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Design and Implementation of Tube Heat Exchanger with Discontinuous Twisting Baffles With Computational Fluid Dynamics Analysis

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***Abstract*— In this study, a three-dimensional numerical analysis has been done to investigate the heat transfer, pressure drop in the shell side and vortex shedding, tubes deformation due to fluid induced vibrations in the shell and tube heat exchanger (STHX). Three-dimensional CFD and two-way FSI has performed with the commercial software ANSYS. To examine the thermo-hydraulic performance and induced vibrations in shell-and-tube heat exchangers with segmental/ helical/ clamping anti-vibration baffles and cylindrical/twisted tubes, numerical simulations are carried out. The numerical models show the thermo-hydraulic performances for the heat exchangers with segmental, helical and novel clamping anti-vibration baffles with cylindrical and square twisted tubes. The result shows that the use of square twisted tubes result in higher heat transfer rate as compared to cylindrical tubes. As far as pressure drop is concerned, it is also greater in the shell and tube heat exchangers with square twisted tubes for segmental, helical and anti-vibration baffles. The deformation in the tubes, velocity of the tubes and vortex shedding formation is minimum in STHX with clamping anti-vibration baffles than in STHXs with helical and segmental baffles.**

Keywords*— *Numerical Simulation, Shell and Tube Heat Exchanger, Vortex Shedding, Fluid Induced Vibrations, Clamping Anti-Vibration Baffles, Square Twisted Tubes.

I. INTRODUCTION

Heat exchangers are popular for many applications. Shell and tube heat exchangers are being used extensively as they are diverse, flexible and multipurpose as per [1]. Enriched performance of STHXs being considered to preserve energy [2]. To enhance thermal performance baffles shapes inside STHXs play a vital role, not only that but they also ensure support to the tube bundles [3].The commonly used baffles are the "segmental baffles", the circular shape of the baffle with a cut termed 'baffle cut' as shown in Figure 1(c). There are some downsides of conventional segmental baffles, pressure drop in all across the shell, fouling resistance, low efficiency in heat transfers for the reason of flow. Heat exchanger is a mechanism that is typically used to happen the resolve of an equipment to switch heat among two procedure streams. The fluids may be detached by using a solid wall to prevent mixing or they may be in direct contact. They are commonly used in space heating, refrigeration, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. Example of heat exchanger is shown in an internal combustion engine where fluids flows through radiator coils and air flows over the coils, which cool the coolant and heats the coming air. Another instance is the heat sink which is a inert heat exchanger that convey the heat generated by an electronic or a mechanical equipment to a fluid norm, air or a liquid fluid.

Helical baffle as causes less shell-side fouling, improved rate in heat transfer/pressure drop ratio in the shell-side, averting flow induced vibrations and less maintenance [5, 6]. An innovative Clamping anti-vibration baffle as is used to eradicate flow induced vibrations and helps effectively to eliminate stagnant turbulent fluid flow zones, as fluid flow longitudinally through the gaps in the baffles. In this study, we will be executing three different kinds of baffle and two different kinds of tubes to analyze their effect on the thermo-hydraulic performance of STHX. By using CFD and two-way FSI, heat transfer characteristics and shell side flow induced vibrations have been examined.

II. LITERATURE REVIEW

Dataset Camilleri et. al [1] This paper presents a computationally economical flow network model to predict the flow distribution in compact multi-channel parallel flow heat exchangers. Compact U-type and Z-type heat exchangers with nine parallel channels were used as legal action thereon the model was valid to at intervals 4-8% in terms of non-dimensional flow distribution magnitude relation, the globe magnitude relation AR could be a crucial overall performance parameter which will indicate the degree of flow mal-distribution.

Hajabdollahi et.al [2] A plate fin device was optimally designed by choosing effectiveness and total annual price as two synchronal fitness functions mistreatment particle swarm optimization algorithmic program. owing to the variation of temperature and pressure within the money handler passages, the non-uniform properties are occurred throughout the warmth money handler to generalize the optimization results, the on top of procedure was performed for varied hot aspect recess temperatures.

Brandner et.al [3] The facility transferred per unit volume is especially a operate of the gap between heat supply and warmth sink the smaller this distance, the higher the warmth transfer. Another parameter governing for the warmth transfer is that the lateral characteristic dimension of the warmth transfer structure; within the case of micro channels, this is often the hydraulic diameter.

