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Design and Analysis of U-Tube Heat Exchanger by Using CFD

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ABSTRACT:

Heat transfer is the most imperative phenomena in numerous industries which prompts design of heat recovery systems and in addition design of sub systems. The devices which are utilized for heat exchange is called as heat exchangers. Heat exchanger is a device used to exchange heat from a fluid on one side of a barrier to a fluid on the opposite side without bringing the fluid into direct contact. Typically, these tubes are produced using metal which has great thermal conductivity keeping in mind the end goal to exchange heat adequately starting with one fluid then onto the next fluid.

The aim of this study is to assess the influence of U tube heat exchanger to get best heat transfer by using U tube heat exchanger. The purpose of this study is to use CFD software and Experimental setup to analyze the Temperature drop, Pressure drop and Friction factors by varying under different Reynolds number such as 4870,8760,11432 and 15130 and changing heat exchanger tube material properties like copper and aluminum.

The experiment is carried out by different rib thicknesses such as 1mm, 2mm, 3mm, 4mm and also by varying cross section such as 1-4mm, 2-5mm, 3-6mm and performed in turbulent flow to get better heat transfer rate.The study of heat transfer coefficient of U tube heat exchanger under various rib thicknesses with different materials, it is predicted that 2mm rib thickness exhibits better heat transfer than the remaining.

Key words: U tube heat exchangers, cfd, catia, Ribs.

1. INTRODUCTION:

1.1 Classification of Heat Exchanger:

The heat exchangers can be classified in a few ways as per the transfer procedure, number of fluids and heat exchange mechanism. Conventional heat exchangers are classified on the premise of construction type and stream arrangement [1]. The other criteria utilized for the classification of heat exchangers are the kind of process functions and fluids included (gas-gas, gas-fluid, fluid, two phase gas etc.).The arrangement as indicated by the surface compactness manages one of the essential class of heat exchangers named as compact heat exchangers. There is a wide assortment of heat exchangers for different sorts of uses, hence the development also would vary broadly. Be that as it may, despite the variety, most heat exchangers can be classified into some basic types in light of some major design concept [2].

1.2 Tubular Heat Exchangers:

Tubular heat exchangers are by and large worked of round, curved and rectangular tubes. Flat twisted tubes have additionally been utilized as a part of a few applications. There is impressive adaptability in design because the core geometry can be varied easily by changing the tube diameter, length, and arrangement. Tubular heat exchangers can be intended for high pressures with respect to condition and high-pressure contrasts between the fluids. Tubular exchangers are utilized principally for liquidto-fluid and fluid to phase change (condensing or evaporating) heat exchange applications [3].

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There are utilized for gas-to fluid and gas-to-gas heat transfer applications fundamentally when the working temperature or pressure is high and fouling is an extreme issue on no less than one fluid side and no different sorts of exchangers work. These tubular exchangers can be named shell-and-tube, double pipe, and spiral tube exchangers. There are all prime surface exchangers aside from exchangers having fins outside/inside tubes [4]. A typical double-pipe heat exchanger consists of one pipe placed concentrically in side another of larger diameter with appropriate fittings to direct the flow from one section to the next, as shown in figure (1.2). Double-pipe heat exchangers can be arranged in various series and parallel arrangements to meet pressure drop and mean temperature difference requirements. The major use of double-pipes exchangers is for sensible heating or cooling of process fluids where small heat transfer areas are required. This configuration is also very suitable [5]. When one or both fluids is at high pressure. The major disadvantage is that double-pipe heat exchangers are bulky and expensive per unit transfer surface. Inner tube being may be single tube or multi-tubes Fig.(1.3). If heat transfer coefficient is poor in annulus, axially finned inner tube (or tubes) can be used. Double-pipe heat exchangers are built in modular concept, i.e., in the form of hair fins.

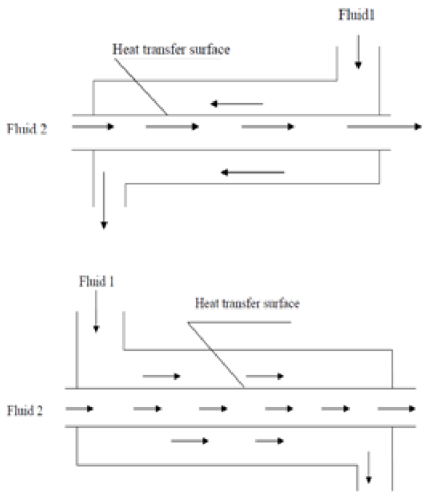

Fig 1.1: Double pipe heat exchanger

1.3 Heat Transfer Considerations:

The energy flow between hot and cold streams, with hot stream in the bigger diameter tube, is as shown in Figure 2.10. Heat transfer mode is by convection on the inside as well as outside of the inner tube and by conduction across the tube. Since the heat transfer occurs across the smaller tube, it is this internal surface which controls the heat transfer process [6]. By convention, it is the outer surface, termed Ao, of this central tube which is referred to in describing heat exchanger area. Applying the principles of thermal resistance

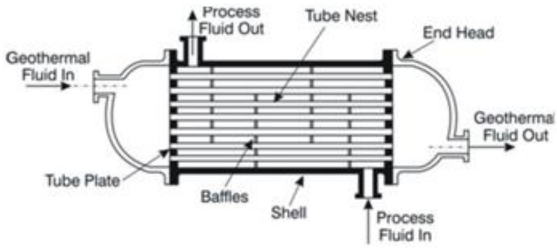

Fig 1.2: Components of Shell and Tube Heat Exchanger

$$R = \frac{1}{h_o A_o} + \frac{\ln\left(r_o / r_i\right)}{2\pi \cdot kl} + \frac{1}{h_i A_i}$$

If we define overall the heat transfer coefficient, Uc, as:

$$U_c = \frac{1}{RA_o}$$

Substituting the value of the thermal resistance R yields:

$$\frac{1}{U_c} = \frac{1}{h_o} + \frac{r_o \ln\left(r_o / r_i\right)}{k} + \frac{A_o}{h_i A_i}$$

Standard convective correlations are available in text books and handbooks for the convective coefficients, *ho* and *hi*. The thermal conductivity, *k*, corresponds to that for the material of the internal tube [8]. To evaluate the thermal resistances, geometrical quantities (areas and radii) are determined from the internal tube dimensions available.

