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Computational Analysis of Heat Exchanger and Maximized Heat Transfer Rate by Using the Double Tube Helical Coil

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ABSTRACT: Working towards the goal of saving energies and making the design for mechanical and chemical devices and plants, the enhancement of heat transfer is one of the key factors in the design of heat exchangers. In this process, without the application of external power, we can enhance the heat transfer rate by modifying the design by providing the helical tubes, extended surface, or swirl flow devices. Helical tube heat exchanger finds applications in automobile, aerospace, power plant, and food industries due to certain advantages such as compact structure, larger heat transfer surface area, and improved heat transfer capability. In this paper numerical study of a helical coil, the tube-in-tube heat exchanger is completed for different boundary conditions, and optimized condition of heat transfer is found out for different D/d ratio. The turbulent flow model with a counter-flow heat exchanger is considered for analysis purposes. The effect of the D/d ratio on heat transfer rate and pumping power is found out for different boundary conditions. The D/d ratio is varied from 10 to 30 with an interval of 5. Nusselt number, friction factor, pumping power required, and LMTD variation of inner fluid concerning Reynolds number is found out for different D/d ratios. The optimized Reynolds number for maximum heat transfer and minimum power loss is found out by graph intersection methods. From the results complicated behavior of fluid flow is captured for both the fluids flowing inside the tube. With increases in D/d ratio (inverse of curvature ratio) the Nusselt number will decrease and the outer wall boundary condition does not have any significant effect on the inner Nusselt number. The Darcy friction factor decreases with increase in Reynolds number. The Pumping power increases with an increase in Reynolds number for all the conditions of D/d ratio and all the boundary conditions. Log mean temperature difference (LMTD) increases at a steady rate with an increase in Reynolds number. The optimization point between Nu and f concerning Re; shifts toward the lower Reynolds number with an increase in D/d ratio.

KEYWORDS: D/d ratio, Nusselt number, friction factor, LMTD, pumping power.

I. INTRODUCTION

Heat exchanger is a device that is used to transfer heat between two fluids which may be in direct contact or may flow separately in two tubes or channels. We find numerous applications of heat exchangers in day to day life. For example condensers and evaporators are used in refrigerators and air conditioners. In thermal power plant heat exchangers are used in boilers, condensers, air coolers and chilling towers, etc. comparably the heat exchangers used in automobile industries are in the form of radiators and oil coolers in engines. Heat exchangers are also used on large scale in chemical and process industries for transferring the heat between two fluids which are at a single or two states.

II. RELATED WORK

Kumar et al. (2006) had investigated the hydrodynamic and heat transfer characteristic of tube in tube helical heat exchanger at pilot plant scale. They had experimented a counter flow heat exchanger. Overall heat transfer coefficients were evaluated. Nusselt number and friction factor coefficient for inner and outer tube was found and compared with numerical value got from CFD package (FLUENT). They observed that the overall heat transfer coefficient increase with inner coil tube Dean Number for constant flow rate in the annulus region.

Kharat et al. (2009) had completed the experiments to study the heat transfer rate on a concentric helical coil heat exchanger and develop the correlation for heat transfer coefficient. Heat transfer coefficient has improved for the tube containing flue gas of the heat exchanger by using CFD simulation and the experimental study. The effect of different



operating variables was studied. The variables they had considered are gap between the concentric coils, diameter of tube and coil diameter.

III. METHODOLOGY

The invention of high speed computers, combined with the accurate numerical methods for solving physical problems, has revolutionized the way we study and practice fluid dynamics and heat transfer problems. This is called Computational Fluid Dynamics (CFD), and it has made it possible to analyze complex flow geometries with the same ease as that faced while solving idealized problems using conventional methods. CFD may thus be regarded as a zone of study combining fluid dynamics and numerical analysis. Historically, the earlier development of CFD in the 1960s and 1970s was driven by the need of the aerospace industries. Modern CFD, however, has applications across all disciplines – civil, mechanical, electrical, electronics, chemical, aerospace technology, ocean science, and biomedical engineering being a few of them. CFD substitutes analytical studies and experimental testing, and reduces the total time of testing and designing.

All the CFD software contain three basic elements

1. Preprocessor
2. Main Solver
3. Postprocessor

The process of CFD modeling starts with an understanding of the actual problem and identifying the computational domain. This step is followed by generations of the mesh structure, which is the most important portion of the pre-processing activity. Both computation time and accuracy of solution rely on the mesh structure. That is finer the grid is more accurate the result is. But the grid size should not made unnecessarily finer so that the computation takes extra time for computing, there should be an optimal grid size in which all the computation should be completed

CFD procedure: For numerical analysis in CFD following five stages are required.

