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A Systematic Review on Thermal Analysis of Shell and Tube Type Heat Exchanger and Its Optimisation

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ABSTRACT

This paper is related to shell and tube heat exchanger, which are heat exchangers comprised of tube bundle installed in shell for flow of first fluid through the tubes called as tubeside fluids and for the flow of second fluid over and around the tubes called as shellside fluids. This paper presents an attempt to optimize a shell and tube heat exchanger of the various types of heat exchanger used in various industries, shell and tube heat exchanger is probably the most versatile and widely used in most industrial sectors. In recent years, there have been notable researches on performance of shell and tube heat exchanger mainly on the effect of baffle inclination angle, increment in heat transfer and reduction in pressure drop Shell and tube heat exchanger, Baffle Inclination Angle, Pressure drop, Overall heat transfer. The analysis has been done on shell side of shell and tube heat exchanger. Helical baffles are implemented on shell side of heat exchange which provides the helical flow to shellside fluid helps in increasing the turbulence as a result the heat transfer rate is increased and fouling is reduced. In this paper the thermal analysis of helical baffle heat exchanger gives us the idea that heat transfer rate per unit pressure drop of helical baffle heat exchanger is more compared to segmental baffle heat exchanger.

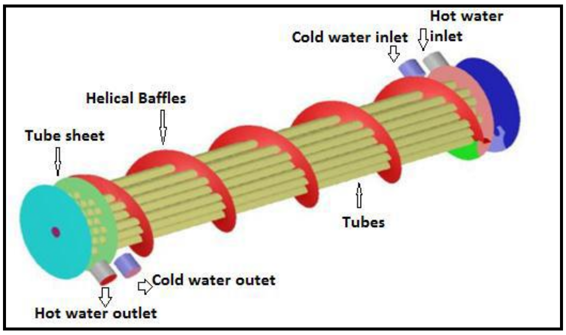
Keywords: Shell and tube heat exchanger, Baffle Inclination Angle, Pressure drop, Overall heat transfer.

1. INTRODUCTION

Heat Exchanger is a device use to transfer the heat from one fluid to another fluid either by direct or indirect contact between the fluids. There are various types of heat exchanger such as shell and tube heat exchanger, plate type heat exchanger, plate fin heat exchanger and many others. Among which the shell and tube heat exchanger is widely used because of its wide pressure and temperature withstanding range, also they provide a large heat transfer area. They are mainly used in industries such as food processing, oil refinery. Chemical industries and many more. It consists of numbers of tubes which are enclosed in closed cylinder called as shell. The fluid flows from tube is called as tube side fluid and the fluid moving around the tubes is called as shellside fluid. There are various components of shell and tube heat exchanger such as Tubes, Baffles, Shell, Tie Rods, Spacers and Supports. The heat transfer efficiency of heat exchanger mainly depends on design of tube, baffle and shell. Among which the baffles are main component for producing turbulence in shellside fluid which effects the overall heat transfer rate between the shell and tubeside fluid. Baffles can be explained as the plates which helps the tubes to retain vibration and direct the flow of shellside fluid to achieve turbulence, there are different types of baffle such as segmental baffle, double segmental baffle, longitudinal flow baffle, orifice baffle, blanking baffle, deresonating baffle and many other. Segmental baffles are mostly used in shell and tube heat exchanger as it provides a zigzag flow to fluid on shellside which helps in achieving more turbulence. But it also reduces the life of tube bundle as the fouling increases on it because of its design and long stay period on tube also at the time of drainage it is not possible to fully empty the vessel. The pumping cost is also increased in segmental baffle. The above defects can be easily overcome by use of Helical Baffle.

The Helical baffle heat exchanger is known as Helixchanger which overcomes the defects noted in shell and tube heat exchanger with segmental baffles. Helical baffles are provided with an angle known as helix angle which determines the pressure drop and turbulence created on shell side. The baffles are of prime importance in increasing heat transfer and improving mixing level in STHX. Moreover the segmental baffle have some adverse effect such as corrosion, large pumping cost and large cross flow area.

The optimal design of helix changer depends on the angle inclination, operating conditions of heat exchanger and tube layout. The important parameters for efficient working of heat exchangers are baffle spacing, equivalent diameter, pressure drop, baffle spacing and heat transfer coefficient.