Kim et.al [4] The thermal performance and uniformity of frost growth between the front- and rear-sides of tiny channel heat cash dealers was investigated as a perform of the depth of the heat money changer, the pitch of the fins, and so the pitch of the channels. Throughout the defrosting cycle, compared with natural convection, forced convection defrosting resulted among the unit long less water between the fins, leading to improved thermal performance.

Iribe et.al [5] In this work, the moment and heat transfers of a non-Newtonian fluid flowing in steady bedded regime through a plate device at constant wall temperature is studied practice CFD. Single-pass U-type plate heat exchangers with multiple flat plates with and whereas not baffles are used.

Pandiyarajan et.al [6] Carried out Associate in Nursing preliminary examination on heat healing from diesel engine fumes utilizing finned shell and tube device and heat reposition framework, a shell Associate in finned tube device incorporated with an IC motor setup to free heat from the fumes gas and a heat vitality reposition tank accustomed store the abundance vitality.

Naphon et.al [7] Carried out numerical study and trial examine on a flat spiral-coil tube to foresee the stream trademark. The quality k–ε two-condition turbulence demonstrates was used to breed the turbulent stream and warmth exchange qualities of the liquid. The warmth rate or heat exchange constant had influenced by the divergent constrain.

Kharat et.al [8] Investigated that the warmth rate of exchange on a coaxial coiling coil device and build up the association for warmth exchange constant. Heat exchange constant has increased for the tube containing vent gas of the warmth money handler by utilizing CFD reenactment and also the exploratory investigation. The impact of varied operating factors was contemplated. The factors that they had thought-about square measure hole between the coaxial coils, distance across of tube and coil dimension. Spadaccini et.al [9] In this work it conduct the fuel cooled thermal management, that is together with energy-absorbing cracking and organic compound fuels reforming, is Associate in Nursing sanctionative technology for traditional aero engines and offers potential for cycle enhancements and waste product emissions management in turbine engine applications.

Jang et.al [10] Conducted the experimental study mistreatment an infrared thermo vision to observe temperature distribution over a plate-fin surface within the plate finned-tube heat exchangers. The differentiation of the temperature perform comes to work out the native convective heat transfer coefficients on the tested fin, employing a native part lumped physical phenomenon equation enclosed the convective result on the boundaries with experimental information. It's disclosed that the infrared diagnostic technique is capable of quickly detection location and transition extent and separation regions of the physical phenomenon over the whole surface of the tested and analyzed models.

Wang et.al [11] Investigated concerning the warmth transfer and pressure drop characteristics of typical wavy fin-and-tube heat exchangers were administrated. Within the current study, eighteen wavy samples of fin and tube heat exchangers with in contrast to geometrical parameters, with the amount of tube rows, fin pitch, and flow arrangements, were tested and analyzed in a very structure.

Muchengwu et.al [12] It investigates the Fluid flow and warmth transfer over a multi-row (1-6 rows) plate-fin and tube device are studied numerically and by experimentation. Fluid flow is incompressible, 3 dimensional and laminar. The consequences of various geometrical parameters like tube arrangement, tube row ranges and fin pitch are investigated well for the Reynolds number starting from sixty to 900.

Anurjew et.al [13] Investigated completely different small structure cross flow heat exchangers and considered their heat exhibitions. The facility transfer per unit volume is directly proportional to the perform of warmth supply and warmth sink for higher heat transfer lesser are going to be the space. They found that heat transfer are often upgraded by decreasing the pressure driven distance across of the small channels and in their work conjointly emphasize the electrically.

Tanget. al [14] In the gift paper they did investigation through by experimentation on fin-and-tube heat exchangers with the Sir Joshua Reynolds range varies from 4000 to ten thousand,and the improvement of warmth money handler with vortex generator(VGs) is additionally self-addressed and at high Reynolds numbers, best heat transfer performance achieved by slit fin device. [15] It is vital to get the warmth transfer characteristics of hard-hitting within the cooler. Heat transfer in convection cooling section of controlled coal gasified with the membrane whorled coils and membrane snaky tubes below air mass is through an experiment investigated.

Yakar et. al [16] Examined by experimentation the air aspect heat exchange constant and also the heat steady electrical phenomenon in finned tubes. Water is employed because the heating medium, in turbulent conditions and streaming at varied temperatures within the tube.

