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Design Methodology of Helical Baffle Heat Exchanger to Improve Thermal Performance

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Abstract — *In present day shell and tube heat exchanger is the most common type heat exchanger widely used in oil refinery and other large chemical process, because it suits high pressure application. 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 varying the baffle angle up to which we get the minimum pressure drop. 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- *Heat Transfer Coefficient, pressure drop, Helical Baffle, Segmental Baffle, Shell and Tube Heat Exchanger*

I. INTRODUCTION

A Heat Exchanger is a device used for efficient heat transfer from one fluid to other fluid a typical heat exchanger is shell and tube heat exchanger. They consist of series of finned tubes in which one of the fluid runs in the tube and the other fluid run over the tube to be heated or cooled During the heat exchanger operation high Pressure High temperature water or steam are flowing at high velocity inside the tube or plate system. Advantages of ,(1) configuration of Shell and Tube heat exchanger provide larger surface area with a small shape(2) This type of heat exchanger is good mechanical layout and good for pressurized operation.(3)Shell and Tube Heat Exchanger is Easy to clean (4) The shell and tube heat exchanger is made up of different type of materials in which selected materials is used for operating pressure and Temperature.

Baffle is an important shell side component of STHXs. Besides supporting the tube bundles, the baffles form flow passages for the shell side fluid in conjunction with the shell. The most commonly used baffles is the segmental baffle, which forces the fluid in a zigzag manner, thus improving the heat transfer but with a large pressure drop penalty. This type of heat exchanger has been well developed [2-5] & probably is still the most commonly used type of the shell & tube heat exchanger. The major draw backs of the conventional shell & tube heat exchangers with segmental baffles are threefold: firstly it causes a large side pressure drop; secondly it results in a dead zone in each component between 2

II. DESIRABLE FEATURES OF A HEAT EXCHANGER

The desirable features of a heat exchanger would be to obtain maximum heat transfer to Pressure drop ratio at least possible operating costs without comprising the reliability. 2.1 Higher heat transfer co-efficient and larger heat transfer area A high heat transfer coefficient can be obtained by using heat transfer surfaces, which promote local turbulence for single phase flow or have some special features for two phase flow. Heat transfer area can be increased by using larger exchangers, but the more cost effective way is to use a heat exchanger having a large area density per unit exchanger volume, maintaining the Integrity of the Specifications. 2.2 Lower Pressure drop

Use of segmental baffles in a Heat Exchanger result in high pressure drop which is undesirable as pumping costs are directly proportional to the pressure drop within a Heat Exchanger. Hence, lower pressure drop means lower operating and capital costs.

2.1 DEVELOPMENTS IN SHELL AND TUBE EXCHANGER

The developments for shell and tube exchangers focus on better conversion of pressure drop into heat transfer i.e 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 grievous undesirable effects such as dead spots or zones of recirculation which can cause increased fouling, high leakage flow that bypasses the heat transfer surface giving rise to lesser heat transfer co-efficient, and large

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cross flow. The cross flow not only reduces the mean temperature difference but can also cause potentially damaging tube vibration

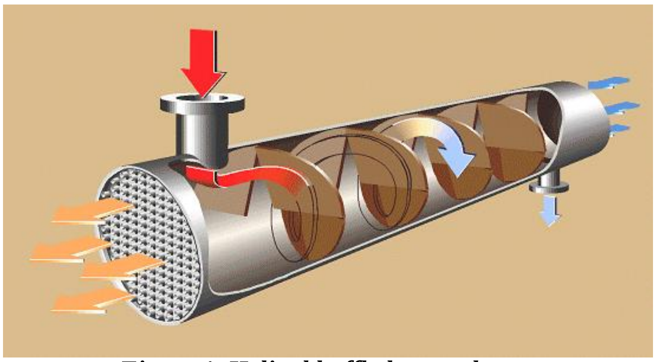

Figure 1. Helical baffle heatexchanger

Helical baffle Heat Exchanger The baffles are of primary importance in improving mixing levels and consequently enhancing heat transfer of shell-and-tube heat exchangers. However, the segmental baffles have some adverse effects such as large back mixing, fouling, high leakage flow, and large cross flow, but the main shortcomings of segmental baffle design remain [3] Compared to the conventional segmental baffled shell and tube exchanger Helixchanger offers the following general advantages. [4]

A. Increased heat transfer rate/ pressure drop ratio.
B. Reduced bypass effects.
C. Reduced shell side fouling.
D. Prevention of flow induced vibration
E. Reduced maintenance

