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Optimization of Shell Side Design of Shell and Tube Heat Exchanger by Numerical Analysis

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Abstract

Shell and Tube Heat Exchanger (STHE) has its own importance in the industrial applications .The improvement of efficiency of the STHE using different design modifications in the shell side results in increase of overall efficiency. In that view, Numerical simulations are carried for a shell and tube heat exchanger for optimum design of baffle. Numerical analysis are conducted on shell and tube heat exchanger with number of baffles (No baffle, 1, 2, 3, 4, 5 and 6), different baffle cuts (10 %, 20 %, 30 %, 40 % and 50 % along the diameter of baffle) and different baffle inclinations (10^0, 20^0, 30^0,and 40^0) At different mass flow rates of water and glycerin are utilized to calculate heat transfer rate and pressure drop variations in shell side of STHE with different baffle modifications. From numerical analysis among all number of baffle arrangements 4 baffle arrangement gives better results and that are 387.03 watts and 0.439891 Pascal's. Keep that 4 number of baffles are constant and calculate thermal performance at altered baffle cuts. At 4 baffle arrangement 30 % baffle cut along the diameter gives better results and that are 390.05 watts and 0.5808 Pascal's Finally keep 4 baffle arrangement and 30 % baffle cut are constant and different baffle inclinations are considered to evaluate heat transfer rate and pressure drop of STHE. From the above results it is concluded that shell and tube heat exchanger with 4 number of baffles, 30 % baffle cut and 400 baffle inclination gives better heat transfer rate at lesser pressure drop and these are 555.84 watts and 0.19254 Pascal's.

Key words: Heat transfer, Pressure drop, Shell and tube heat exchanger, baffle cut, baffle angle.

1.Introduction :Heat exchangers are one of the mostly used equipment in the process industries. Heat exchangers are used to transfer heat between two process streams. One can realize their usage that any process which involve cooling, heating, condensation, boiling or evaporation will require a heat exchanger for these purpose. Process fluids, usually are heated or cooled before the process or undergo a phase change. Different heat exchangers are named according to their application. For example, heat exchangers being used to condense are known as condensers, similarly heat exchanger for boiling purposes are called boilers. Performance and efficiency of heat exchangers are measured through the amount of heat transfer using least area of heat transfer and pressure drop. A better presentation of its efficiency is done by calculating over all heat transfer coefficient. Pressure drop and area required for a certain amount of heat transfer, provides an insight about the capital cost and power requirements (Running cost) of a heat exchanger. Usually, there is lots of literature and theories to design a heat exchanger according to the requirements. M. Thirumarimurugan T.Kannadasan and E.Ramasamy [1] have investigated heat transfer study on a solvent and solution by using Shell and Tube Heat Exchanger. In which Steam is taken as the hot fluid and Water and acetic acid-Water miscible solution taken as cold fluid. A series of runs were made between steam and water, steam and Acetic acid solution .The flow rate of the cold fluid is maintained from 120 to 720 lph and the volume fraction of Acetic acid is varied from 10-50%. Experimental results such as exchanger effectiveness, overall heat transfer coefficients