1.4: Temperature Differences between Hot and Cold Process Streams:

From the heat exchanger equations shown earlier, it can be shown that the integrated average temperature difference for either parallel or counter flow may be written as:

$$\Delta\theta = LMTD = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

The effective temperature difference calculated from this equation is known as the log mean temperature difference, frequently abbreviated as LMTD, based on the type of mathematical average that it describes. While the equation applies to either parallel or counter flow, it can be shown that Δθ will always be greater in the counter flow arrangement [7]. Another interesting observation from the above Figure is that counter flow is more appropriate for maximum energy recovery.

2. LITERATURE REVIEW

J.Y.Liu et.al. [1] In their paper they described the study of design of Shell and tube heat exchangers the tube sheets are very heavy. The reason is attributed to the over simplified mechanical model for the calculation of the tube sheet thickness especially the insufficient consideration of the tube support to the tube sheet. In their paper a 3-D finite element model was established for a U-tube heat exchanger consisting of tube sheet, tube channel, part of shell and tubes. A static stress analysis was performed under tube side pressure loading. Optimal computation or light weight design was carried out for minimum thickness of the tube sheet optimization design, the thickness of the tube sheet with the precondition of strength requirements conforming to the design by analysis. It is found that with the optimization design the thickness of the tube sheet could be decreased by 31%, meaning that by using finite element method together with the design by analysis the thickness of the tube sheet can be significantly reduced.

A. F.Elmozughi et.al. [2] In his research paper he described the study of U-tube type of ground coupled heat exchanger, which is used in air-conditioning applications to improve the COP as external heat exchanger. This technique is wildly used in the last decades, and it is attracting the increasing research interest for such application. This study presents the simulation of U-tube heat exchanger. The U-tube ground heat exchanger is modeled, constructed and grid generated using Gambit and Fluent software is used to simulate the model to solve diffusion energy equations at unsteady state. Temperature distributions against different shank space (50, 70 and 90 mm) are plotted at different radial point and vary with time for each mode.

Xiangli Li et.al. [3] In their study they simulated the heat transfer performance of the U-tube heat exchangers with backfill materials of shape-stabilized phase change materials (PCMs) and crushed stone concrete in this paper. The shape-stabilized PCMs refer to a mixture of decanoic acid and lauric acid that the mass concentration of decanoic acid is 60% with10% silica and 6% expanded graphite. It makes the shape-stabilized PCM has the coefficient of thermal conductivity of 1.528 W/(m•K) and the latent heat of 109.2 kJ/kg. After the simulation of the time for 12 hours, the heat exchange for unit borehole depth of backfilling with shape stabilized PCM is 1.23 times of the heat exchange for unit borehole depth of backfilling with crushed stone concrete. And the influence radius of backfill materials of shape-stabilized PCM is 0.9 times of the influence radius of backfill materials of crushed stone concrete. So under same area of buried pipes region the shape-stabilized PCM backfill can get heat exchange is 1.37 times of crushed stone concrete backfill. In addition, the heat conductivity coefficient of PCMs has great influence on heat pump coefficient.

N.R.parthasarathyet.al. [4] In his research paper he described the study of triple tube heat exchanger. The heat exchanger consist of triple tube in various diameter. Triple tubes are located to concentric method with U tube arrangement. Hot fluid enters to one end and leave the cold fluids another end. The coolant fluid flow to middle of the tube. The hot fluid flow to remaining two tube with laminar flow of inside of the tubes. This flow is increase the effectiveness of heat transfer rating with U shape. The experimental setup is calculate the convective heat transfer with conduction on the tube heat transfer and effectiveness of heat exchanger. This arrangement is especially reduce the distance of tube length and to increase heat transfer area and reduce the cooling time with U shape.

Zhen Gao et.al. [5] In their paper they described the study of Combined heat exchanger with the ground-source heat pump engineering in Hefei, a 100-meter-deep vertical u-shaped buried pipe was analyzed, and the experimental study on the heat transfer performance of different operating mode, the unit energy efficiency and the change of soil temperature field was taken under a typical climate condition in the summer of Hefei. The change of soil temperature field around the heat exchanger after running for a long time was simulated and analyzed. The results show that soil temperature increased by 1.2 °C after the system ran for 5 years.

Sonali Gholapet.al. [6] In their research paper they described the study of analysis results wherein Naphtha fluid was maintained at a desired temperature in a stacked u-tube heat exchanger The main objective of work was finite element analysis of pressure vessel at different boundary condition. The stresses developed in pressure vessel were analyzed by using ANSYS.

3. CATIA MODELING

CATIA(Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Assault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Assault Systems product lifecycle management software suite. CATIA competes in the CAD/CAM/CAE market with Siemens NX, Pro/E, Autodesk Inventor, and Solid Edge as well as many others.

Used Catia Tools:
Circle, Rectangular Pattern, Circular Pattern, Pad, Pocket and Plane.

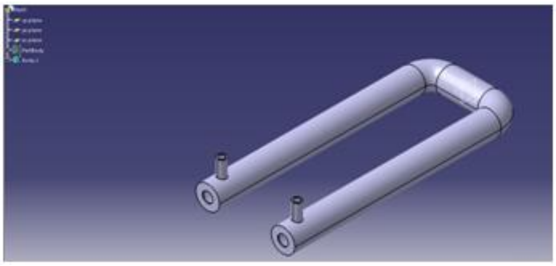

Fig.3.1 Designed Catia model of U Tube

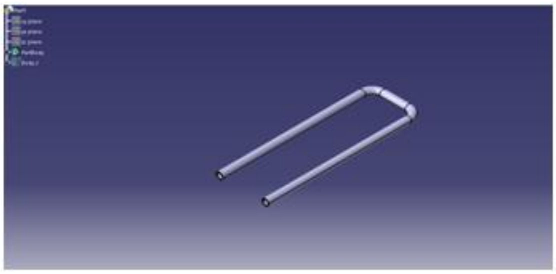

Fig 3.2 Designed Catia model of inner tube

Used Catia Tools:
Plane, Project 3D Elements, Pad, Pocket and Rectangular Pattern.

