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Experimental & CFD Analysis of Heat Exchangers Using Different Orifice Baffles Design

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***Abstract* –A shell and tube type heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. There is no precise criterion to determine baffle spacing in the Heat Exchanger Design Handbook (HEDH). Most of the work in past few decades has been centered on the shell and tube heat exchanger with segmental or helical baffles, very few work is performed on the design parameters of the orifice type baffles. To consider suitable baffle spacing and other baffle design parameters in the design process, this study intends to perform design and CFD analysis which will enables to determine the optimum baffle spacing, orifice sizes , opening shapes for orifice type baffled shell and tube heat exchanger to maximize the heat transfer rate between hot and cold fluid. Multiple iterations of CFD analysis will be performed using ANSYS FLUENT.**

Keywords:- Computational Fluid Dynamics(CFD), Orifice type baffle, Parametric Optimization , Shell and Tube type heat exchanger (STHE).

I. INTRODUCTION

A STHE is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid matter and a fluid, at different temperatures and in thermal contact. In heat exchangers, generally there are no external heat and work interactions. Typical applications involve heating or cooling of a fluid flow of concern and evaporation or condensation of single- or multi component fluid streams. In some cases, the aim may be to dissipation of heat or retrieve, pasteurize, sterilize, fractionate, distill, crystallize, concentrate, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact.

In STHE, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type. In shell and tube heat exchangers usually have fluid leakage from one fluid to the other, due to pressure differences and matrix rotation/valve switching. General examples of heat exchangers are STHE, condensers, evaporators used in HVAC system, air pre-heaters and cooling towers automobile radiators. If no phase change occurs in any of the fluids in the heat exchanger, it is sometimes referred to as a sensible heat exchanger. In some application there could be internal heat sources in the exchangers, such as in electric heaters and nuclear fuel reactors. Chemical reaction and combustion may take place within the exchanger, such as in boilers, fired heaters, and fluidized-bed exchangers. Mechanical devices may be used in some exchangers such as in scraped surface exchangers who are commonly used in food industry, agitated vessels, and stirred tank reactors. Heat transfer in recuperator generally takes place by conduction through separating wall. However, in a heat pipe, the heat pipe not only acts as a separating media for fluid stream, but also facilitates the transfer of heat by conduction, condensation and evaporation of the working fluid inside the heat pipe. In general, if the fluids are immiscible, the separating wall may be eliminated, and the interface between the fluids replaces a heat transfer surface, as in a direct-contact heat exchanger.

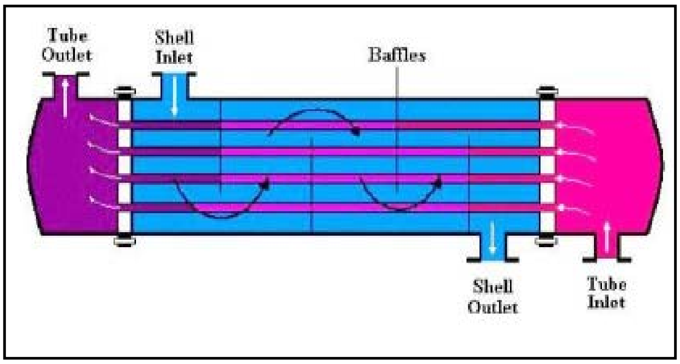

Fig. 1 Shell & tube type heat exchanger [3]

II. PROBLEM STATEMENT AND OBJECTIVE

Many researchers have worked on the parametric optimization and analytical solutions for the design of optimum helical baffle and segmental baffle in the heat exchanger, while there is hardly some research works related to orifice type heat exchanger. In this study we focus on designing a orifice type heat exchanger with detailed parametric study using Computational Fluid Dynamics and manufacturing testing of the optimized orifice type heat exchanger is done to compare results with the CFD output. Objectives of the paper as follows:-

1. Design orifice type heat exchanger for the common heat exchanger application of small capacity and identify the parameters to be optimized.
2. Optimize the designed orifice type heat exchanger using simulation and prove the results obtained by simulation using actual prototype manufacturing and validation.

III. LITERATURE REVIEW

"Flow analysis of shell side on the effect of baffle spacing of shell and tube heat exchanger" presented by Su Pon Chit, Nyein Aye San and Myat Myat Soe. In this paper, the flow analysis in shell side on the effect of baffle spacing of shell and tube heat exchanger has been carried out using both theoretical and numerical methods. The researched is focused on shell and tube heat exchanger for oil cooler of Locomotive. The pressure drop at shell side for acceptable limits is 0.3 bar for shell and tube heat exchanger of oil cooler of Locomotive. In the theoretical method, authors consider the effect of different geometric parameters and thermal energy exchange in shell side flow. Theoretical value is calculated for eight baffle spacing's are namely 0.2 to 0.9 of inside diameter of shell. Then, suitable baffle spacing found 0.5 of inside diameter of shell as it is less than allowable pressure drop. The design is acceptable because the pressure drop for shell side 0.289 bar which is lower than the limited pressure drop,0.3 bar. The analysis of is carried out using COMSOL Multi physics with suitable baffle spacing. The pressure values from the simulations results compared with theoretical. [1]