were calculated. From the comparisons it can be said that the mathematical model developed and simulated using MATLAB and compared with the experimental values for the system is very close. Usman Ur Rahman [2] had investigated an un-baffled shell-and-tube heat exchanger design with respect to heat transfer coefficient and pressure drop by numerically modelling. The heat exchanger contained 19 tubes inside a 5.85m long and 108mm diameter shell. The flow and temperature fields are resolved using a commercial CFD package and it is performed for a single shell and tube bundle and is compared with the experimental results. Standard k- ε model is used first to get the flow distribution but it is not good for predicting the boundary layer separation and impinging flows. 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 mix with the inner shell fluid and will automatically increase the heat transfer. Jian-Fei Zhang, Ya-Ling He, Wen-Quan Tao [3] developed a method for design and rating of shell-and-tube heat exchanger with helical baffles based on the public literatures and the widely used Bell–Delaware method for shell-and-tube heat exchanger with segmental baffles (STHXSB). The accuracy of present method is validated with experimental data. Four design cases of replacing original STHXsSB by STHXsHB are taken. In case 1 comprehensive performance is greatly improved by using tube-core with 40 degree middle overlapped helical baffles, and the pressure drop is 39% lower and 16% decrease in heat transfer area. In case 2 the usage of tube-core with 40 deg middle overlapped helical baffles can reduce the over-all pressure drop by 46% and the heat transfer area is 13% lower. In case 3 pressure drop of the heat exchanger with 40 deg middle-overlapped helical baffles is equivalent, the heat transfer area reduced by 33%. Muhammad Mahmoud Salam Bhutta, Nasir Hayat, Muhammad HassanBashir,AhmerRaisKhan,KanwarNaveed Ahmad, SarfarazKhani[4] , It focuses on the applications of Computational Fluid Dynamics (CFD) in the field of heat exchangers. It has been found that CFD employed for the fluid flow mal-distribution, fouling, pressure drop and thermal analysis in the design and optimization phase. Different turbulence models such as standard, realizable and RNG, k – ε, RSM, and SST k - ε with velocity-pressure coupling schemes such as SIMPLE, SIMPLEC, PISO and etc. 25 . have been adopted to carry out the simulations. Conventional methods used for the design and development of Heat Exchangers are expensive. The simulations results ranging from 2% to 10% with the experimental studies. In some exceptional cases, it varies to 36%. ŽarkoStevanović, GradimirIlić, NenadRadojković,MićaVukić,VelimirStefanović, GoranVučković [5] has developed an iterative procedure for sizing shell-and-tube heat Exchangers according to given pressure drop and the thermo-hydraulic calculation and the geometric optimization on the basis of CFD technique have been carried outThe optimization of flow distribution is an essential step in heat exchanger design optimization because an optimal flow distribution can result in a higher heat transfer rate and lower pressure drop. Ender Ozden, IlkerTari. [6] Has investigated the design of shell and tube heat exchanger by numerically modeling in particular the baffle spacing, baffle cut and shell diameter dependencies of heat transfer coefficient and pressure drop. The flow and temperature fields are resolved by using a commercial CFD package and it is performed for a single shell and single tube pass heat exchanger with a variable number of baffles and turbulent flow. By varying baffle