Figuare.1 Helixchanger

In present research, compared to segmental baffle the helical baffle provides the following advantages (6)

- Increased Heat Transfer
- Pressure drop
- Decrease bypass effect
- Decease shellside fouling
- Reduce flow induce vibration
- Low maintenance

The kern's method restrict the baffle cut to 25% and cannot account for tube to baffle and baffle to shell leakages. Although it is not accurate but it allows a rapid calculation for shell side heat transfer coefficient and pressure drop. (6)

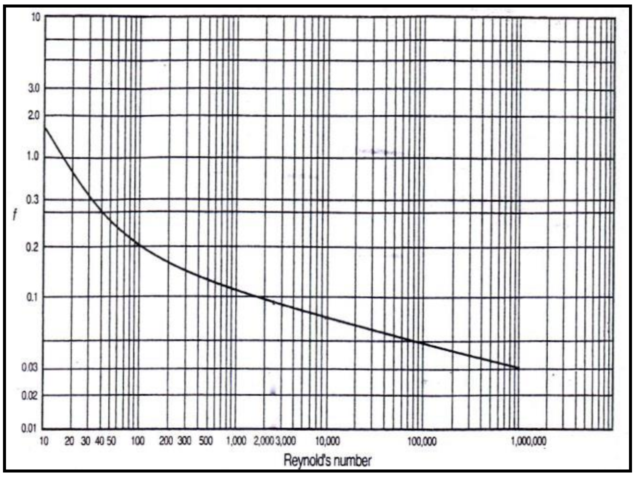
Based on experimental results it has been observed that

Heat transfer rate and pressure drop are affected by angle inclination of baffle in shell and tube heat exchanger. At an angle inclination of 30 degree the heat transfer rate increases and there's a drop in heat transfer rate after 45 degree of angle inclination. While up to 45 degree of angle inclination the shell side pressure drop is continuously reducing which helps in low pumping cost.

BRIEF LITRATURE SURVEY ON PERFORMANCE OF HEAT EXCHANGER:-

A: (Sunil kumar shinde, 2012)

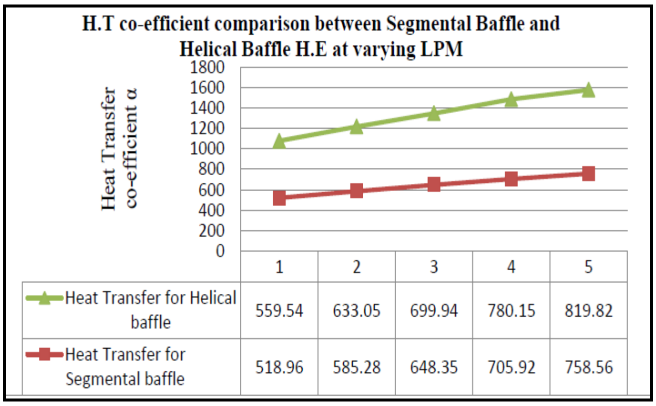
In present work using segmental baffles in a heat exchanger result in high pressure drop which is not favourable as pumping cost are directly proportional to the pressure drop within a heat exchanger. Hence, lower pressure drop means lower operating cost.



Figuare.2 Variation of 'f' with Reynold's number

Here the Reynold's number is dimensionless quantity use to predict flow pattern in differential fluid flow situations.

The points are plotted at 40, 50, 60, 70 and 80 LPM respectively. These points indicate the Heat Transfer coefficient and Pressure drop at inlet Volume flow rates.



Figuare3. Heat Transfer Comparison between helical and segmental baffle

B: (S.Sathish, 2014)

Helical baffle shows the higher heat transfer and lower pressure drop compared to segmental baffle in shell and tube heat exchanger.

Helix Angle	H.T.Coefficient	Pressure Drop	Heat transfer coefficient/Pressure Drop
15	102.25	36.6	28.4
35	604.24	5.23	116.2
45	403.73	36.72	109.9

Table1. Effect of helix angle on heat transfer coeffient

From the above work we can conclude that most appropriate angle for helical baffle is 35 degree as heat transfer coefficient is maximum and pressure drop obtained is also very minimal.