Jayakumar et. al. [17] The heat exchanger is analyzed considering conjugate heat transfer and temperature dependent properties of warmth transport media. The CFD predictions match fairly well with the experimental results inside experimental error limits. Supported the results a correlation was developed to calculate the inner heat transfer constant of the turbinate coil.

Venugopal et al [18] Conducted associate experimental study k regarding on the amalgamated convective heat move in an exceedingly vertical channel loaded with tinny porous structures. The semi permeable medium model created within the gift examination shows thermo-hydrodynamic execution like those found in metal froths.

Lingdong et.al [19] Conducted Numerical studies to research the airside thermal-hydraulic characteristics of blank tube bank and plain finned tube heat exchangers meant to be used in aero-engine cooling. The exchangers use little diameter tubes (3.0 mm) with compact tube layout and operate at high temperatures with massive temperature changes over the money handler depth.

Pawar et.al [20] Investigated the experimental analysis on constant temperature steady state and non-isothermal unsteady state conditions in spiraling coils. that they had thought of each the Newtonian moreover as non-Newtonian fluids for operating fluid. For Newtonian fluid they thought of water and glycerol–water mixture (10 and 2 hundredth glycerol).

III. MATERIAL CFD ANALYSIS

A. Steps to be followed

- Study of heat exchanger and there types.
- Literature survey and problem identification.
- Development of solid model of heat exchanger on the basis of geometry given in the base paper.
- Development of CFD model of the heat exchanger for numerical analysis.
- Validation of the numerical analysis with the experimental analysis performed in the base paper.
- Finding the effect of different shape of perforation on the heat transfer inside the heat exchanger.
- Finding the effect of transformation in velocity on the heat transfer.
- Calculating the value of nusselt number and friction factor for altered geometry at different velocity.
- Comparison of different types of baffles for heat transfer.
- Report preparation.

B. Material Used

Here in this work water is used as a hot fluid, which is flowing in the inner tube, whereas air is used as a cold fluid which is flowing in the outer tube. Here in this work inner tube is prepared of copper whereas outer tube is of Plexiglas.

C. For Hot Fluid

Water is used as a hot fluid which is flowing in the inner tube. Here properties of water are a function of temperature.

IV. RESULT AND DISCUSSION

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. To enhance the heat transfer from water to air baffles were placed in the outer surface of inner tube. Due to the baffles turbulence and contact time were increased which helps in increasing the heat transfer. In this work it considered three different shapes of perforated helical baffles that are triangular, square and circular perforated helical baffles to enhance heat transfer rate. 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 increasing due to baffles hear it also calculate the value of thermal performance for different perforated baffles. To complete the objective numerical model of the heat exchanger is develop in the below section.

A. Development of numerical model of heat exchanger

Development of solid model of heat exchanger

The solid model of heat exchanger is develop on the basis of geometry considered by 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
Pitch ratio (PR)	1.83	
Open area ratio	0.0625	
Fin thickness (mm)	2	

The solid model of the heat exchanger is shown in the fig. 1 below.

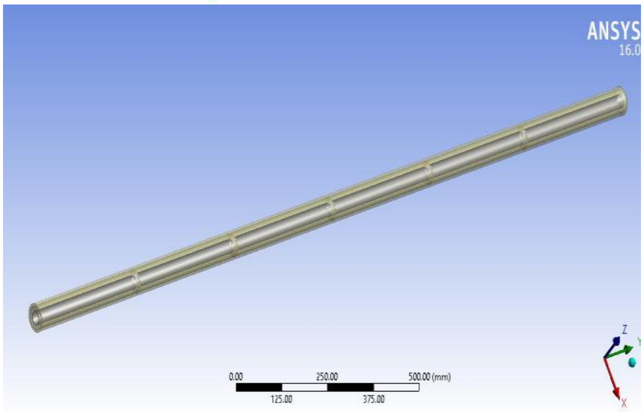

Fig. 1: solid model of the heat exchanger with perforated helical baffles

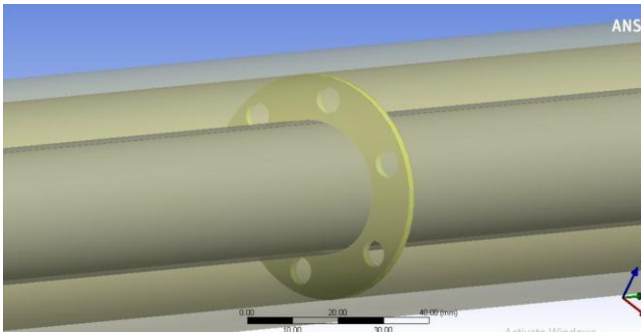

Fig. 2: shows the circular perforation helical baffles

For the initial analysis here it considered circular perforated helical discontinuous baffles. To corroborate the numerical model of heat exchanger, same geometric and boundary condition where considered for the initial analysis as considered in experimental analysis performed.

