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CFD Analysis of STHE with and Without Strips in Elliptical Tubes

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ABSTRACT:
In the recent years, high cost of energy and material accessibility has resulted in an augmented effort aimed at producing additional efficient heat exchange equipment. Heat exchangers are extensively used in several industries, such as thermal power plants, air conditioning equipment chemical processing plants, refrigerators, radiators for space vehicles as well as automobiles etc. The thermal performance (heat transfer and pressure drop) in shell side of the shell and tube heat exchanger mainly depends on different modifications in shell side as well as tube side. For getting minimum pressure drop and maximum heat transfer in shell side of shell and heat exchanger, circular tubes are replaced by elliptical tubes and also helical strips are inserted inside of the tubes. The main advantage of elliptical tubes are increases heat transfer by increases surface area and reduces pressure drop along the length of the shell. In the present work it is proposed to conduct fluid flow analysis of shell and tube heat exchanger by using CATIA and FLUENT software. Andrew Ozden explained about shell side pressure drop in shell and tube heat exchanger with circular tubes and his experimental values were validated in this research with numerical results by using CFD analysis. The percentage of error in between Andrew Ozden's research and this research is about 1%. For further analysis elliptical tubes with and without strips were considered in a turbulent region with in a range of 5000-20000 for getting minimum pressure drop in shell side of the heat exchanger. Fluid flow analysis was conducted on shell and tube heat exchanger with water as a working fluid for shell and tube side. Copper and Stainless Steel are considered as a structural material for Tube and Shell respectively.

Here we acquired k-ε as turbulent model for all analyses. Shell side pressure drop and heat transfer of shell and tube heat exchanger are calculated at different Reynolds numbers and tabulated. Among all elliptical tube with helical strip insert gives maximum heat transfer rate.

1. INTRODUCTION:
Heat exchanger is a universal device in many industrial applications and energy conversion systems. Various heat exchangers are designed for different industrial processes and applications. In heat exchangers, shell and tube heat exchanger presents great sustainability to meet requirements and gives efficient thermal performance. STHE are widely used in petro-chemical industry, Power generation, and energy conservation and manufacturing industry. Most of the Shell and tube heat exchanger's circular tubes. The heat transfer rate reduces and creates high pressure drops due to geometry. To overcome this, different design modifications in tube side are used to improve the heat transfer performance of the shell and tube heat exchanger. The literature is studied and the methods are explained below. Cong Dong et.al [1] directed numerical investigation to ascertain heat exchange execution on shell and tube heat exchanger with trisection helical puzzle. They utilized four diverse trisection helical confuses (a circumferential cover plot, a center hub cover conspire, a blocked V-scores plot and a conclusion to-end conspire), heat exchanger with same tube geometry and pitch for this investigation. H. Li, V. Kottke [2] examined a shell-and-tube heat exchanger's shell side's nearby heat exchange coefficients with circle and-donut formed puzzles.

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They specified that mass transfer gaging method is utilized as a part of this examination. They expressed that because of lower rate of baffle shell spillage, these circle and-donut baffles heat exchanger gives enhanced heat exchange rate to pressure drop than single-segmental puzzle. LIU Wei et al [3] planned another kind of mix of pole and van sort spoiler with shell-and-tube heat exchanger. They contrasted the segmental baffle with the pole and vane sort spoiler heat exchange rate increments and stream pressure diminishes at high Reynolds numbers. They utilized a few number of pole baffles and baffle rings were lessened by introducing the vane sort spoiler because of this the heat obligation builds, the heaviness of heat exchanger diminishes lastly the cost of heat exchanger can be decreased. Wang Yongqing et.al [4] numerically investigated the liquid stream and heat move physiognomies in a shell-and-tube heat exchanger with the segmental baffle, pole astound and H-shape baffle.