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spacing between 6 to 12 , and the baffle cut values of 36%and 25% for 0.5 and 2kg/s flow rate ,the simulation results are compared with the results from the kern and Bell-Delaware methods. It is observed that the CFD simulation results are very good with the Bell-Delaware methods and the differences between Bell-Delaware method and CFD simulations results of total heat transfer rate are below 2% for most of the cases. The novelty of this work is numerical investigation conducted on altered baffle numbers, baffle inclinations and baffle cuts to evaluate thermal performance of heat exchanger.

2. Numerical Analysis

The availability of affordable high performance computing hardware and the introduction of user-friendly interfaces have led to the development of commercial CFD packages. Before these CFD packages came into the common use, one had to write his own code to carry out a CFD analysis. All formal CFD software contain three elements (i) a pre-processor, (ii) the main solver, and (iii) a post-processor

A. Pre-processor

Pre-processing is the first step of CFD analysis in which the user

(a) defines the modeling goals,

(b) Identifies the computational domain, and

(c) Designs and creates the grid system

B. Processor

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

C. Post-processor

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

3. Virtual models

1. Supporting plates:

Diameter = 100mm

Pitch = 30mm

Hole bundle geometry = Circular

No. of Holes = 7

Hole diameter = 20mm

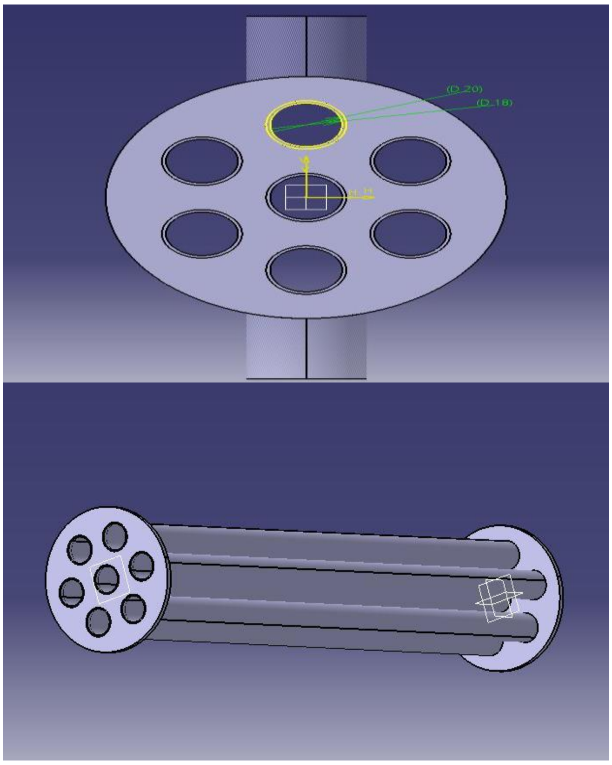

Fig.1 Designed CATIA model of supporting plates and tubes

2. Normal Baffle:

Baffle Diameter = 90mm

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Baffle thickness = 2mm
Baffle spacing = 86mm
No. of Baffles = 6

3.Inclined Baffle:
Baffle Inclination = 30o
Baffle Diameter = 90mm
Baffle thickness = 2mm
Baffle cut = 36%
Baffle spacing = 87mm
No. of Baffles = 6

