CFD Analysis of Shell and Tube Heat Exchanger with Different Number of Baffels

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Abstract- **Heat exchangers such as shell-and-tube, plate type and finned tube are used in various industries for different applications such as heating, cooling, condensation or evaporation process. The present work deals with the numerical investigation of heat and fluid flow in shell and tube heat exchanger with different numbers of baffles on shell side. Three different heat exchangers containing 3, 4 and 5 baffles are investigated numerically by modelling a full length continuous helical baffled shell-and-tube heat exchanger for constant mass flow rates and different cold fluid inlet temperature conditions.**

Thus, the objective of the present study is "to examines the thermo-hydraulic performance of a shell and tube heat exchanger with different number (i.e. for three, four and five) of flat plate baffles using numerical along with experimental validation"

Index Terms- Shell and Tube Heat Exchanger, Hot Fluid Outlet Temperature, Cold Fluid Outlet Temperature, Turbulence Eddy Dissipation, Wall Heat Transfer Coefficient, Baffles.

I. INTRODUCTION

1.1 General

Heat transfer device, for example, heat exchangers, boilers, condensers, radiators, heaters, heaters, coolers, and sun based authorities are composed fundamentally based on heat transfer examination. The heat transfer issues experienced practically speaking can be considered in two gatherings:

(1) Rating and

(2) Sizing issues.

The rating issues manage the assurance of the heat transfer rate for a current framework at a predetermined temperature contrast. The sizing issues manage the assurance of the measure of a framework so as to transfer heat at a predetermined rate for a predefined temperature contrast.

1.2 Heat Exchanger

A heat exchanger is a gadget that is utilized to transfer warm vitality (enthalpy) between at least two liquids, between a strong surface and a liquid, or between strong particulates and a liquid, at various temperatures and in warm contact. In heat exchangers, there are typically no outside heat and work communications. Run of the mill applications include heating or cooling of a liquid stream of concern and dissipation or build-up of single-or multicomponent liquid streams.

II-LITERATURE REVIEW

Driven by the purpose of the energy saving and emission reduction, heat exchangers play a vital role in various fields of the modern industry, particularly in chemical processing, electric power, and waste heat recovery. The shell and tube heat exchanger (STHX) are one of the most widely used heat exchangers owing to its versatile usability, convenient maintenance, high-pressure resistance, and high-temperature resistance

Limited works have been achieved in the field of flow distribution within geometrical changes of a tubular heat exchanger.

Improvement of heat transfer through shell and tube exchangers stills taking high consideration by specialists. Ammar Ali Abd et al;2018, explored the impact of shell distance across and tube length on heat transfer coefficient and weight drop for shell agree with both triangular and square pitches. What more, the impact is of astound separating and cutting space on heat transfer coefficient and weight drop were contemplated. Also, standards fouling rates utilized for both shell and tube sides to appraise the decreased heat transfer. Expanding shell distance across with a triangular pitch and draw through floating head recorded 3% expanding in heat transfer coefficient for just 0,05m expanding in shell width. While 2.8% expansion in heat transfer coefficient for shell side by 0.05m expanding in shell distance across with split-ring floating head and square pitch. Heat transfer coefficient for shell side decreased by 15.15% by expanding bewilder space by 0.2 from shell breadth and the weight drop by 41.25%. Expanding slicing space from 15% to 25% reductions heat transfer coefficient by 5.56% and the weight drop lessened by 26.3%. Expanding tube length by 0.61m prompts upgrade the heat transfer coefficient by 31.9% and weight drop by 14.11% for tube side. For shell side, expanding tube length by 0.61m gives 2.2% expanding in heat transfer coefficient and 21.9% expanding for weight drop. Fouling obstruction change on shell side demonstrates a high impact on heat transfer more than same rate change on the tube side.

3. NUMERICAL STUDY

3.2.1 Numerical Analysis Model

In this study, CFD tools are used to simulate the flow in a tubular heat exchanger in order to investigate the influence of the number of baffles on the distribution of the fluid. Figure 3.1, 3.2 and 3.3 shows the geometry of the heat exchanger in all the three conditions i.e. 3 Baffles, 4 Baffles and 5 Baffles shell and tube heat exchanger.

Figure 3.1 Geometry of 3 Baffles Shell and Tube Heat Exchanger

Figure 3.2 Geometry of 4 Baffles Shell and Tube Heat Exchanger

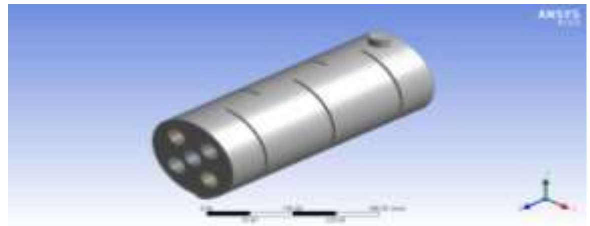

Figure 3.3 Geometry of 5 Baffles Shell and Tube Heat Exchanger

3.2.2 Physical model

The selected shell and tube heat exchanger are an educational medium type heat exchanger used in experimental analysis as shown in figure 3.4, it contains a single pass with 5 tubes for the 3 number of baffles. The geometric parameters of the heat exchanger are shown in Table 3.1.