He expressed that by presenting the H sort astound in shell side, to bolster the structure and build up the stream headings are cross liquid stream and longitudinal liquid stream. He additionally, specified that the game plan of H shape baffle to stay away from the stream motor vitality misfortune, liquid stream speed, reductions the stream stunned district, and more noteworthy transversely stream module saves the better serious scour activity of segmental baffle. He at long last presumed that because of the state of the puzzle, it makes turbulence in liquid stream and improve most extreme heat exchange by makes limit layer around the tube dividers. Jie Yang et.al [5] broke down the three dimensional numerical re-enactments of a pole confuse shell-and-tube heat exchanger with four modified displaying strategies are created and approved with test comes about. The present work directs a correlation on numerical precision, lattice framework measure, computational period, and confinement for four unique models, examining exchange offs between computational exactness and requests, giving the points of interest and weaknesses of each displaying way to deal with scholastic analysts and building architects. The rambling model expends nearly little assets and the unit demonstrate devours the least. Q.W. Dong et.al [6] numerical reenactments are directed to compute the heat exchange rate and pressure drop in occasional unit conduit of ROD baffle heat exchanger. Fluid stream in shell side in this heat exchanger is longitudinal and periodical. What's more, liquid stream is of symmetry in scene introduction. This shell and tube heat exchanger is taken to compute shell side parameters with longitudinal stream, with higher speed and unwavering quality. The trial to the numerical heat exchange coefficient and liquid speeds are looked at and the mistake is under 10% in pressure drop is less than20%. The heat transfer execution and liquid stream are figured by utilizing intermittent unit channel of ROD astound heat exchanger.

The upgrade of heat move in the tube embed innovation is ascribed to a few elements to be specific the lessening water powered distance across, make turbulence, produce twirl stream, increment the liquid stream way and build up the mass stream rate toward liquid way those are joined to expand the heat exchange rate. Heat execution increment because of supplements the outside gadget in the tube sides of heat exchanger. The numerical and trial studies are including increase strategies in tubes prompted with various turned tapes are talked about beneath the writings. Eiamsa-ard S et.al [7] directed numerous trial examinations by supplement of single contorted tape, full-length double and routinely dispersed double turned tapes to assess heat exchange rate and pressure misfortunes in a tube underneath indistinguishable divider heat flux conditions. The heat exchange and rubbing element were talked about by them at single contorted tape, diverse round proportions of full-length double curved tapes, distinctive space proportions of routinely separated double bent tapes at various Reynolds number. They likewise expressed that the Nusselt number increments with diminished curve proportion in single distorted tape and full-length double twisted tapes and diminished space proportion gives expanded heat move rate in the frequently dispersed double turned tapes. Kumar An et.al [8] drove a few Experimental examinations to assess grinding variable, heat exchange rate and heat sanctioning of a sunlight based water heater with turned tape embeds. They settled that the heat exchange attributes are improved at different mass stream rates by utilizing bent tapes with various curve pitch to tube measurement proportions. They came to realize that when contrasted with plain tube the heat exchange rates and pressure drops are expanded by 18–70%, and 87–132% in tube with round tape embeds. They likewise expressed that Nusselt number affiliations are set up to gauge the heat exchange rate for curved tape and plane gatherers. Lastly presumed that because of the impact of bent geometry, stream and power of radiation expands the heat execution up to 30% as contrast with plain tube. Zimparov et. al [9] figured heat exchange rate and pressure drop in a ridged tubes with twisted tape embed strategies. They made examinations between the layered tube and smooth tube for improvement of heat exchange and contact figure.

