

Fabrication & Experimental Evaluation of Heat Transfer Enhancement Techniques in Heat Exchangers

Prem Kumar Vyda, Rupesh Palwadi, Ravi Chandra Parepalli

Abstract— Various heat enhancement techniques are identified and studied for double pipe heat exchangers. Experimental evaluation is done by fabricating basic double pipe heat exchanger and heat exchangers with modifications. Fabrication of heat exchangers is done as per the ISO standards. The material used for the construction of heat exchanger is copper, owing to its high thermal conductivity. Testing has been carried out for both parallel flow and counter flow connections at different flow rates. The results show that the three different enhancement techniques worked well, with the annular disks and the extended surfaces (fins) enhancement techniques, respectively, being the highest and the lowest. Experimental results of these modifications are validated using fluid flow analysis software; the software used here is Autodesk ALGOR Simulation Multiphysics. For this evaluation, 3D models of different variations of heat exchangers are generated using CATIA software. These models are then converted into *.iges format and the analysis is carried out. The analysis results validated the experimental results by showing that among the modified heat exchangers, heat exchanger with annular ring modification and the heat exchanger with extended surfaces (fins), respectively, has the highest and lowest heat transfer capability.

Keywords— Annular Rings, CATIA, Extended Surfaces, Flow Analysis, Heat Exchangers, Heat Transfer, LMTD, ALGOR Simulation

1 INTRODUCTION

Heat exchangers are devices used to transfer heat energy from one fluid to another. Typical heat exchangers experienced by us in our daily lives include condensers and evaporators used in air conditioning units and refrigerators. Boilers and condensers in thermal power plants are examples of large industrial heat exchangers. There are heat exchangers in our automobiles in the form of radiators and oil coolers. Heat exchangers are also abundant in chemical and process industries. There are a wide variety of heat exchangers for diverse kinds of uses, hence the construction also would differ widely. However, in spite of the variety, most heat exchangers can be classified into some common types based on some fundamental design concepts. Heat transfer enhancement in heat exchangers is gaining industrial importance because it gives one the opportunity to reduce the heat transfer surface area required for a given application and thus reduce the heat exchanger size and cost, increase the heat duty of the exchanger for fixed surface area, reduce logarithmic mean temperature difference (LMTD) for fixed heat duty and surface area, and reduce pumping power for fixed heat duty and surface area. The automotive and refrigeration industries routinely use enhanced surfaces in their heat exchangers. Heat transfer enhancement in heat exchangers has been the subject of many experimental and analytical investigations. These techniques can be categorized as 'ac-

tive' or 'passive'. The active techniques require external agitation, such as surface vibration, fluid vibration, injection, suction, and electric or acoustic fields. Passive techniques employ special surface geometries for enhancement, such as extended surfaces, rough surfaces, displacement enhancement devices, swirl flow devices, obstruction devices, and treated surfaces. In the present work only passive enhancement techniques were considered. Three different ones were employed. One of these techniques is simple inserts into the inner copper tube, while the other two were modifications to the annulus. The insert device is a swirl flow device. This type of device is inserted into the flow channel to improve heat transfer indirectly by promoting turbulence and flow mixing. The swirl flow device was a twisted-tape insert. This creates rotating and/or secondary flow that enhances the heat transfer. One of the modifications to the annulus was the use of extended surfaces. This type of modification is routinely employed in many heat exchangers. Fins were placed on the outer surface of the copper tube. A special shape of the fin was employed to increase the heat transfer coefficient. Also, extended surfaces may take the form of interrupted fins, which forces the redevelopment of boundary layers. The other modification technique to the annulus was an obstruction device. This was accomplished by periodically restricting the flow with annulus rings or disks. The opening in the disk is located in the center and forces the liquid to pass through a narrow opening near the surface of the copper tube. Because this opening is much smaller than the rest of the annulus, the liquid velocity is high through the opening. The rapid expansion on the far side of the opening triggers transition from laminar to turbulent flow, thus enhancing the rate of heat transfer.

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2 DEVELOPMENT OF HEAT EXCHANGER

2.1 SPECIFICATIONS OF HEAT EXCHANGER USED

The experimental study is done on a double pipe heat exchanger having the specifications as listed below:-

Specifications of Heat Exchanger:

Inner pipe ID = 13.8mm

Inner pipe OD = 15.8mm

Outer pipe ID = 38mm

Outer pipe OD = 42mm

Material of construction = Copper

Heat transfer length = 400mm

Water at room temperature was allowed to flow through the inner pipe while hot water (set Point 55°C) flowed through the annulus side in the counter current direction.