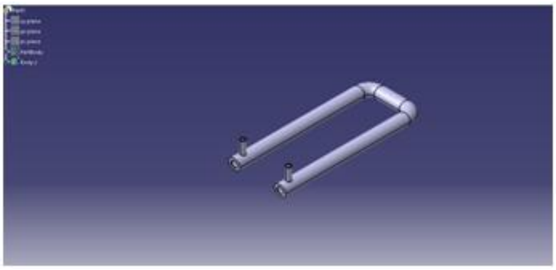

Fig 3.3 Designed Catia model of U tube without rib

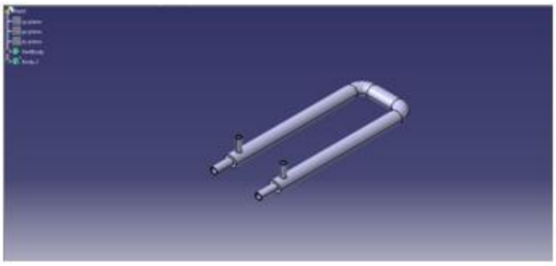

Fig 3.4 Designed Catia model of U tube with rib

1) Rib Thickness

Dimensions:

Rib thickness = 1mm,2mm,3mm,4mm.

Used Catia Tools:

Helix, Point, Line, Rectangle and Pad.

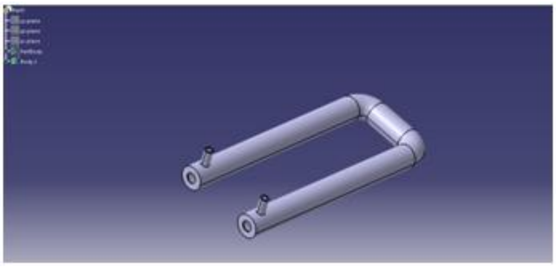

Fig 3.5 Designed Catia model with 1mm rib

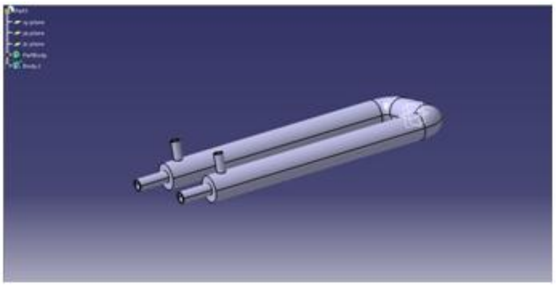

Fig 3.6 Designed Catia model with 2mm rib

3.2 DESIGNED CATIA MODEL:

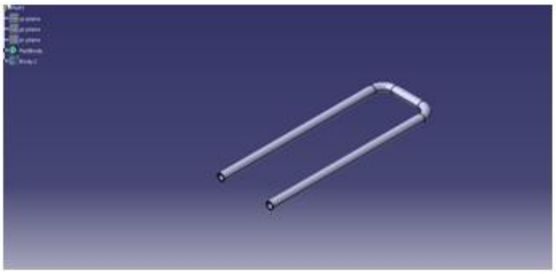

Fig 3.7 Designed Catia model with 1-4 convergent

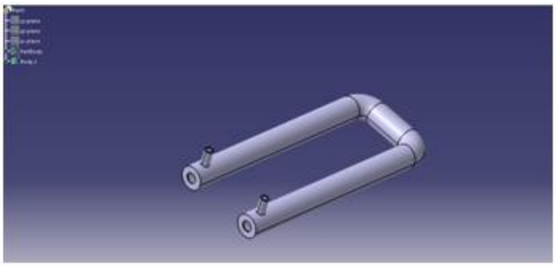

Fig.3.8 Designed Catia model with 2-5 convergent

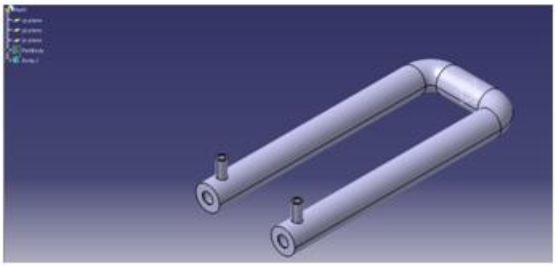

Fig 3.9 Designed Catia model with 3-6 convergent

PROBLEM DESCRIPTION:

Here we had calculated the effectiveness of heat exchanger by varying the velocities of fluids by considering the same mass flow rates. The experimental analysis is carried out by taking the combination of different fluids. The experimental is done on U-tube heat exchanger. Two reservoirs or tanks were constructed for storage of two fluids (i.e.., hot and cold fluids) The analysis is done for laminar flow of both fluids [10]. The laminar flow is obtained by keeping constant mass flow rate. Constant mass flow rate is obtained by operating the valves of tank (Opening and Closing of valves) whether the flow is laminar or turbulent is known by calculating Reynolds number. Reynolds number (R_e) is a dimensional less number. For the analysis of heat exchanger of following combinations of fluids had been used

Kerosene (hot fluid) – water (cold fluid)

Transformer oil (hot fluid) – water (cold fluid)

Diesel (hot fluid) – water (cold fluid)

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Fig.4 U Tube Heat Exchanger

4. CFD ANALYSIS:

Computational fluid dynamics (CFD) study of the system starts with the construction.