"Analysis of Segmental and Helical Baffle in Shell and tube Heat Exchanger" presented by P.S..Gowthaman and S.Sathish. In this study the analyses of two different baffle in a Shell and Tube Heat Exchanger was carried out by using Ansys fluent. Baffle is an shell side Component of shell and tube heat exchanger which support tubes and divert flow. The segmental baffle divert the liquid flow in a Zigzag manner and improving heat transfer rate and a high pressure drop and increase the fouling resistance and Helical Baffle have a Effective Performance of increasing heat transfer rate. The desirable features of heat exchanger obtain a maximum heat transfer Coefficient with a lower pressure drop. From the Numerical Experimentation result the performance of heat exchanger is increased in helical baffle instead of segmental baffle. In this study authors design a model to evaluate results of a helical and segmental baffle heat exchanger as well as the comparative analysis between the thermal parameters between the segmental and helical angle has been showed. Authors also conduct numerical experimentation and results of it confirmed that the performance of a tubular heat exchanger can be improved using helical baffles instead of segmental baffles. Helical baffles in heat exchanger reduces shell side pressure drop which reduce manufacturing cost in terms of pumping cost, weight, fouling etc as compare to segmental baffle for a new installation.[2]

"Helical baffle design in shell and tube type heat exchanger with CFD analysis", published by Dipankar De ,Tarun K. Pal and Shantanu B. yopadhyay. The aim of this study was focus on to design of shell and tube type heat exchanger with helical baffle and comparing with straight baffle with CFD analysis tool using Ansys fluent. Authors developed a model contains 7 Copper tubes each having 20 mm external diameter and thickness of 1.5mm, length 600 mm and shell with outer diameter 110mm and thickness of 5mm. 7 tubes are hold by 6 straight or helical baffle made up of aluminium material and the helix angle of baffle is varying from 0º to 30º. All the models are design by using CATIA software tools. In this paper pressure drop and variation in overall heat transfer coefficient due to different helix angle has been studied when the flow rate is constant. The fluid flow pattern in the shell side of the heat exchanger with continuous helical baffles are tends to be rotational and helical due to the geometry of the continuous helical baffles, which results in a increase in heat transfer coefficient per unit pressure drop in the heat exchanger. In shell side the pressure drops are lower than the conventional straight baffle heat exchanger. The pressure drop is decreases with the increases of helix angle in all the cases considered. However, the effects of helix angles on pressure drop are small when helix angle greater than 12 degrees. [3]

IV. DESIGN OF HEAT EXCHANGER

Shell and tube heat exchangers consist of a number of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs around the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned etc. There are several thermal design parameters that are to be taken into account while designing the shell and tube heat exchangers such as tube diameter, tube thickness, length and pitch. So, as per Kern method and TEMA guidelines, orifice baffle shell and tube heat exchanger is designed.

Tube side	Shell side
Flow rate= 180 Kg/hr	Flow rate= 360 Kg/hr
Temperature= 338 K to 313 K	Temperature= 283 K to 295.5 K
Passes= 2	Passes= 1
OD=20x10^{-3}m, BWG=14	Shell Diameter= 0.095 m
Triangular pitch, = 0.030m	Baffle thickness = 3mm
Material used= Copper	Material used= Plain C steel
No. tubes = 7	No of baffles= 3
Tube sheet thickness=0.002 m	Shell thickness=0.003 m
Length of tube =0.6 m	Baffle pitch = 117 mm
Tube central distance (mm) = 30	Baffle cut = 36%

Table No. 1 Design of Heat Exchanger.

V. CFD ANALYSIS

Heat exchanger is generally provided with different types of baffles to support the tube against buckling and vibrations as well as to work as a flow guide who helps flow effectively develop in to the required turbulent flow and increase the efficiency of the heat exchanger.

This study is focused on finding out the best suited shape orifice type baffle for the given application of cooling heat exchanger. CATIA V5 is used to model the heat exchanger for the application of cooling of experimental set up hot liquid water of 65 degrees coming out of gas geyser at the flow rate of 0.05 kg/s. Cold water at 10 degrees maintained by cooling system is flown at the rate of 0.2 kg/sec. Results for different iterations are shown in the below.

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Baseline iteration is performed on the shell and tube type heat exchanger with copper tubes and Steel structure for rest of the body of heat exchanger. This baseline model is created without addition of any baffle in the structure. Below are the procedure plots and results plots for the analysis performed.

