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Design and Thermal Analysis of Segmental baffle and Helical baffle in Shell and Tube Heat Exchangers using Kern method

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Abstract— *Shell and Tube Heat exchangers are the most common type of heat exchanger widely used in oil refineries, automobiles, aerospace applications because it suits for high pressure applications. An effort is made in this paper to design Shell and Tube Double Pass Heat Exchanger with helical baffle and comparing with segmental baffle using kern method. The helixangle of baffle is varying from 0 to 50 degrees .The paper also consists of thermal analysis of a heat exchanger with helical baffles using the Kern method, which has been modified to approximate results for different helical angles. The result obtained shows us a clear idea that the Overall heat coefficient is maximum in helix changer as compared to segmental baffle. The pressure drop decreases with the increase in helix angle. Helix angle of 6 degree has better heat transfer than the one with an angle of 18 degree as it expenses pumping cost.*

Keywords— Kern method, helical baffle heat exchanger, helix angle, heat transfer coefficient, pressure drop, shell and tube heat exchanger.

I. INTRODUCTION

Generation of Motive Power was the Mother of Heat Exchanger Invention. The role of heat exchanger is to serve in a straight forward manner i.e. controlling the system's temperature by adding or removing the thermal energy. In other words, a heat exchanger is a device in which heat transfer from one fluid to another fluid occurs. The heat transfer device, used since the dawn of civilization, is a simple boiler for preparation of food, placed above an open fire. A good Heat exchanger is a true Mediator. It mediates the process by doing the action called heat transfer. The elementary steam boiler is considered as the first heat exchanger. There are different types of heat exchangers which are classified on the basis of nature of heat exchange process, relative direction of fluid motion, design and constructional features and physical state of fluids. Heat exchangers being one of the most important heat & mass transfer apparatus in industries like oil refining, chemical engineering, electric power generation etc. are designed with preciseness for optimum performance and long service life.

A. Shell and Tube Heat Exchanger:

Highest Thermal performance is the key factor determining the efficiency of any shell and Tube Heat exchanger [1]. Shell and Tube Heat Exchanger (STHE) consists bundle of tubes enclosed with in cylindrical shell pass through the tubes and second fluid flows between the tube and shells. The basic components of a shell and tube heat exchangers are tubes, tube sheets, shell and shell Nozzles, tube side channels and nozzles, channel covers, pass divider, baffles etc. Most commonly used STHE have large heat transfer surface area-to-volume ratios to provide high heat transfer efficiency in comparison with others. Shell and tube heat exchangers with segmental baffles have low heat transfer co-efficient due to the segmental baffle arrangement causing high leakage flow by passing through the heat transfer surface and high pressure drop that causes a big problem for industries as the pumping costs increases.

B. Developments in Shell and Tube Heat exchangers:

Shell-and-tube heat exchangers (STHXs) are widely used in many industrial areas, such as power plant, chemical engineering, petroleum refining, and food processing, etc. 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 cross flow. The cross flow not only reduces the mean temperature difference but can also cause potentially damaging tube vibration. To overcome the

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above-mentioned drawbacks of the conventional segmental baffle, a number of improvements or structures were proposed to obtain higher heat transfer coefficient, low possibility of tube vibration, and reduced fouling factor with a mild increase in pumping power. The improvement process includes use various types of baffles such as deflector baffles, disk-and-donut configura- tion, spacing-optimized baffles (Mukherjee, 1992; Saffar-Avval and Damangir, 1995; Li and Kottke, 1998; Stehlik and Wadekar, 2002; Bell, 2004; Soltan et al., 2004). While maintaining a reasonable pres- sure drop across the heat exchangers, the principal shortcomings of the conventional segmental baffle still remain in above-mentioned improvements. Further improvement is to adopt a new type of baffle, called helical baffle, which is the major concern of the present paper. This type of baffle was first proposed by Lutcha and Nemcansky (1990) and then enhanced by Stehlik et al. (1994) and Kral et al. (1996).

