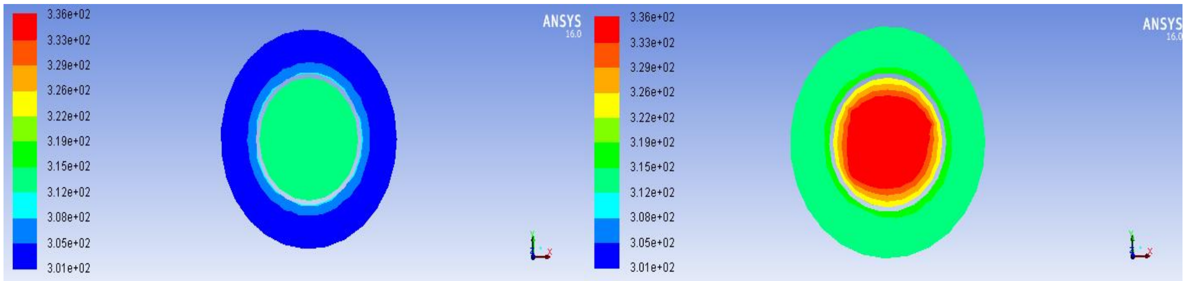

Fig. 3 temperature contour for Re 6000

Table.7 Value of Nusselt number at different Re number

Reynolds Number	Nusselt number from base paper	Nusselt number for numerical analysis	Error (%)
6000	33.49	35.20	4.85
8000	40.38	42.34	4.62
10000	46.87	48.37	3.10
12000	52.63	55.40	5

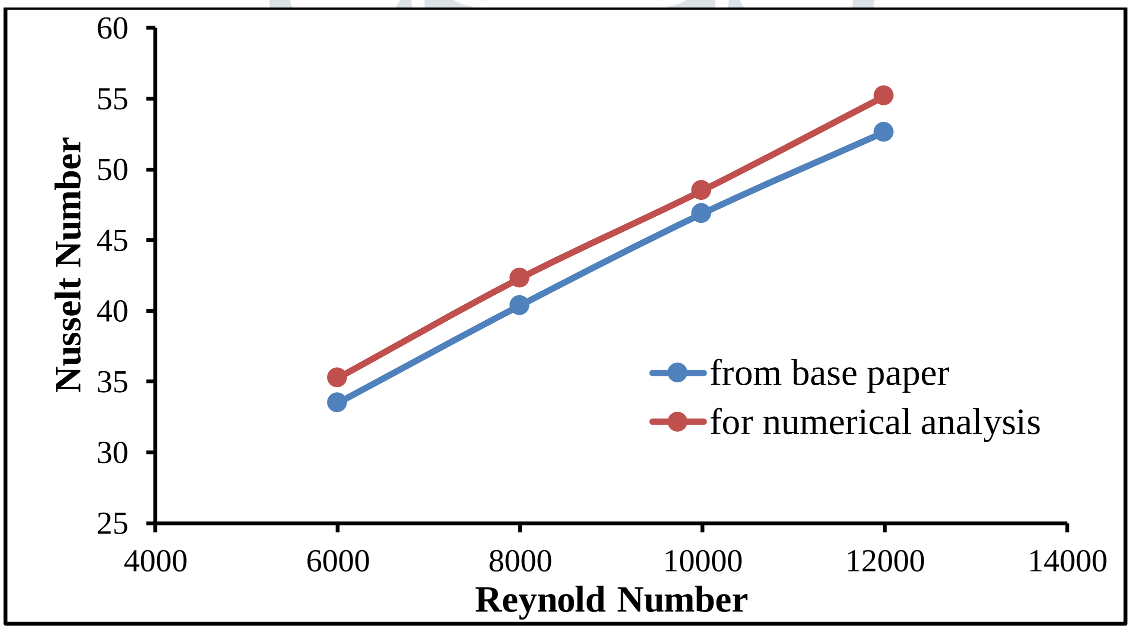

Fig.4 Comparison of value of Nu for different Re numbers

Form 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 number obtained from the base paper. So the numerical model of discontinuous circular 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

$$f = \frac{2\,\Delta P\, D_H}{L\,\rho\, u^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

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.