Figure 3.4 Experimental Set-up (curtsey:

Table 3.1 The Specification of Experimental Model having Shell and Tube Heat Exchanger

No.	Description	Unit	Value
1	Cross Sectional Area of Shell	mm^2	31416
2	Shell (Diameter)	mm	200
3	Tube (Diameter)	mm	40
4	Number of tubes		5
5	Shell/Tube length	mm	500
6	Thickness of the Shell	mm	04
7	No. of Baffles		03

3.2.3 Governing Equation

The working fluid in shell side of the three heat exchangers is water which is steady, turbulence, and incompressible. The fluid physical properties are constant and the effect of gravity is also considered. The renormalization group RNG k −e turbulence model with standard wall functions which was applicable to predict high strain rate and larger degree of streamline curvature flow is employed to accurately simulate the thermo-hydraulic performance. The standard wall function method was used to model the near-wall region. The governing equations for continuity, momentum, energy, k and e in computational domain can be written as follows:

Continuity:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0$$

Momentum

$$\frac{\partial}{\partial x_i}(\rho u_i u_k) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_k}{\partial x_i}\right) - \frac{\partial p}{\partial x_i} + \rho g_i$$

Energy

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial T}{\partial x_i}\right) + \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_k}{\partial x_i} u_i\right)$$

Turbulent Kinetic Energy

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}(\alpha_k \mu_{eff}\frac{\partial k}{\partial x_j}) + G_k + G_b - \rho\varepsilon$$

G_k the generation of turbulence kinetic energy due to the mean velocity gradients, m^2/s^2

G_b the generation of turbulence kinetic energy due to buoyancy, m^2/s^2

μ is the dynamic viscosity, Pa·s

ρ is the density, kg/m^3

3.2.4 Boundary conditions and numerical methods

For the present numerical study following assumptions are made:

1. All the simulations are carried by considering transient analysis.
2. The thermo-physical properties of working liquid are consistent.
3. Heat misfortune to encompassing is immaterial.
4. Leakages among astounds and tubes are irrelevant.

3.2.5 Grid Generation

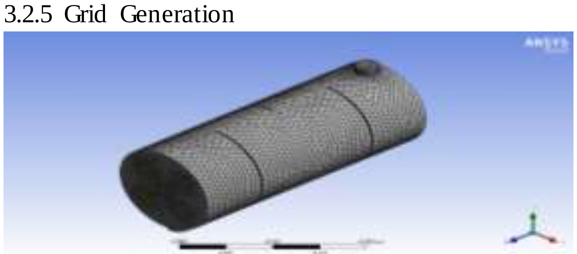

Figure 3.5 Mesh generated of 3 baffles shell and tube heat exchanger

Figure 3.6 Mesh generated of 4 baffles shell and tube heat exchanger

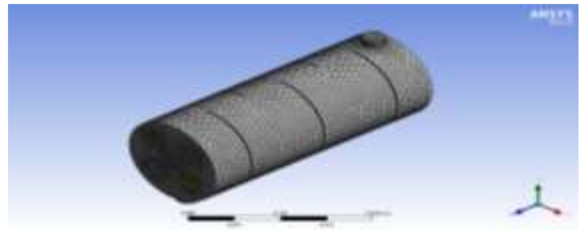

Figure 3.7 Mesh generated of 5 baffles shell and tube heat exchanger

The meshing process is carried out using unstructured mesh Tetrahedron / hybrid elements. Figure 3.5, 3.6 and 3.7 shows the mesh generated for 3,4 and 5 baffles shell and tube heat exchangers respectively. Almost 63150 Nodes and 305212 Elements have been generated during the mesh generation process after a good refining mesh.

IV-RESULT ANALYSIS

4.1 Model Validation

For the model validation the numerical results after the CFD analysis of the heat exchanger i.e. Temperature at outlet for both chilly and hot liquid were contrasted and the test information of the Shell and Tube Heat Exchanger

Table 4.1 Comparison table for Experimental and FEA results.

Sr. No.	Hot Water Flow rate (kg/s)	Cold Water Flow rate (kg/s)	Hot Water Inlet temp	Cold Base Fluid Inlet temp	Experimental Result		FEA Result		Difference (%)	
					Hot Water Outlet temp	Cold Base Fluid Outlet Temp	Hot Water Outlet temp	Cold Base Fluid Outlet Temp	Hot Water Outlet temp	Cold Base Fluid Outlet Temp
1	0.5	1	50	10	48	25	47.7	23.1	0.62	7.6
2	0.5	1	50	15	48.4	32	48	30	0.83	6.3
3	0.5	1	50	20	48.7	34	48.3	32.8	0.82	3.5

Figure 4.1 demonstrates the Comparison in Experimental and Finite Element Analysis Result.