They came to realize that at whatever point the contorted proportions are fluctuated, consider the creased tallness, pitch and winding edges are consistent. The investigation was considered by them as a turbulent stream in the Reynolds number scope of 5000 to 60000. They reasoned that heat exchange coefficient and erosion components are more in tube with distorted tape as contrast with plain tube at same conditions, since auxiliary streams created because of round tape. M.Rahimi S et.al [10] directed a few investigations on Computational Fluid Dynamics examination on a tube with three distinctive curved tape supplements to assess Nusselt number, rubbing variable and water driven execution. They expressed that the heat exchange rate increments because of turbulence force is made more close by the dividers. They thought about three diverse contorted tapes, the barbed curved tape embed indicated higher Nusselt number and heat execution than other two additions and almost 31% and 22% for the exemplary one. R. J. Yadav et.al [11] performed 3D numerical reproduction to look at the heat exchange and erosion qualities in a round tube with half-length upstream contorted tape, half-length downstream round tape, full-length curved tape and contrast these qualities and the plain tube. They utilized three diverse curve parameters used to make turbulent fluid stream administration and upgrade heat exchange. From the above they chose that, full-length bent tape gives better outcomes. The heat exchange coefficient and pressure drop were 29–86% and203–623% higher in full-length round tape when contrasted with plain tube. They contrasted half-length upstream round tape and plain tube, the parameters were expanded by 8–37% and 36–170% and it is 9–47% and 31–144% higher when they considered half-length downstream bent tape. Y. Cui et.al [12] led exploratory and numerical examination on round tube with great Spiral-Twisted-Tape embeds and edge Fold-Twisted Tape additions to assess the pressure drop and heat exchange rate. In this strategy RNG turbulence model is utilized to make twirl in the stream field.

It was uncovered that the Nusselt number and grinding variable are increments in the edge Fold-Twisted Tape because of bend edge, the crevice width between the tube and embeds and higher unrelated speeds are made close by the tube divider along the length. They expressed that the above parameters are expanded up to 3.9% − 9.2% and 8.7% − 74% in tube with edge Fold-Twisted Tape when contrasted with tube with Spiral-Twisted-Tape. They presumed that, the exploratory results and numerical qualities are in great concurrence with 1.6% − 3.6% in Nusselt number and 8.2% − 13.6% in grinding variable. Y. Chiu and J. Jang [13] led numerous trial and numerical examinations on round tube with various tube embeds (with and without gaps) and turned tapes to discover the thermo pressure driven attributes. Limited volume strategy was utilized to discretize the overseeing equities in numerical investigation.

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They expressed that, the tube with longitudinal strip (without gaps) demonstrates higher heat exchange coefficient and the pressure drop up to 7–16% and 100–170% than plain tube. They at last finished up the above parameters were expanded at a rate of 13–61% and 150–370% contorted tapes are supplanted in plain tube. S. Eiamsa-ard et.al [14] directed a few trial examinations on a tube with twin counter bent tapes and twin co-round tapes to decide Nusselt number, rubbing element and heat enlargement list. Twin counter turned tapes were utilized by them at four diverse curve proportions, distinctive Reynolds numbers to produce co-twirl stream in the test area. Authorization of tube with single twisted tape were ascertained for correlation

3. NUMERICAL ANALYSIS:

For the numerical analysis, the actual model is represented as a virtual computer model by using CATIA software package and analysis is performed with finite volume method as a CFD tool. The inlet and outlet boundary conditions for the analysis is carried out as follows.

3.1 Geometry and It's Boundary Conditions:

Based on the above experimental model virtual model is prepared for CFD analysis and whatever be the geometric parameters for the actual model the same dimensions are considered for virtual also. Hence the geometry scale in between actual model to virtual model is 1:1. As a result one can minimize the deviation of CFD analysis values and the practical values obtained. The heat exchanger is designed with water as working fluid for both hot and cold conditions. The properties of water directly implemented for the analysis. For the shell stainless steel is consider and for tube copper material is considered as per the actual model. The Reynolds numbers are greater than 4000 for the different inlet mass flow rates as mentioned in the boundary conditions. Hence the flow in the pipe as well as shell is considered as turbulent.

The hot water is entered at a temperature of 348k and different mass flow rates such as 0.184 kg/sec, 0.333 kg/sec, 0.503 kg/sec, and 0.671 kg/sec are given at the inlet of heat exchanger tube side nozzle. From the tube flow is considered to atmosphere pressure only. Based on the given inlet and outlet conditions the inbuilt program of fluent software calculated remaining parameters. The cold fluid enters at a temperature of 298k and different mass flow rates such as 0.34589kg/sec, 0.8403kg/sec, 1.2245kg/sec and 1.5762kg/sec are given at inlet of heat exchanger shell side nozzle. The flow of cold water is guided by the baffles provided over the tubes the water is entered at 298k and atmospheric pressure and it is exited from the shell outer nozzle into atmospheric pressure. Hence the pressure boundary is defined at the outlet of the shell. No slip condition for tube shell inner and outer surfaces are given. Tube shell and inlet outlet nozzles with uniform cross sections are defined for the analysis. The direction of flow was defined normal to the boundary. Hydraulic diameter and turbulent intensity were specified at inlet nozzle of both hot and cold fluid. The flow is assumed as incompressible turbulent flow the gradient of temperature is required at all the points of the heat exchanger. Hence the grid generator for both tube and shell and they are separated by the boundaries.