B. Meshing

To perform the numerical analysis here it has to discretize the solid model in to number of elements. 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 3.

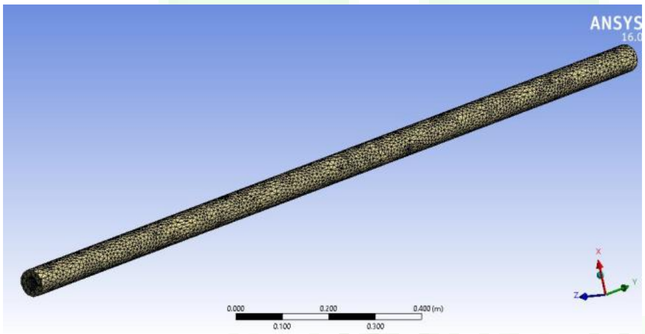

Fig. 3: shows the mesh of the helical baffle heat exchanger

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 2.

Table 2 Value of temperature for different number of elements

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

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 analysis. Mesh with minimum optimum number of element is shown in the below fig.

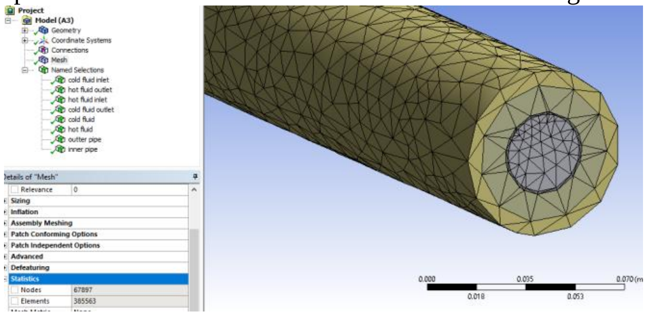

Fig. 4: showing the number of elements used for the numerical analysis

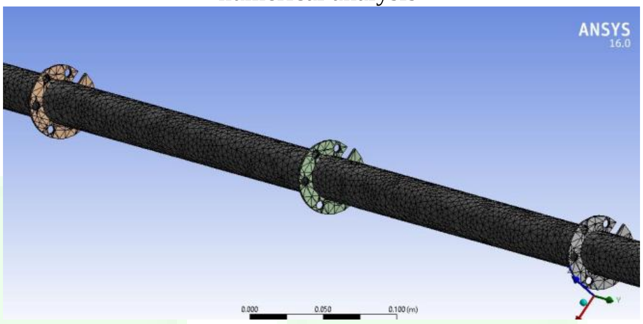

Fig. 5: showing the mesh of the helical baffle used in heat exchanger

Here in this section different component of heat exchanger is named to apply the boundary condition on that part of heat exchanger. The name selection of different component of heat exchanger is shown in the below fig.

Cold fluid

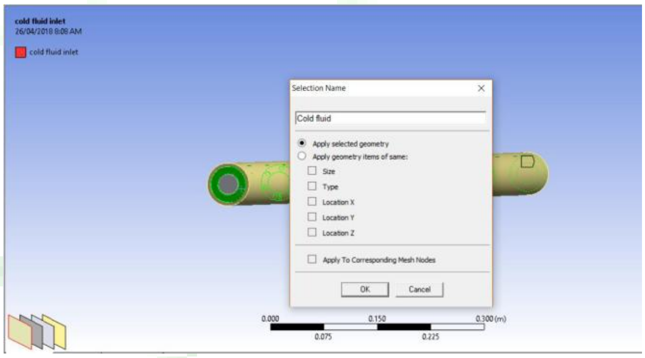

Fig. 6: showing the cold fluid (air) inlet

Hot fluid

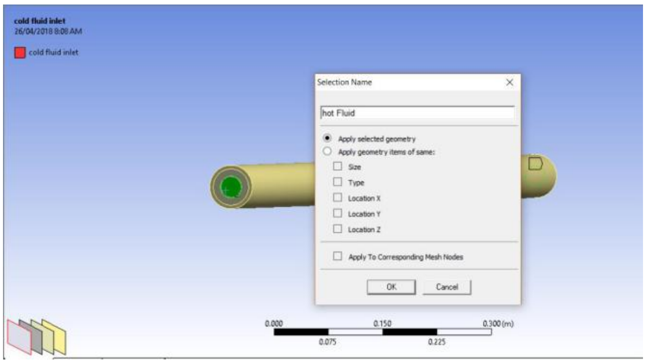

Fig. 7: Showing the hot fluid body (water)