4.1 GEOMETRY:

Heat exchanger is built in the ANSYS workbench design module. It is a counter-flow heat exchanger. First, the fluid flow (fluent) module from the workbench is selected. The design modeler opens as a new window as the geometry is double clicked.

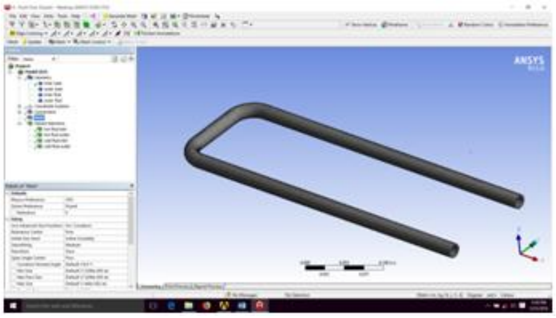

Fig. 4.1 Imported model in geometry

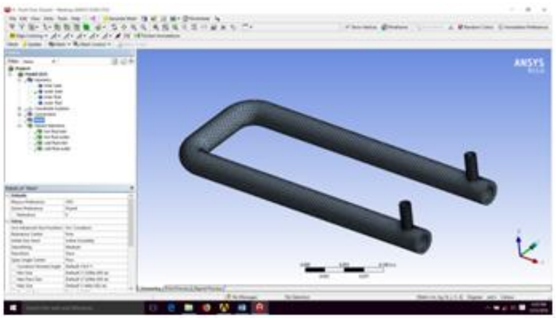

Fig. 4.2 Meshed model of Outer tube

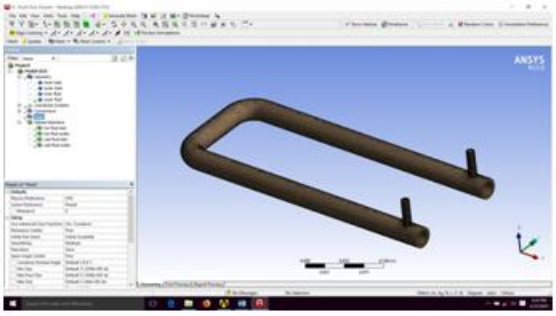

Fig. 4.3 Fine Meshed model of Outer tube

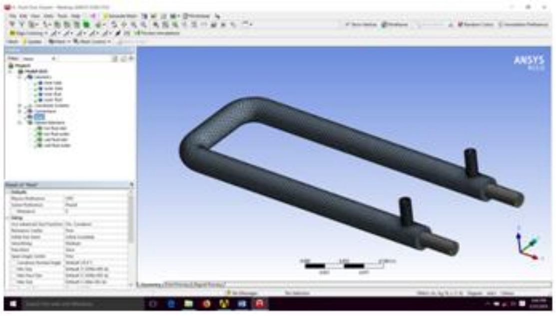

Fig. 4.4 Fine Meshed model of U tube

PART NUMBER	PART OF THE MODEL	STATE TYPE
1.	INNER FLUID	FLUID
2.	OUTER FLUID	FLUID
3.	INNER TUBE	SOLID
4.	OUTER TUBE	SOLID

Table.4.1 geometry type and model

4.1.1 The Main Solver

The solver is the heart of CFD software. It sets up the equation set according to the options chosen by the user and meshes points generated by the pre-processor, and solves them to compute the flow field. The process involves the following tasks:

- selecting appropriate physical model,
- defining material properties,
- prescribing boundary conditions,
- providing initial solutions,
- setting up solver controls,
- set up convergence criteria,
- solving equation set, and
- saving results

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Once the model is completely set up, the solution starts and intermediate results can be monitored in real time from iteration to iteration. The progress of the solution process is displayed on the screen in terms of the residuals, a measure of the extent to which the governing equations are not satisfied.

4.2 MESHING:

Initially a relativelycoarser mesh is generated. This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries. Care is taken to use structured hexahedral cells as much as possible. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a well manner, particularly near the wall region. Later on, a fine mesh is generated. For this fine mesh, the edges and regions of high temperature and pressure gradients are finely meshed. Save project again at this point and close the window. Refresh and update project on the workbench. Now open the setup. The ANSYS Fluent Launcher will open in a window. Set dimension as 3D, option as Double Precision, processing as Serial type and hit OK. The Fluent window will open.

4.3 SETUP:

The mesh is checked and quality is obtained.

4.3.1 MATERIALS:

The create/edit option is clicked to add water-liquid, steel and copper to the list of fluid and solid respectively from the fluent database.

4.3.2 CELL ZONE CONDITIONS:

In cell zone conditions, we have to assign the conditions of the liquid and solid.

Table 4.2 cell zone conditions

Different material properties	Density (ρ) kg/m^3	Thermal conductivity(K) W/mk	Specific heat C_P j/kgK
Copper	8978	387.6	381
Aluminium	2719	203.2	871

4.3.3 BOUNDARY CONDITIONS:

Boundary conditions are used according to the need of the model. The inlet and outlet conditions are defined as velocity inlet and pressure outlet. As this is a counter-flow with two tubes so there are two inlets and two outlets. The walls are separately specified with respective boundary conditions. No slip condition is considered for each wall. Except the tube walls each wall is set to zero heat flux condition. The details about all boundary conditions can be seen in the table as given below.

Table 4.3 boundary conditions

	BOUNDARY CONDITION TYPE	MASS FLOW RATE (kg/s)	TEMPERATURE (k)
INNER INLET	Mass flow inlet	0.444	298
INNER OUTLET	Pressure outlet	-	-
OUTER INLET	Mass flow inlet	1.7377	348
OUTER OUTLET	Pressure outlet	-	-

4.4 SOLUTION:

RUN CALCULATION:

After giving the boundary conditions to the inner and outer fluid, finally we have to run thecalculations. The number of iteration is set to 500 and the solution is calculated and various contours, vectors and plots are obtained.