3.4 NUMERICAL SOLUTION CHOSEN FOR THE ANALYSIS:

The CFD solver FLUENT was employed to solve the governing equations. The SIMPLE algorithm was used to resolve the coupling between pressure and velocity field. The second order upwind scheme was used for discretization pressure, momentum, energy, turbulent kinetic energy and turbulent dissipation rates. The analysis is related to fluid flow which is continuously shear hence the finite volume method which is flux based method is chosen for the analysis. In finite volume technique, computational fluid dynamics (CFD) analysis: In finite volume method (FVM) the domain can be divided into number of control volumes

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and place number of nodal points in between points shown in Fig.5.

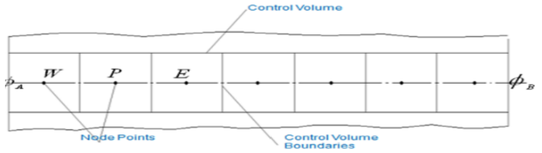

Figure .5 Control volumes and Nodal points in the flow domain

Discretization of Integrated equation into algebraic equation. The Nodal Point P shown in Fig.6.

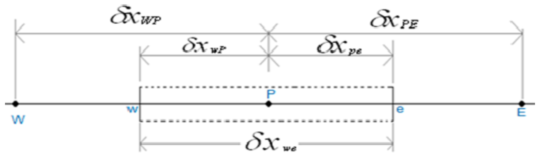

Figure .6 Nodal point details in control volume

The general equation for the fluid, when the fluid is in-compressible, viscous, turbulent is

$$\int_{cv}\frac{\partial}{\partial t}(\rho\phi)dv+\int_{cv}div(\rho\phi u)dv=\int_{cv}div(\Gamma grad\phi)dv+\int_{cv}S(\phi)dv$$

The general transport equation for a variable Ø in finite volume method is

(Rate of increase of Ø of fluid element) + (Net Rate of fluid flow of Ø out of fluid element) =

(Rate of increase of Ø due to diffusion) + (Rate of increase of Ø due to source)

$$a_P\varphi_P=a_W\varphi_W+a_E\varphi_E+S_u$$

Where $a_W=\frac{\Gamma_w A_w}{\delta x_{WP}}, a_E=\frac{\Gamma_e A_e}{\delta x_{PE}} \;\&\; a_P=(a_W+a_E-S_P)$

The resulting system of linear algebraic equations is then solved to obtain the distribution of the property Ø at the nodal point. The algebraic equations are solved by using direct methods (Cramer's rule, matrix inversion and Gauss elimination) and indirect or iterative methods (Jacobi and Gauss-seidel).The flow is incompressible turbulent hence the k-ε model is considered for the analysis. K-ε model is simplest turbulence model for which only initial boundary conditions need to be supplied and used for 3D analysis in which the changes in the flow direction are always so slow that the turbulence can adjust itself to local conditions.

As per the grid density the number of algebraic equations are generated for unite volume the algebraic equations are solved by numerically.

3.5 PROBLEM TAKEN FROM THE ANALYSIS:

Validation:

Ender Ozden in his research studied about pressure drop in shell side of shell and tube heat exchanger with segmented baffles and CFD analysis was carried out and finally he concluded that at 36% baffle cut gives minimum pressure drop and maximum thermal performance. According to Ender Ozden's research the boundary conditions were the shell inlet temperature is set to be 298 K, Zero gauge pressure is assigned to outlet nozzle in order to obtain relative pressure drop between inlet and outlet, no slip condition is assigned to the surfaces, zero heat flux boundary is assigned to outer shell wall and tube side temperature of 348 K. The percentage of error in between Andrew Ozden's research and this research is about 1% and the analyses shown below. for the analysis of virtual model with modifications. Consequently experimental results are approached to numerical results and the final concept is formulated towards CFD analysis for various configurations.