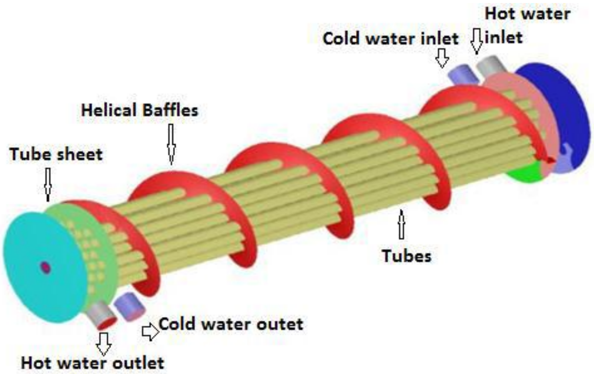

Figure 2. Component of helical baffle heat exchanger

Design aspects An optimal design of a helical baffle arrangement depends largely on the operating conditions of the heat exchanger and can be accomplished by appropriate design of helix angle, baffle overlapping, and tube layout. The original Kern method is an attempt to co-relate data for standard exchangers by a simple equation analogous to equations for flow in tubes. However, this method is restricted to a fixed baffle cut of 25% and cannot adequately account for baffle-to-shell and tube-to-baffle leakages. Nevertheless, although the Kern equation is not particularly accurate, it does allow a very simple and rapid calculation of shell side co-efficients and pressure drop to be carried out and has been successfully used since its inception. [5]

A. Important Parameters
B. Pressure Drop (ΔP_S)
C. Helical Baffle pitch angle (ϕ)
D. Baffle spacing (L_b)
E. Equivalent Diameter (D_E)
F. Heat transfer coefficient (α_o)

In designing a helical Baffle Heat Exchanger, the pitch angle, baffle's arrangement, and space between the two baffles with the same position are some of the important parameters. Baffle pitch angle (ϕ) is the angle between the flow and perpendicular surface on exchanger axis and LB is the space between two corresponding baffles with the same position. Optimum design of helical baffle heat exchangers is dependent on the operating conditions of the heat exchanger. Consideration of proper design of Baffle pitch angle, overlapping of baffles and tube's layout results in the optimization of the Heat Exchanger Design. In segmental heat exchangers, changing the baffle space and baffle

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cut can create wide range of flow velocities while changing the helix pitch angle in helical baffle system does the same. Also, the overlapping of helical baffles significantly affects the shell side flow pattern.

III. DESIGN METHEDOLOGY OF HEAT EXCHANGER

Data used in design

Heat Exchanger Data at the shell side

Table 1. Properties of fluid – Shell Side

Property	Symbol	Unit	Hot Steam (Shell)	Cold Juice (Tube)
Specific heat	C_P	KJ/kg K	4.178	$4.16 * 10^3$
Thermal conductivity	K	W/m. K	16	16
viscosity	μ	kg/m. s	0.001	$5.37 * 10^{-4}$
Prandlt's number	Pr	-	5.42	0.13962
density	ρ	kg/m3	1000	1004-1006

Table 2. Input data – Shell Side

Sr No	Quantity	Symbol	Value
1	Volume flow rate	(s)	0.02669
2	Shell side Mass flow rate	(s)	26.80
3	Shell ID	(D_{is})	1
4	Shell length	(L_s)	4.01
5	Tube pitch	(P_t)	0.057
6	No. of passes		32
7	Mean Bulk Temperature	(MBT)	50
8	No. of baffles	(N_b)	0

Table3 . Input data – Tube side

Sr no.	Quantity	Symbol	Value
1	Volume flow rate	(t)	0.033
2	Tube side Mass flow rate	(t)	33.132
3	Tube OD	(D_{ot})	0.045
4	Tube thickness		0.0015
5	Number of Tubes		384
6	Mean Bulk Temperature	(MBT)	50
7	Length of tube	L_s	4.01

3.1 Calculation for No of tube required for heat exchanger

$$Q = m_{pc} * c_{pc} * (t_2 - t_1) = m_{ph} * c_{ph} * (T_2 - T_1)$$

$$LMTD = \frac{(T_2 - T_1) - (t_2 - t_1)}{\ln\left(\frac{T_2 - T_1}{t_2 - t_1}\right)} = \frac{(120 - 95) - (60 - 30)}{\ln\left(\frac{120 - 95}{60 - 30}\right)} = 27.427$$

Area reqired for heat transfer

$$A = \frac{Q}{LNTD * F_T * U} = \frac{28.89 * 4160 * 30}{27.45 * 0.889 * 600} = 246$$

No of tube reqired

$$n_t = \frac{A}{\pi * d_0 * L_t} = 434$$

3.2 Thermal analysis of segmental Baffle Heat Exchanger

1. Tube clearance $C'' = P_t - D_{ot} = (0.057 - 0.045)$
2. Cross-flow Area (AS)

$$A_s = \frac{D_{is} * C' * L_B}{P_t} = \frac{1 * 0.012 * 0.25}{0.057} = 0.0526$$

