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Thermal Analysis of Shell and Tube Heat Exchanger Using Different Fin Cross Section

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Abstract

The objective of this paper is to analyze the performance of a shell and tube heat exchanger for three configurations with and without fins on tube surface. Numerical analysis is carried out using commercially available software FLUENT. The model of shell and tube heat exchanger was designed using CATIA V5. The convective heat transfer process is analyzed for rectangular finned, trapezoidal finned and bare tube type heat exchanger. The convection boundary condition is applied for tube walls in terms of heat transfer coefficient and ambient temperature. The flow of temperature, pressure and velocity has been observed to evaluate the overall heat transfer in both the finned configurations. The results indicated that there is a heat transfer enhancement in trapezoidal finned tube heat exchanger compared to rectangular finned configuration as the temperature drop across the trapezoidal finned model is more. The FLUENT post processes temperature results were used to calculate the LMTD and over all heat transfer rate. Rectangular finned model showed 32 % heat transfer more than bare tube model. Trapezoidal finned model showed 56 % heat transfer more than bare tube model. Trapezoidal finned model showed 18 % heat transfer more than rectangular finned model.

INTRODUCTION

We look up a project on Heat Exchanger that is static instrumentality at Hindustan organic chemicals limited. Heat Exchanger is also outlined as instrumentality that transfers the energy from a hot fluid to a cold fluid with most rate and minimum investment and running price.

It is used to cut back temperature of 1 process fluid, that is cool ,by transferring heat to a different fluid that is desirable to heat while not intermixing the fluid or vary the physical state of the fluid.

Heating may be a very important operation within the petroleum and chemical industrial plant. Thence failure of a device result ineffective transfer of energy. Traditional operation of heat exchanger sometimes needs very little operator attention. However, operative lifetime of a device are often drastically curtailed by improper start up and shut down practices. Thus properly planed maintenance schedule is necessary for industries having heat exchangers on their main instrumentality in their process plant.

A detailed maintenance schedule of plant associated machinery of a industry involves chiefly observance while not disturbing the operation of the plant as an entire.

A project titled "Failure analysis of shell and tube heat exchanger" presents an over view on differing types of heat exchangers, their functions, benefits and drawbacks and also the maintenance procedure adopted for smooth operation of the heat exchanger. The operation of heat exchanger involves the production of phenol from TAR COLUMN.

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The case study deals with the failure analysis of heat exchanger and design is checked and so correct solutions are given to enhance the effectiveness of heat exchanger.

HEAT EXCHANGERS

Heating, compression and Cooling are operations important to the petroleum and chemical industrial plant. These operations are accomplished by tubular exchanger equipment (Shell and Tube). Different equipments used for compression and cooling are air cooled heat exchangers and box coolers.

A heat exchanger could also be outlined as an instrumentation that transfers the energy from the hot fluid to a cold fluid or contrariwise, with most rate and minimum investment and running price. The heat exchanger is employed to scale back the temperature of 1 process fluid, that is to be heated while not intermixing the fluids or ever-changing the physical state of the fluids. Condensers are used to cool the temperature of process vapors to the purpose wherever it'll become a liquid by the transfer of heat to a different fluid while not intermixing the fluids. Water or air is employed to condense the vapors.

In HOCL heat exchangers are used for compression the hot vapors of the products obtained by crude distillation and storing them within the liquid form.

Components of Heat Exchangers

The figure given below shows a typical heat exchanger and its components

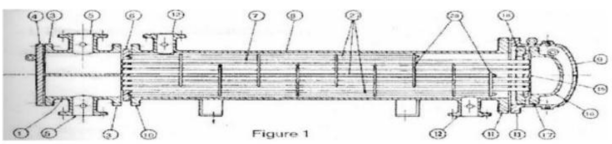


Fig 1: components of heat exchanger

BUILDING THE MODEL

Building a finite element model needs a lot of an ANSYS user's time than any different partof the analysis. Initial you specify the work name and analysis title. Then, outline the component sorts, real constants, and material properties, and therefore the model geometry.

ANSYS, Analyzing computer code, has been used in this project. ANSYS Mechanical computer code is a comprehensive FEA analysis (finite element) tool for structural analysis, as well as linear, nonlinear and dynamic studies. The engineering simulation product provides a whole set of components behavior, material models and equation solvers for a large vary of mechanical style issues. In addition, ANSYS Mechanical offers thermal analysis and coupled physics capabilities involving acoustic, electricity, thermal structural and thermo electrical analysis.