Table.8 Value of Friction Factor for different Re number

Reynolds Number	Friction factor from base paper	Friction factor for numerical analysis	Error (%)
6000	0.0579	0.0606	4.45
8000	0.0507	0.0529	4.15
10000	0.0460	0.0475	3.15
12000	0.0428	0.0448	4.46

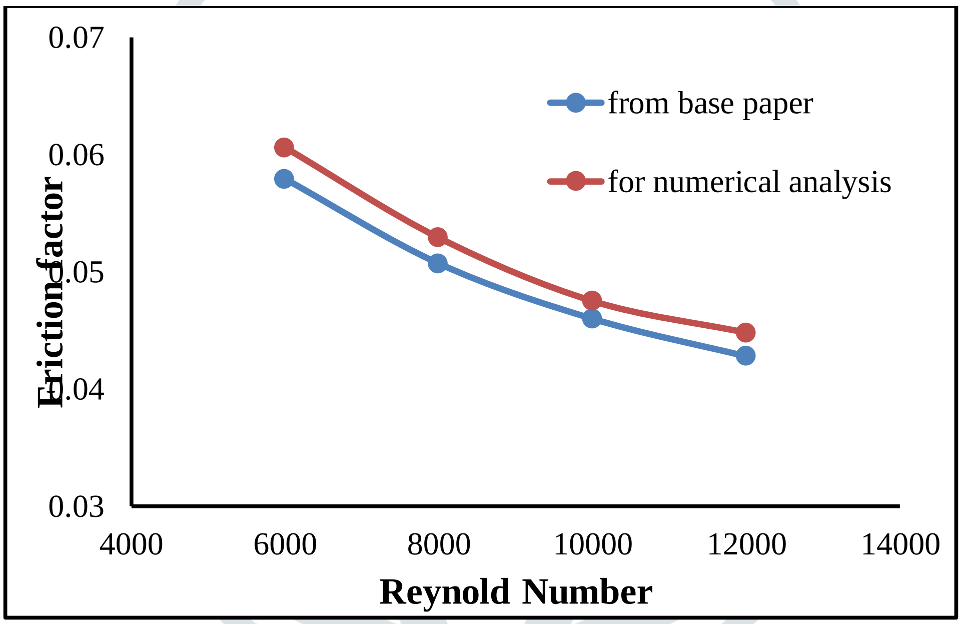

Fig.5 comparison of value of friction factor for different Reynolds number

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.

6. 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. Table shows the evaluation of different parameter is

Table.9 Comparison of Nu number for different perforation shapes

Reynolds Number	Nusselt number for circular perforation	Nusselt number for rectangle perforation	Nusselt number for triangular perforation	Nusselt number for elliptical perforation
6000	35.20	38.79	45.21	41.62
8000	42.34	44.57	52.13	47.42
10000	48.37	51.54	57.83	53.95
12000	55.40	58.37	66.83	62.66