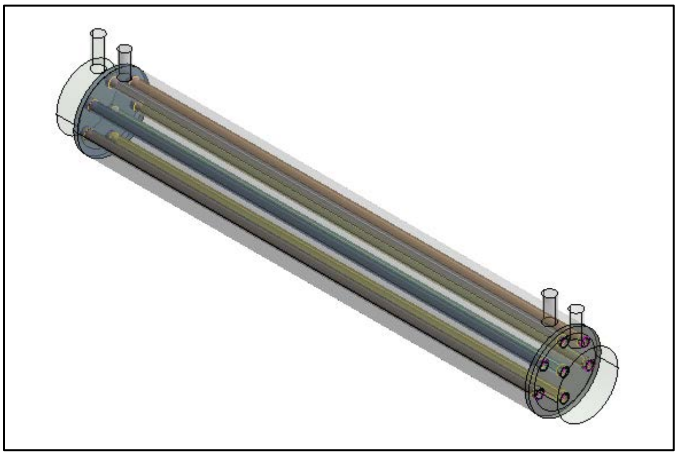

Fig. 2 Shell & Tube Type Heat Exchanger without baffles

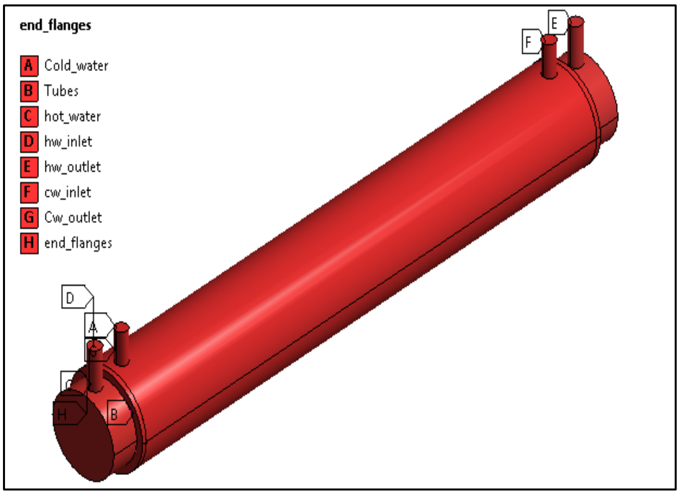

Fig. 3 Nomenclature of heat exchanger

Boundary condition plots are given as follows. Hot fluid at 65 degrees and 0.05 kg/s provided through the inlet 1 which is to flow through the copper tubes and from one head to the other head of the heat exchanger as shown in the figure below. Opposite end of the model provided with the 0.2 kg/sec 10 degrees cold water to simulate the cross flow heat exchanger condition. Cross flow was applied as it is commonly known for better performance when compared with parallel flow heat exchanger condition. Boundary condition for all iteration remains same.