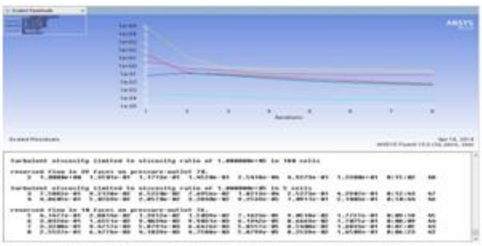

Fig 4.5 Calculations was running

4.5The Post-processor:

The post-processor is the last part of CFD software. It helps the user to examine the results and extract useful data.

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The results may be displayed as vector plots of velocities, contour plots of scalar variables such as pressure and temperature, streamlines and animation in case of unsteady simulation. Global parameters like drag coefficient, lift coefficient, Nusselt number and friction factor etc. may be computed through appropriate formulas. These data from a CFD post-processor can also be exported to visualization software for better display. Several general-purpose CFD packages have been published in the past decade. Prominent among them are:PHOENICS,FLUENT, STAR-CD,CFX, CFD-ACE,ANSWER, CFD++, FLOW-3D and COMPACT. Most of them are based on the finite volume method. CFD packages have also been developed for special applications; FLOTHERM and ICEPAK for electronics cooling, CFX-TASCFLOW and FINE/TURBO for turbo machinery and ORCA for mixing process analysis are some examples. Most CFD software packages contain their own grid generators and post processors. Software such as ICEM CFD, Some popular visualization software used with CFD packages are TECPLOT and FIELDVIEW.

4.6 OVERVIEW OF FLUENT PACKAGE:

FLUENT is a state-of-the-art computer program for modeling fluid flow and heat transfer in complex geometries. FLUENT provides complete mesh flexibility, solving your flow problems with unstructured meshes that can be generated about complex geometries with relative ease. Supported mesh types include 2D triangular/quadrilateral, 3D FLUENT also allows user to refine or coarsen grid based on the flow solution. FLUENT is written in the C computer language and makes full use of the flexibility and power offered by the language. Consequently, true dynamic memory allocation, efficient data structures, and flexible solver control are all made possible. In addition, FLUENT uses a client/server architecture, which allows it to run as separate simultaneous processes on client desktop workstations and powerful computer servers, for efficient execution, interactive control, and complete flexibility of machine or operating system type. All functions required to compute a solution and display the results are accessible in FLUENT through an interactive, menu-driven interface. The user interface is written in a language called Scheme, a dialect of LISP. The advanced user can customize and enhance the interface by writing menu macros and functions.

5. RESULTS AND DISCUSSIONS:

The objective of this project is to predict that at which condition the maximum heat transfer rate is obtaining in U tube Heat Exchanger by introducing water and by changing parameters like inlet flow conditions, flow arrangements i.e. counter flow & parallel flow which are further divided into laminar flow & turbulent flow by maintaining constant temperature at inner inlet and outer inlet. Different materials like copper & aluminium were used by introduced. The thickness of ribs are changed as 1mm,2mm,3mm,4mm. Simultaneously the inner rib thickness was also changed as 1-4mm and 2-5mm and 3-6mm thicknesses forming a convergent inside the tube. Material properties were derived from tables based on the temperature which was being calculated in the model. The material was defined in FLUENT using its material browser. For the different flow arrangement problem model certain properties were defined by the user prior to computing the model, these properties were: thermal conductivity, density, heat capacity at constant pressure, ratio of specific heats, and dynamic viscosity.

5.1 REPORTS:

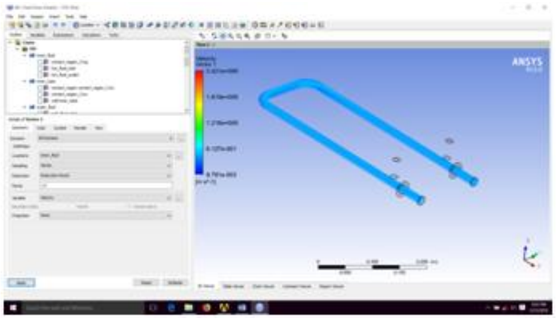

Fig 5.1 Velocity variation in Hot fluid at 1mm

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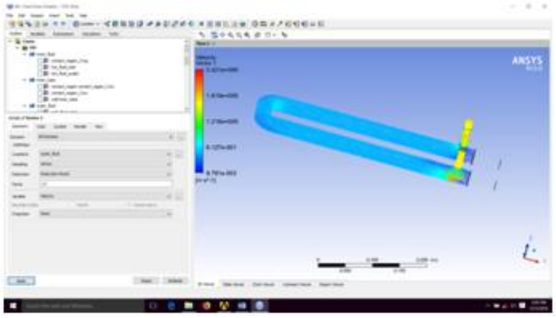