C. 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 [5]

Compared to the conventional segmental baffled shell and tube exchanger Helix changer offers the following general advantages. [6]

1. Increased heat transfer rate/ pressure drop ratio.
2. Reduced bypass effects.
3. Reduced shell side fouling.
4. Prevention of flow induced vibration.
5. Reduced maintenance

Research on the helix changer has forced on two principle areas.

1. Hydrodynamic studies and experimentation on the shell side of the Heat Exchanger
2. Heat transfer co-efficient and pressure drop studies on small scale and full industrial scale equipment.

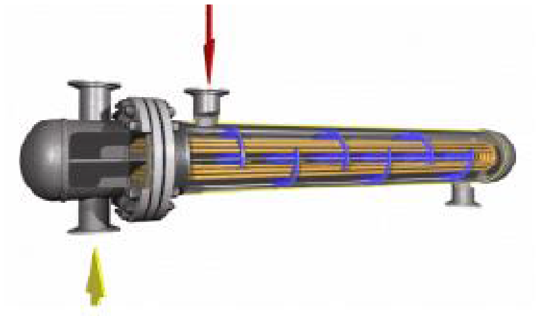


Fig.1: Helical baffle shell and tube Heat Exchanger

D. Kern Method

The first attempt is to provide methods for calculating shell-side pressure drop and heat transfer coefficient were those in which correlations were based on experimental data for typical heat exchangers. One of these methods is the well-known Kern method, which was an attempt to correlate 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 (25%) and cannot adequately account for baffle-to-shell and tube-to-baffle leakages. However, the Kern equation is not particularly accurate; it does allow a very simple and rapid calculation of shell-side coefficients and pressure drop to be carried out and has been successfully used since its inception.

E. Literature Review: Lutcha and Nemcansy upon investigation of the flow field patterns generated by various helix angles used in helical baffle geometry found that the flow patterns obtained in their study are similar to plug flow condition which is expected to decline pressure at shell side and increase heat transfer process significantly. Stehlik et al studied the effect of optimized segmental baffles and helical baffles in heat exchanger based on Bell-Delaware method and demonstrated the heat transfer and pressure decline correction factors for a heat exchanger.

Gang yong Lei et al [1] have showed the effects of baffle inclination angle on flow and heat transfer of a heat exchanger with helical baffles, where the helical baffles are separated into inner and outer parts along the radial direction of the shell. While both the inner and outer helical baffles baffle the flow consistently, smoothly and gently, and direct flow in a helical fashion so as to increase heat transfer rate and decrease pressure drop and impact vibrations, the outer helical baffle becomes easier to manufacture due to its relatively large diameter of inner edge.

Kral et al (1996) discussed the performance heat exchangers with helical baffles based on test results of various baffles geometries. A comparison between the test data of shell side heat transfer coefficient versus shell-side pressure drop was provided for five helical baffles and one segmental baffle measured from a water–water heat exchanger. A gain the case of 40^0 helix angle behaved the best. Wang (2002) measured the flow field in STHXs with helical baffles using laser Doppler anemometry. He pointed out that the optimum helix inclination angle depends on the Reynolds number of the working fluid on the shell side of the heat exchanger. Dr.B.Jayachandriah et al compared the segmental baffle with the helical baffle and found that the effects of helix angles on pressure drop are small when helix angle greater than 18 degree. Shinde et al, [6] has done analyses the conventional segmental baffle heat exchanger by using the modified formulas of Kern method with varied shell side flow rates. He evaluated form his results High Heat Transfer Co-efficient and lower pressure drop are more effectively obtained in a Helix changer. The flow pattern in the shell side of the continuous helical baffle heat exchanger is rotational & helical due to the geometry of continuous helical baffles results in significant increase in heat transfer coefficient.

II. OBJECTIVE OF THE PAPER

This paper contains comparison of helical baffle heat exchanger with segmental baffles. The Main objective of this paper is to show that the helical baffle inside the STHE has greater heat transfer coefficient and can be operated with lower pressure than the segmental baffle.