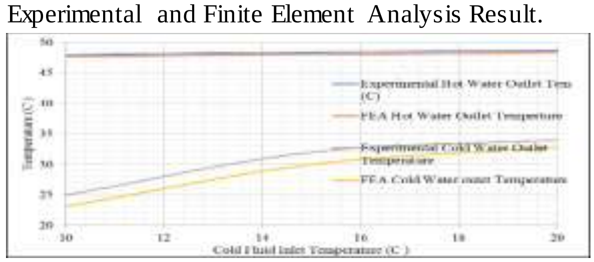

Figure 4.1 Comparison in Experimental and Finite Element Analysis Result

4.2 Finite Element Analysis Result

After the validation process the two different shell and tube heat exchangers having 4 and 5 number of vessels have been analysed using CFD Fluent as workbench. The following results have been obtained. For the analysis the hot fluid inlet temperature have been considered as constant i.e. 50°C and the cold fluid inlet temperature varies i.e. 10°C , 15°C and 20°C respectively.

4.2.1 Results for 3 Baffles Shell and Tube Heat Exchanger

4.2.1.1 Results for 3 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

Figure 4.2, 4.3, 4.4 and 4.5 shows the Hot Fluid Outlet Temperature, Cold Fluid Outlet Temperature, Turbulence Eddy Dissipation and Wall Heat Transfer Coefficient for 3 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature respectively.

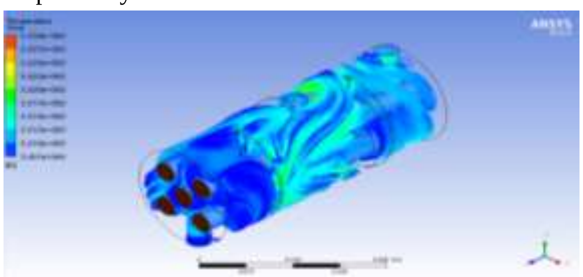

Figure 4.2 Hot Fluid Outlet Temperature for 3 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

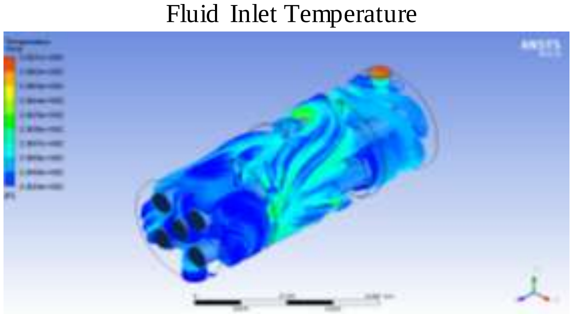

Figure 4.3 Cold Fluid Outlet Temperature for 3 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

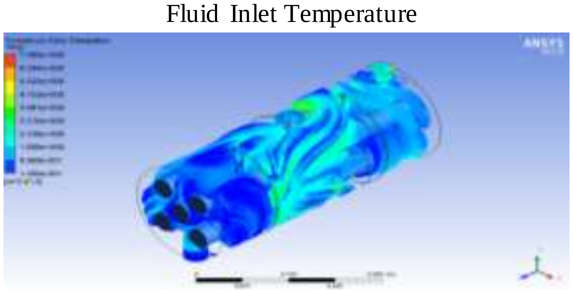

Figure 4.4 Turbulence Eddy Dissipation for 3 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

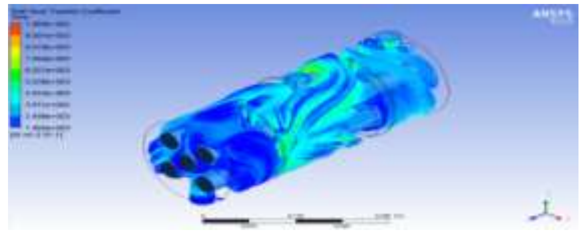

Figure 4.5 Wall Heat Transfer Coefficient for 3 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

4.2.1.2 Results for 3 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

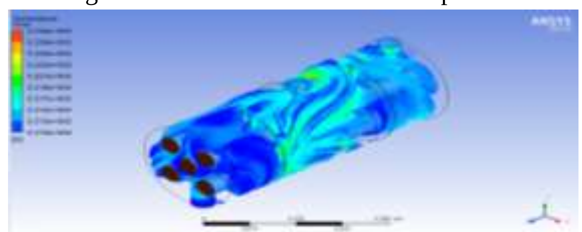

Figure 4.6 Hot Fluid Outlet Temperature for 3 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

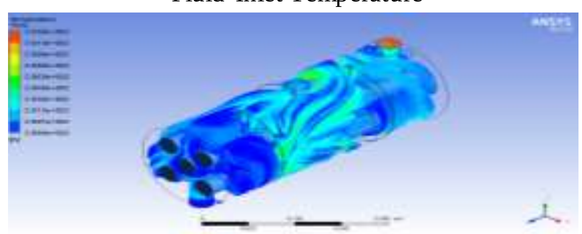

Figure 4.7 Cold Fluid Outlet Temperature for 3 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