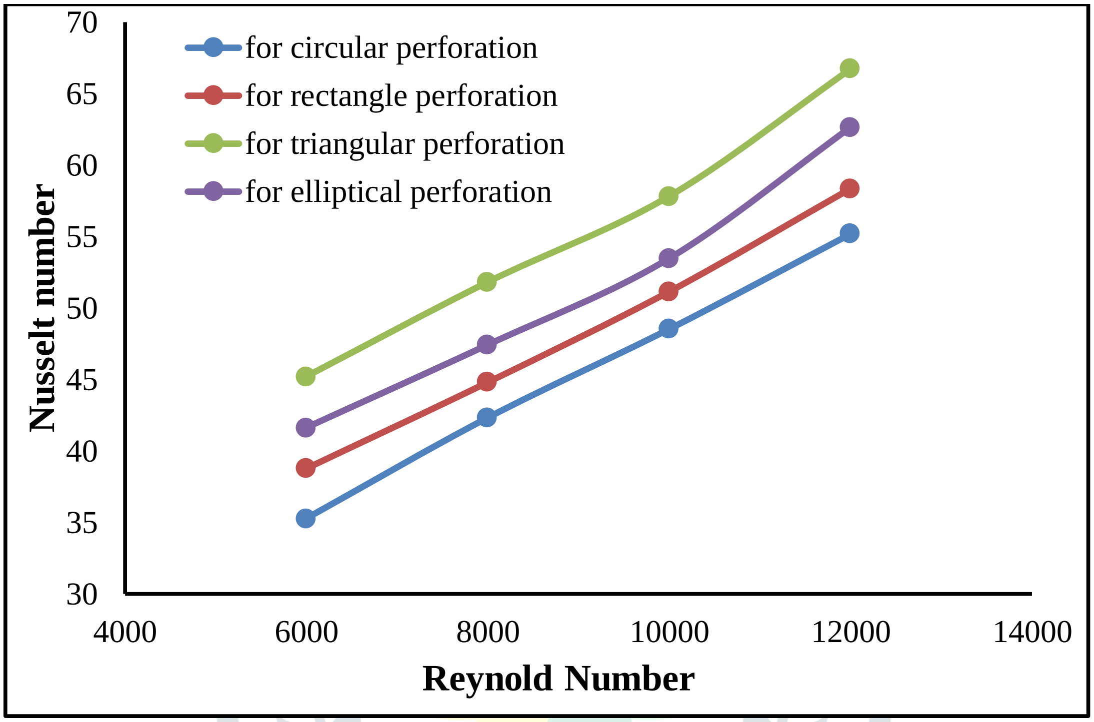

Fig.6 comparison of Nusselt number for different perforation shape

Table.10 Comparison of Friction factor for different perforations shapes

Reynolds Number	Friction factor for circular perforation	Friction factor for rectangle perforation	Friction factor for triangular perforation	Friction factor for elliptical perforation
6000	0.0606	0.0661	0.0756	0.0703
8000	0.0529	0.0554	0.0637	0.0585
10000	0.0475	0.0504	0.0558	0.0524
12000	0.0448	0.0470	0.0531	0.0501

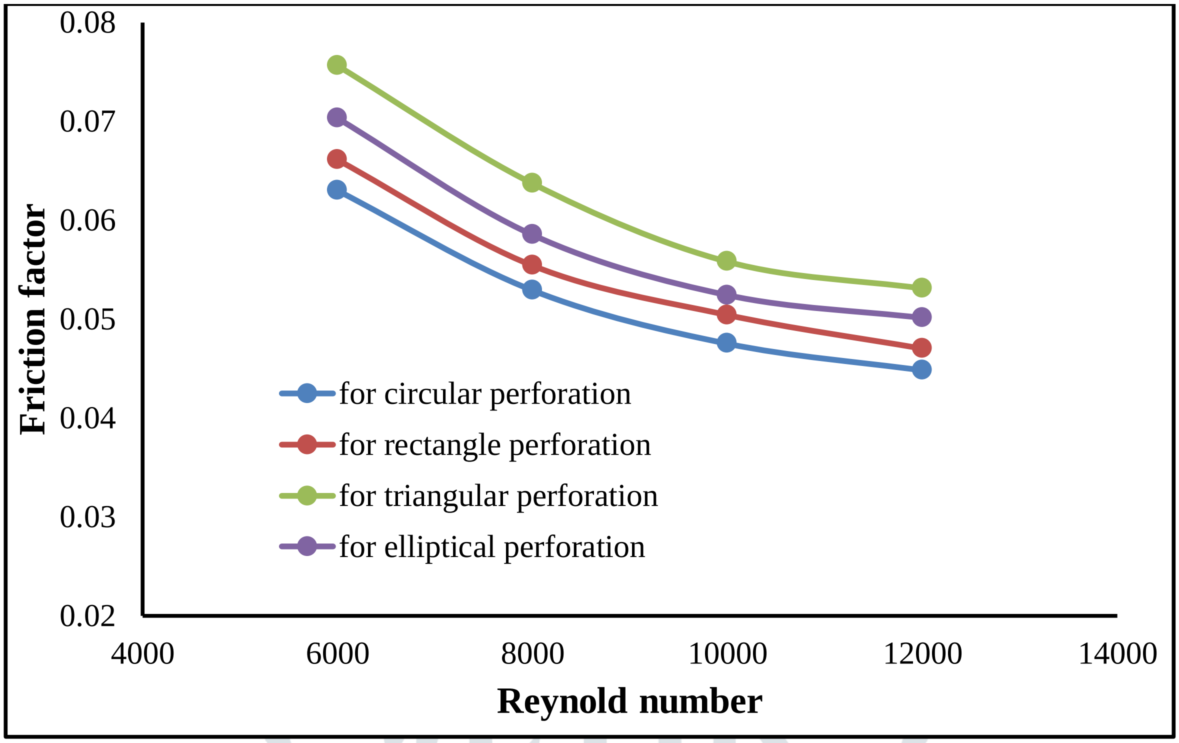

Fig.7 Comparison of friction factor for different perforation of discontinuous circular baffles

From the above graph it is found that the Nu number increases as the Re number increases, which shows that heat transfer increases as Re number increases. The value of friction factor decreases with increase in Re number. From above fig. it is found that the value of Nu number is maximum in case of discontinuous circular baffles with triangular perforation as compared to rectangular, elliptical and circular perforation for all Re number. It means that the heat transfer is extreme in case of triangular perforation. 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.