The ANSYS Mechanical software suite is trusted by organizations around the world to apace solve complicated structural issues with ease. Structural mechanics solutions from ANSYS offer the ability to simulate each structural side of a product, as well as nonlinear static analysis that gives stresses & deformations,

Fig 2: Shell and Tube Heat Exchanger of type water to oil

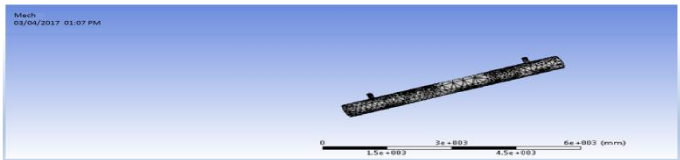
Geometrical Modeling

The geometric model of finned tube heat exchanger was made on Gambit. The heat exchanger specifications are as follows:

1.	Shell outer diameter	323mm
2.	Shell Thickness	6 mm.
3.	Length of the shell	500 mm
4.	Tube outer diameter	12.5 mm
5.	Tube Thickness	1.65 mm
6.	Tube type	Finned tube
7.	Transverse Pitch	37.5 mm
8.	Longitudinal pitch	37.5 mm
9.	Type of Tube layout	circular layout
10.	Type of Tube arrangement	In line arrangement
11.	No of tube inside the shell	36
12.	Fin Thickness	2 mm
13.	Fin height	6 mm
14.	Type of Fin	Rectangular, Trapezpidal fin

Table 1: heat exchanger specifications

Statistics	
Nodes	13493
Elements	6760
Mesh Metric	None



Properties	
Volume	9.3015e+007 mm³
Mass	730.17 kg

Table 2: properties

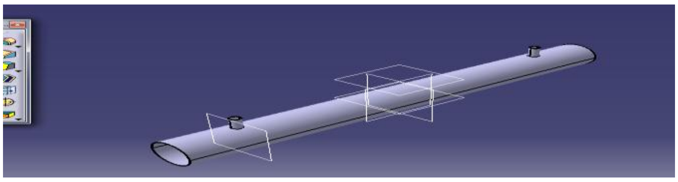
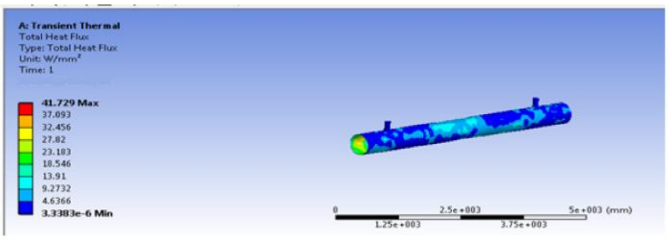