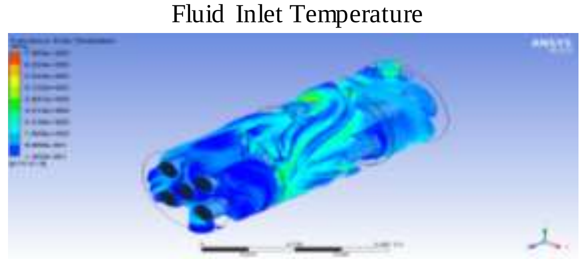

Figure 4.8 Turbulence Eddy Dissipation for 3 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

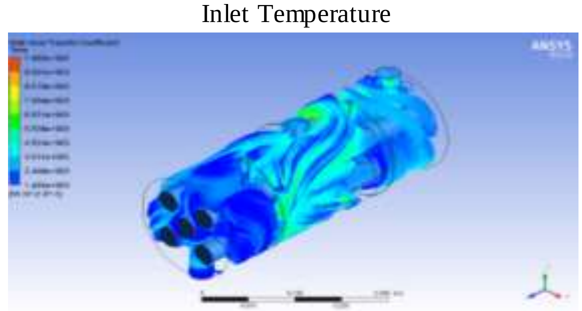

Figure 4.9 Wall Heat Transfer Coefficient for 3 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

4.2.1.3 Results for 3 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

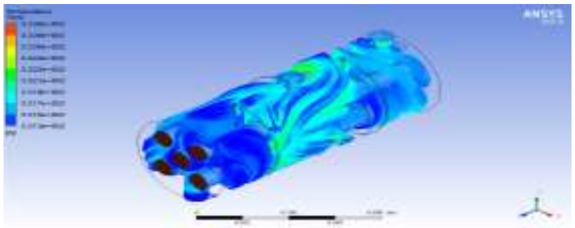

Figure 4.10 Hot Fluid Outlet Temperature for 3 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

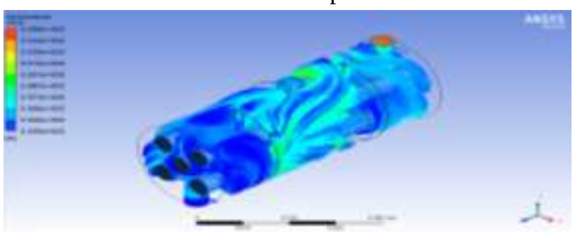

Figure 4.11 Cold Fluid Outlet Temperature for 3 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

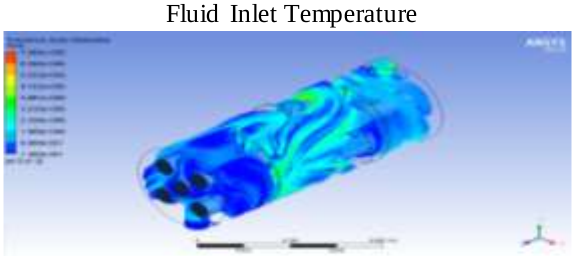

Figure 4.12 Turbulence Eddy Dissipation for 3 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

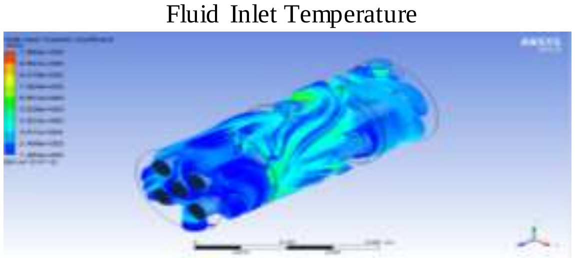

Figure 4.13 Wall Heat Transfer Coefficient for 3 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

4.2.2.1 Results for 4 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

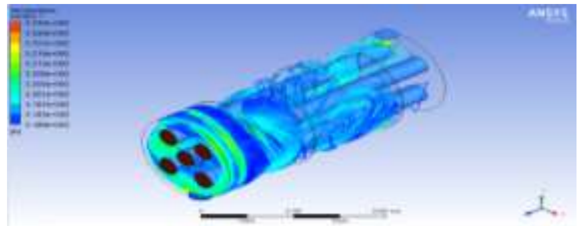

Figure 4.14 Hot Fluid Outlet Temperature for 4 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

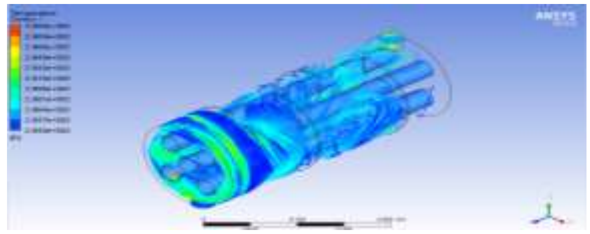

Figure 4.15 Cold Fluid Outlet Temperature for 4 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