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

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

The value of f_s and Nu_s for smooth pipe for different Re number is shown in the below table

Table.11 Value of nusselt number and friction factor for different Re number

Reynolds number	Nu_{num}	f_{num}	Nu_s	f_s
6000	35.20	0.0606	27.11	0.040
8000	42.34	0.0529	33.76	0.0333
10000	48.37	0.0475	39.55	0.0298
12000	55.40	0.0448	44.79	0.0274

Using eq. 3 we have calculated the value of thermal performance for discontinuous helical baffles with different categories of perforation. The value of thermal performance for different types of perforation were compared in the below table.

Table.12 Value of thermal performance for different types of perforation

Reynolds Number	Thermal performance for circular perforation	Thermal performance for rectangle perforation	Thermal performance for triangular perforation	Thermal performance for elliptical perforation
6000	1.130	1.209	1.348	1.272
8000	1.073	1.114	1.244	1.163
10000	1.050	1.093	1.201	1.144
12000	1.027	1.088	1.174	1.129

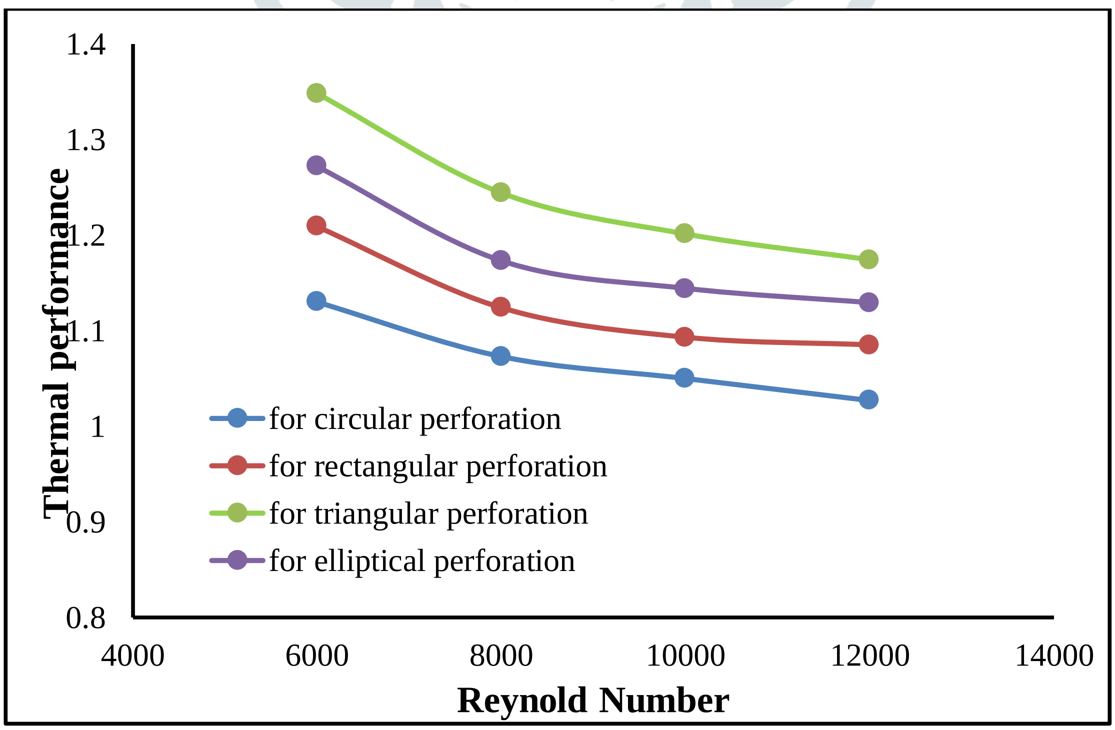

Fig.8 comparison of thermal performance for different perforated heat exchanger

From the above calculation graph of thermal performance it is found that the value of thermal performance is reducing with increase in Re number whereas the value of thermal performance of heat exchanger having triangular perforation is supreme as compared to the other perforation. At every Re number the thermal performance of triangular perforation is supreme as compared to rectangular, elliptical and circular perforations. It shows that heat exchanger having discontinuous circular triangular perforation turbulator shows extreme heat transfer.

7. Conclusion

From the numerical investigation of discontinuous circular perforated turbulator, it is determine that the heat transfer rises with increase in Re number. The value of Nu number rises with rise in Re number of cold fluid flowing in the outer pipe. The value of Nu number is greater for heat exchanger having circular baffles with triangular perforation as compared to the heat exchanger with circular, elliptical 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 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. Form the numerical analysis it is determine that the heat transfer is supreme in case of heat exchanger having circular baffles with triangular perforation.

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