Fig 5.2 Velocity variation in Cold fluid 1mm

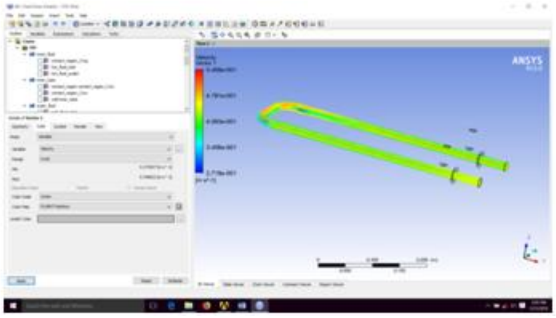

Fig 5.3 Velocity variation in hot fluid at 2mm

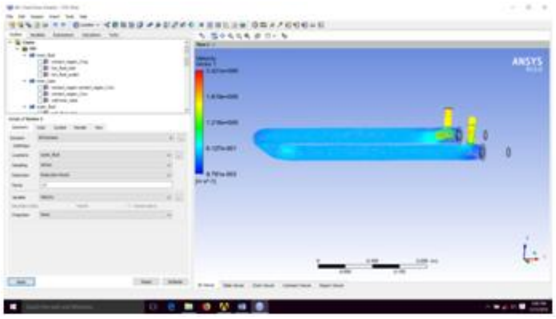

Fig 5.4 Velocity variation in cold fluid at 2 mm

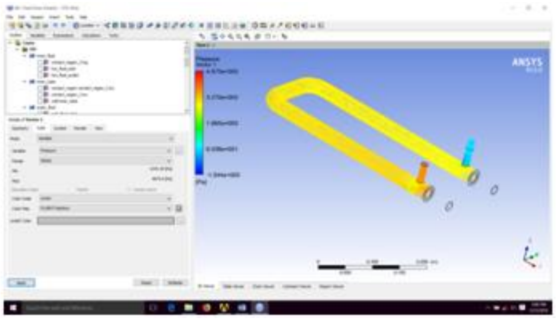

Fig 5.5 Pressure variation in cold fluid at 2 mm

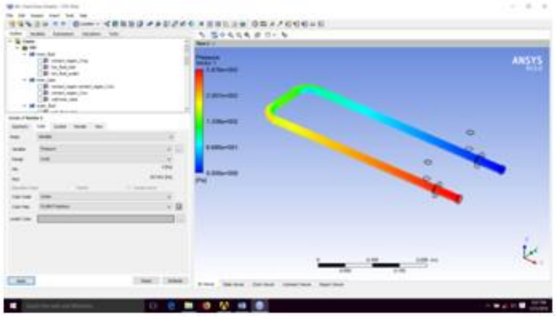

Fig 5.6 Pressure variation in hot fluid at 2 mm

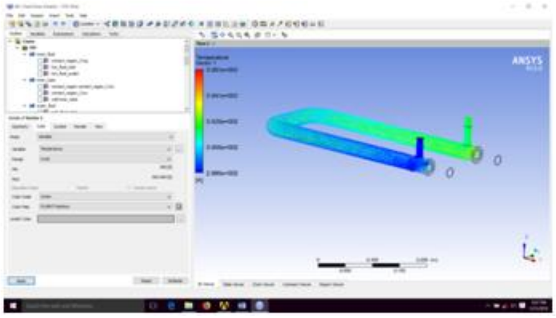

Fig 5.7 Temperature variation in cold fluid at 3 mm

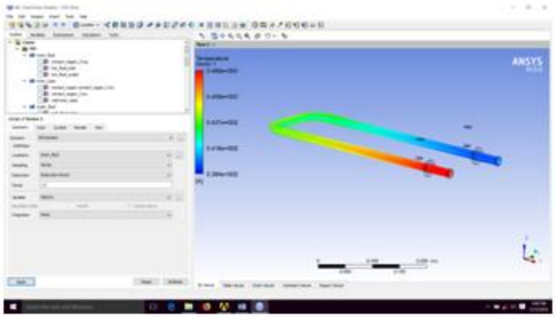

Fig 5.8 Temperature variation in hot fluid at 3 mm

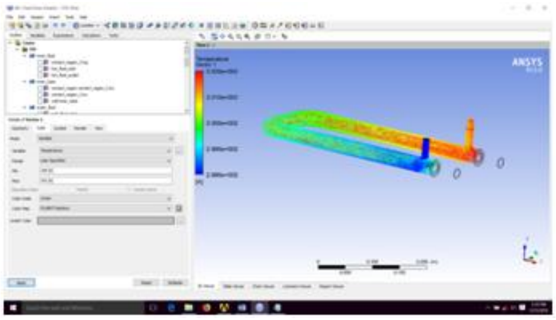

Fig 5.9 Temperature variation in cold fluid at 4 mm

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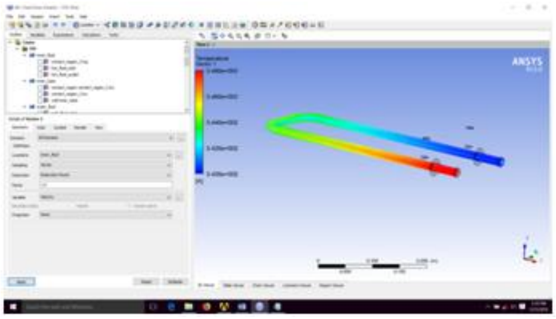

Fig 5.10 Temperature variation in cold fluid at 4 mm

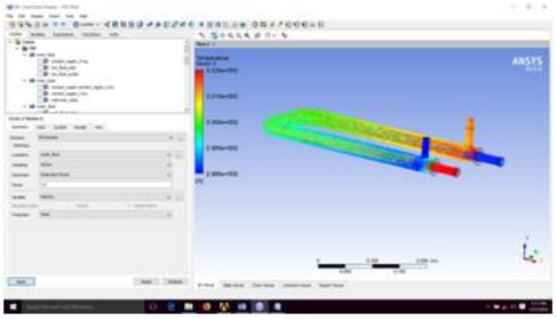

Fig 5.11 Temperature variation in heat exchanger at 4 mm

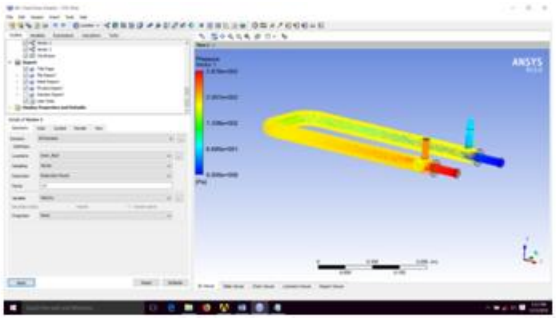

Fig 5.12 Pressure variation in heat exchanger at 4 mm

By comparing the above results we got best results in 2mm rib thickness and further the simulation was carried out to the convergent thicknesses and varying cross section.

5.2 Rib with varying cross section:

In this case normal ribs are replaced by different varying thicknesses. The thermal analysis results and flow patterns are shown below.

Due to decrement shape of the ribs it reduces the dead zones in between inner tube and outer tube.