Outer pipe

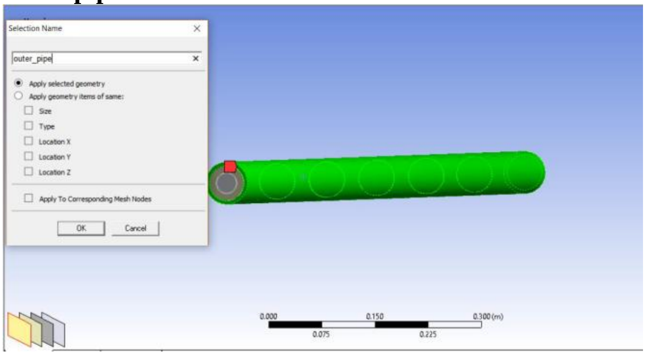

Fig. 8: Showing outer pipe body

Hot fluid inlet

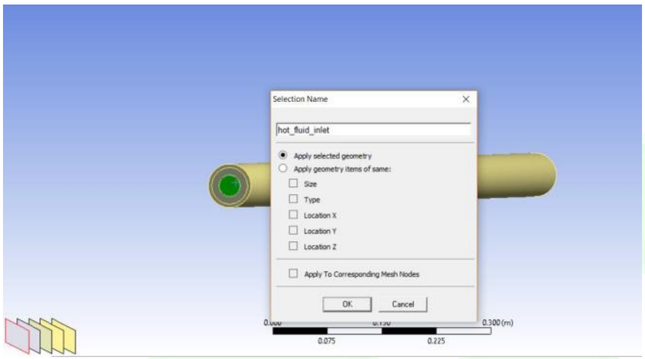

Fig. 9: Showing the hot fluid (water) inlet

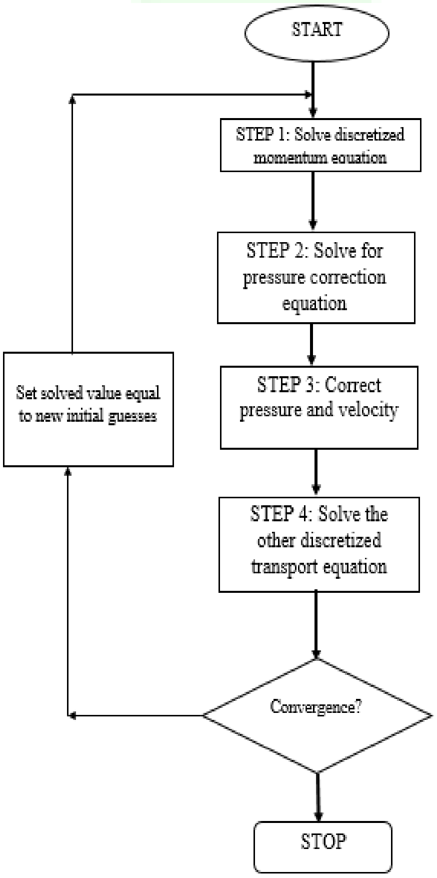

Fig. 10: Block diagram of solution method used during the analysis

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 m/s and temperature of cold fluid at inlet 301.16 K as considered during the experimental analysis. The Fig. 11 showing the boundary conditions are shown below.