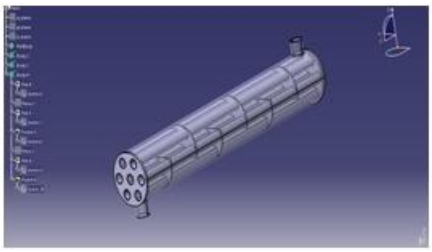

Figure.7 Virtual model of shell and tube heat exchanger

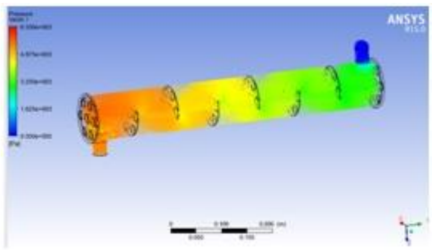

Figure.8 Shell side vector diagram of pressure drop

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4. DATA APPRECIATION:

The heat transfer rate and ultimately pressure drop was calculated from the initial data on the flow rates and the inlet and outlet temperatures of both shell and tube side of STHE. The heat transfer rate is obtained by the following equation.

$Q=AU\Delta T_m$ (1)

Where Q=average heat flux between the cold and the hot fluid in watts

$= (Q_{C+}Q_h)/2$

$Q_C = m_c\, c_{pc}\, (T_{co} - T_{ci})$

$Q_h = m_h\, c_{ph}\, (T_{hi} - T_{ho})$

m_c, m_h cold and hot fluid mass flow rates in kg/sec.

$c_{pc,}$ c_{ph} are specific heats under constant pressure of cold and hot fluids in kj/kg k.

5 RESULTS & DISCUSSSION:

The flow parameters are varied by introducing of different tube geometry and helical strip inserts. Subsequently more turbulence is created in the flow by introducing physical characteristics and mathematical model is reformed for more numerical analysis. Observations as per this type of analysis found more heat transfer efficiency for dropping the pressures along the length of shell and tube of STHE.

5. ELLIPTICAL TUBES WITHOUT HELICAL STRIP INSERTS OF STHE:

The cross section of tubes which is having geometry such as circular, square, triangle elliptical etc. will influence the thermal analysis due to variation of surface area. Generally higher surface area gives higher heat transfer performance comparatively having less surface area. In analysis circular tubes have low surface area than elliptical tubes. Visualisations are made on elliptical model is comparison to elliptical with helical strip model mathematical analysis. The flow parameters are varied due to introduction of different tube orientation, different tube geometry, different baffle cuts and also helical strip inserts. Subsequently more turbulence is created in the flow by introducing physical characteristics and mathematical model is reformed for more numerical analysis.

Temperature distribution for streamline diagram indicates the heat transfer rate increase if tube geometry changes from elliptical tube without helical strip to elliptical tubes with helical strip and the graphs indicates the variations of heat transfer of with respect to change of Reynolds number.

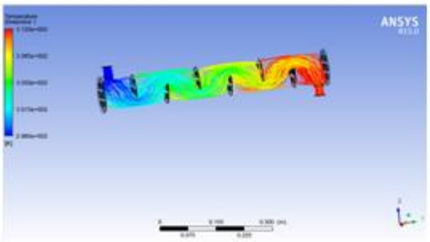

Figure.11 Temperature stream lines of elliptical tubes without helical strip

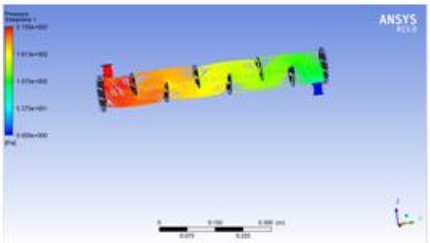

Figure.12 Stream lines of shell side pressure drop without helical strip in elliptical tubes