IV. EXPERIMENTAL RESULTS

Geometry creation

In geometry creation we have to create the helical pipe. For this we have to open the ANSYS 13, go to CFD fluent package and open the DESIGN MODELER then change the property to three dimensional. In DM first we have to create the profile for our problem circle is the profile. So to create the circle select the XY-plane then set the unit to the millimeter. Then go to sketching and draw the circle then specify the dimension for example its radius, and distance of the circle from the XY-axis. Then generate the circle. Compare generate other two circles for outer tube. For generating the path draw a line perpendicular to XY-plane. Give it dimension as mention in the problem.

For generating the helical tube we have to do the SWEEP procedure. For sweep we have to select the profile and the path, then the operation should be ADD FROZEN. Then specify the number of turns, for this problem we select two numbers of turns. Then generate it to create the helical pipe. Same procedure is followed for generating the two annulus helical tubes. After generating the three tubes specify the body type that is whether it is FLUID or SOLID. The outer and innermost tubes are in a FLUID condition and middle tube is in the SOLID state.

To create the annular tube go for the BOOLEAN operation and subtract the inner tube from the outer tube while preserving the tool body. In FLUENT for heat transfer we need conjugate heat transfer condition for this we have to make the three parts three bodies to one part three bodies. For this select three bodies and right-click on it then form NEW PART. Then save the project and close the DESIGN MODELER.

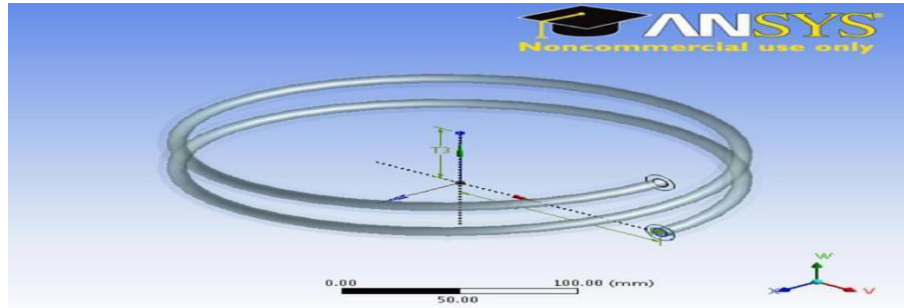


Fig. 4.1 showing the geometry of double tube helical coil heat exchanger created in ANSYS 13 work bench. Grid generation

In grid generation first go to the MESH option located in FLUENT tree then press the GENERATE MESH button. It will create the automatic grid. Then we have to modify the grid or make the grid finer so that accurate results will come. For generating fine mesh go for the sizing option then select the EDGE for making the division. Then specify the number of divisions.

For generating the uniform mesh we have to MAP the face, for that we have to select the MAPPED FACE option and select the face for which we have to do the operation. This will create uniform mesh throughout the face of the geometry. Compar in MESHING METHOD we can specify the type of mesh we want to create for example QUAD, TRI, QUAD/TRI etc.

After that we have to name each face of the geometry. For that right click on the face and go to CREATE NAME SELECTION then name each face (for example inlet, outlet, wall etc). Then update the project.