2.2 BASIC HEAT EXCHANGER



Fig. 2.1 Fabricated model of a basic heat exchanger

The heat exchanger is a simple, double-pipe heat exchanger. The inner tube is copper, of inside diameter 13.8 mm and out side diameter 15.8mm. The outer tube is a mild steel pipe with an inside diameter of 38mm and outside diameter of 42mm. Hot water flows through the copper tube and the cold water flows through the mild steel pipe. Two thermocouples are installed in each end, they measure the temperatures of the hot water, and the cold water. These measurements are necessary to determine the LMTD. The flow rates of both the cold and hot flows are controlled and measured by two separate flow rotameters. Depending on the connections of the inlet and the outlet of the cold flow, the heat exchanger can be operated either as a counter-flow heat exchanger or as a parallel-flow heat exchanger.

2.3 MODIFIED HEAT EXCHANGERS

2.3.1 Extended surfaces: Addition of fins to the outer surface of the copper tube. A total of 42 fins were placed on the inner tube. These fins were placed in seven banks of six fins each. The six fins in each bank were radially spaced, in increments of 60 degrees, on the outside surface of the inner tube. The fins were made of copper due to its high thermal conductivity. The maximum allowable fin height based on the outer diameter of the tube and the inner diameter of the shell was calculated to be 11.1mm. Given this constraint, a fin height of 11mm was chosen for ease of manufacturability, assembly, and material availability. The fin thickness was chosen to be 0.8inch, since ma-



terial of this gage was readily available and inexpensive. The base of each fin was soldered to the inner copper tube. Plumbing solder was used because of its the surface area, but they also increase turbulence, and induce a mixing effect inside the water jacket. This was accomplished by bending the top-rear corner of the fin towards the center of the tube. The increase in turbulence and the induced mixing tend to increase the heat transfer coefficient

2.3.2 OBSTRUCTION DEVICES: ANNULAR RINGS OR DISKS

Orifices or other temporary restrictions to flow often induce turbulence. Our approach, therefore, was periodically to restrict the flow with annular rings or disks. A schematic of the disk/ring is shown in Fig. The opening in the disk is in the center. This forces all the fluid to pass through a narrow opening near the surface of the copper tube. Because this opening is much smaller than the rest of the annulus, velocity is high through the opening. Also, the rapid expansion on the opposite side of the opening triggers the transition from laminar to turbulent flow. The outside edges of the disks are sealed to the mild steel pipe to force the fluid through the narrow opening near the copper tube. The resulting high liquid velocity and flow turbulence tend to increase the heat transfer coefficient.

The problem is then how to install and support the annular disks inside the mild steel pipe. The method that was chosen was to make the disk an integral part of a thin walled tube that slipped inside the mild steel pipe. To do this, seven annular disks were made and installed. The end result was a tube 400 mm long, with disks having a 1.5mm openings spaced on 50mm centers along the tube.



2.3.3 Swirl flow device: a Twisted-tape insert

The thin twisted helical tape was made of a copper sheet (1.6 mm thick). The tape was twisted eight times. There was a small clearance between the twisted tape and the walls of the copper tube to allow easy insertion of the tape. The work by Manglik and Bergles on twisted tapes presented an updated understanding of the heat transfer for both laminar and turbulent flows. The blockage caused by the finite tape thickness increases the average velocity. Heat transfer enhancement may occur for two reasons. First, the tape reduces the hydraulic diameter of the inner copper tube; this tends to increase the heat transfer coefficient, even for zero tape twist. Secondly, the twist of the tape causes a tangential velocity component. This causes the speed of the flow to increase, particularly near the wall. The enhancement in the heat transfer is a result of the mixing by the secondary flow and the increased shear stress at the wall.

3 EXPERIMENTATION WITH VARIATIONS

3.1 EXPERIMENTAL SETUP

Testing was done and compared the three modified heat exchangers to the basic heat exchanger. First, the basic heat exchanger was set up to both hot and cold water flows in a counter-flow mode and parallel flow mode. The cold water flow was an open circuit while the hot water flow was a closed circuit. The water was heated to the desired temperature by heating element. Adjusting the electrical energy input to the heating element controlled the water temperature.



