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Thermal analysis of Helical Baffle in Heat Exchanger

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Abstract: ***An attempt made to decrease the pressure drop and to increase the heat transfer and the ratio of heat transfer and pressure drop in shell and tube type heat exchanger by tilting the baffle angle up to which we get the minimum pressure drop. This study however, considers shell and tube type heat exchanger with the aid of computer programming. It involves developing a simple user-friendly computer programme for the heat transfer calculations and ensures that the computational time is kept minimal. Analysis has been done in shell and tube type heat exchanger at shell side. It analyzes the conventional segmental baffle heat exchanger using the Kern's method with fixed shell side flow rates and varied volume flow rate. Since Kern' method used in design of heat exchangers with a baffle cut of 25% (fixed). The thermal analysis of helical baffle heat exchanger using this method give us clear idea that the ratio of heat transfer coefficient per unit pressure drop is maximum in helical baffle heat exchanger as compared to segmental baffle heat exchanger.***

Keywords: Shell and tube heat exchanger, helical angle, pressure drop, heat transfer, ratio of heat transfer and pressure drop, Kern's method, baffle cut of 25%.

1. Introduction

Heat exchangers have always been an important part to the life-cycle and operations of many systems. A heat exchanger is a device built for efficient heat transfer from one medium to another in order to carry and process energy. Typically one medium is cooled while the other is heated. They are widely used in petroleum refineries, chemical plants, petrochemical plants, natural gas processing, Air conditioning, refrigeration and automotive applications. One common example of a heat exchanger is the radiator in a car, in which it transfers heat from the water (hot engine-cooling fluid) in the radiator to the air passing through the radiator.

There are two main types of heat exchangers:

Direct contact heat exchanger where both media between which heat is exchanged are in direct contact with each other.

Indirect contact heat exchanger where both media are separated by a wall through which heat is transferred so that they never mix.

Shell and tube type heat exchanger is an indirect contact type heat exchanger as it consists of a series of tubes, through which one of the fluids runs. The shell is a container for the shell fluid. Usually, it is cylindrical in shape with a circular cross section, although shells of different shapes are used in specific applications. For this particular study E shell is considered, which a one pass shell is generally. E shell is the most commonly used due to its low cost and simplicity, and has the highest log-mean temperature- difference (LMTD) correction factor. Although the tubes may have single or multiple passes, there is one pass on the shell side, while the other fluid flows within the shell over the tubes to be heated or cooled. Shell-and-tube heat exchangers in various sizes are widely used in industrial operations and energy conversion systems. The optimum thermal design of a shell and tube heat exchanger involves the consideration of many interacting design parameters which can be summarized as follows:

Process
1. Process fluid assignments to shell side or tube side.
2. Selection of stream temperature specifications.
3. Setting shell side and tube side pressure drop design limits.
4. Setting shell side and tube side velocity limits.
5. Selection of heat transfer models and fouling coefficients for shell side and tube side.

Mechanical
1. Selection of heat exchanger TEMA layout and number of passes.
2. Specification of tube parameters - size, layout, pitch and material.
3. Setting upper and lower design limits on tube length.
4. Specification of shell side parameters – materials, baffles cut, baffle spacing and clearances.
5. Setting upper and lower design limits on shell diameter, baffle cut and baffle spacing.

Table 1.1: Heat Exchanger Applications in Different Industries

S. No	*Industries*	*Applications*
1	Food and Beverage	Ovens, cookers, Food processing and pre-heating, Milk pasteurization, beer cooling and pasteurization, juices and syrup pasteurization, cooling or chilling the final product to desired temperatures.
2	Petroleum	Brine cooling, crude oil pre-heating, crude oil heat treatment, Fluid interchanger cooling and acid gas condenser.
3	Hydrocarbon processing	Preheating of methanol, liquid hydrocarbon product cooling, feed pre-heaters, Recovery or removal of carbon dioxide, production of

		ammonia.
4	Polymer	Production of polypropylene, Reactor jacket cooling for the production of polyvinyl chloride.
5	Pharmaceutical	Purification of water and steam, For point of use cooling on water For Injection ring.
6	Automotive	Pickling, Rinsing, Priming and Painting.
7	Power	Cooling circuit, Radiators, Oil coolers, air conditioners and heaters, energy recovery
8	Marine	Marine cooling systems, Fresh water distiller, Diesel fuel pre-heating.

2. Desirable Features of Shell and Tube Heat Exchanger

If very large heat exchange areas are required. Shown below is a bundle of small-diameter tubes which are arranged parallel to each other and reside inside a much larger-diameter tube called the "shell". The tubes are all manifold together at either end.