Fig 3: Design in CATIA

Analysis of Heat Exchanger

Material used: Aluminium-2000



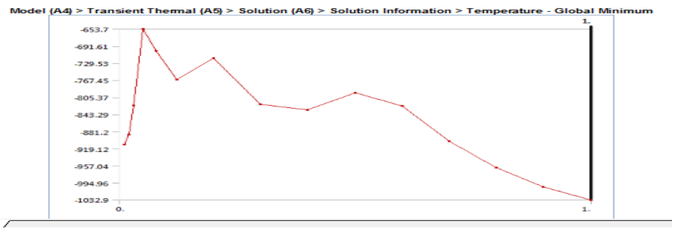


Fig 4: Temperature

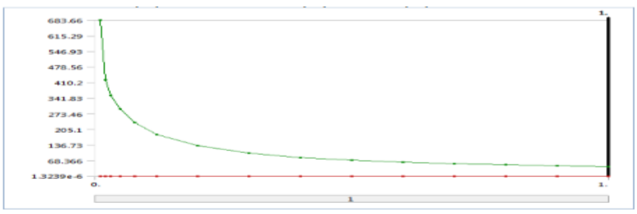


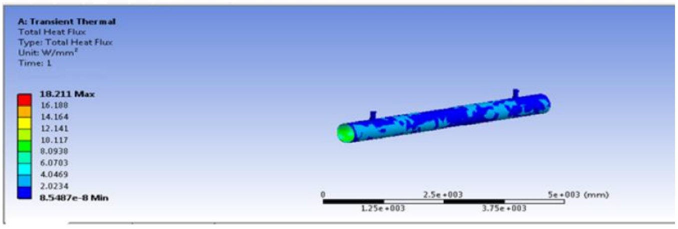
Fig 6: Total heat flux

Model (A4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.e-002	2.1093e-005	683.66
2.e-002	2.974e-006	421.46
3.0554e-002	2.1626e-006	352.88
4.8875e-002	3.1145e-006	293.56
7.7176e-002	2.6597e-006	235.65
0.1213	8.0156e-006	182.4
0.19906	1.1033e-005	133.42
0.29906	6.9156e-006	100.59
0.39906	5.3499e-006	81.685
0.49906	7.4665e-006	69.695
0.59906	2.7794e-006	61.34
0.69906	5.2184e-006	55.008
0.79906	1.519e-006	49.885
0.89906	1.3239e-006	45.546
1	3.3383e-006	41.729

Table 3: Table for total heat flux

Stain less steel -2000



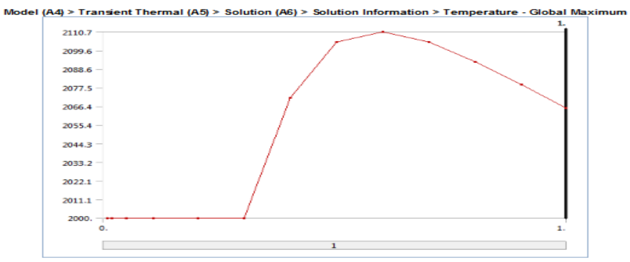


Fig 7: Temperature

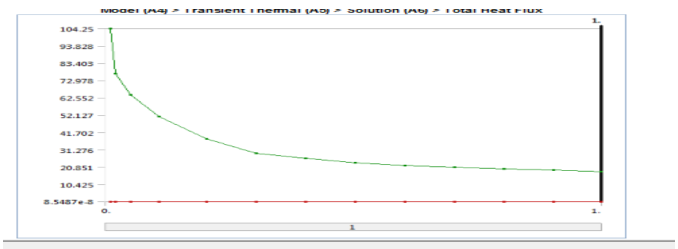


Fig 8: Graph for total heat flux

Model (A4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.e-002	3.895e-006	104.25
2.e-002	4.1989e-006	77.041
5.e-002	2.5291e-006	64.316
0.10871	8.8293e-007	51.409
0.20454	7.8261e-007	37.8
0.30454	2.4004e-007	29.045
0.40454	2.2388e-007	26.009
0.50454	1.5723e-007	23.421
0.60454	1.8904e-007	21.887
0.70454	2.4513e-007	20.817
0.80454	2.4373e-007	19.851
0.90454	1.1798e-007	18.975