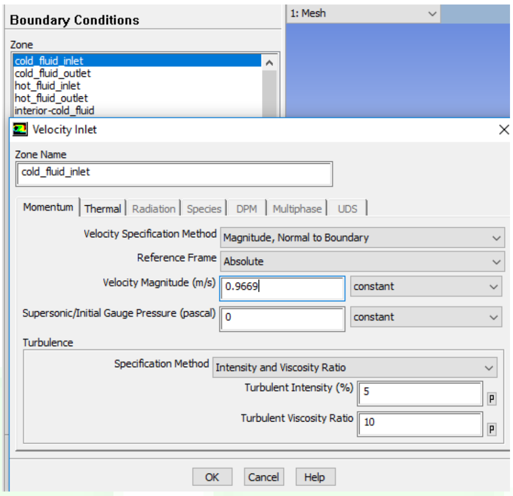

Fig. 11 showing the boundary condition of cold fluid

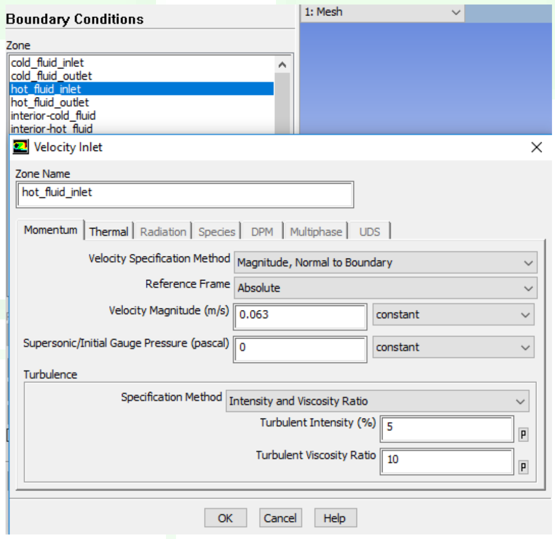

Fig. 12 showing the boundary condition of hot fluid

Result

Here in this work, through numerical investigation it has calculated the value of Nusselt number for altered Re number. It also calculated the value of Darcy friction factor for with respect to different Re number of heat exchanger having different types of shape of perforation. To analyze the effect of different perforation of helical baffles on heat transfer here in this work three different type of perforation were considered. For analyzing the effect circular, square and triangular shape perforations where considered during the analysis. To calculate the heat transfer enhancement due to different types of perforation here it has calculated the value of thermal performance for different geometry of heat sink. During the analysis the velocity of hot fluid remain constant whereas the velocity of cold fluid Changes that is Re number varies 6000, 8000, 10000, 12000.

Validation of CFD model

For validating the CFD model of heat exchanger having helical discontinuous turbulator, here in this work it examine the heat exchanger having helical discontinuous turbulator with circular perforation were consider during the experimental analysis. 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 **For Re 6000.** The temperature contours for 6000 Re number is shown below

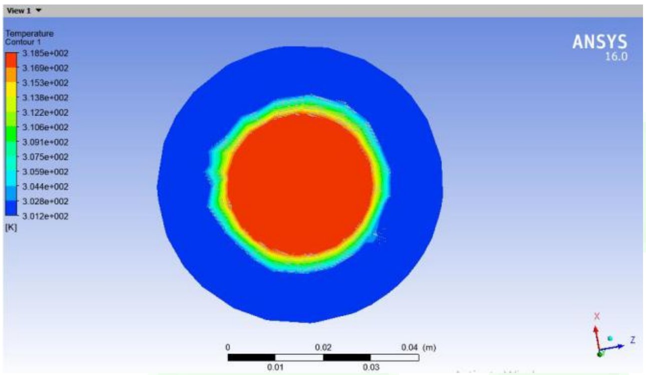

Fig. 13. Temperature contour of hot fluid outlet for Re 6000

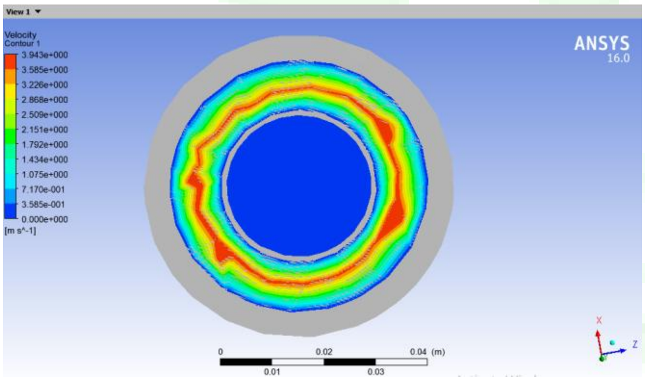

Fig. 14 Velocity contours of hot and cold fluid for Re 6000

For Re 8000

The contours of temperature for Re 8000 at the exit of heat exchanger is shown in the below fig.