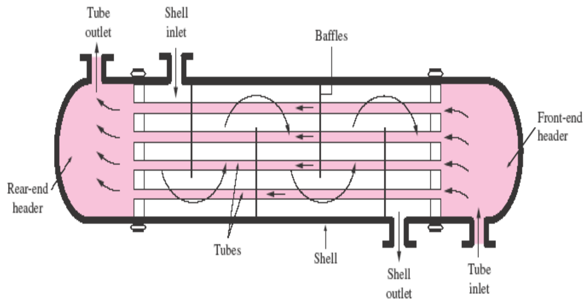


Figure 1: Single pass of shell-1 pass of tube

3. Design Consideration

The various design considerations of a heat exchanger are: selection of working fluid, development of analytical model, analytical consideration and assumptions, procedure, input parameters required, computed parameters. The developments for shell and tube heat exchangers focus on better results for lower pressure drop and for higher heat transfer co-efficient to pressure drop ratio, by improving the conventional baffle design. With single segmental baffles, most of the overall pressure drop is wasted in changing the direction of flow. This kind of baffle arrangement also leads to more undesirable effects such as dead spots or dead zones of recirculation which can cause increased fouling, high leakage flow that bypass heat transfer surface giving rise to lesser heat transfer co-efficient, and large cross flow which not only reduces the mean temperature difference but can even damage the tube.

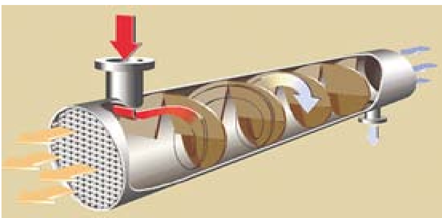


Figure 2: Helical Baffle Heat Exchanger

4. Input Parameters

Input Data – Shell side

S. No.	*Parameter*	*Symbol*	*Shell side*
1	Fluid		Water
2	Flow rate	($\dot{Q}_s$)	80 lpm.
3	Mass flow rate	($\dot{m}_s$)	1 to 1.4 kg/sec
4	Inner Diameter	(D_{is})	0.153 m
5	Length	(L_s)	1.123 m
6	Nozzle ID		0.023 m
7	Specific Heat		0.30 Kcal/kg°C
8	Design Test Pressure		12 kg/cm^2g
9	Design Temperature		342°C

Input Data – Tube side

S. No.	*Parameter*	*Symbol*	*Shell side*
1	Fluid		Water
2	Flow rate	($\dot{Q}_t$)	80 lpm.
3	Mass flow rate	($\dot{m}_t$)	1 to 1.4 kg/sec
4	Outer Diameter	(D_{ot})	0.153 m
5	Thickness		1.123 m
6	Nozzle ID		1
7	Specific Heat		0.33 Kcal/kg°C
8	Design Test Pressure		34 kg/cm^2g
9	Design Temperature		342°C

Fluid Properties

S. No.	*Property*	*Symbol*	*Unit*	*Cold Water (Shell side)*	*Hot Water (Tube side)*
1	Specific Heat	Cp	KJ/kg-K	4.178	4.178
2	Thermal Conductivity	K	W/m-K	0.615	0.615
3	Viscosity	μ	kg/m-s	0.001	0.001
4	Prandtl's Number	Pr	-	5.42	5.42
5	Density	ρ	kg/m^3	996	996

5. Detail values of Heat Exchanger

S. No	*Parameter*	*Segmental Baffle Heat Exchanger*	*10°*	*20°*	*30°*	*40°*	*50°*	*60°*
1	C′	0.0105	.0105	0.0105	0.0105	0.0105	0.0105	0.0105
2	L_b	0.06	0.0847	0.174	0.2775	0.4	0.573	0.832
3	A_s	0.004284	0.0060	0.012	0.0198	0.0285	0.0409	0.0594
4	D_E	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417
5	P_r	5.42	5.42	5.42	5.42	5.42	5.42	5.42
6	N_b	17	13	7	4	3	2	2

6. Observation Table and Calculation

6.1 Mass flow rate (Ms) = 1 kg/sec

S. No.	*Parameter*	*Segmental Baffle Heat Exchanger*	*10°*	*20°*	*30°*	*40°*	*50°*	*60°*
1	Vmax	0.31	0.219	0.106	0.067	0.046	0.032	0.022
2	Re	12902	9135.46	4425.	2790.03	1926.93	1356.73	933.51
3	α_o	1690.51	1398.16	938.5	728.18	594.063	489.81	398.77
4	Mf	233.43	165.28	80.07	50.48	34.73	24.45	16.83
5	f	0.05	0.055	0.06	0.08	0.09	0.11	0.12
6	ΔPs	366.65	149.51	20.51	7.46	3	1.43	0.585
7	$\alpha_0/\Delta Ps$	4.61	9.351	45.75	97.611	198.021	342.524	681.658