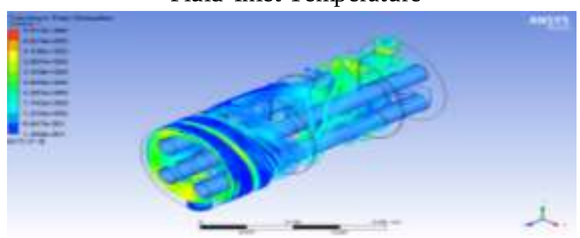

Figure 4.16 Turbulence Eddy Dissipation for 4 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

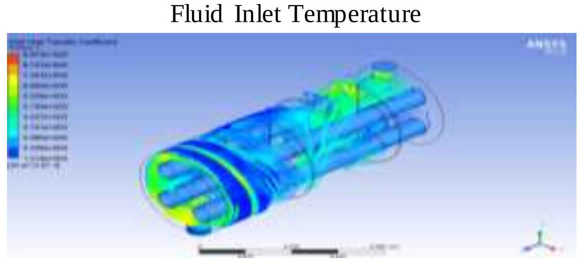

Figure 4.17 Wall Heat Transfer Coefficient for 4 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

4.2.2.2 Results for 4 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

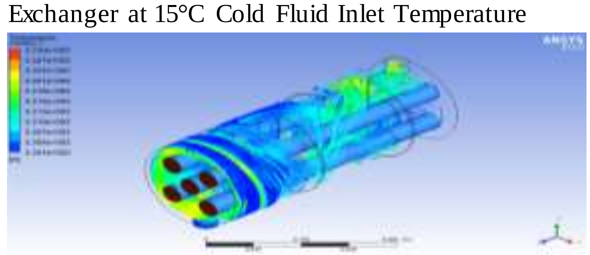

Figure 4.18 Hot Fluid Outlet Temperature for 4 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

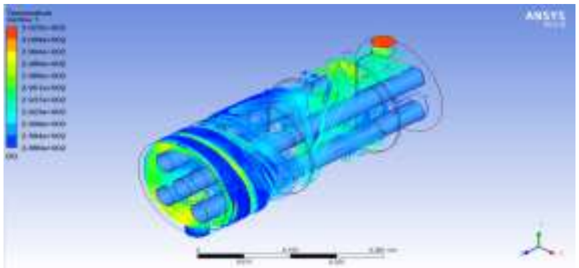

Figure 4.19 Cold Fluid Outlet Temperature for 4 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

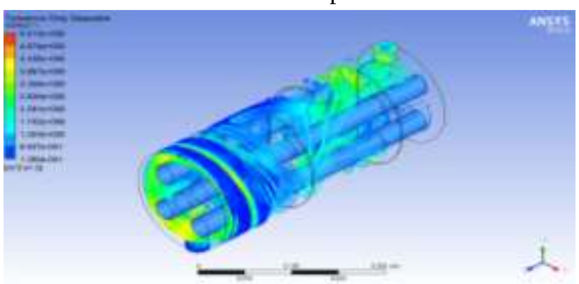

Figure 4.20 Turbulence Eddy Dissipation for 4 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

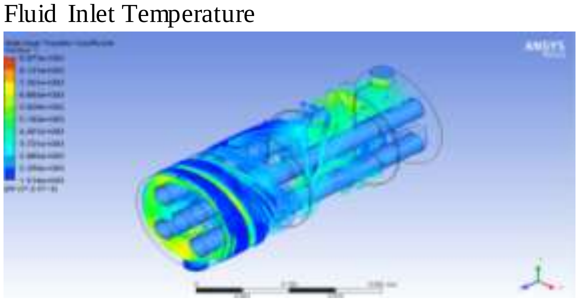

Figure 4.21 Wall Heat Transfer Coefficient for 4 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

4.2.2.3 Results for 4 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

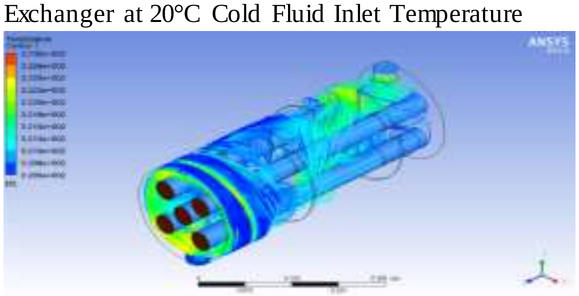

Figure 4.22 Hot Fluid Outlet Temperature for 4 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

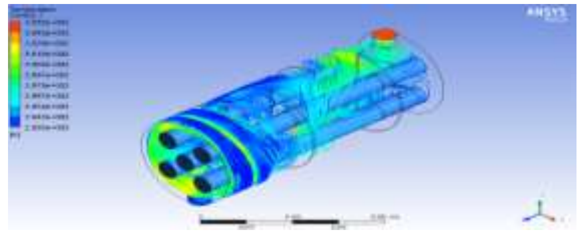

Figure 4.23 Cold Fluid Outlet Temperature for 4 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