Table 4:- Total heat flux table

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Carbon steel-2000

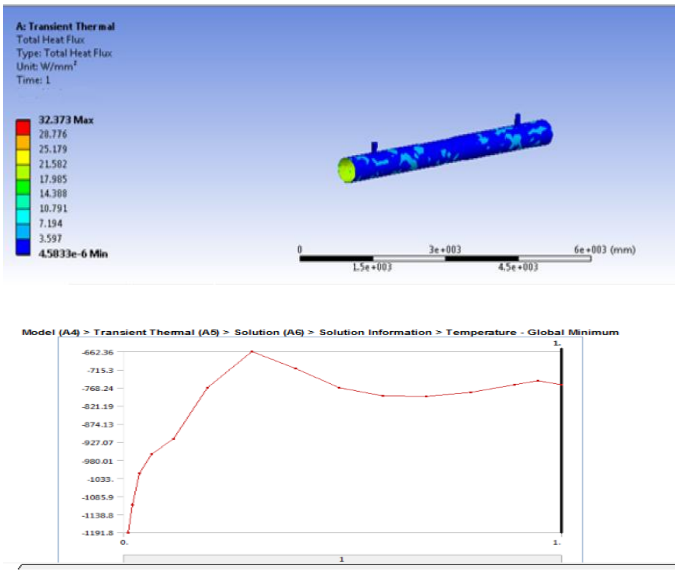


Fig 9: Temperature Transient Thermal

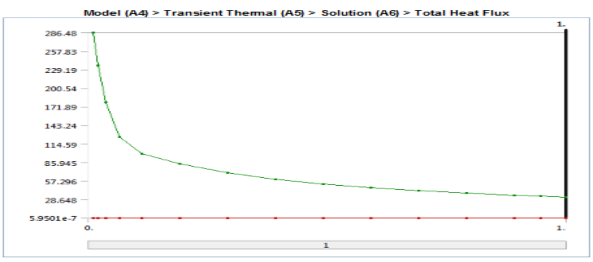


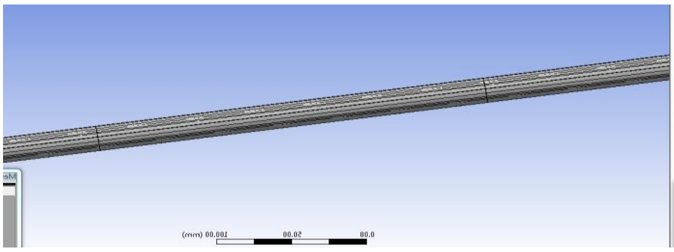
Fig 10: Heat flux

Model (A4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.e-002	1.5302e-005	286.48
2.e-002	8.937e-006	235.52
3.6576e-002	3.9478e-006	178.29
6.4666e-002	1.0092e-006	125.51
0.11262	9.1932e-007	99.61
0.19216	5.9501e-007	83.474
0.29216	8.6854e-007	69.903
0.39216	9.4924e-007	60.089
0.49216	2.93e-006	52.686
0.59216	3.0244e-006	46.904
0.69216	5.3035e-006	42.266
0.79216	7.0191e-006	38.469
0.89216	5.8018e-006	35.313
0.94608	5.1358e-006	33.772
1.	4.5833e-006	32.373