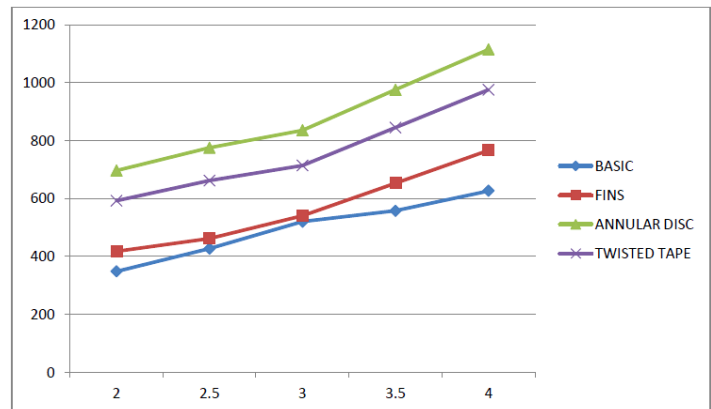
Both rates of flows were controlled by rotameters. The temperatures at the inlet and exit were measured by the use of four thermocouples that were connected to a data acquisition device. After the system had reached steady-state conditions the following data were measured and recorded: hot water flow rate, cooling water flow rate, inlet and exit hot water temperatures, T_{hi} and T_{ho} , respectively and inlet and exit cooling water temperatures, T_{ci} and T_{co} , respectively. This was carried out for several flow rates. In order to evaluate the enhancement techniques, the same experimental procedure was repeated for the modified heat exchangers and data were recorded for the same experimental conditions. There are several parameters that can be determined from these measurements, such as the heat duty, Q , the overall heat transfer coefficient, U , and the LMTD, that can be employed in the evaluation of the degree of enhancement of the modified heat exchangers presents the performance, based on heat duty, Q , of the basic and the four modified heat exchangers. The four different enhancement techniques performed well, with the annular disks and the spiraled rod enhancement techniques, respectively, being the highest and the lowest.

3.2 RESULTS AND DISCUSSIONS

The results obtained for various variations in both parallel flow and counter flow are tabulated and plotted. Various formulae used for calculating the experimentation variables:

Plot 3.1 M_c vs Q FOR PARALLEL FLOW:

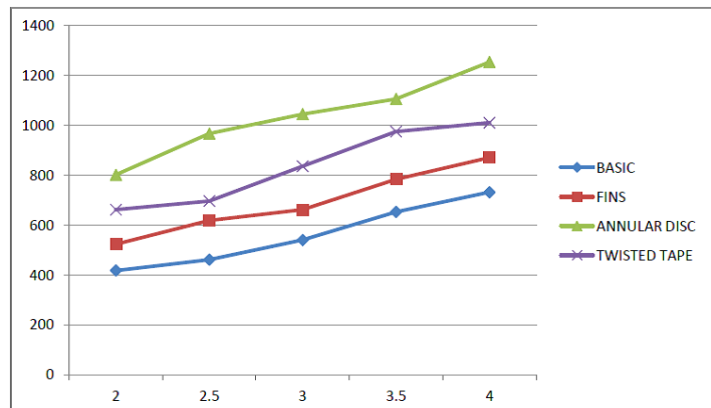
X- Axis – Mass flow rate of cold water (LPM)
 Y- Axis – Heat Loss from Hot Flow (Watts)



It is observed that the heat exchanger with annular disc has the highest heat loss from hot flow followed by heat exchanger with twisted tape insert and then heat exchanger with fins. The amount of heat loss also increases with increase in mass flow rate of cold water.

Plot 3.2 M_c vs Q FOR COUNTER FLOW:

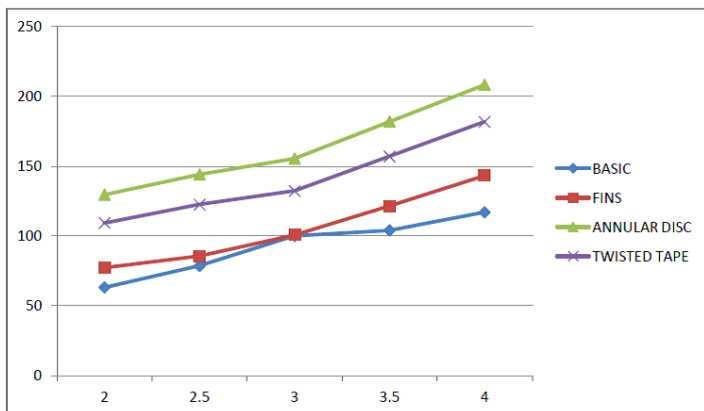
X- Axis – Mass flow rate of cold water (LPM)
 Y- Axis – Heat Loss from Hot Flow (Watts)



It is observed that the heat exchanger with annular disc has the highest heat loss from hot flow followed by heat exchanger with twisted tape insert and then heat exchanger with fins. The amount of heat loss also increases with increase in mass flow rate of cold water in the counter flow conditions also.