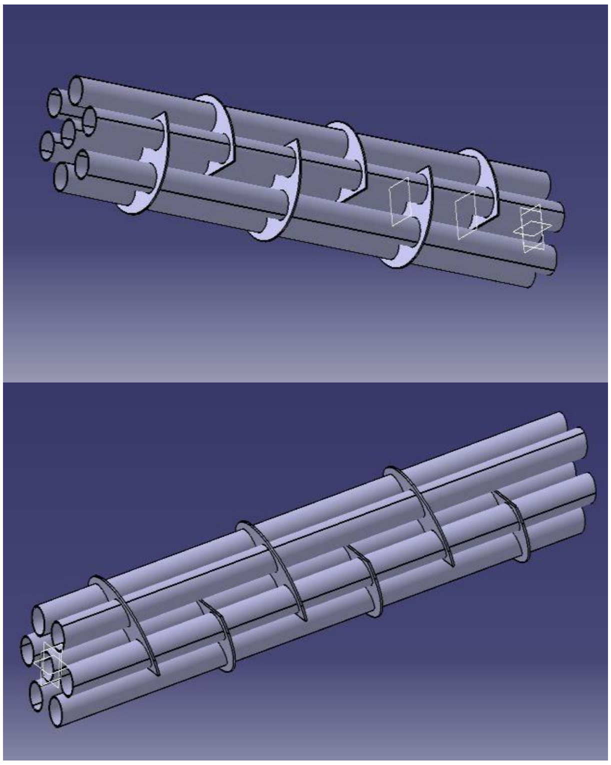

Fig.2 Designed CATIA model of Normal and inclined Baffle

4. Shell:
Shell inner Diameter = 90mm
Shell Thickness = 5mm
Shell Length = 600mm

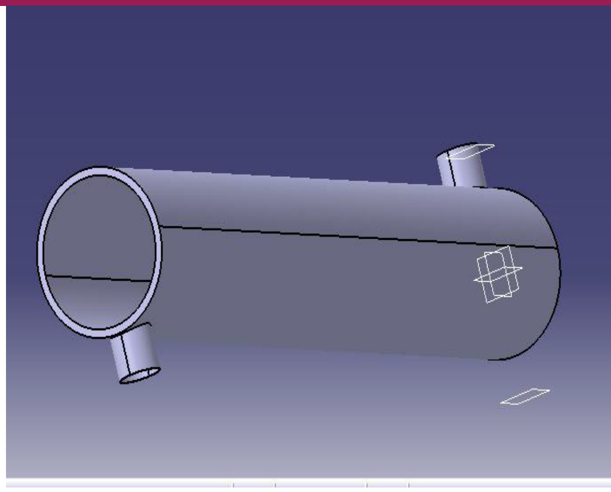

Fig.3 Designed CATIA model of Shell

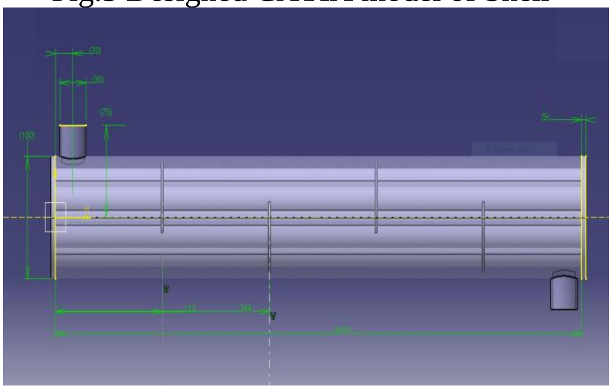

Fig.4 Designed CATIA model of Shell and tube Heat Exchanger

4.Meshing

Initially a relatively coarser 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.

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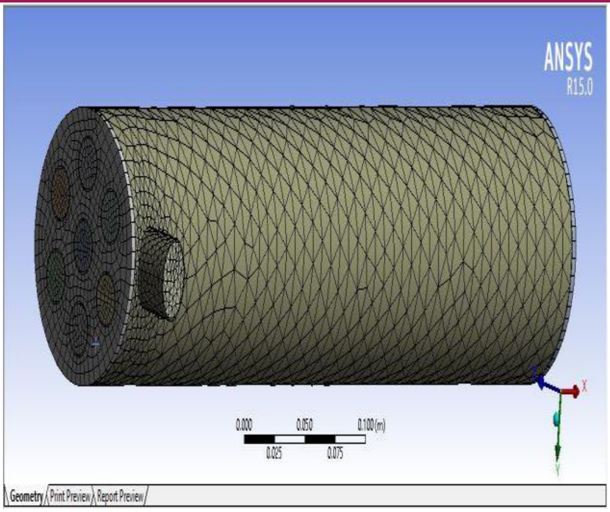

Fig.5 Meshed model of Shell and tube Heat Exchanger

5.Cell Zone Conditions: In cell zone conditions, we have to assign the conditions of the liquid and solid.

Sno.	PART/BODY	MATERIAL
1.	TUBE FLUID	GLYCERINE
2.	SHELL FLUID	COOL WATER
3.	SHELL	STEEL
4.	TUBES	COPPER
5.	BAFFLES	STEEL

6.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. 34

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

	BOUN DARY CONDITION TYPE	VELOCITIES (m/s)	TEMPERATURE (k)
HOT INLET	Velocity inlet	1.24	323
HOT OUTLET	Pressure outlet	-	-
COLD FLUID INLET	velocity inlet	0.00538	293
COLD FLUID OUTLET	Pressure outlet	-	-

The objective of this project is to evaluate the minimum pressure drop in shell side of Shell and Tube Heat Exchanger. Whenever pressure difference is more, it will causes for increasing of entrance velocity and discharge. Baffles are the main parameters which influence the pressure drop. These Baffles are optimized by using fluid flow analysis.

7. Results And Discussions

In this project we are calculate the shell side pressure drop of Shell and Tube Heat Exchanger by varying different types of baffles(without baffle, normal baffle, inclined baffle). From literature survey as compared to all baffles helical baffles gives lesser pressure drop, but the construction and insert the helical baffles in tubes are complicated. So here staggered baffle itself with some design modifications are considered to get lesser pressure drop in shell side of STHE.