Table 5: Total heat flux

Tube mesh



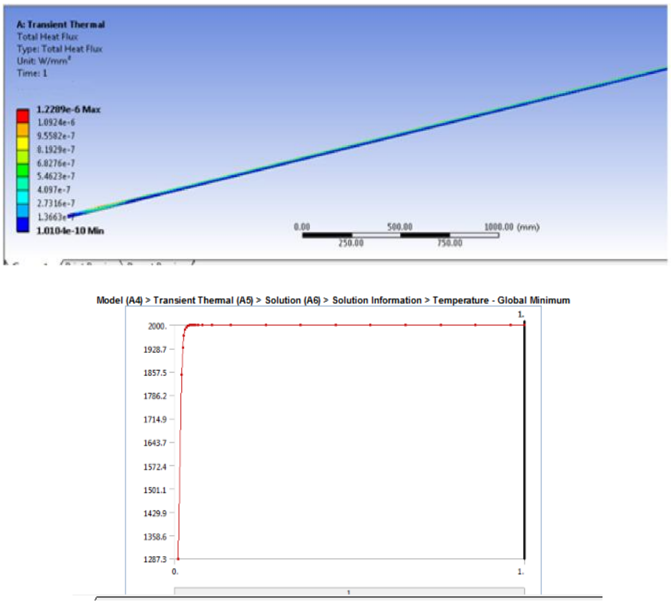


Fig 11: Temperature

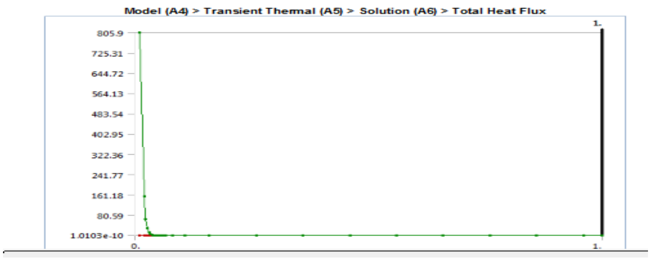


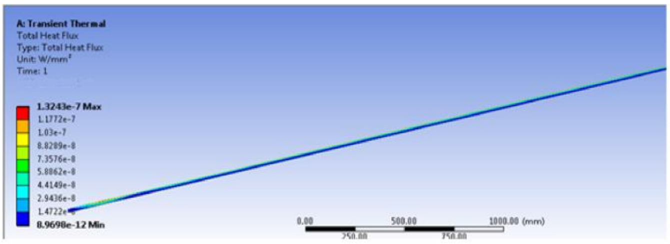
Fig 12: Total Heat Flux

Model (A4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.e-002	5.6389e-003	805.9
2.e-002	6.4504e-004	154.39
2.3333e-002	9.0655e-004	64.447
2.6667e-002	6.2205e-004	28.073
3.e-002	3.3756e-004	12.756
3.3333e-002	1.6144e-004	5.7863
3.6667e-002	7.1102e-005	2.6206
4.e-002	2.9609e-005	1.1852
4.3333e-002	1.1643e-005	0.53537
4.6667e-002	4.3449e-006	0.24199
5.e-002	1.3772e-006	0.10999
5.3333e-002	3.7771e-007	4.998e-002
5.6667e-002	8.3186e-008	2.2704e-002
6.e-002	4.9796e-009	1.031e-002
6.6667e-002	4.5391e-009	3.0276e-003

Table 6: Total heat flux

BRASS -2000



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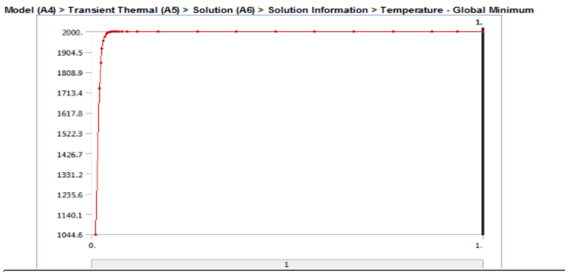


Fig 13: Temperature

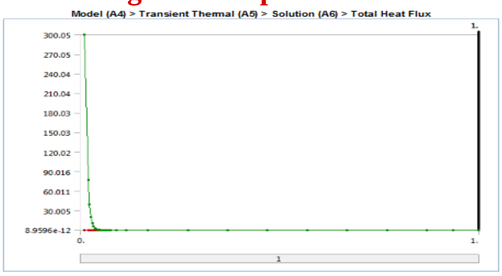


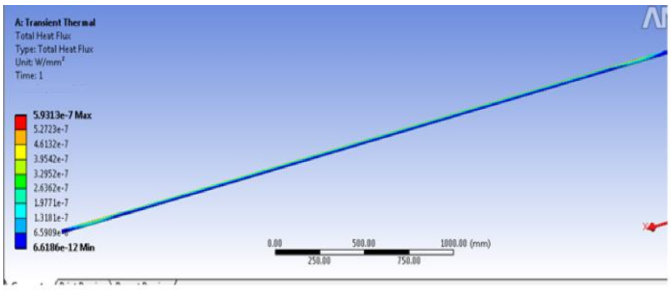
Fig 14: Heat Flux

Model (A4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.e-002	2.3815e-003	300.05
2.e-002	1.5903e-004	77.024
2.3333e-002	4.1551e-004	39.326
2.6667e-002	3.8393e-004	20.137
3.e-002	2.716e-004	10.989
3.3333e-002	1.6826e-004	6.0285
3.6667e-002	9.5949e-005	3.3033
4.e-002	5.1537e-005	1.808
4.3333e-002	2.6417e-005	0.98856
4.6667e-002	1.3006e-005	0.54003
5.e-002	6.1945e-006	0.29477
5.3333e-002	2.8479e-006	0.161
5.6667e-002	1.2451e-006	8.8362e-002
6.e-002	5.1723e-007	4.8487e-002
6.3333e-002	1.6469e-007	2.6604e-002