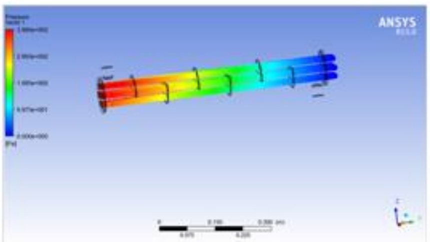

Figure.13 Stream lines of tube side pressure drop without helical strip in elliptical tubes

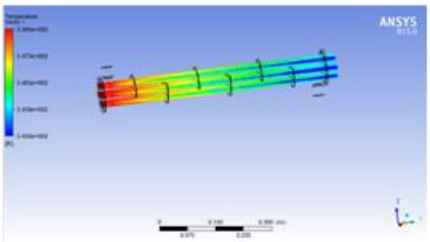

Figure.14 Temperature stream lines of tube side without helical strip in elliptical tubes

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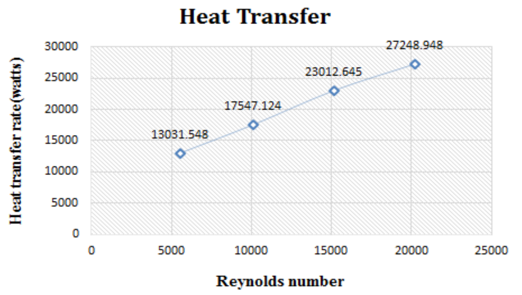
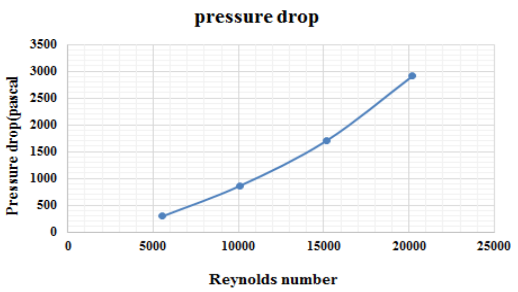


Heat Transfer V/S Reynolds Number for Elliptical Tubes without strip



Pressure Drop V/S Reynolds Number for Elliptical Tubes without strip

5.2 ELLIPTICAL TUBES WITH HELICAL STRIP INSERTS OF STHE:

In case of current shell and tube heat exchanger, it consists of tubes with elliptical cross section and strips inserted into the tubes of the shell and tube heat exchanger. As we already know that the rate of heat transfer as well as pressure drop greatly changes, if we increase turbulence in the flow of fluid. That means it clearly indicates that increase in turbulence increases heat transfer rate as both are directly proportional to each other. Turbulence is the phenomenon in which disturbance is occurred in the flow of the fluid which leads to increase in pressure drop i.e. the pressure difference. The strip inserts present in the tubes of the shell and tube heat exchanger helps in creating turbulence which in turn helps in increasing heat transfer rate and decrease pressure drop. Twirl flow devices cause auxiliary flow in the liquid and this optional flow expands the heat exchange rate. The devices utilized here are tube strips, changed tube flow courses of action that are contorted tape strips, screw–type strips and wire loops and furthermore pipe geometry adjustments like ribs, helically wound tubes and so forth. Among all twirl flow devices, wound tape strips give better heat move execution in single stage liquids.

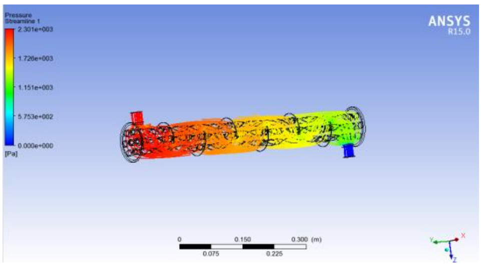
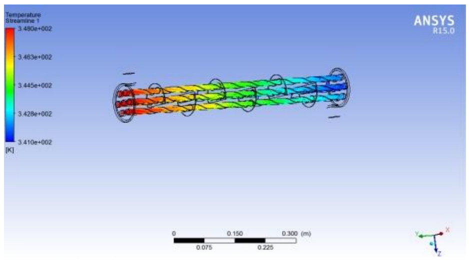