7.1 Effects of Heat Transfer & Pressure Drop In Without Baffle

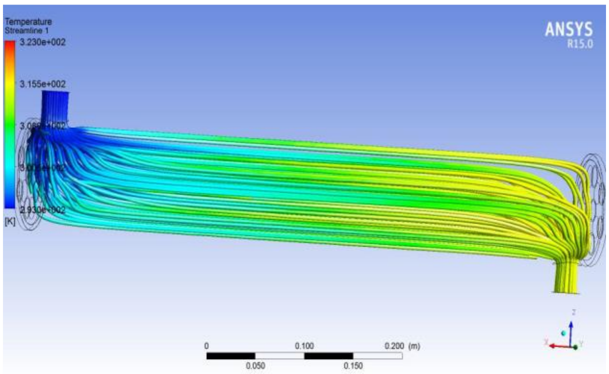

Fig.6 Numerical result of Shell and tube Heat Exchanger

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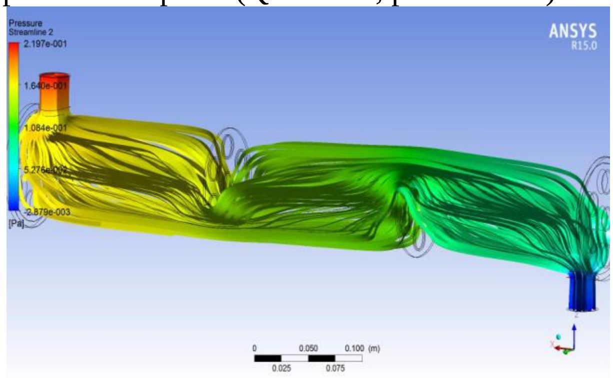
BAFFLES	S.no	mh	cph	mc	cpc	Tci	Tco	Thi	Tho	Qh	QC	Q	Pci	Pco	Pc
without baffles	1	0.3931259	2583	0.003309	4178	293	319.71594	323	322.91077	90.60809	369.3479	229.978	0.12441457	0.016957026	0.107458
	2	0.524136	2583	0.00439203	4178	293	317.34756	323	322.92892	96.23118	446.7753	271.5033	0.19910088	0.028351652	0.170749
	3	0.65517	2583	0.00551	4178	293	315.56369	323	322.93613	108.0875	519.4337	313.7606	0.29291025	0.043976784	0.248933
	4	0.7862043	2583	0.0066156	4178	293	313.93985	323	322.94217	117.4392	578.777	348.1081	0.37633491	0.062597953	0.313737

After doing all the analysis of without baffles, we can obtain the rate of heat transfer (Q) is 348.1081 and pressure drop (P) is 0.313737.

7.2 Effect of Heat Transfer & Pressure Drop in Number of Baffles

In the process we can compare the results of with and without baffles, inserted baffles will give max rate of heat transfer at lower pressure drops

While comparing 1, 2, 3, 4 baffles. 4thbaffle will give more rate of heat transfer at less pressure drops i.e (Q=387.03, p=0.439891).



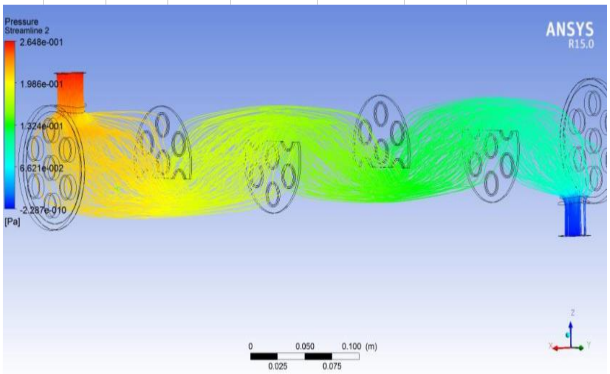


Fig.7 Pressure variation of Shell and tube Heat Exchanger

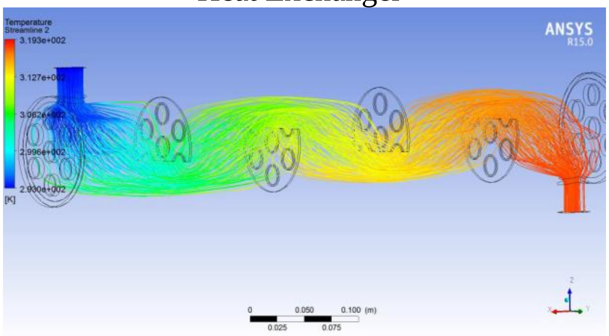
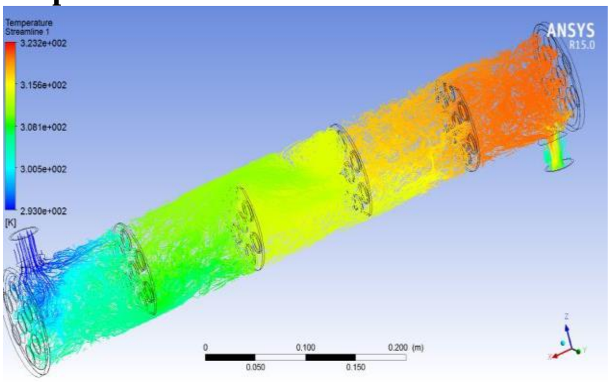