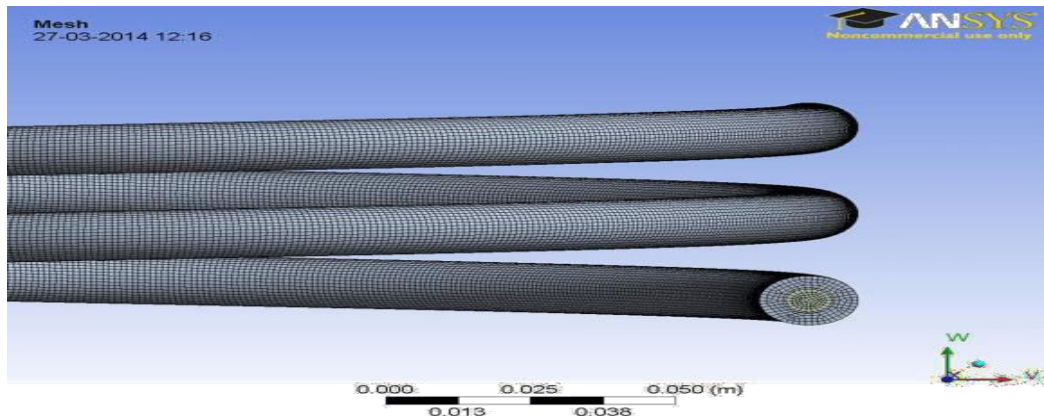


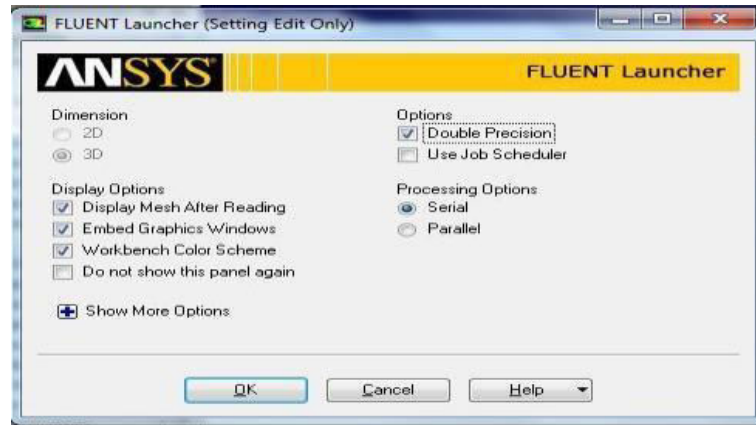
Fig. grid generation for the double tube helical coil heat exchanger

SETUP AND FLOWSPECIFICATION

In SETUP we generally set the operating conditions, flow specifications, boundary conditions, define the appropriate model for solving the problem.



First open the SETUP and specify it DOUBLE PRESSION for more accurate answer.

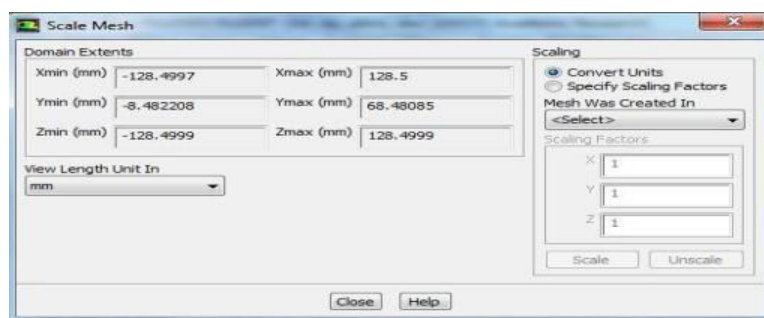
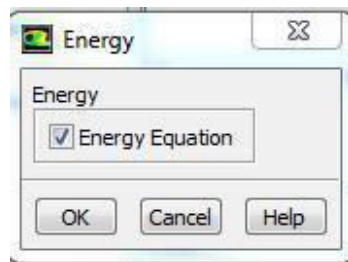


Then in the problem set up tree go for the GENERAL option and change the scale form meter to millimeter.

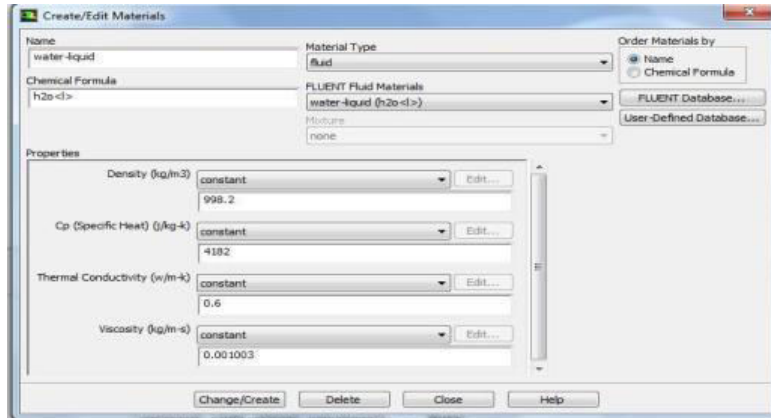
In the MODEL tree option the energy equation should be turned on for calculating the temperature profile for the heat exchanger.

For turbulent model standard K-εmodel was used. For this viscous model standard k-εmodel was turned on.