Table 7: Total heat flux

NICKEL-2000



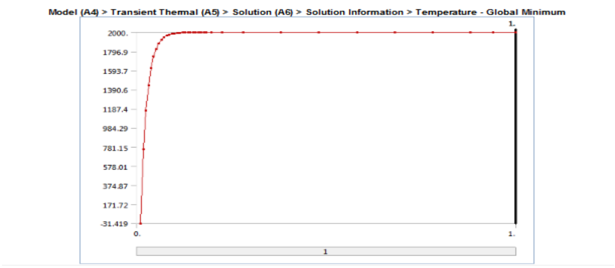


Fig 15: Temperature

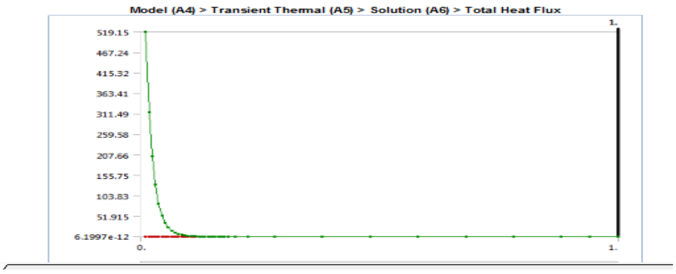


Fig 13: Total Heat

Model (A4) > Transient Thermal (A5) > Solution (A6) > Total Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]
1.e-002	5.9235e-003	519.15
1.7767e-002	2.6842e-003	314.81
2.439e-002	6.9272e-004	203.11
3.1014e-002	3.7439e-004	131.27
3.7868e-002	8.7233e-004	83.951
4.474e-002	9.5546e-004	53.726
5.1624e-002	8.3688e-004	34.917
5.852e-002	6.5706e-004	23.512
6.5425e-002	4.8188e-004	15.814
7.2338e-002	3.3685e-004	10.625
7.9258e-002	2.2702e-004	7.131
8.6185e-002	1.4838e-004	4.7818
9.3118e-002	9.4542e-005	3.2038

Table 8: Total heat flux

CFD Analysis

Computational Fluid Dynamic (CFD) study of the system starts with building desired geometry and mesh for modeling the domain. Generally, geometry is simplified for the CFD studies. Meshing is the discretization of the domain into small volumes where the equations are solved by the help of iterative methods. Modeling starts with defining the boundary and initial conditions for the domain and leads to modeling the entire system domain. Finally, it is followed by the analysis of the results.

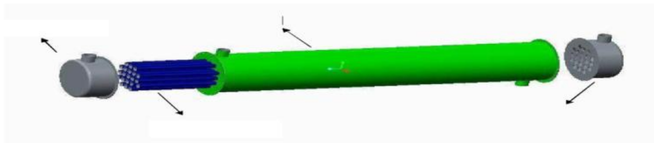


Fig 14: Shell and tube heat exchanger original geometry

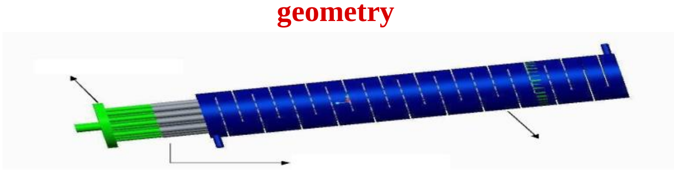


Fig 15: Fluid assembly model of the shell and tube heat exchanger

In our staring of the project we have calculated the design values for our heat exchanger. Those values calculated were used in the CFD simulation for the

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analysis of our heat exchanger designed. Now to study our design our through Ansys we studied the temperature pressure and velocity profiles for our heat exchanger.

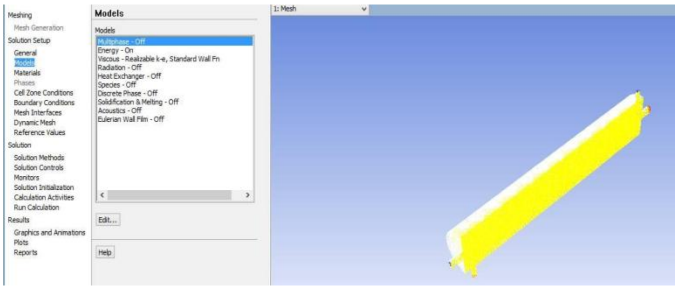
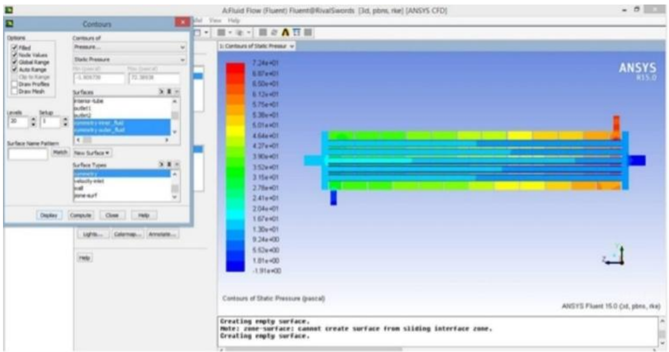