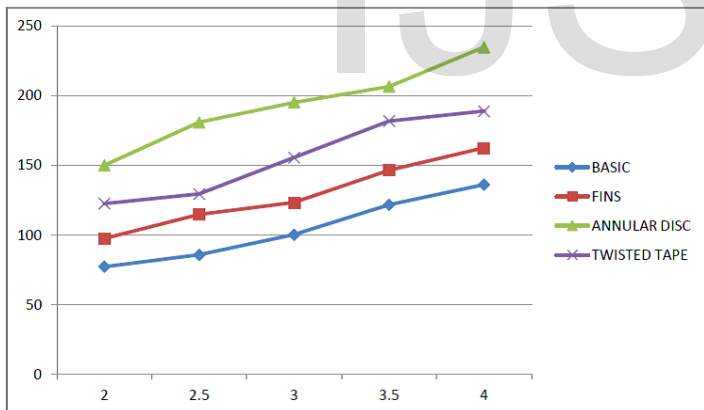
Plot 3.3 Mc vs U FOR PARALLEL FLOW:

X- Axis – Mass flow rate of cold water (LPM)
 Y- Axis – Overall heat transfer coefficient (W/m^2k)



It is observed that the heat exchanger with annular disc has the highest overall heat transfer coefficient followed by heat exchanger with twisted tape insert and heat exchanger with fins. The overall heat transfer coefficient also increases with increase in mass flow rate of cold water.

Plot 3.4 Mc vs U FOR COUNTER FLOW:



It is observed that the heat exchanger with annular disc has the highest overall heat transfer coefficient followed by heat exchanger with twisted tape insert and heat exchanger with fins. The overall heat transfer coefficient also increases with increase in mass flow rate of cold water in counter flow conditions also.

4 VALIDATION WITH COMPUTER MODELING

4.1 3D MODELLING OF HEAT EXCHANGERS

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systemes. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systemes product lifecycle management software suite. Through its exceptionally easy to use user interface, it delivers maximum productivity and creativity from concept to final product.

The Fabricated Designs are made in CATIA Software and exported to *.iges format for further Analysis. The different designs modeled are shown.

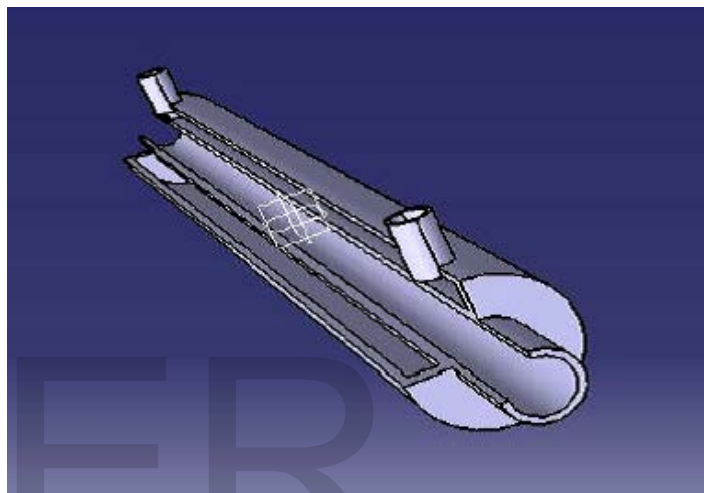


Fig. 4.1 A 270° cut section view of the basic heat exchanger

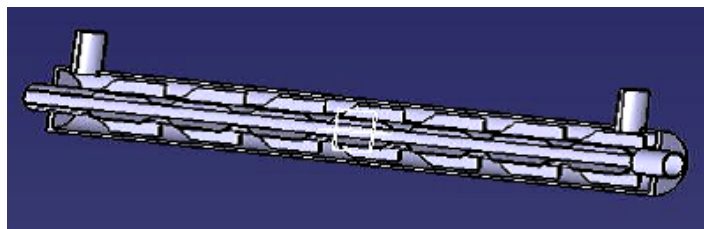


Fig. 4.2 A 180° cut section view of the finned heat exchanger



Fig. 4.3 Cut section view of twisted tape insert

5 SIMULATION USING AUTODESK ALGOR

5.1 SIMULATION SETUP

Various analysis types are available in this software and Multi-Physics module is used in this Analysis. After converting the file into the *.iges format , the computer model can be imported into the software by selecting open button or by pressing ctrl+o