Fig.8 Temperature variation of Shell and tube Heat Exchanger

BAFFLES	S.no	mh	cph	mc	cpc	Tci	Tco	Thi	Tho	Qh	QC	Q	Pci	Pco	Pc
1 BAFFLE	1	0.393126	2583	0.003309	4178	293	319.87943	323	322.91037	91.01426	371.6082	231.3112	0.13530712	0.016815789	0.118491331
	2	0.524136	2583	0.004392	4178	293	317.68283	323	322.92831	97.05703	452.9275	274.9923	0.22389385	0.028081974	0.195811876
	3	0.65517	2583	0.00551	4178	293	315.92422	323	322.94147	99.05056	527.7334	313.392	0.30434233	0.043111656	0.261230674
	4	0.786204	2583	0.006616	4178	293	314.18961	323	322.94016	121.521	585.6803	353.6007	0.39727193	0.064649604	0.332622326
2 BAFFLES	1	0.393126	2583	0.003309	4178	293	320.07382	323	322.90192	99.59477	374.2956	236.9452	0.14668113	0.017348729	0.129332401
	2	0.524136	2583	0.004392	4178	293	317.79117	323	322.91669	112.7887	454.9155	283.8521	0.23790234	0.028934611	0.208967729
	3	0.65517	2583	0.00551	4178	293	316.04367	323	322.92148	132.8797	530.4833	331.6815	0.33040679	0.044111427	0.286295363
	4	0.786204	2583	0.006616	4178	293	314.43671	323	322.92667	148.916	592.5102	370.7131	0.44524091	0.06154849	0.38369242
3 BAFFLES	1	0.393126	2583	0.003309	4178	293	319.879	323	322.90021	101.3312	371.6022	236.4667	0.15845148	0.017475057	0.140976423
	2	0.524136	2583	0.004392	4178	293	317.5528	323	322.90573	127.6268	450.5415	289.0841	0.24146101	0.030075181	0.211385829
	3	0.65517	2583	0.00551	4178	293	315.91519	323	322.9166	141.1382	527.5255	334.3319	0.35912657	0.043584272	0.315542298
	4	0.786204	2583	0.006616	4178	293	314.3728	323	322.92148	159.4557	590.7437	375.0997	0.47270018	0.060242612	0.412457568
4 BAFFLES	1	0.393126	2583	0.003309	4178	293	320.24597	323	322.89548	106.1342	376.6756	241.4049	0.16732897	0.016820213	0.150508757
	2	0.524136	2583	0.004392	4178	293	317.98978	323	322.9068	126.1782	458.56	292.3691	0.28147906	0.029233065	0.252245995
	3	0.65517	2583	0.00551	4178	293	316.2706	323	322.91068	151.1566	535.7074	343.432	0.39417484	0.043735296	0.350439544
	4	0.786204	2583	0.006616	4178	293	314.68698	323	322.914	174.6459	599.4276	**387.0367**	0.50193286	0.062041249	0.439891611
5 BAFFLES	1	0.393126	2583	0.003309	4178	293	319.99451	323	322.89462	107.0075	373.1992	240.1033	0.18491551	0.016902646	0.168012864
	2	0.524136	2583	0.004392	4178	293	317.85318	323	322.90457	129.1973	456.0534	292.6253	0.29805079	0.028933538	0.269117252
	3	0.65517	2583	0.00551	4178	293	316.12936	323	322.90851	154.8289	532.4559	343.6424	0.42329988	0.045039929	0.378259951
	4	0.786204	2583	0.006616	4178	293	314.49991	323	322.91248	177.7326	594.257	385.9948	0.56143713	0.062068064	0.499369066
6 BAFFLES	1	0.393126	2583	0.003309	4178	293	319.58594	323	322.91321	88.1304	367.5507	227.8405	0.47065824	0.016805431	0.453852809
	2	0.524136	2583	0.004392	4178	293	316.90762	323	322.93179	92.34565	438.7025	265.5241	0.44431999	0.029005419	0.415314571
	3	0.65517	2583	0.00551	4178	293	315.08389	323	322.93869	103.7552	508.3884	306.0718	0.6550867	0.044194713	0.610891987
	4	0.786204	2583	0.006616	4178	293	313.53665	323	322.94464	112.4232	567.6325	340.0279	0.89000499	0.062696151	0.827308839