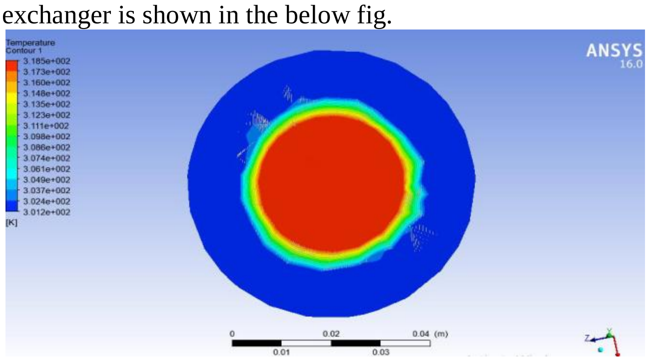

Fig. 15 Contour of temperature at the hot fluid exit of heat exchanger

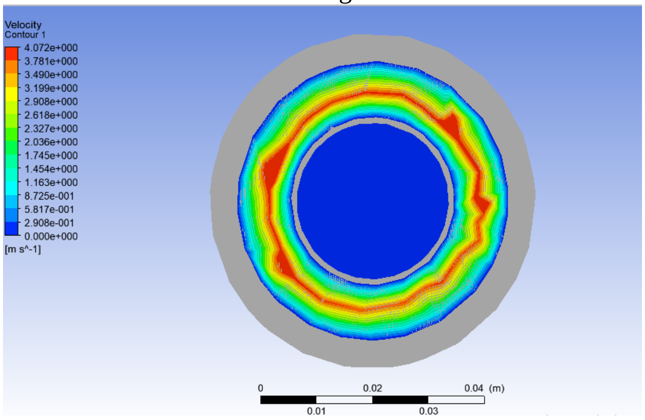

Fig. 16: Velocity contours to hot and cold fluid for Reynolds number 8000

Form the above graph it is found that the turbulence is maximum at the perforation, which helps in increasing the heat transfer from the cold fluid.

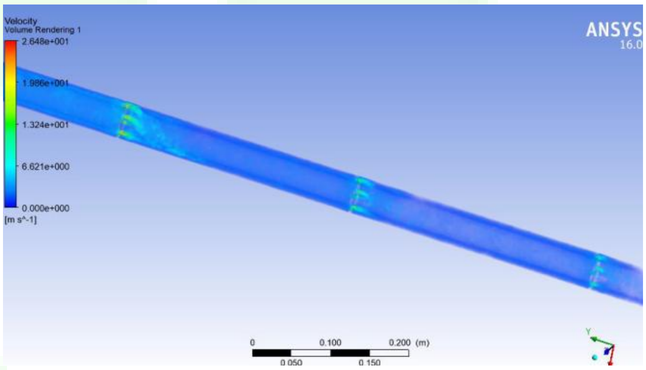

Fig..17: Shows the flow of air from the perforated baffles

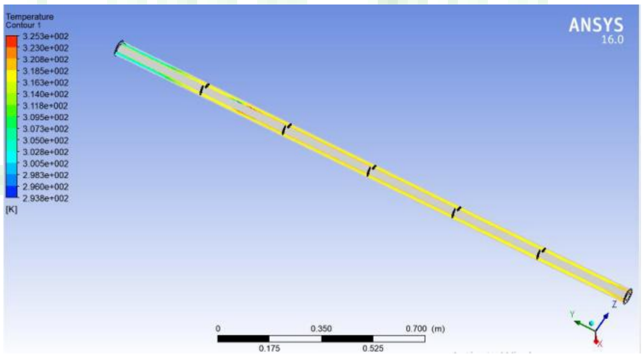

Fig. 18 Shows increase of air temperature from inlet to outlet

From the above fig. it is found that temperature of air increases from inlet to outlet and it is maximum at the exit of heat exchanger. As counter flow heat exchanger is used in this analysis, maximum heat transfer is taken place. With the support of numerical investigation we have calculated the value of nusselt number for different Re number and through calculation we have calculated the evaluate of Darcy friction factor and Thermal performance. The evaluate of nusselt (Nu) for circular perforation discontinuous helical baffles is shown in the below table

Table 3 Value of Nu number for circular perforation calculate through numerical analysis

Reynolds Number	Nusselt (Nu) number for numerically analysis
6000	44.32
8000	53.98
10000	67.79
12000	76.44

Comparison of Nu calculated through numerical analysis and experimental perform in base paper

Table 4. Shows the comparison of Nu number

Reynolds Number	Nusselt no. from base paper	Nussel no.from numerically analysis	Error (%)
6000	43.65	44.32	1.53
8000	51.5	53.98	4.81
10000	64.06	67.79	5.82
12000	74.01	76.44	3.28

Validation of CFD model 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. 19.