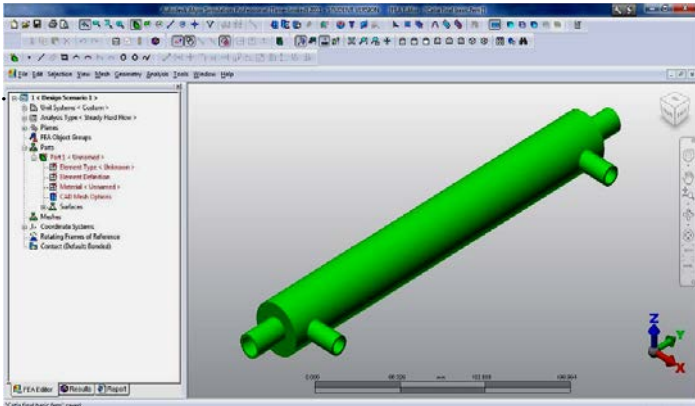


Fig 5.1 Imported Part into ALGOR

After the model has been imported into the analysis software, for the analysis to be performed , the model must be meshed in order to evaluate the results. The mesh contains various nodes and nodal elements at which the values can be calculated by the solver.

The model mesh settings option allows us to select the various meshing parameters to make the mesh for the geometry as per the desired specification.

The lower the meshing size, the more are the number of nodes and nodal elements and the more accurate the result that can be obtained. The model mesh settings window can be obtained by clicking on the respective button on the taskbar. Now the mesh type to be selected is of solid mesh and the pointer to be dragged to 60% of the original mesh value.

Now click on the options button and another dialog box will pop up requesting for further mesh details as shown below. Now, on the left hand side of the dialog box obtained, select the solid and select the tetrahedral and wedges (boundary layer). This type of mesh setting is selected as the analysis criterion here involves fluid flow in combination with heat transfer analysis. We have selected this type of mesh setting as it involves a boundary layer flow without including viscous heating effects. This type of mesh setting enables us to make the part as a water tight jointed part as the said part is assumed to be carrying water.

Now , after clicking on the mesh model button on the mesh settings dialog box, the meshing will be done and the mesh is verified for any errors in the resulting mesh after the meshing operation is done. After the mesh is verified for errors and if there are no errors found , then the part will be meshed successfully.

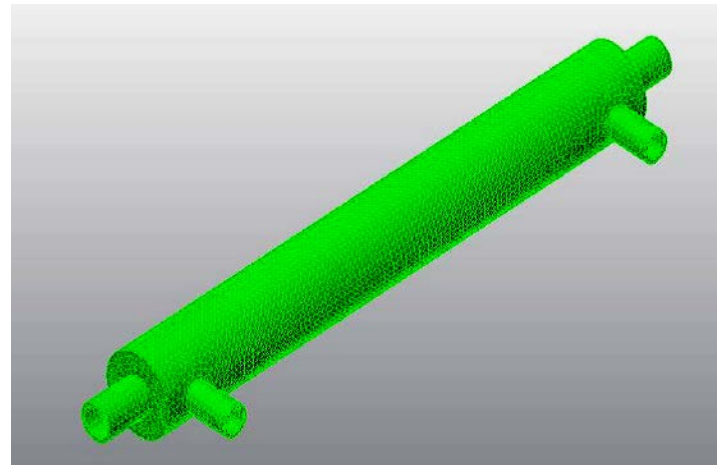


Fig 5.2 Meshed Model

Now, before performing the analysis, initially, some analysis parameters have to be specified and some initial setting has to be done with the part geometry.

Firstly, the unit systems have to be changed to the SI system of units so as to benefit the ease of calculation.

Next, the analysis type has to be specified so that the solver can understand the problem definition and pass the required criteria of information and parsers (evaluators) specific to that problem definition.

In the process of changing the analysis parameters, a pop up window will ask for the change of design scenario of the current analysis. Design scenarios help us to perform one or more analysis on the same part repeatedly.

In such situations, select NO in the resulting pop up dialog box to retain the original parameters. If YES is pressed, then newer parameters has to be passed.

Here, we use the coupled fluid flow and thermal analysis as it involves both the heat transfer and fluid flow simulation.

To change the analysis type, on the left hand side of the GUI(Graphical User Interface of the software), right click on the analysis type and select the set current analysis type and in the resulting sub-menu select the multiphysics option through which another sub menu will result in. select the steady state one from the menu. Now the analysis specification is over and the change of analysis type dialog box results in pressing NO on it and the present scenario is used.