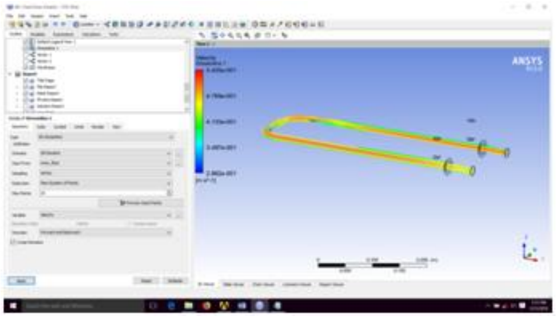

Fig 5.13 Velocity variation in hot fluid at 1- 4 mm

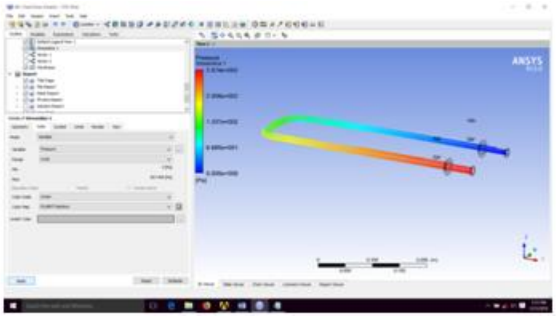

Fig 5.14 Pressure variation in hot fluid at 1- 4 mm

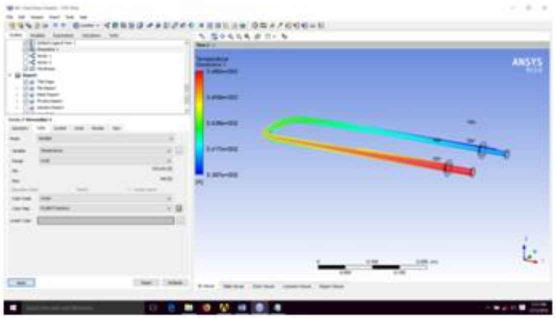

Fig 5.15 Temperature variation in hot fluid at 1- 4 mm

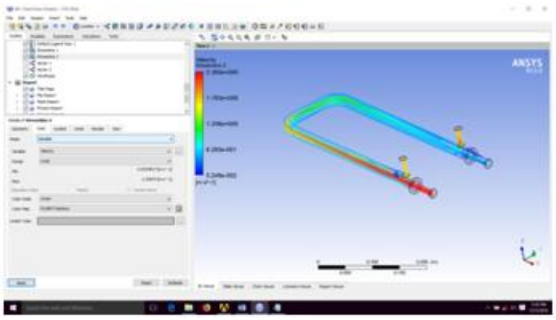

Fig 5.16 Velocity variation in heat exchanger at 1- 4 mm

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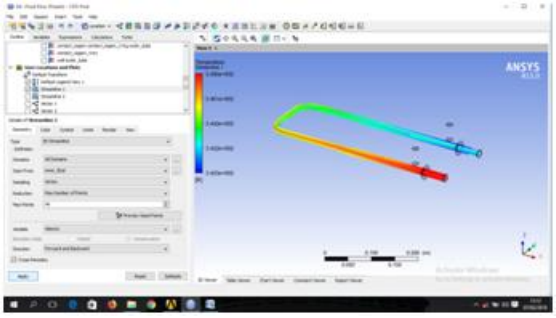