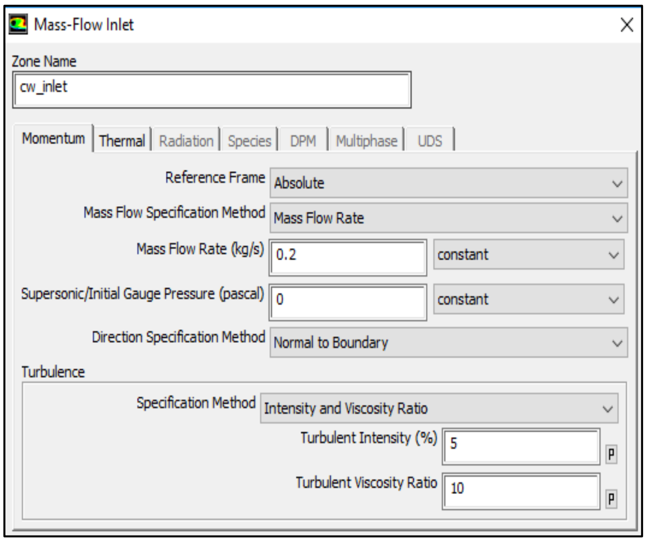

Fig. 4 Cold Inlet boundary conditions baseline

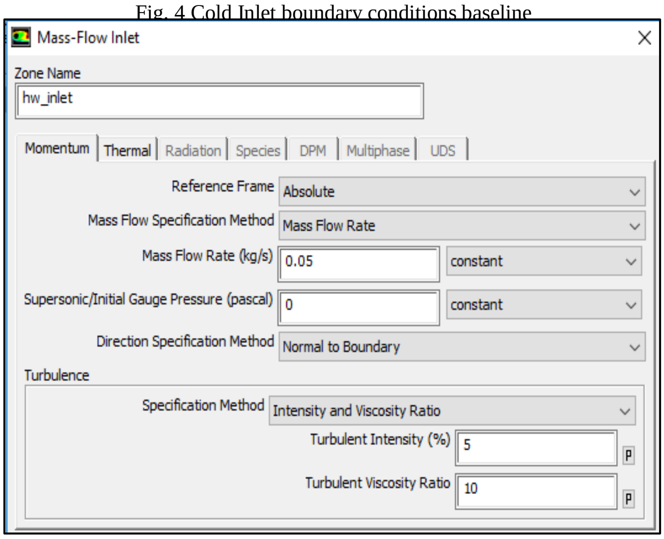

Fig. 5 Hot Inlet boundary conditions baseline

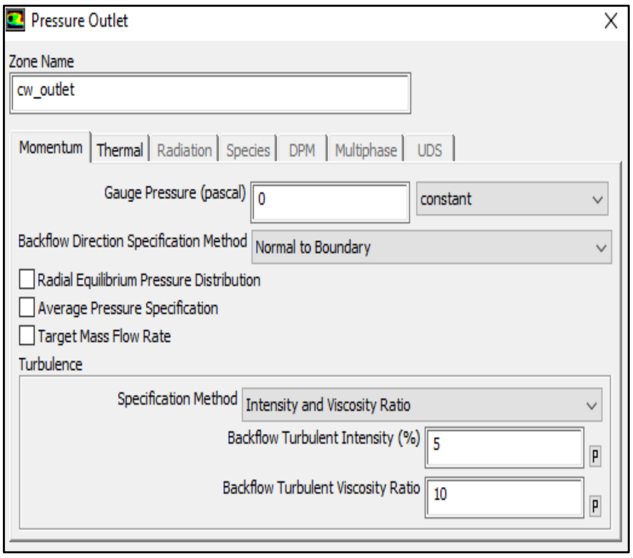

Fig. 6 Outlet boundary conditions baseline

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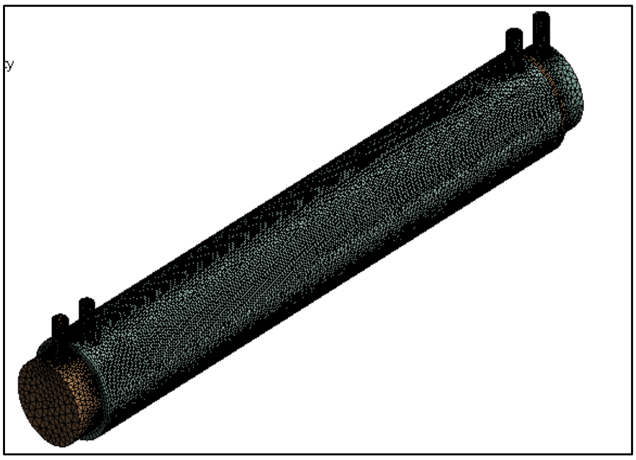

Fig. 7 Meshing of the component with different refinement baseline

For meshing higher order elements are used for higher accuracy with mid-side nodes. Tetrahedron element shape is used for ease of meshing the geometry. Total of 608043 Nodes and 1824038 elements are used to mesh the geometry of the baseline iteration. 1 mm mesh size is chosen by the mesh convergence study conducted.

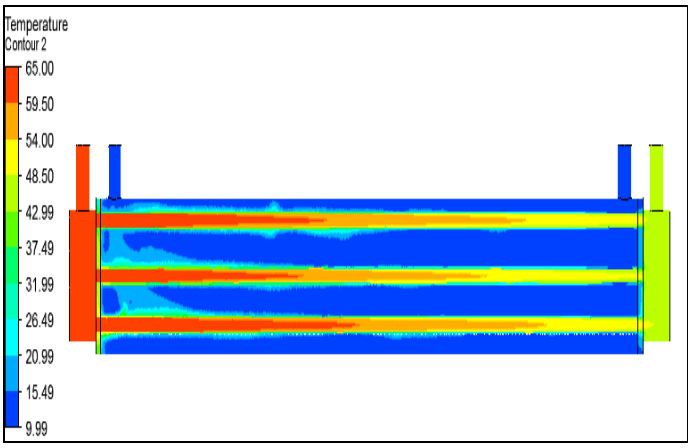

Fig. 8 Temperature distribution plot of without baffles iteration

Fig. 8 shows temperature distribution of without baffle model having hot water inlet temperature 65°C and outlet temperature 46.85°C.So, drop observed is 18.15°C. Maximum velocity observed in the Fig. 9 is 1.78 m/s.

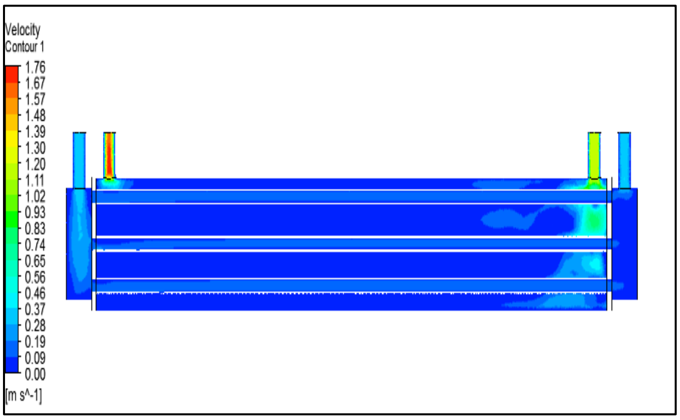

Fig. 9 Velocity contour plot of without baffles iteration

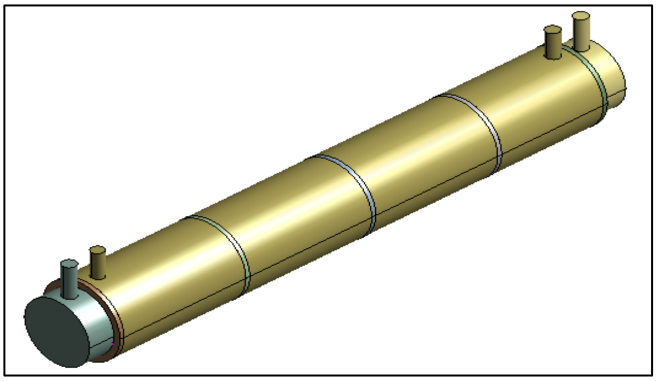

Fig. 10 Heat Exchanger with circular orifice type baffles model created in CATIA V5 baseline.

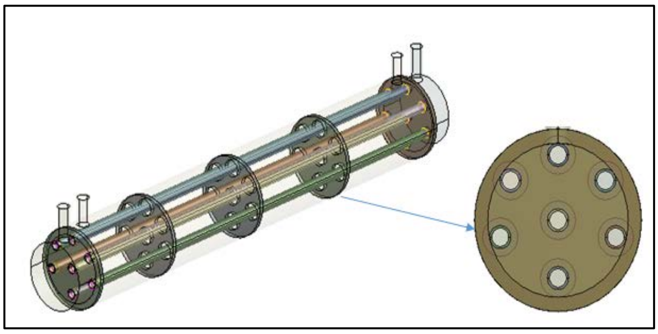

Fig. 11 Heat Exchanger with circular orifice baffles model created in CATIA V5 baseline.