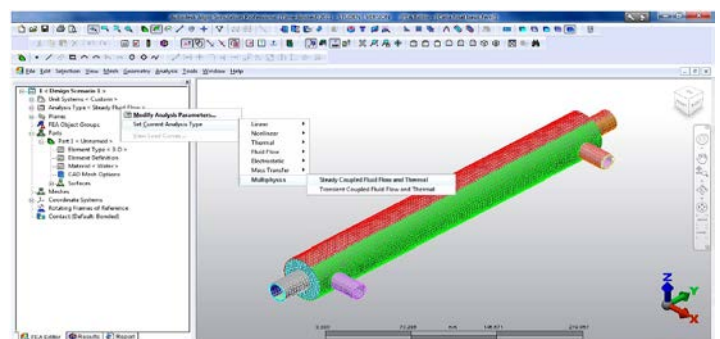


Fig 5.2 Passing Parameters

The analysis can be continued by coupling steady state heat transfer with steady fluid flow simulation and results in the same output as the coupled fluid analysis. This method of coupling them individually involves an ease in the analysis and also results in a more accurate result orientation. This is the best method preferred for performing the analysis as the other method consumes a lot of time and processor resources and results obviously in errors and bug tracking phenomena. Now, the various parameters like heat flux and the temperature inputs are given as follows.

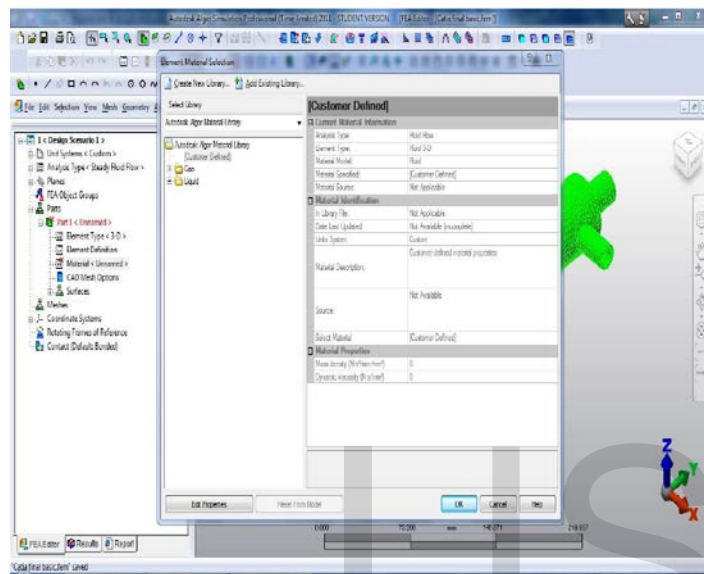


Fig 5.3 The material selection window for fluid flow

The various parameters that have to be given are as shown below. They can be incorporated by selecting the various surfaces and their respective fluid or heat flux domains and applying them carefully as any change may lead to erratic results.

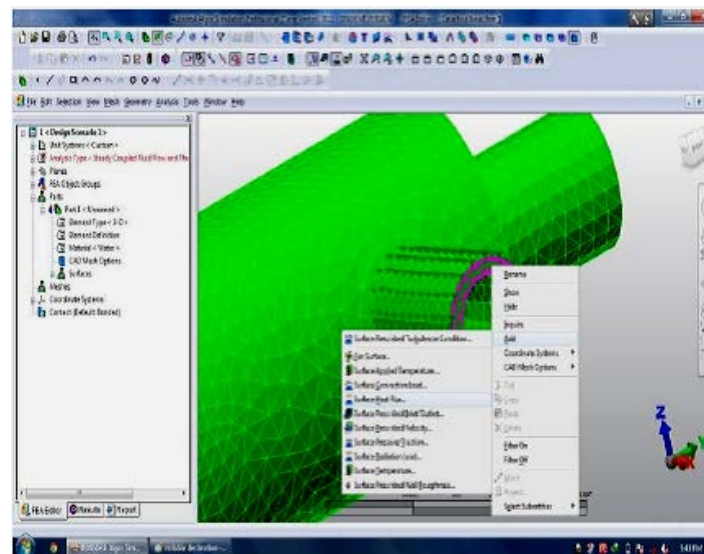


Fig 5.4 Fluid and Heat Flux Parameters

Now the fluid domain must be created in order to make the fluid flow simulation and the selected design scenario active. be accomplished by selecting the internal fluid generation from the mesh option in the toolbar.

The internal fluid generation option is selected as the fluid flows within both the tubes only.

Now, we have to select the surfaces that are adjacent to the fluid domain to make the fluid flow domain closed without any leaks.

Now the parameters for the multiphysics and the fluid flow are given by clicking on the analysis button on the taskbar and selecting the parameters option.