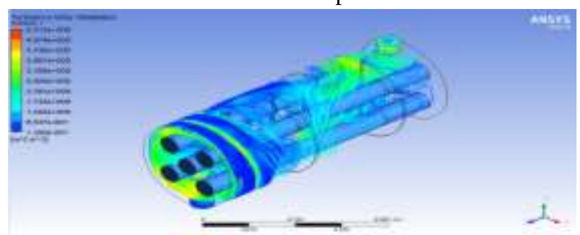

Figure 4.24 Turbulence Eddy Dissipation for 4 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

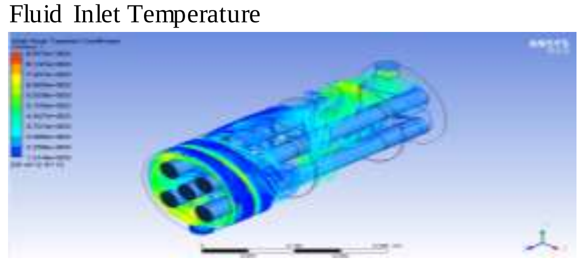

Figure 4.25 Wall Heat Transfer Coefficient for 4 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

4.2.3.1 Results for 5 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

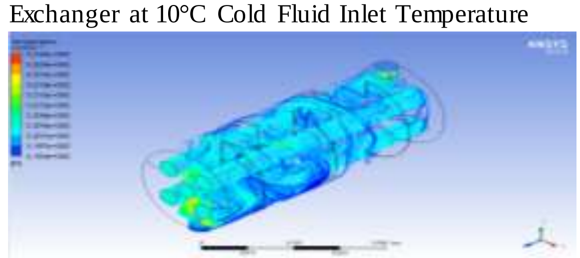

Figure 4.26 Hot Fluid Outlet Temperature for 5 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

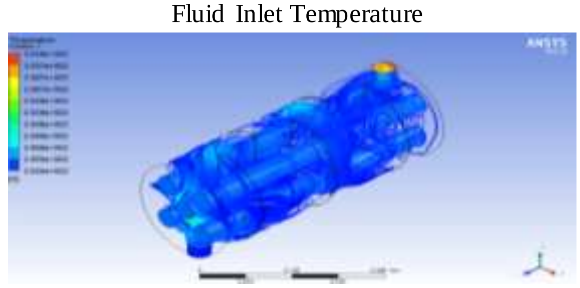

Figure 4.27 Cold Fluid Outlet Temperature for 5 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

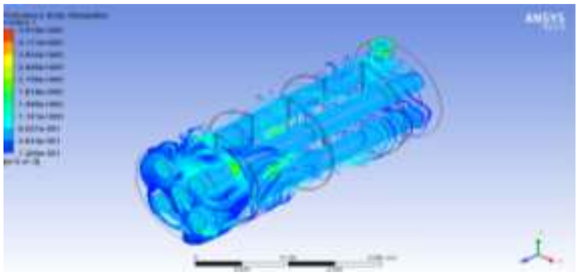

Figure 4.28 Turbulence Eddy Dissipation for 5 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

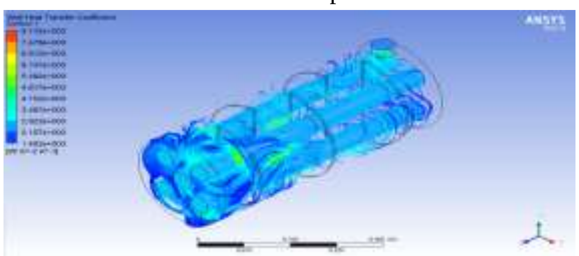

Figure 4.29 Wall Heat Transfer Coefficient for 5 Baffles Shell and Tube Heat Exchanger at 10°C Cold Fluid Inlet Temperature

4.2.3.2 Results for 5 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

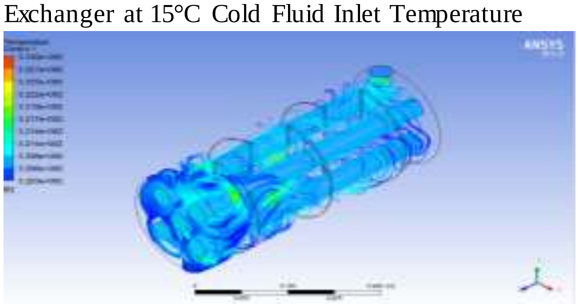

Figure 4.30 Hot Fluid Outlet Temperature for 5 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

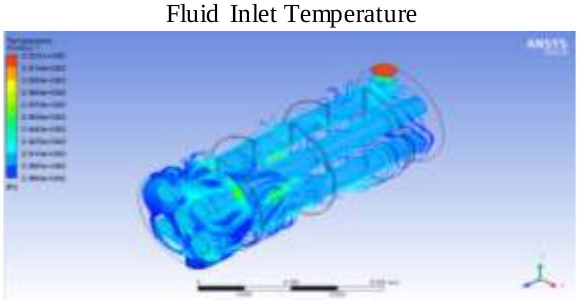

Figure 4.31 Cold Fluid Outlet Temperature for 5 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