Solution was run for the given boundary conditions and certain parameters below are the observations from the run.

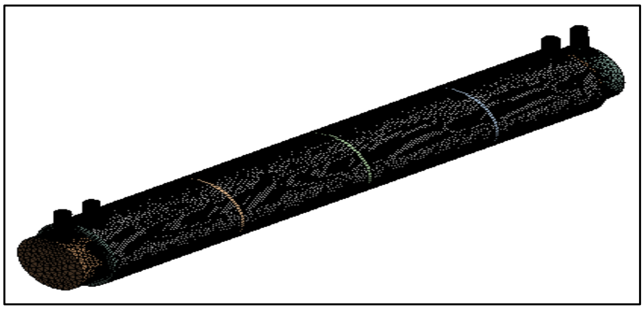

Fig. 12 Meshing of circular baffle iteration

For meshing higher order elements are used for higher accuracy with mid-side nodes. Tetrahedron element shape is used for ease of meshing the geometry. Total of 610045 Nodes and 1804367 elements are used to mesh the geometry of the baseline iteration. 1 mm mesh size is chosen by the mesh convergence study conducted.

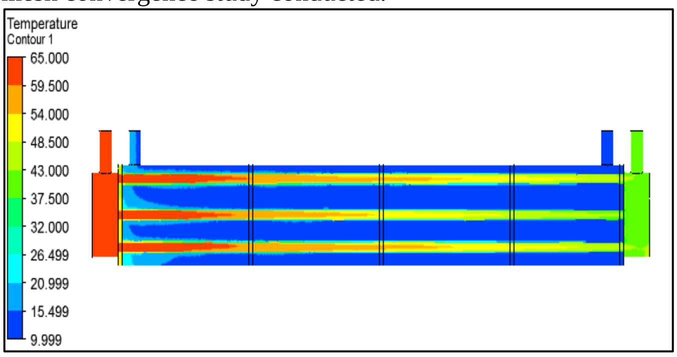

Fig. 13 Temperature distribution plot of circular baffles iteration

Fig. 13 shows temperature distribution of circular orifice baffle having hot water inlet temperature 65°C and outlet temperature 40.85°C .So, drop observed is 24.15°C.

Fig. 14 Pressure plot of circular orifice baffle

Fig. 14 shows that pressure has dropped from 1.3MPa to Atmospheric pressure from cold water inlet to outlet. Every time flow passes through the constriction it causes high velocity zone which increases the heat transfer between cold and hot water zones.

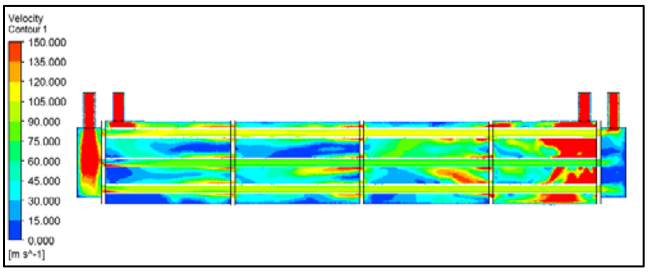

Fig. 15 Velocity plot at circular baffle heat exchanger with hot spots highlighted

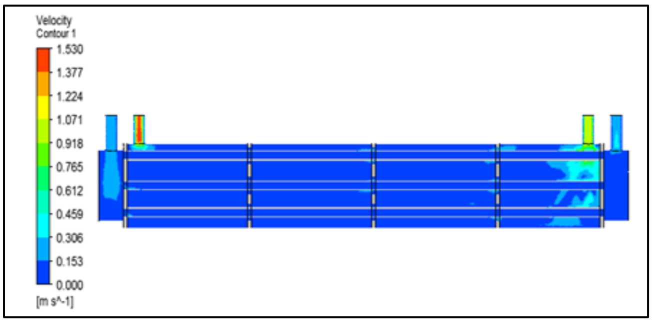

Fig. 16 Velocity contour plot of circular orifice baffles iteration

Fig. 16 shows the velocity plot for circular baffles having maximum velocity observed at the outlet of cold water.

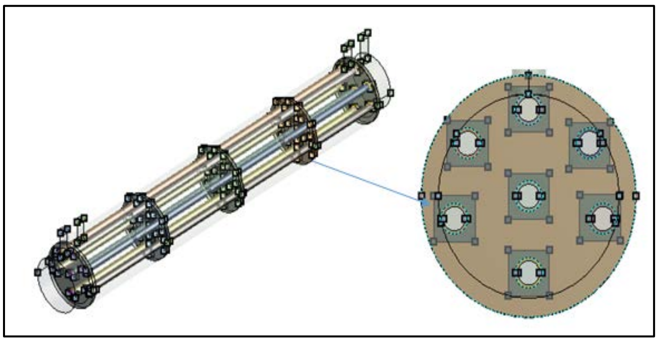

Fig. 17 Heat Exchanger with Square orifice baffles model created in CATIA V5.