6.2 Mass flow rate (Ms) = 1.1 kg/sec

S. No.	Parameter	*Segmental Baffle Heat Exchanger*	*10°*	*20°*	*30°*	*40°*	*50°*	*60°*
1	Vmax	0.31	0.219	0.106	0.067	0.046	0.032	0.022
2	Re	12902	9135.46	4425.7	2790.03	1926.93	1356.73	933.51
3	α_o	1690.51	1398.16	938.53	728.18	594.063	489.81	398.77
4	Mf	256.77	181.81	88.07	55.53	38.2	26.89	18.51
5	f	0.05	0.055	0.06	0.08	0.09	0.11	0.12
6	ΔPs	443.64	180.91	24.82	9.03	3.63	1.73	0.71
7	α_o/ΔPs	3.81	7.728	37.813	80.64	163.653	283.127	561.647

6.3 Mass flow rate (Ms) = 1.2 kg/sec

S. No.	Parameter	*Segmental Baffle Heat Exchanger*	*10°*	*20°*	*30°*	*40°*	*50°*	*60°*
1	Vmax	0.31	0.219	0.106	0.067	0.046	0.032	0.022
2	Re	12902	9135.46	4425.7	2790.03	1926.93	1356.73	933.51
3	α_o	1690.51	1398.16	938.53	728.18	594.063	489.81	398.77
4	Mf	280.11	198.34	96.08	60.57	41.68	29.35	20.19
5	f	0.05	0.055	0.06	0.08	0.09	0.11	0.12
6	ΔPs	527.96	215.29	20.54	10.75	4.32	2.053	0.843
7	α_o/ΔPs	3.201966	6.49431	45.692	67.737	137.514	238.58	473.03

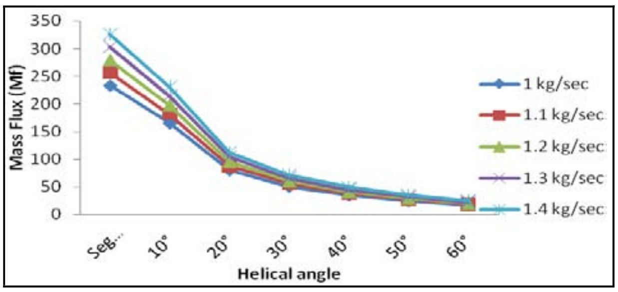
6.4 Mass flow rate (Ms) = 1.3 kg/sec

S. No.	Parameter	*Segmental Baffle Heat Exchanger*	*10°*	*20°*	*30°*	*40°*	*50°*	*60°*
1	Vmax	0.31	0.219	0.106	0.067	0.046	0.032	0.022
2	Re	12902	9135.46	4425.7	2790.03	1926.93	1356.73	933.51
3	α_o	1690.51	1398.16	938.53	728.18	594.063	489.81	398.77
4	Mf	303.45	214.86	104.09	65.62	45.15	31.79	21.87
5	f	0.05	0.055	0.06	0.08	0.09	0.11	0.12
6	ΔPs	619.62	252.67	34.67	12.62	5.067	2.41	0.989
7	α_o/ΔPs	2.728301	5.533	27.07	57.7	117.24	203.242	403.205

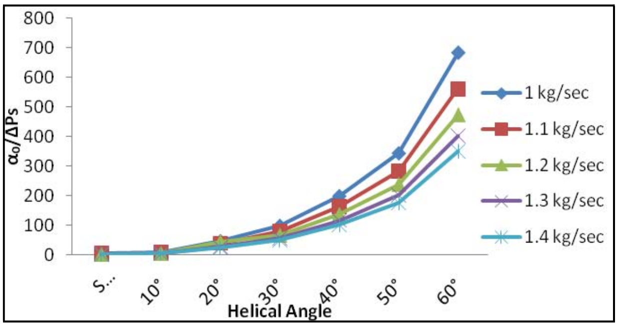
6.5 Mass flow rate (Ms) = 1.4 kg/sec

S. No.	Parameter	*Segmental Baffle Heat Exchanger*	*10°*	*20°*	*30°*	*40°*	*50°*	*60°*
1	Vmax	0.31	0.219	0.106	0.067	0.046	0.032	0.022
2	Re	12902	9135.46	4425.7	2790.03	1926.93	1356.73	933.51
3	α_o	1690.51	1398.16	938.53	728.18	594.063	489.81	398.77
4	Mf	326.8	231.39	112.09	70.66	48.62	34.24	23.56
5	f	0.05	0.055	0.06	0.08	0.09	0.11	0.12
6	ΔPs	718.62	293.037	40.2	14.64	5.88	2.79	1.14
7	α_o/ΔPs	2.3524	4.771	23.346	49.739	101.03	175.55	349.79