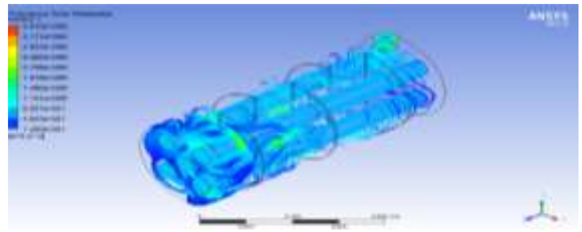

Figure 4.32 Turbulence Eddy Dissipation for 5 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

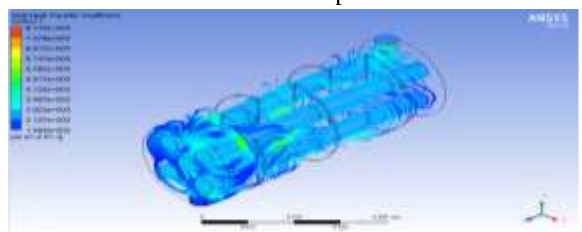

Figure 4.33 Wall Heat Transfer Coefficient for 5 Baffles Shell and Tube Heat Exchanger at 15°C Cold Fluid Inlet Temperature

4.2.3.3 Results for 5 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

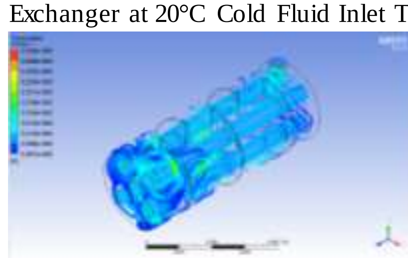

Figure 4.34 Hot Fluid Outlet Temperature for 5 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

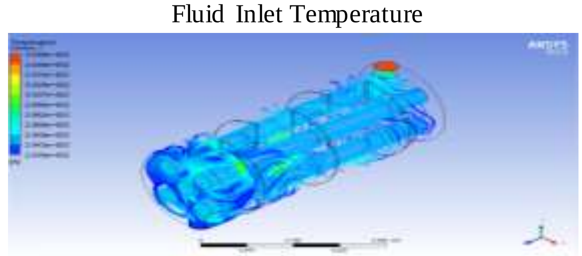

Figure 4.35 Cold Fluid Outlet Temperature for 5 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

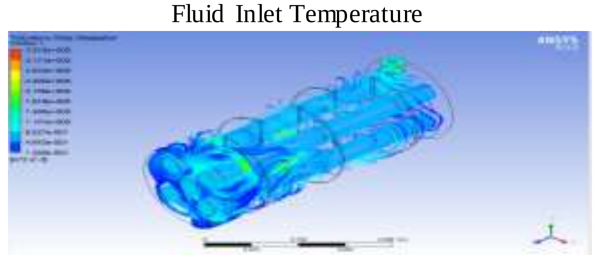

Figure 4.36 Turbulence Eddy Dissipation for 5 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

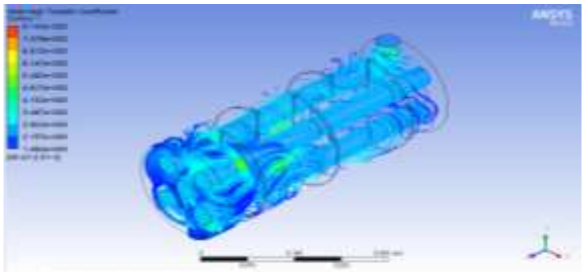

Figure 4.37 Wall Heat Transfer Coefficient for 5 Baffles Shell and Tube Heat Exchanger at 20°C Cold Fluid Inlet Temperature

4.3 Discussion

The results obtained after the analysis and calculations for 3,4 and 5 Baffles Shell and Tube Heat Exchangers are summarised in table 4.2,4.2 and 4.4 respectively.

Table 4.2 Results obtained considering 3 Baffles Shell and Tube Heat Exchanger

Sr. No.	Hot Water Flow rate (kg/s)	Cold Water Flow rate (kg/s)	Hot Water Inlet temp	Hot Water Outlet temp	Cold Base Fluid Inlet temp	Cold Base Fluid Outlet Temp	Heat Transfer rate from Hot water	Heat Transfer Rate to Cold Water	LMTD	Average Heat Transfer Rate	Overall Heat Transfer Coefficient
1	0.5	1	50	47.7	10	23.1	4.81	54.84	31.68	29.83	9.61
2	0.5	1	50	48	15	30	4.19	62.79	25.56	33.49	13.37
3	0.5	1	50	48.3	20	32.8	3.56	53.58	21.96	28.57	13.26