For selecting the material we have to go for problem set up tree and then go for the MATERIAL option then go for

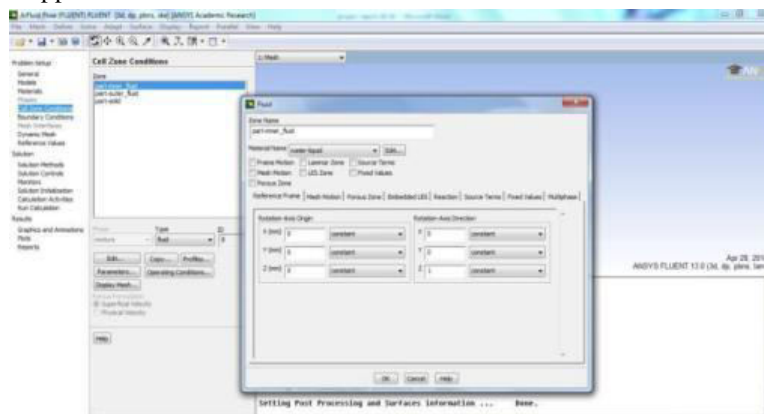


change and edit option where we can select the material from fluent database. After selecting the suitable material



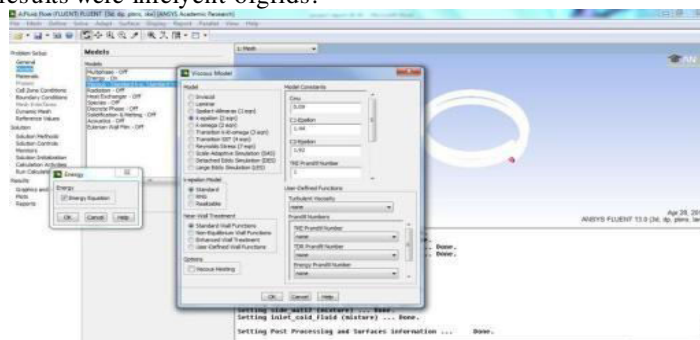
(copper for solid and water for fluid), we can change their property according to our requirements.

Then we have to specify the domain or the cell zone condition. For inner and outer fluid it should be water-fluid and for solid it should be copper.



For setting the boundary condition go to BOUNDARY CONDITION option in problem set up tree then chose the different boundary condition zone with specifying the type of boundary (velocity inlet/pressure outlet/wall) etc. Then in each boundary condition go for the EDIT option then specify the values according to the requirements.

Grid independence test is the one of the most important test which should be completed in the numerical analysis of a problem. Grid independence test was completed to check the final results should be inrelyent of the number of grids. In numerical problem the results are always relyent on the number of grids generated. So if we change the number of grids the results were changed. While changing the number of grids a stage may come when the results are inrelyent of the number of grids. These minimum number of grids after which there is no change in results were observed was known as optimum grid size and the results were inrelyent of grids.





In this problem first the grid independence test were carried out for different D/d ratio. Starting from D/d=10; considering outer wall insulated condition and keeping the inlet velocity of hot fluid at 1.5072m/sec (Re=10000) and temperature at 355K the grid size was varied from 64770 to 138775. The properties considered for checking the grid independence are the temperature of cold and hot fluid at the outlet, pressure at inlet and outlet of hotfluid.

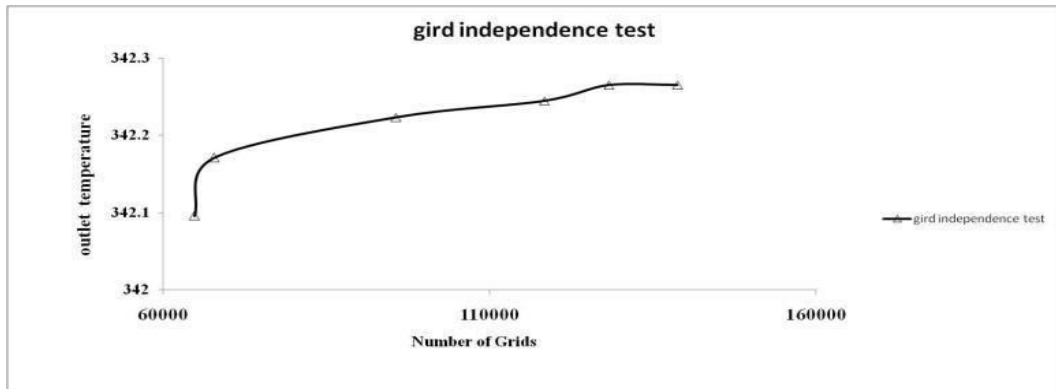


Fig. grid independence test based on the outlet of hot fluid temperature

In the above two graphs outlet fluid temperatures were taken in Y-axis and number of grids in X-axis. The grids divisions were increased and the corresponding temperature of hot fluid in Fig.4.3 (a) and outlet of cold fluid temperature in Fig. 4.3 (b) were shown. After 138700 numbers of divisions the results not rely on grids hence result is gridinrelyent.