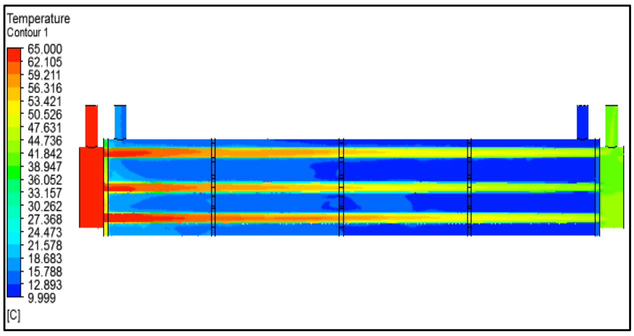

Fig. 18 Temperature distribution plot of square orifice baffle iteration

Fig. 18 shows temperature distribution of square orifice baffle having hot water inlet temperature 65°C and outlet temperature 41.45°C .So, drop observed is 23.55°C.

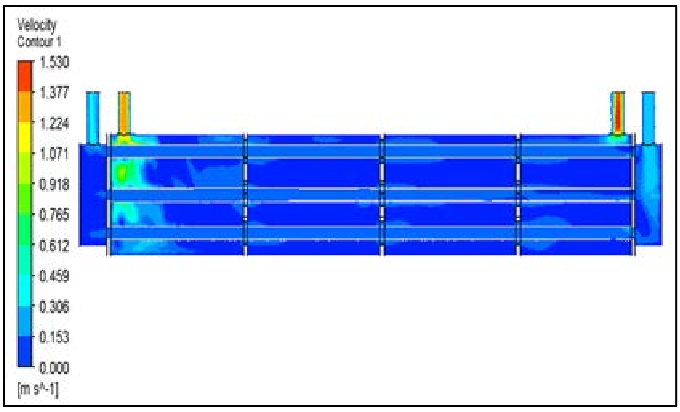

Fig. 19 Velocity contour plot for square orifice baffles iteration

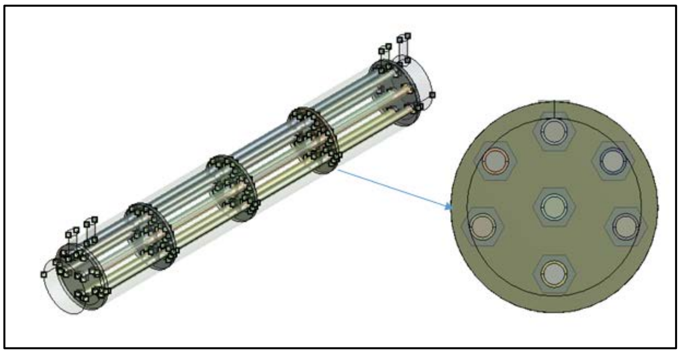

Fig. 20 Heat Exchanger with hexagonal orifice baffles model created in CATIA V5.

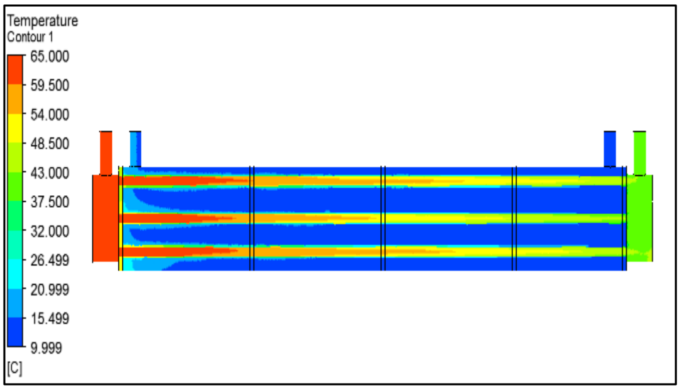

Fig. 21 Temperature distribution plot for hexagonal baffles iteration

Fig. 21 shows temperature distribution of hexagonal orifice baffle having hot water inlet temperature 65°C and outlet temperature 46.35°C. So, drop observe is 18.65°C.

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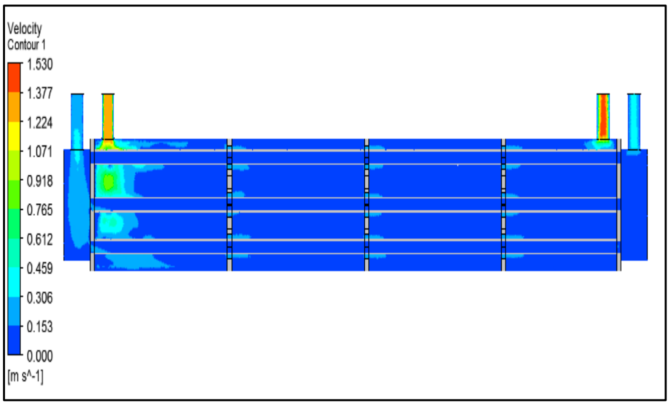

Fig. 22 Velocity contour plot for hexagonal baffles iteration

VI. EXPERIMENTAL TESTING

Experimental testing is carried out on the circular orifice and square orifice type baffles heat exchanger. For the testing heat exchanger is manufactured at workshop. Below fig. shows the experimental setup. The hot water from a gas geyser of temperature 65°C given as input to the tube side inlet. For the cold water, the storage tank is used. Measuring flask is used for measurement of flow rate. Counter flow of cold water is given to meet the setup condition. Temperature measurement at Inlet and outlet is done with the help of PT1000 RTD sensor and multimeter. The temperature reading taken in terms of resistance and then converted into temp with the help of STD PT1000 temp VS Resistance chart.