7.3 Effect of Heat Transfer & Pressure Drop In Baffle Cuts



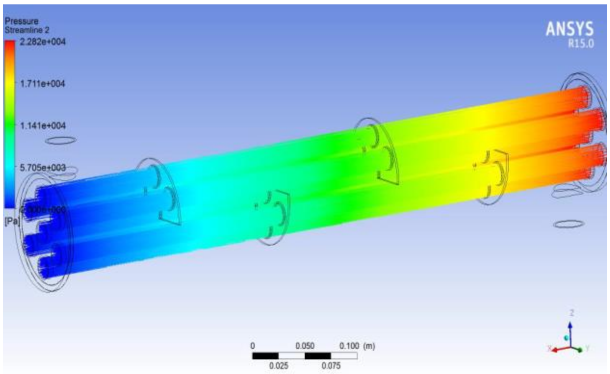


Fig.9 Numerical result of Shell and tube Heat Exchanger

BAFFLE CUTS	S.no	mh	Cph	mc	Cpc	Tci	Tco	Thi	Tho	Qh	QC	Q	Pci	Pco	Pc
10p	1	0.393126	2583	0.003309	4178	293	321.84134	323	322.93802	62.93723	398.7316	230.8344	0.72589445	0.0915187	0.634376
	2	0.524136	2583	0.004392	4178	293	302.5036	323	322.89932	136.3049	174.3901	155.3475	7.3562646	2.0014195	5.354845
	3	0.65517	2583	0.00551	4178	293	317.26834	323	322.91837	138.1428	558.6761	348.4095	6.7862144	0.08412268	6.702092
	4	0.786204	2583	0.006616	4178	293	316.01852	323	322.92877	144.6514	636.2314	390.4414	3.03828	0.06888679	2.969393
20p	1	0.393126	2583	0.003309	4178	293	320.79898	323	322.91159	89.77542	384.321	237.0482	0.23423456	0.0173818	0.216853
	2	0.524136	2583	0.004392	4178	293	318.66428	323	322.89084	147.7855	470.937	309.3613	0.23542367	0.01724879	0.218175
	3	0.65517	2583	0.00551	4178	293	317.04242	323	322.93228	114.6028	553.4753	334.039	0.29543719	0.04726702	0.24817
	4	0.786204	2583	0.006616	4178	293	316.03141	323	322.94217	117.4392	636.5876	377.0134	0.39443619	0.03925903	0.355177
30p	1	0.393126	2583	0.003309	4178	293	320.19177	323	322.89417	107.4645	375.9263	241.6954	0.1935011	0.01707698	0.176424
	2	0.524136	2583	0.004392	4178	293	318.44913	323	322.90155	133.2859	466.989	300.1374	0.30692086	0.0279868	0.278934
	3	0.65517	2583	0.00551	4178	293	316.67084	323	322.90665	157.9766	544.9212	351.4489	0.40846911	0.04492576	0.363543
	4	0.786204	2583	0.006616	4178	293	314.69818	323	322.91068	181.388	599.7372	**390.5626**	0.62986511	0.04901965	0.580845
40p	1	0.393126	2583	0.003309	4178	293	320.22873	323	322.90518	96.28442	376.4372	236.3608	0.15672192	0.01722194	0.1395
	2	0.524136	2583	0.004392	4178	293	318.37625	323	322.91226	118.7862	465.6517	292.2189	0.23546979	0.03025682	0.205213
	3	0.65517	2583	0.00551	4178	293	316.64896	323	322.92603	125.1797	544.4175	334.7986	0.35534215	0.04467557	0.310667
	4	0.786204	2583	0.006616	4178	293	314.98303	323	322.93103	140.0619	607.6104	373.8362	0.46456677	0.06060128	0.403965
50p	1	0.393126	2583	0.003309	4178	293	320.18399	323	322.90991	91.48137	375.8187	233.65	0.14377443	0.01743178	0.126343
	2	0.524136	2583	0.004392	4178	293	322.90991	323	322.91833	110.5684	548.8439	329.7061	0.21881472	0.02995336	0.188861
	3	0.65517	2583	0.00551	4178	293	316.53534	323	322.93396	111.7598	541.8019	326.7808	0.32081175	0.04401107	0.276801
	4	0.786204	2583	0.006616	4178	293	314.7916	323	322.93219	137.7062	602.3193	370.0128	0.41790697	0.06521945	0.352688