Fig 16: Fluent setup



Sl. No	Velocity (m/s)	Inlet temp (K)	Outlet temp (K)	Mean temp (K)	Reynolds no	Prandtl no	Nusselt no
1.	0.85	298	336	317	10574.15	4.80	71.38
2.	1.00	298	334	316	12440.17	5.12	83.42
3.	1.15	298	333	315.5	14306.21	5.45	95.65
4.	1.30	298	331	314.5	16172.23	5.69	107.34

Table 9: Tube side data

SL. No	Tube fluid velocity (m/s)	Shell fluid velocity (m/s)	Shell inlet Temp (K)	Shell Outlet Temp (K)	Mean Temp (K)	Prandtl No	Reynolds No	Nusselt No
1.	0.85	0.0709	393	356	374.5	0.221	2427.40	7.46
2.	1.00	0.0709	393	354	373.5	0.227	2455.55	7.59
3.	1.15	0.0709	393	350	371.5	0.230	2467.78	7.65
4.	1.30	0.0709	393	342	367.5	0.234	2479.43	7.72
5.	1.45	0.0709	393	340	366.5	0.238	2484.56	7.77

Table 10: Shell side data

Sl. No	Velocity (m/s)	Inner Heat Transfer Co-eff.(W/m²K)	Outer Tube Heat Transfer Co-eff. (W/m²K)	Friction factor.(f)	Overall Heat Transfer co-eff. (W/m²K)
1	0.85	2226.25	2042.34	0.00779	317.75
2	1.00	2443.85	2342.50	0.00748	330.45
3	1.15	2764.30	2576.32	0.00722	343.85
4	1.30	2957.51	2897.45	0.00701	355.46
5	1.45	3219.46	3157.92	0.00681	363.80

Table 11: Overall Heat Transfer coefficient (W/m^2K)

RESULT

The heat transfer rate is poor because most of the fluid passes without the interaction with baffles. Thus the design can be modified for better heat transfer in two ways either the decreasing the shell diameter, so that it will be a proper contact with the helical baffle or by increasing the baffle so that baffles will be proper contact with the shell. It is because the heat transfer area is not utilized efficiently. Thus the design can further be improved by creating cross-flow regions in such a way that flow doesn't remain parallel to the tubes. It will allow the outer shell fluid to have contact with the inner shell fluid, thus heat transfer rate will increase. The shell and tube heat exchanger is designed is simulated using Computational Fluid Dynamic (CFD).

Thus improvement is expected if complete geometry is modeled. Furthermore, the enhanced wall functions are not used in this project due to convergence issues, but they can be very useful with k−epsilon models. The heat transfer is found to be poor because the most of the shell side fluid by-passes the tube bundle without interaction.

CONCLUSION

The heat transfer and flow distribution is discussed in detail and proposed model is compared With increasing baffle inclination angle. The model predicts the heat transfer and pressure drop with an average error of 20%. Thus the model can be improved. The assumption worked well in this geometry and meshing expect the outlet and inlet region where rapid mixing and change in flow direction takes place. Thus improvement is expected if the helical baffle used in the model should have complete contact with the surface of the shell, it will help in more turbulence across shell side and the heat transfer rate will increase. If different flow rate is taken, it might be help to get better heat transfer and to get better temperature difference between inlet and outlet. Moreover the model has provided the reliable results by considering the standard k-e and standard wall function model, but this model over predicts the turbulence in regions with large normal strain. Thus this model can also be improved by using Nusselt number and Reynolds stress model, but with higher computational theory.

Further more the enhance wall function are not use in this project, but they can be very useful. The header selection for the heat exchanger has also been based on the Computational Fluid Dynamic (CFD) simulation. We can see that the uniform flow in tubes can be achieved using a suitable header. The nozzle placement normal to the plane of tubes and also eccentric to the head side of the headers has been the most effective. The simplified geometry of the shell and tube heat exchanger is used. The assumption of plane symmetry works well for most of the length of heat exchanger except the outlet and inlet regions where the rapid mixing and change in flow direction takes place. Thus improvement is expected if complete geometry is modeled. Furthermore, the enhanced wall functions are not used in this project due to convergence issues, but they can be very useful with k−epsilon models. The heat transfer is found to be poor because the most of the shell side fluid by-passes the tube bundle without interaction. Thus the design can be modified in order to achieve the better heat transfer in two ways. Either, the shell diameter is reduced to keep the outer fluid mass flux lower or tube spacing can be increased to enhance the inner fluid mass flux.

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