Fig. 23 Experimental setup

Resistance	Reading 1	Reading 2	Reading 3
R1	1252Ω	1255Ω	1263Ω
R2	1039Ω	1047Ω	1047Ω
R3	1155Ω	1163Ω	1171Ω

Table No. 2 Readings of PT 1000 in Ω for Circular Orifice

Resistance	Reading 1	Reading 2	Reading 3
R1	1252Ω	1252Ω	1256Ω
R2	1039Ω	1047Ω	1047Ω
R3	1167Ω	1170Ω	1170Ω

Table No. 3 Readings of PT 1000 in Ω for Square Orifice

Where
R1= Resistance of PT1000 at hot water Inlet
R2= Resistance of PT1000 at cold water Inlet
R3= Resistance of PT1000 at hot water Outlet

From the standard PT1000 chart temperature is calculated and the average temperature is considered.

Temp	Reading 1	Reading 2	Reading 3	Average
T1	65°C	66°C	68°C	66.33°C
T2	10°C	12°C	12°C	11.33°C
T3	40°C	42°C	44°C	42.00°C

Table No. 4 Readings of temperature at various points for Circular Orifice

Temp	Reading 1	Reading 2	Reading 3	Average
T1	65°C	65°C	66°C	65.33°C
T2	10°C	12°C	12°C	11.33°C
T3	43°C	44°C	44°C	43.66°C

Table No. 5 Readings of temperature at various points for Square Orifice

Where,

T1= temperature at hot water Inlet

T2= temperature at cold water Inlet

T3= temperature at hot water Outlet

Circular orifice baffle: Change in hot water temperature,

T_c =T1- T3 = 66.33- 42 = 24.33℃

Square orifice baffle: Change in hot water temperature,

T_c =T1- T3 = 65.33- 43.66 = 21.67℃

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VII. RESULTS AND DISCUSSION

Heat Exchanger Analysis			
Design Iteration	Hot Inlet Temp (Degree Celsius)	Hot Outlet Temp (Degree Celsius)	Change in Temperature
Iteration 1 Without Baffle	65	46.85	18.15
Iteration 2 With Circular Orifice Baffles	65	40.85	24.15
Iteration 3 With square Orifice Baffles	65	41.45	23.55
Iteration 4 With hexagonal Orifice Baffles	65	46.35	18.65

Table No. 6 Heat Exchanger Analysis from CFD results

From the Flow simulation it is observed that the heat transfer performance of circular orifice baffles is more than that of without baffle heat exchanger, square and hexagonal baffles heat exchanger. Graph for the "Hot outlet temp vs. Iterations" and "Change in temp VS. Iterations" are given below.

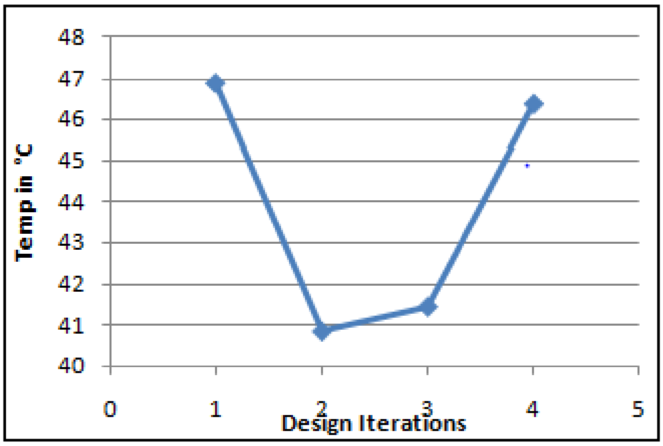

Fig. 24 Graph of Hot Outlet temp. Vs Iterations

From Fig. 24 it can be clearly observed that iteration 2 have minimum average temperature at the hot water outlet which is 40.85°C. Iteration 2 is one with circular shape orifice type baffles. Highest temperature drop is also observed in the same iteration as shown in the Fig. 25 which is 24.15°C.

Design Iterations	Hot Inlet Temp. ˚C	Hot Outlet Temp. ˚C	Change in Temp
Circular Baffle	66.33	42	24.33
Square Baffle	65.33	43.66	21.67