III. DATA COLLECTION

Table.1: Fluid properties

Property	Symbol	Unit	Cold water (Tube)	Hot Water (Shell)
Specific heat	C_p	KJ/Kg.K	4.178	4.179
Thermal Conductivity	K	w/m k	0.608	0.618
Viscosity	µ	Kg/m.sec	9.040×10^{-4}	7.74×10^{-4}
Prandtls number	Pr	-	6.11	5.31
Density	ρ	Kg/m^3	1000	1000

Table.2: Geometrical parameters-Shell Side

S.NO	DESCRIPTION	UNIT	VALUE
1.	No. of Passes	-	2
2.	Shell inner Diameter , D_i	m	0.387
3.	Shell outer Diameter, D_o	m	
4.	Tube inner diameter, d_i	m	0.0254
5.	Tube outer diameter, d_o	m	0.0220
6.	Number of tubes N_t	-	40
7.	Tube pitch (Triangular) P_t	m	0.031
8.	Baffle inclination angle θ	Deg	0 to 30
9.	Baffle spacing B	m	0.2322
10.	Baffle cut	-	25%
11.	Mean Bulk Temperature	Deg	31.6
12.	Tube length, l	m	6

Table.3: Geometrical parameters-Tube Side

S.NO	Quantity	Symbol	Value
1.	Tube side fluid		Water
2.	Tube side mass flow rate	$\dot{m}_t$	35.28 Kg/sec

3.	Tube outer diameter	d_o	0.0254 m
4.	Tube thickness	-	0.00124 m
5.	Number Tubes	N_t	41
6.	Mean Bulk Temperature	MBT	25.3

IV. MATHEMATICAL ANALYSIS

A. Thermal Analysis of Segmental Baffle

1. Tube Clearance (C)

$$C = P_t - d_{ot}$$

= 0.0238 – 0.0190

= 0.00475m

2. Bundle Cross-flow Area (AS)

$$A_s = (D_{is} \cdot C \cdot B) / P_t$$

= (0.038 • 0.023 • 0.304)/ 0.023

= 0.0235 m^2

3. Equivalent Diameter (D_e)

$$D_e = 4\left[(p_t^2\sqrt{3}/4) - (d_o^2 \cdot \Pi/8)\right] - [\Pi \cdot d_0 / 2]$$

=4[(0.0238^2.0.433)-(0.019^2 .0.392)]-0.029

=0.0131 m

4. Maximum Velocity (V_{max})

V_{max}= m_s /ρ.A

=0.187 m/sec

5. Reynolds's number (Re)

Re=ρ .V_{max}. D_e /μ

=1000. 0.187. 0.0131/(7.74×10^{-4})

=3163.76

6. Prandtl Number Pr = $\mu_s C_p / k_s$

=5.23

7.Heat Transfer coefficient (h_s)

h_s= (0.36.K_s .$Re^{0.55}$.$Pr^{0.99}$)/D_e

= (0.36 . 0.6181 . 3163.76$^{0.55}$ .5.23$^{0.99}$)/D_e

=7353.91 W/m^2k

8. Number of Baffles (N_b)

N_b= L/B

=6/0.3048

=19.68

= approx 20

9. Pressure Drop (ΔP_s)

ΔP_s= [f_s.G_s^2.(N_b+1) D_s]/2ρDeϕ_s

=0.384.937.02^2.(20+1).0.387/(2 . 1000 .0.0131 .1)

=104.58 Kpa

B. Thermal Analysis of Helical Baffle Heat Exchanger

1. Tube Clearance (C)

$$C = P_t - d_{ot}$$

= 0.0238 – 0.0190

= 0.00475m

2. Baffle spacing (L_b)

L_b=Π .D_{is} .Tanϕ

=Π.0.384.Tan (18^0)