Fig: Streamlines showing pressure drop in shell side



Streamlines of temperature difference in tube side

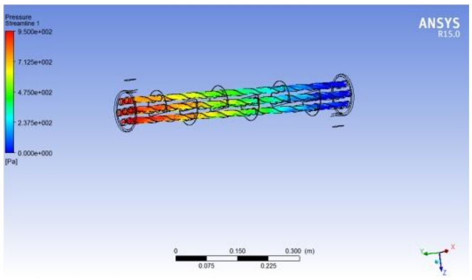


Fig: 4.50 Streamlines of pressure drop in tube side

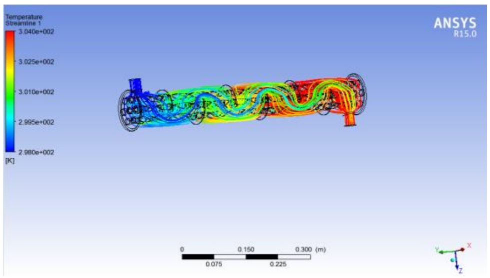


Fig: 4.51 Streamlines of temperature difference in shell side

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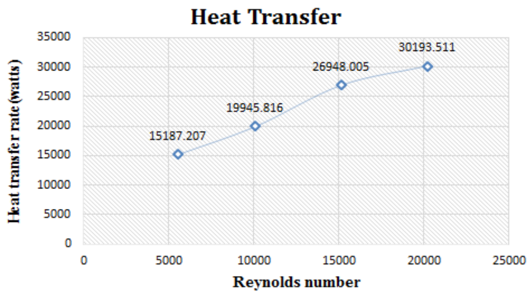
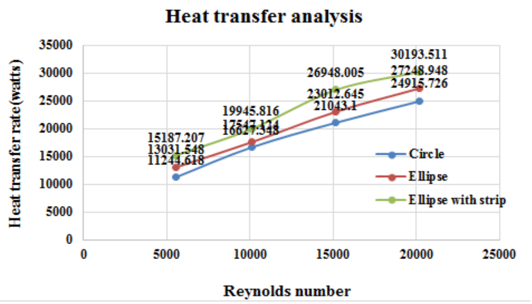
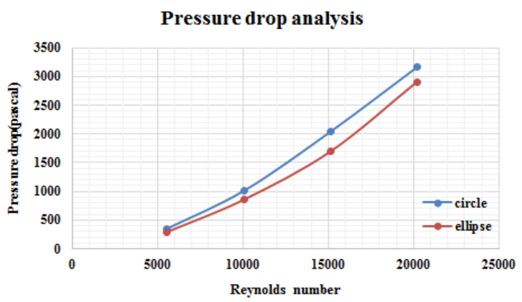


Graph-5 Heat Transfer V/S Reynolds Number for Elliptical Tubes with Strip Inserts



Graph-6 Heat Transfer Variation at Different Cases



Graph-7 Pressure drop variation in circular and elliptical tubes

6. CONCLUSION:

In the present study CFD analysis is conducted on elliptical models with and without helical strips of the STHE with various Reynolds number. The tube geometry and strips are considered to enhance the heat transfer rate by minimizing the pressure drop. Based on the simulation results following conclusions are derived. The effect of tube geometry and strip inserts are subjected to evaluate the pressure drop and heat transferal rate in Shell and tube heat exchanger.

As the surface area of the tube is increased by replacing circular tube with elliptical tube, heat transfer rate increased. By inserting strips into the tubes it helps in creating turbulence which increases Reynolds number which in turn helps in further increase in heat transfer rate. Here elliptical tubes with strips and elliptical tubes without strips are considered so, heat transfer is very high in the case elliptical tubes with strips when compared with elliptical tubes without strips. From the above three cases, we investigated that the elliptical tube with strip inserts gives maximum heat transfer rate of 30193.511 Watts and pressure drop of 2911 Pascal.

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