Fig 5.17 Temperature variation in hot fluid at 1-4mm

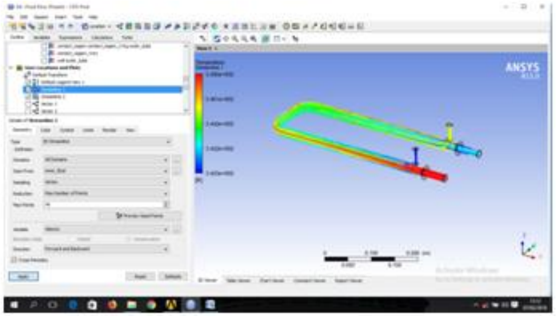

Fig 5.18 Temperature variation in heat exchanger at 2- 5mm

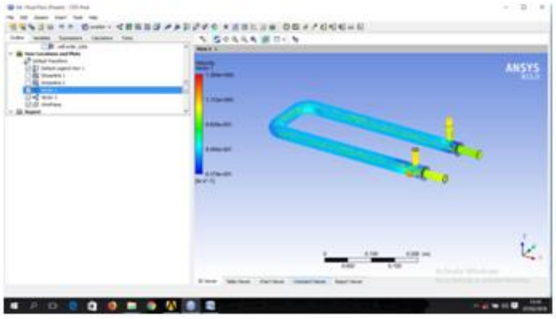

Fig 5.19 Velocity variation in hot fluid at 2- 5mm

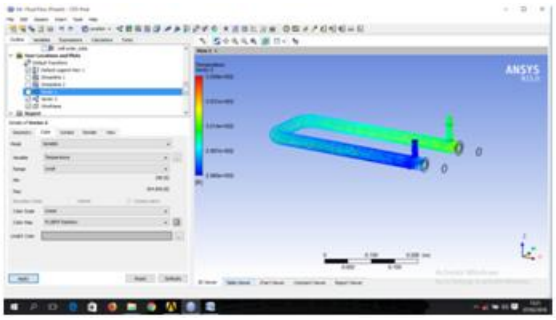

Fig 5.20 Temperature variation in cold fluid at 2-5mm

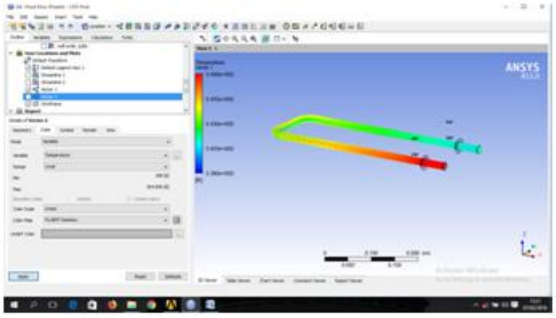

Fig 5.21 Temperature variation in hot fluid at 2-5mm

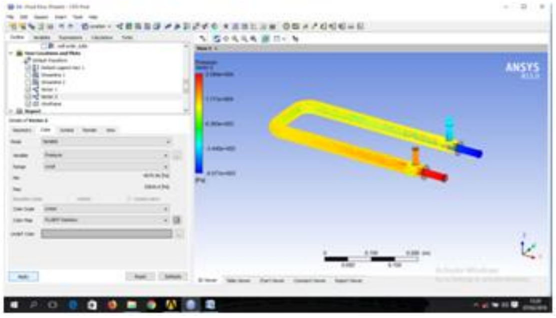

Fig 5.22 Pressure variation in heat exchanger at 2-5mm

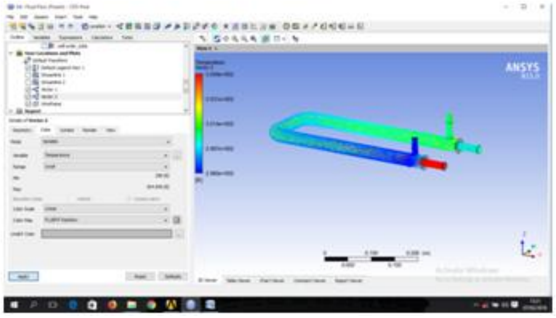

Fig 5.23 Temperature variation in heat exchanger at 3- 6mm

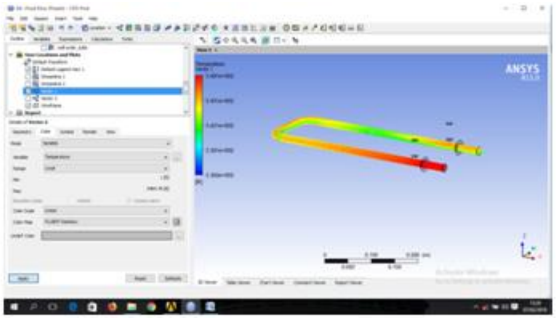

Fig 5.24 Temperature variation in hot fluid at 3-6mm

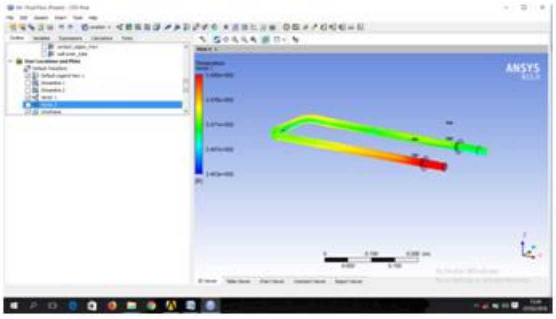

Fig 5.25 Temperature variation in hot fluid at 3-6mm

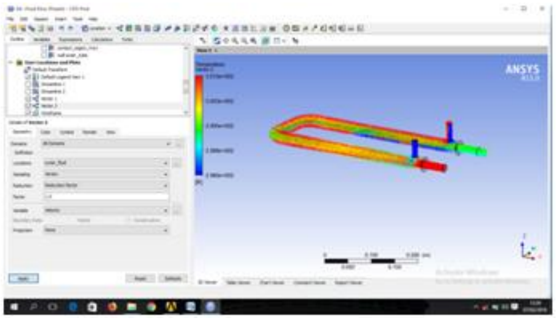

Fig.5.26 Temperature variation in heat exchanger at 3- 6mm

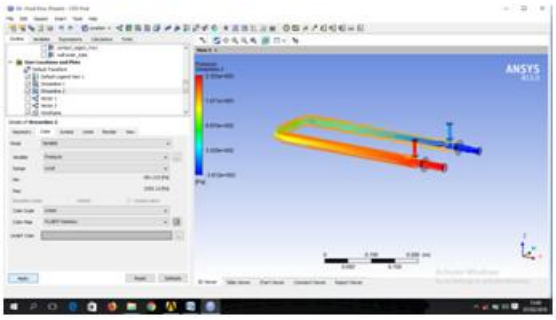

Fig.5.27 Pressure variation in heat exchanger at 3-6mm

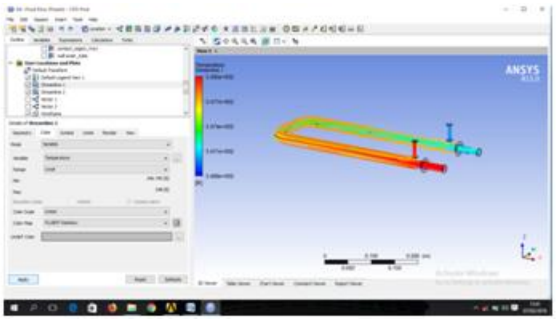

Fig.5.28 Temperature variation in heat exchanger at 3- 6mm

6. CONCLUSION:

At first, the main objective of this project is to create a validation between Experimental & CFD results which was performed using different organic solutions like Kerosene, Water and Transformer oil to check the percentage error, in order to affirm the experimental setup. As the percentage of error is within 4% the experimental setup is validated. We have done experimental analysis on U-tube heat exchanger by varying different fluid combinations at constant inlet condition like mass flow rates for Turbulent flow. Following are the required results obtained from the experimental investigation. Hence from the above results we have concluded that Kerosene (Hot) - Water (Cold) combination have been proven as the best combination, which gives maximum effectiveness i.e. 35.6%. The experiment is carried out by different rib thicknesses such as 1mm, 2mm, 3mm, 4mm and also by varying cross section such as 1-4mm, 2-5mm, 3-6mm and performed in turbulent flow to get better heat transfer rate. The study of heat transfer coefficient of U tube heat exchanger under various rib thicknesses with different materials, it is predicted that 2mm rib thickness exhibits better heat transfer than the remaining.

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