=0.3919

2. Bundle Cross-flow Area (AS)

$$A_s = (D_{is} \cdot C \cdot L_b) / P_t$$

= (0.038 • 0.0047 • 0.3919)/ 0.0238

= 0.030 m^2

3. Equivalent Diameter (D_e)

$$D_e = 4\left[(p_t^2\sqrt{3}/4) - (d_o^2 \cdot \Pi/8)\right] - [\Pi \cdot d_0 / 2]$$

=4[(0.0238^2.0.433)-(0.019^2 .0.392)]-0.029

=0.0131 m

4. Shell Side Mass Velocity (Gs)

Gs= m_s / A_s

=22.02/0.030

=734 Kg/m^2·sec

5. Reynolds's number (Re)

Re=D_e.Gs/μ_s

= 0.0131.734 /(7.74×10^{-4})

=12422.99

6. Prandtl Number Pr = $\mu_s C_p / k_s$

=5.23

7.Heat Transfer coefficient (h_s)

h_s= (0.36.K_s .$Re^{0.55}$.$Pr^{0.99}$)/D_e

= (0.36. 0.6181. (12422.99)$^{0.55}$. 5.23$^{0.99}$)/D_e

=15603.82 W/m^2k

8. Number of Baffles (N_b)

N_b= L/B

=6/0.3919

=15.3

= approx 15

9. Pressure Drop (ΔP_s)

ΔP_s= [f_s.G_s^2.(N_b+1) D_s]/2ρDeϕ_s

=0.384.734^2.(15+1).0.387/(2 . 1000 .0.0131 .1)

=37.39 Kpa

C. Thermal analysis for Tube Side:

1. Tube Clearance (C)

$$C = P_t - d_{ot}$$

= 0.0238 – 0.0190

= 0.00475m

2. Mass Velocity (G_t)

$G_t = m_t / a_t$

$=35.28/0.0172$

$=2051.162$ kg/m^2.sec

3. Reynolds number (Re_t)

$Re_t = d_i.G_t/\mu_t$

$= (0.01656\times2051.162)/(9.040\times10^{-4})$

$=37574.38$

4. Nusselt Number(Nu)

$Nu=0.023 .Re^{0.8}.Pr^{0.4}$

$=0.023.37574.303^{0.8}.6.213^{0.4}$

$=218.206$

5. Heat Transfer (h_t)

$h_t= (Nu.k_t)/d_i$

$= (218\times206\times0.60812)/0.01656$

$=8013$ w/m^{2}k

OVERALL HEAT TRANSFER COEFFICIENT (U_o)