In the process we can compare the results of 4thbaffle and baffle cuts, baffles cuts will give max rate of heat transfer at lower pressure drops

While comparing 10%, 20%, 30%, 40%, 50%baffle cuts. 30%baffle cut will give more rate of heat transfer at less pressure drops i.e (Q=390.5,p=0.58).

7.4 Effect Of Heat Transfer & Pressure Drop In Baffle Inclination

In the process we can compare the results of 30%baffle cut and baffle inclinations, baffles inclinations will give more rate of heat transfer at lower pressure drops

While comparing 100, 200, 300,and 400 baffle inclinations. 400baffle inclination will give max rate of heat transfer at less pressure drops i.e. (Q =555.84, p=0.192541).

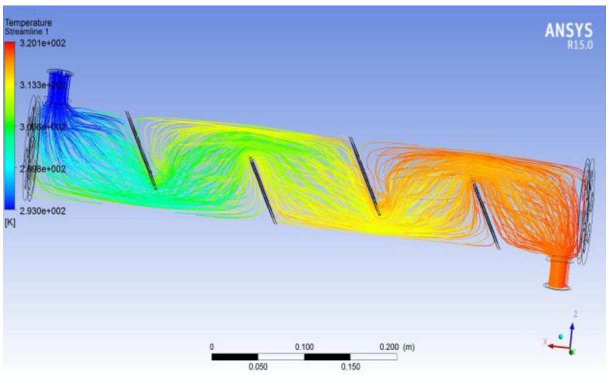


Fig.10 Numerical result of Shell and tube Heat Exchanger

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CONCLUSION

Heat exchanger is a device used to transfer the thermal energy from one fluid to another fluid. The thermal performance of the STHE depends upon different design modifications in the shell side and tube side. The shell side flow mainly depends upon different baffle arrangements. In that view, Numerical simulations are carried for a shell and tube heat exchanger for optimum design of baffle. Numerical analysis are conducted on shell and tube heat exchanger with

a) Number of baffles (No baffle, 1, 2, 3, 4, 5 and 6)

b) Different baffle cuts (10 %, 20 %, 30 %, 40 % and 50 % along the diameter of baffle)

c) Different baffle inclinations (100, 200, 300,and 400)

At different mass flow rates of water and glycerin are utilized to calculate heat transfer rate and pressure drop variations in shell side of STHE with different baffle modifications. From numerical analysis among all number of baffle arrangements 4 baffle arrangement gives better results and that are 387.03 watts and 0.439891 Pascal's. Keep that 4 number of baffles are constant and calculate thermal performance at altered baffle cuts. At 4 baffle arrangement 30 % baffle cut along the diameter gives better results and that are 390.05 watts and 0.5808 Pascal's Finally keep 4 baffle arrangement and 30 % baffle cut are constant and different baffle inclinations are considered to evaluate heat transfer rate and pressure drop of STHE. From the above results it is concluded that shell and tube heat exchanger with 4 number of baffles, 30 % baffle cut and 400 baffle inclination gives better heat transfer rate at lesser pressure drop and these are 555.84 watts and 0.19254 Pascal's. Numerical analysis is a powerful tool and it is used to evaluate thermal performance of STHE without conducting experimentation. By this way it reduces experimentation time and cost. 49 .

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