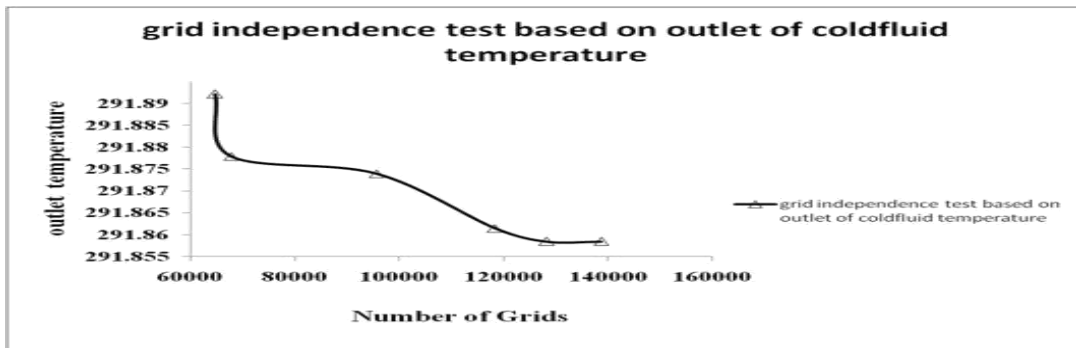


Fig. grid independence test based on outlet of cold fluid temperature

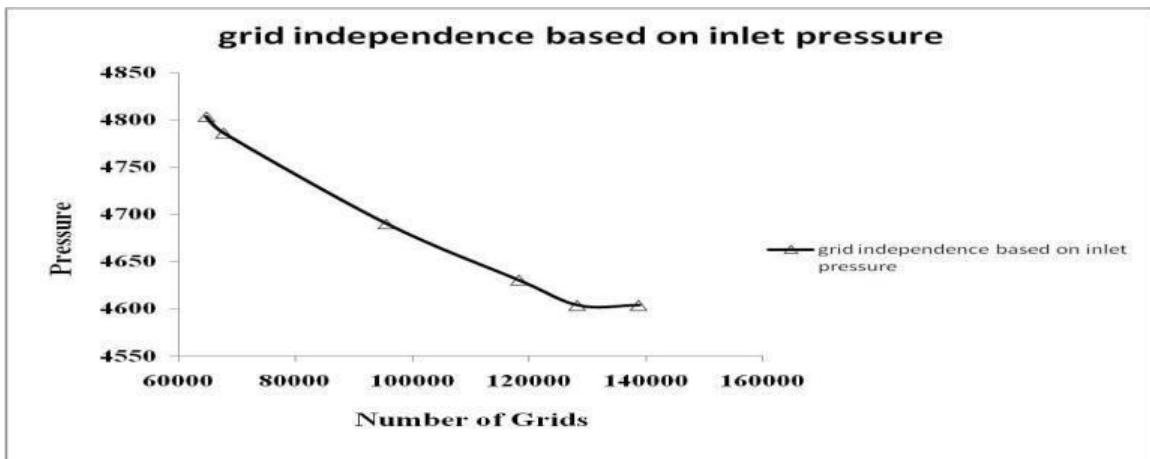


Fig. 4.3(c) grid independence test based on the pressure of hot fluid at inlet

Compar for other D/d ratio the grid independence test has been completed on the basis of outlet temperature of hot fluid

and cold fluid and optimum grids were chosen for further numerical analysis.

V. CONCLUSION

- With increase in the Reynolds number, the Nusselt number for the inner tube increase. However, with increases in flow rate turbulence between the fluid element increases which will enhance the mixing of the fluid and ultimately the Nusselt number or the heat transfer rate increases.
- With increases in D/d ratio (inverse of curvature ratio) the Nusselt number will decrease; for a particular value of Reynolds number. Nusselt number has maximum value for D/d=10.
- The outer wall boundary condition does not have any significant effect on the inner Nusselt number, which can be confirmed from the results.
- Friction factor decreases with increase in Reynolds number due to relative roughness of surface, and velocity of flowing fluid.
- Pumping power increases with increase in Reynolds number for all the condition of D/d ratio and for all the boundary conditions. This is due to increase in pressure loss caused by more turbulent flow. Pumping power is independent of the outer wall boundary conditions.
- Log mean temperature difference increases at a steady rate with increase in Reynolds number.
- As long as the heat transfer is concerned from the hot fluid any boundary condition can be assumed for outer wall of external tube because it does not affect significantly the heat transfer rate.
- From the optimization graph shown between Nu and f with reference to Re; the intersection point shifts toward the lower Reynolds number with increase in D/d ratio. It indicates that lower Reynolds number is required to get maximize condition for higher D/d ratio because the power requirement is more as we move towards higher D/d ratio.
- The optimum Reynolds number decreases with increase in D/d ratio.

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