Table No 7. Experimental Comparison between Circular and Square orifice Baffles

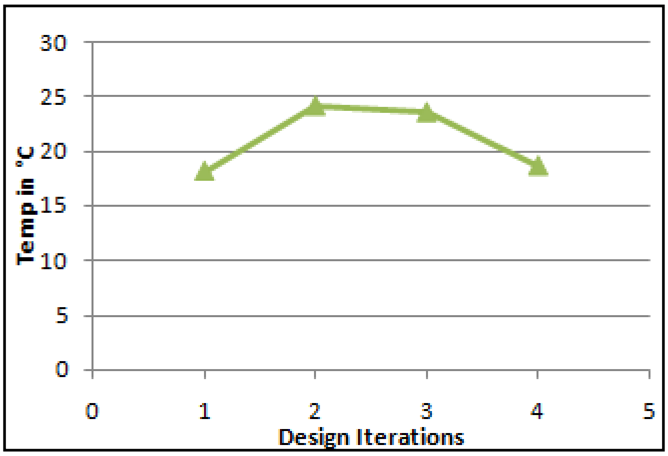

Fig. 25 Graph of Change in Temp vs. Iterations

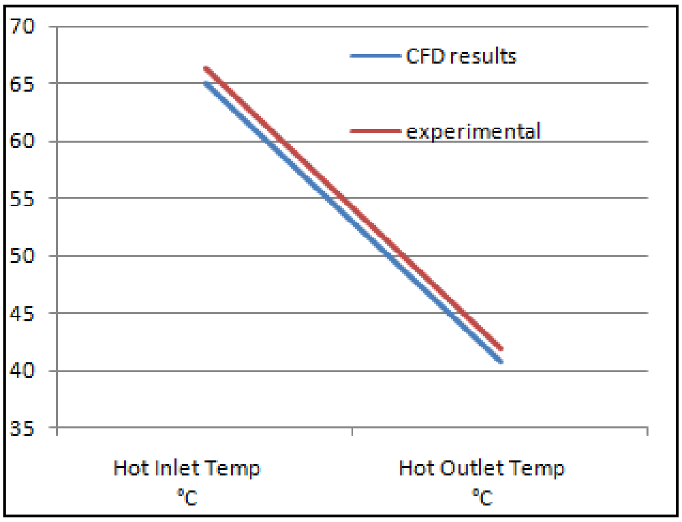

Fig. 26 Graph of temp drop for CFD VS Experimental results for Circular Baffle

Fig. 26 shows the graph for change in temperature of hot water for both CFD and experimental results for circular baffle. For hot water, 2% error observed in the inlet temperature and 2.81% error observed in outlet temperature.

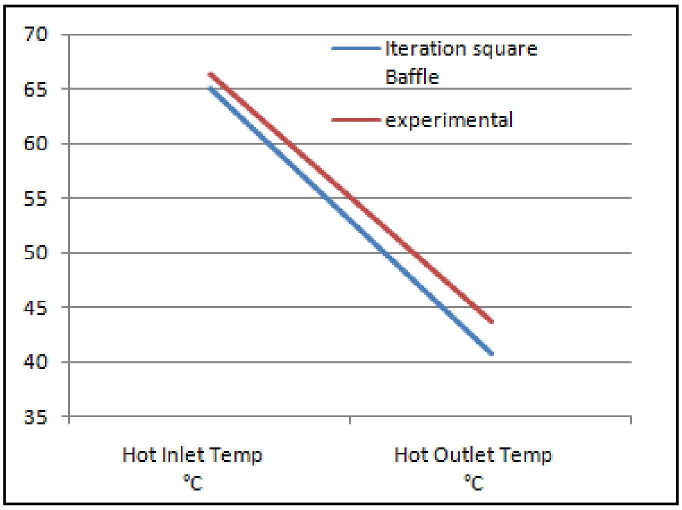

Fig. 27 Graph of temp drop for CFD VS Experimental results for Square Baffle

Fig. 27 shows the graph for change in temperature of hot water for both CFD and experimental results for square baffles. For hot water, 0.5% error observed in the inlet temperature and for outlet temperature 5.33% error is observed

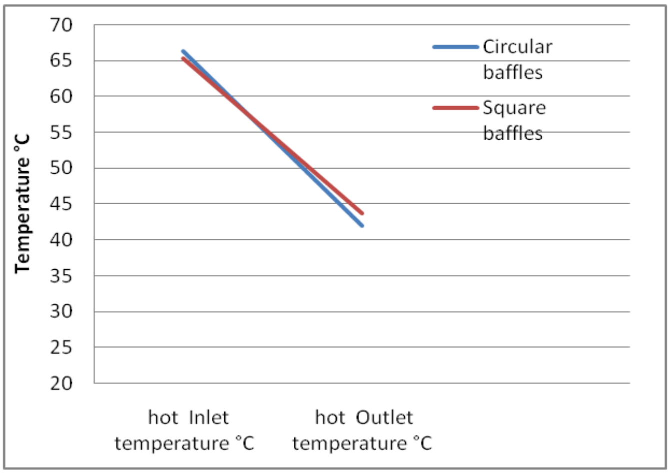

Fig. 28 Graph of temp drop from experimental results for Circular VS Square baffle

Fig. 28 shows the graph for change in temperature of hot water for both circular and square baffles as per experimental results. For hot water, 1.5% error observed in the inlet temperature and for outlet temperature 3.95% error is observed.

VIII. CONCLUSION

CFD analysis successfully conducted on the shell and tube type heat exchanger model with different shapes of orifice type baffles used for guiding the flow in the shell zone.

1. It can be observed that maximum temperature difference in the hot fluid with circular orifice baffle shape. Temperature of the 65°C hot water is lowered to 40.85°C which gives temperature drop of 24.15°C. That also means highest rate of heat transfer between the fluids is achieved by the circular shape orifice type baffle.
2. Lowest efficiency is shown by the hexagonal type baffle in all the iterations tested. Performance of the hexagonal shape orifice type baffle is almost near to without baffle type heat exchanger analyzed in the iteration 1 model.
3. The experimental results shows that circular orifice baffles have more heat transfer efficiency as compared to the square orifice baffles

IX. FUTURE SCOPE

Work can be further increased to find better shape of the orifice for the low flow cold water. Combinations of baffles such as circular, square or elliptical can be used to improve efficiency of heat exchanger.

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