3. Equivalent Diameter

$$D_E = 4[\frac{P_t^2 - \pi * \frac{D_{ot}^2}{4}}{\pi * D_{ot}} = 4[\frac{0.057^2 - \pi * \frac{0.045^2}{4}}{\pi * 0.045} = 0.0494$$

4. Maximum Velocity (Vmax)

$$V_{max.} = \frac{Q_S}{A} = \frac{0.02669}{\pi * \frac{1^2}{4}} = 0.03399$$

5. Reynold"s number (Re)

$$R_e = \frac{\rho * V_{max.} * D_E}{\mu} = \frac{1004 * 0.03399 * 0.0494}{5.37 * 10^{-4}} = 3139.6962$$

6. Prandtl"s no.

$$P_r = \frac{\mu * C_p}{k} = \frac{5.37 * 10^{-4} * 4.16 * 10^3}{16} = 0.13962$$

7. Heat Transfer Co-efficient (αo)

$$\alpha_0 = \frac{0.36 * K * R_e^{0.55} * P_r^{0.33}}{R * D_E}$$

$$= \frac{0.36 * 16 * 3139.6962^{0.55} * 0.13692^{0.33}}{0.537 * 0.0494}$$

$$= 9.4\ KW/m^2K$$

8. Pressure Drop (ΔPS)

$$\Delta P_s = \frac{[4 * f * m_s * D_{is} * (N_b + 1)]}{2 * \rho * D_E} = \frac{4 * 0.08 * 1 * 1}{2 * 1004 * 0.0494} = 837.79\ Pa$$

3.3 Thermal analysis of Helical Baffle Heat Exchanger (Baffle helix angle 15^0)

1. Tube clearance

$$C'' = P_t - D_{ot} = (0.057 - 0.045) = 0.012$$

2. Baffle Spacing (Lb)

$$L_b = \pi * D_{is} * \tan \emptyset = \pi * 1 * \tan 15° = 0.84176$$

3. Cross-flow Area (A_S)

$$A_s = \frac{D_{is} * C' * L_B}{P_t} = \frac{1 * 0.012 * 0.84176}{0.057} = 0.17721$$

4. Equivalent Diameter

$$D_E = 4[\frac{P_t^2 - \pi * \frac{D_{ot}^2}{4}}{\pi * D_{ot}} = 4[\frac{0.057^2 - \pi * \frac{0.045^2}{4}}{\pi * 0.045} = 0.0494$$

5. Maximum Velocity (Vmax)

$$V_{max.} = \frac{Q_S}{A} = \frac{0.02669}{0.17721} = 0.150612$$

6. Reynold"s number (Re)

$$R_e = \frac{\rho * V_{max.} * D_E}{\mu} = \frac{1004 * 0.150612 * 0.0494}{5.37 * 10^{-4}} = 13910.6028$$

7. Prandtl's no.

$$P_r = \frac{\mu * C_p}{k} = \frac{5.37 * 10^{-4} * 4.16 * 10^3}{16} = 0.13962$$

8. Heat Transfer Co-efficient (α_o)

$$\alpha_0 = \frac{0.36 * K * R_e^{0.55} * P_r^{0.33}}{R * D_E}$$
$$= \frac{0.36 * 16 * 13910.6028^{0.55} * 0.13692^{0.33}}{0.537 * 0.0494} = 21.52 \text{ KW/m}^2\text{K}$$

9. No. of Baffles (Nb)

$$N_b = \frac{L_S}{L_b + \Delta_{SB}} = \frac{4.01}{0.84176 + 0.005} = 4.78 \cong 5$$

10. Pressure Drop (ΔPS)

$$\Delta P_s = \frac{[4 * f * m_s * D_{is} * (N_b + 1)]}{2 * \rho * D_E}$$
$$= \frac{4 * 0.08 * 151.2644^2 * 1 * (5 + 1)}{2 * 1004 * 0.0494} = 442.87\ Pa$$

Table 4. Summary of designed heat exchanger

Helix angle	Heat Transfer Co-efficient (αo)	Pressure Drop (ΔPS)	No of baffles
Without helical baffles	9.4	837.79	-
15°	21.52	442.87	5
25°	13.49	53.98	3
35°	12.69	32.425	2

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45°	10.37	15.9	2
55°	8.5	5.19	1

V. CONCLUSION

In the present study, an attempt has been made to design and modify the simple heat exchanger by providing helical baffles. Use of Helical Baffles in Heat Exchanger Reduces Shell side Pressure drop, pumping cost, weight, fouling etc as compare to Segmental Baffle for a new installation. The Pressure Drop in Helical Baffle heat exchanger is appreciably lesser as Compared to Segmental Baffle heat exchanger.

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