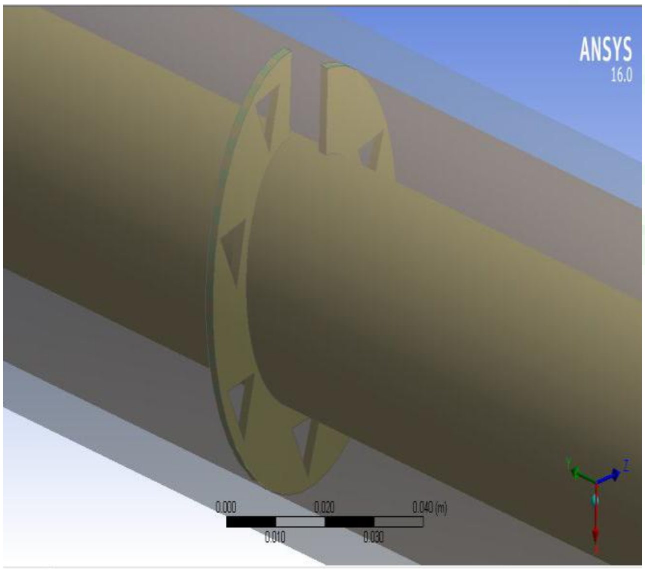

Fig. 19: Solid model of heat exchanger having Triangular perforation

Mesh of the solid model of heat exchanger having discontinuous helical tabulator having triangular perforations is shown in the below Fig.20

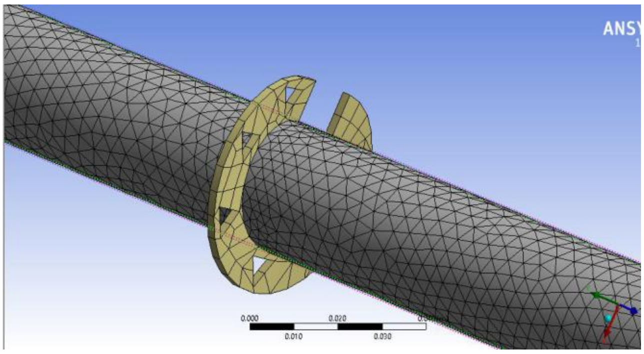

Fig 20: Meshing of the solid model of heat exchanger with triangular perforations

The contour of temperature and velocity for different Re of heat exchanger having discontinuous helical triangular perforation is shown in below figures.

4.5.1 For Re = 6000

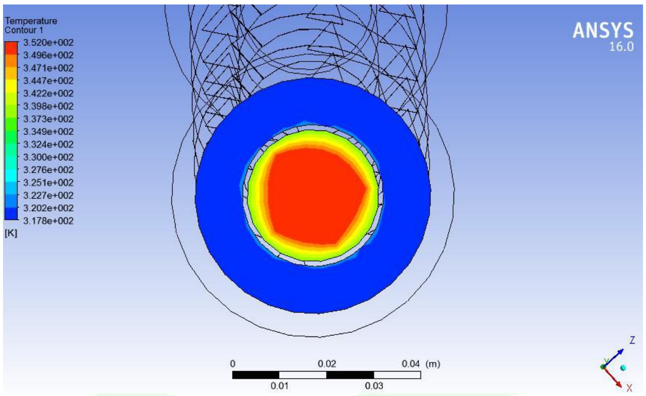

Fig. 21: Contour of temperature at cold fluid (air) outlet for Re = 600

V. Conclusion

From the above analysis following conclusion were drawn

- From the numerical investigation of discontinuous helical perforated baffles, 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 discontinuous helical baffles with square perforation as compared to the heat exchanger with circular and triangular perforation.
- Darcy friction factor is reducing with increase in Re Number. Whereas the value of Friction factor is supreme for square perforation as compared to the other perforation shapes.
- Thermal performance was calculated to measure the overall thermal enhancement in heat exchanger having different shapes of perforations.
- Through calculation it is found that the value of thermal performance of heat exchanger

having discontinuous helical baffles with square perforation is maximum as compared to the circular and triangular perforations.

- Form the numerical analysis it is determine that the heat transfer is supreme in case of heat exchanger having discontinuous helical baffles with square perforation

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