After all the input parameters are provide in the software for the part geometry, the direction of fluid flow and the heat fluxes are represented by arrows and yellow rings respectively.

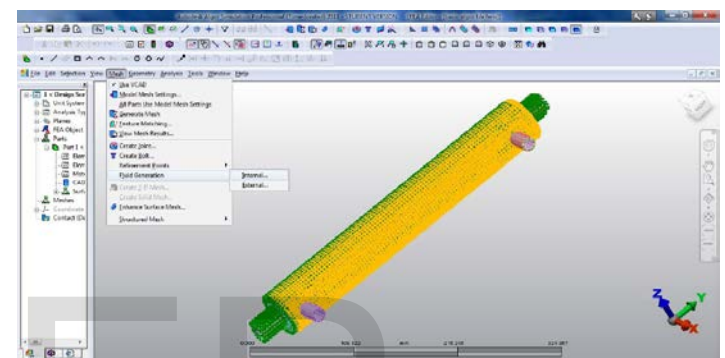


Fig 5.5 Internal Fluid generation window

5.2 PERFORMING ANALYSIS

After assuring that all the input parameters are declared, the perform analysis button is clicked and then the software once again verifies for the validation of the information and the meshing details and then continues to the solver and initiates the solver.

We can be assured of the completeness of the input parameters when there is nothing marked red on the left hand side of the software window. The analysis will continue to be performed for the geometry. Now, after the analysis has been performed the results are evaluated and then displayed in the hyperview 4.0 environment module and the various results can be obtained henceforth.

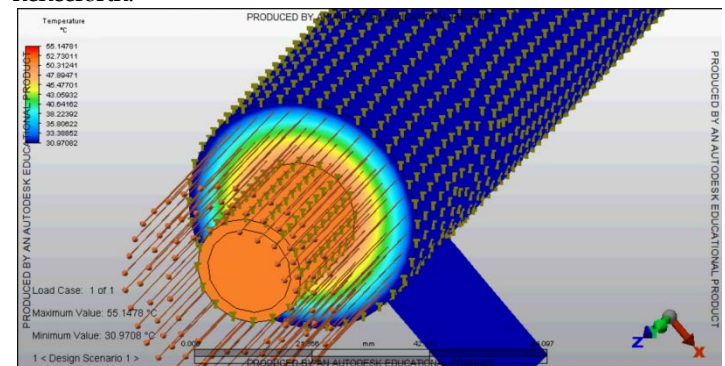


Fig 5.6 Simulation in Progress

5.3 RESULTS

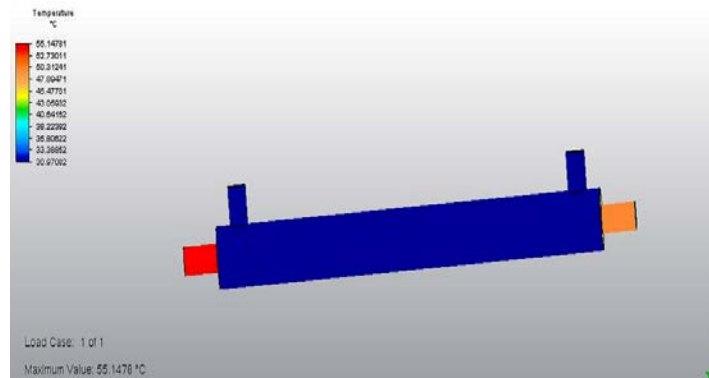


Fig 5.7 Analysis results for Basic Heat Exchanger

Temperature at the hot water inlet of the heat exchanger is 55°C, heat transfer takes place to the cold water as the hot water flows through the pipe and the temperature at the hot water outlet is 50°C. Therefore the fall of hot water temperature through the pipe is 5°C.

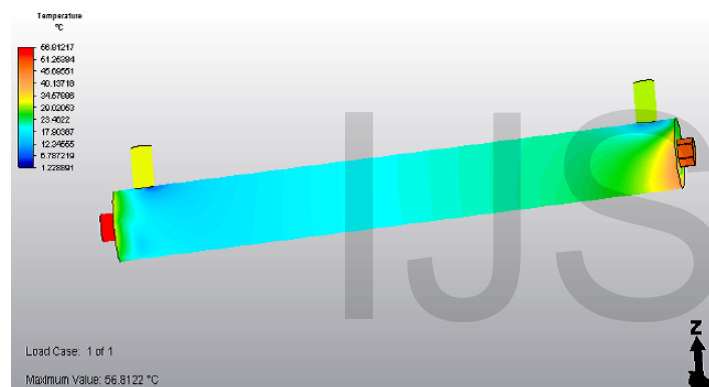


Fig 5.8 Results for Modified Heat Exchanger with Fins

Temperature at the hot water inlet of the modified heat exchanger with fins is 56°C, heat transfer takes place to the cold water as the hot water flows through the pipe and the temperature at the hot water outlet is 49°C. Therefore the fall of hot water temperature through the pipe is 7°C.