Over All Heat Transfer Coefficient for both shell side & tube side is given by

$1/U_o= [1/h_o] + [1/h_i .d_o/d_i] + [r_o \ln(r_o/r_i)/K_t$

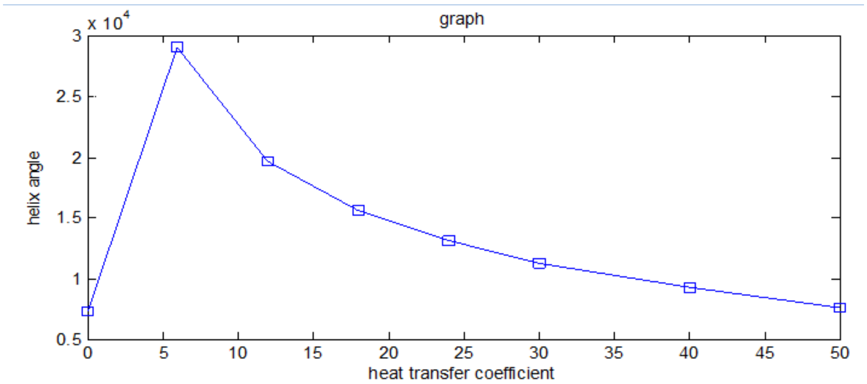
$U_o = 3578.329$ w/m^{2}k

V. RESULTS

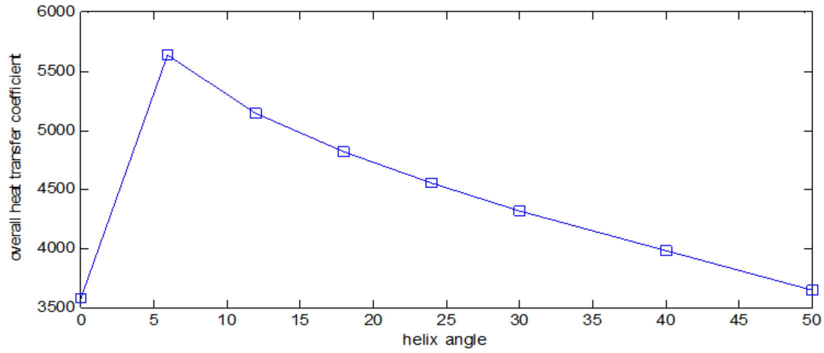
A. Shell Side: The Table.3 shows the results of Overall heat transfer coefficient, Pressure drop at various helix angles of Helical Baffles including Segmental Baffle.

Helix Angle (deg)	**Heat Transfer Coefficient W/m^{2}k**	**Over all heat transfer coefficient W/m^{2}k**	**Pressure drop Kpa**
Segmental	7353.91	3578.32	104.58
6	29106.83	5640.15	291.82
12	19715.70	5147.74	80.8
18	15603.82	4816.02	37.39
24	13111.41	4549.17	21.15
30	11312.43	4311.27	13.20
40	9256.33	3975.19	6.72
50	7634.63	3642.45	3.56

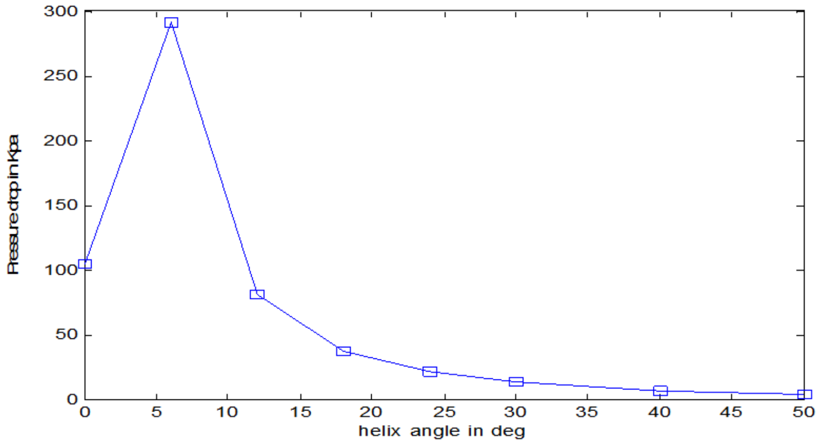
GRAPH PLOTS:



Graph.1:Heat Transfer coefficient VS Helix Angle



Graph.2: Overall heat transfer coefficient VS Helix Angle



Graph.3: Pressure drop vs. helix angle

VI. CONCLUSIONS

- In the present study, an attempt has been made to modify the existing Kern method for continuous helical baffle heat exchanger, which is originally used for segmental baffles Heat Exchanger.
- The above graph plots give us a clear idea that the helical baffle Heat Exchanger has far more better heat transfer coefficient than the conventional segmental Heat Exchanger.
- The above graph plots also indicate that the pressure drop ΔP_s in a helical baffle heat exchanger is appreciably lesser than the segmental baffle heat exchangers due to increased cross flow area resulting in lesser mass flow. The pressure drop decreases with the increases of helix angle in all the cases considered. However, the effects of helix angles on pressure drop are small when helix angle is greater than 18 degree.
- From the graph plots shown , there is an increase of overall heat transfer in 6 deg helix angle than 0 deg segmental baffle.
- Suitable helix angle may be selected based upon the desired output and industrial applications. Helix angle of 6° may provide better heat transfer than the one with an angle of 18°, however at the expense of pressure drop.

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