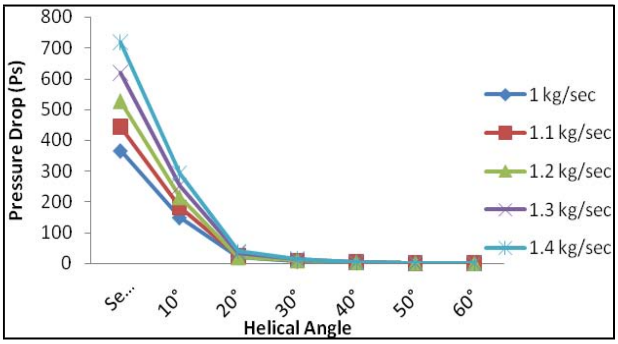
7. Results and Discussions



Graph plot between shell-side mass flux and helical angle



Graph plot between ratios of heat transfer co-efficient & pressure drop and helical angle



Graph plot between pressure drop and helical angle

8. Conclusion

An analytical model has been developed to evaluate thermal analysis of a segmental baffle and helical baffle heat exchanger as well as the comparative analysis between the thermal parameters between segmental and helical angle has carried out. The model evaluates the rate of pressure drop of a segmental baffle as well as for the helical baffle heat exchanger. Computational obtained at 5° to 60o tilt angle for the baffle. The significant observations and conclusions obtained from the above analysis is that Compared to the conventional segmental baffled shell and tube exchanger Helix changer offers the following general advantages.

a) Reduced bypass effects.
b) Reduced shell side fouling.
c) Prevention of flow induced vibration.
d) Reduced maintenance.

The helix-changer type heat exchangers can save capital cost as well as operating and maintenance cost and thus improves the reliability and availability of process plant in a cost effective way.

9. Future Scope

- The study can be carried out using different fluid in the shell side heat exchanger such as iso-propane, iso-butane and other fluid and one side fluid and other side air can also be carried out.
- In present work only shell-side heat transfer coefficient, pressure drop and its ratio is been analyzed further tube side heat transfer coefficient, pressure drop and its ratio can also be analyzed.

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Nomenclature

Symbol	*Quantity*
A_s	Cross-section area (m^2)
L_b	Baffle spacing (m)
B_c	Baffle cut (25%) fixed
C'	Tube Clearance (m)
D_E	Equivalent Diameter (m)
D_{otl}	Outer tube limit diameter (m)
D_s	Inside diameter of shell (m)
f	Friction Factor
K	Thermal Conductivity (W/m-k)
α_o	Shell-side heat-transfer coefficient ($W/m^2.k$)
N_b	Number of baffles
P_r	Prandtl's number
R_e	Shell-side Reynolds number
S_{sb}	Shell-to-baffle leakage area (m^2)
S_{tb}	Tube-to-baffle leakage area (m^2)
V_{max}	Maximum Velocity (m/sec)

Greek Symbols

Symbol	*Quantity*
ΔP_C	Cross flow pressure drop (Pa)
ΔP_s	Shell-side pressure drop (Pa)
ΔS_b	Shell-to-baffle clearance (m)
ΔS_{tb}	Tube-to-baffle clearance (m)
μ	Viscosity ($kg\text{-}s/m^2$)
ρ	Fluid density (kg/m^3)
Vmax	Maximum inter-tube velocity (m/s)
$\dot{Q}_s$	Volume flow rate
$\dot{m}_s$	Mass flow rate
$\dot{M}_f$	Shell side mass flux
α	Helical angle (degree)

Author Profile

Mayank Vishwakarma has done B.E from Hitkarini College of Engineering and Technology (HCET), Jabalpur (M.P) India, in 2009 and is now pursuing Master of Engineering IV Semester in Mechanical Engineering with Heat Power Engineering as specialization from Shri Ram Institute of Technology, Jabalpur (M.P) India, having 2 years teaching experience.

Professor K. K. Jain, working as a Head of the Department, Department of Mechanical Engineering at Shri Ram Institute of Technology, Jabalpur obtained B.E (Hons) in Mechanical Engineering and M.E (Heat Power Engineering) from Government Engineering College, Jabalpur, (M.P) India, worked as Principal, Secretary, M.P Board of Technical Education, Madhya Pradesh guided about 15 M.E thesis, number of B.E. projects 25 years of teaching and 16 years Administrative experience. Publication of about 20 research papers in various national & International Journals & Conference.