Table 4.3 Results obtained considering 4 Baffles Shell and Tube Heat Exchanger

Sr. No.	Hot Water Flow rate (kg/s)	Cold Water Flow rate (kg/s)	Hot Water Inlet temp	Hot Water Outlet temp	Cold Base Fluid Inlet temp	Cold Base Fluid Outlet Temp	Heat Transfer rate from Hot water	Heat Transfer Rate to Cold Water	LMTD	Average Heat Transfer Rate	Overall Heat Transfer Coefficient
1	0.5	1	50	45.8	10	27	8.7906	71.16	28.07	39.97	14.32
2	0.5	1	50	47.1	15	29.3	6.0697	59.85	21.43	32.96	13.2
3	0.5	1	50	47.5	20	32.2	5.2325	51.06	21.63	28.13	13.13

Table 4.4 Results obtained considering 5 Baffles Shell and Tube Heat Exchanger

Sr. No.	Hot Water Flow rate (kg/s)	Cold Water Flow rate (kg/s)	Hot Water Inlet temp	Hot Water Outlet temp	Cold Base Fluid Inlet temp	Cold Base Fluid Outlet Temp	Heat Transfer rate from Hot water	Heat Transfer Rate to Cold Water	LMTD	Average Heat Transfer Rate	Overall Heat Transfer Coefficient
1	0.5	1	50	46.3	10	29.6	7.74	82.8	26.6	44.89	17.17
2	0.5	1	50	47.3	15	30.1	5.6	63.20	23.0	34.42	14.02
3	0.5	1	50	47.7	20	32.9	4.83	53.98	21.5	29.40	13.94

4.3.1 Overall heat transfer coefficient

A heat exchanger ordinarily includes two streaming liquids isolated by a strong divider. Heat is first transferred from the hot liquid to the divider by convection, through the divider by conduction, and from the divider to the chilly liquid again by convection.

The general heat transfer coefficient is given by:

$1/U=1/hi +1/ho$

The individual convection heat transfer coefficients inside and outside the tube, howdy and ho, are resolved utilizing the convection relations.

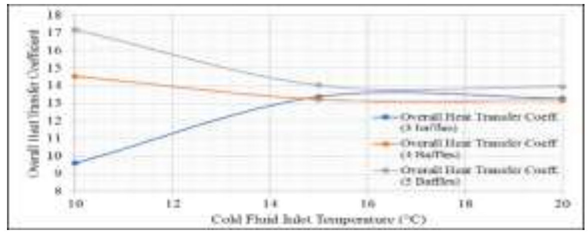

Figure 4.40 Overall heat Transfer Coefficient variation with respect to Cold Fluid Inlet Temperature

4.3.2 Heat Transfer rate

This is the most imperative amount in the choice of a heat exchanger.

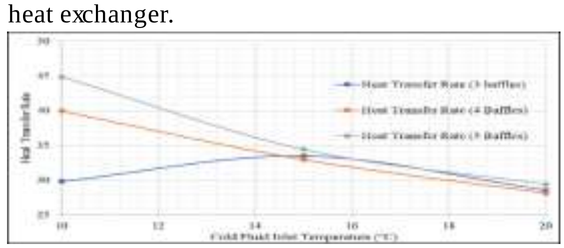

Figure 4.41 Heat Transfer Rate variation with respect to Cold Fluid Inlet Temperature

4.3.3 Turbulence Eddy Dissipation

Baffles are used to create the turbulence and hence enhance the heat transfer. Less eddy dissipation means more turbulence in the fluid flow.

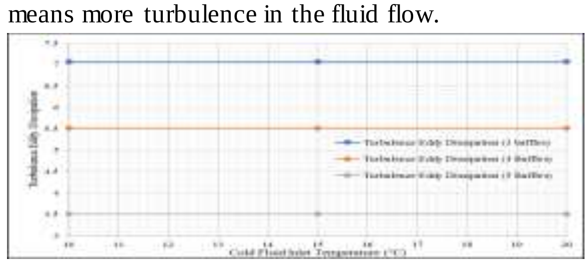

Figure 4.42 Turbulence Eddy Dissipation variation with respect to Cold Fluid Inlet Temperature

V-CONCLUSION

In the present study, a numerical analysis has been carried out to calculate and compare the effect of number of baffles in the performance of shell and tube heat exchanger. Increasing the number of baffles beyond certain number gives serious effects on parameters like Hot Fluid Outlet Temperature, Cold Fluid Outlet Temperature, Turbulence Eddy Dissipation and Wall Heat Transfer Coefficient in shell and tube heat exchanger. The following conclusions can be made:

- The overall heat transfer coefficient at 10°C inlet temperature of cold fluid is higher for 5 baffles Heat exchanger and it decreases 15.4% and 33.8% as the number of baffles decreases 4 and 3 Baffles respectively. At 15°C and 20°C inlet temperature of cold fluid, the overall heat transfer coefficient is almost same for 3 and 4 baffle heat exchangers but it is maximum for 5 Baffle heat exchangers about 5.69%.

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