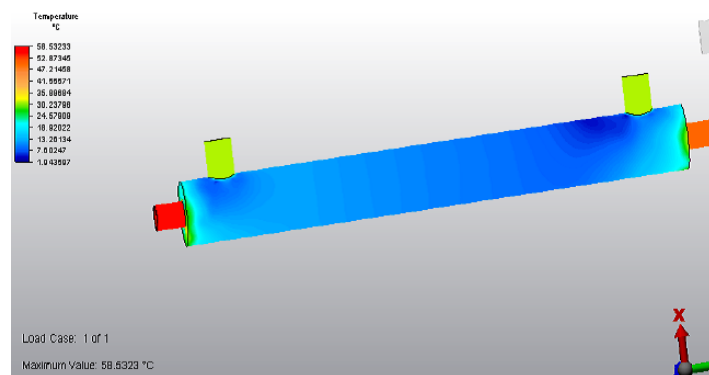


Fig 5.9 Results for Modified Heat Exchanger with Annular Rings.

Temperature at the hot water inlet of the modified heat exchanger with annular disc is 58°C, heat transfer takes place to the cold water as the hot water flows through the pipe and the temperature at the hot water outlet is 47°C. Therefore the fall of hot water temperature through the pipe is 11°C.

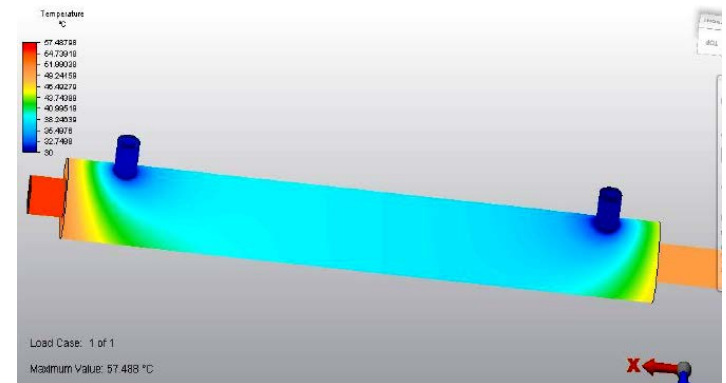


Fig 5.9 Results for Modified Heat Exchanger with twisted insert

Temperature at the hot water inlet of the modified heat exchanger with twisted tape insert is 57°C, heat transfer takes place to the cold water as the hot water flows through the pipe and the temperature at the hot water outlet is 48°C. Therefore the fall of hot water temperature through the pipe is 9°C.

Therefore it is analytically proven that the heat transfer ability of modified heat exchanger with annular disc is highest followed by modified heat exchangers with twisted tape insert, then extended surfaces (fins) and basic heat exchanger.

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7 CONCLUSION

In the present work various heat transfer enhancement techniques are identified for double pipe heat exchangers and the passive heat transfer techniques are selected for their simplicity and ease of testing. Three passive heat transfer enhancement techniques viz. extended surfaces (Fins), annular disc and swirl flow device (Twisted Tape) are tested in this work. Experimental evaluation is done by fabricating basic double pipe heat exchanger and heat exchangers with these specified modifications. Fabrication of these heat exchangers is done as per the ISO standards. Testing was performed for both parallel

flow and counter flow connections at different flow rates. The results show that the three different enhancement techniques worked well, with the annular discs and the extended surfaces (fins) enhancement techniques, respectively, being the highest and the lowest. Experimental results of these modifications are validated using a fluid flow analysis software. For this, 3D models of different variations of heat exchangers are generated using CATIA software. These models are then converted to *.iges format and the analysis were done. The analysis results have validated the experimental results by showing that among the modified heat exchangers, heat exchanger with annular disc modification and the heat exchanger with extended surfaces (fins), respectively, has the highest and lowest heat transfer capability

8 SCOPE OF FUTURE WORK

In the present work only passive heat transfer techniques are used for a double pipe heat exchanger. These techniques can be extended to other type of heat exchangers. Active techniques can also be effective for heat transfer enhancement. These active techniques can be used in combination with the passive techniques for improving the heat transfer ability. Passive techniques can also be used in different combinations for enhancing the heat transfer rate

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