The ratio of heat transfer to pressure drop is 116.2 for 35 degree of helix angle. (5)

C: (Hardik Tandel, 2015)

Helical baffle heat exchanger have shown very effective performance especially for the cases in which the heat transfer coefficient is controlled ;or less pressure drop and less fouling are expected it can also be very effective, where heat exchanger are predicted to be faced with vibration conditions. (2)

The present work has shown that heat transfer coefficient varies with different angle of helical baffle and they have reviewed various research paper based on discovery of helical baffle showing the difference in heat transfer with various angle of helical baffle.

A numerical model is solved at shellside Reynolds number from 6813 to 22326 for a shell and tube heat exchanger with helical baffle and acceptable accuracy is illustrated by comparison with segmental baffle. The difference in velocity and temperature together with distribution of convective heat transfer on the shell side with and without helical baffle is observed.

From the result it is clear that with implementation of helical baffle the fluid velocity and convective heat transfer coefficient vary in uniform way in mid-range of helical baffle heat exchanger.

D: (Mayank Vishvakarma, 2013)

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

An analytical model has been developed to evaluate thermal analysis of a segmental baffle heat exchanger and helical baffle heat exchanger, the comparative analysis between the thermal parameters of segmental and helical angle has been 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 degree to 60 degree tilt angle for the baffle. The significant observations and conclusions obtained from the above analysis is that compared to the segmental baffled shell and tube exchanger Helix changer offers the following general advantages.

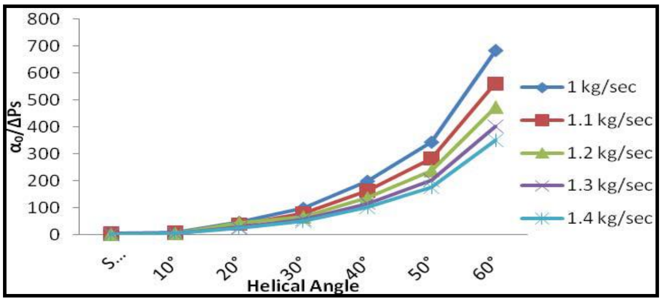
a) Decrease bypass effects.

b) Decrease shell side corrosion.

c) Reduction in flow induced vibration.

d) Low 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. (3)



Figuare4. Graph Plot between Heat transfer coefficient and pressure drop and helical angle.

E: (Neeraj Kumar, 2014)

In present work, experimentation of shell and tube heat exchanger having segmental baffles at different orientations has been conducted to calculate heat transfer rate and pressure drop at different Reynolds number in laminar flow. In the present work, an attempt has been made to study the effect of increase in Reynolds number at different angular orientation "θ" of the baffles. The range of "θ" vary from 0° to 45° (i.e. 0°, 15°, 30° and 45°) and Reynolds number ranges from 500 to 2000 (i.e. 500,1000, 1500 and 2000) (3).

A prototype model of shell and tube type heat exchanger has been fabricated to carry out the experiments. This experimental setup had been placed on the ground of the heat and mass transfer lab, Department of Mechanical Engineering, Jabalpur Engineering College, Jabalpur (M.P). The experiments were performed to determine the effect of baffle orientation on the performance of shell and tube heat exchanger. Water is taken as the working fluid used in both shell and tubes. The objective of the present work is to predict the variation of heat transfer rate, LMTD, heat transfer coefficient, and pressure drop to the shell side with change in range of Reynolds number at different baffle orientations. (4)

Based on the experimental result has been Observed that the angular orientation of baffles and the Reynolds number effects heat transfer rate and pressure drop in the shell and tube heat exchanger. The heat transfer rate increases up to 30° angular Orientation of the baffles and after that there is a drop in heat transfer rate at 45 degree. The pressure drop to the shell sides decreases continuously from 0° to 45° Which helps in reducing the pumping cost of the shell and tube heat exchanger. (4)

EFFECT OF BAFFLE DESIGN (6)

Heat Exchanger Data at Shell Side:

Sr no	Quantity	Symbol	value
1	Shell side fluid		water
2	Volume flow rate	Q_S	40 to 80 LPM
3	Shell side mass flow rate	m_s	0.67 to 1.33kg/sec
4	Shell ID	D_{is}	0.153 m
5	Shell length	L_s	1.123 m
6	Tube pitch	P_t	0.0225 m
7	No. of passes		1
8	Baffle cut		25%
9	Baffle pitch	L_B	0.060 m
10	Shell side nozzle ID		0.023 m

11	Mean bulk temperature	MBT	30^0C
12	NO. of baffles	N_b	17
13	Shell side mass velocity/mass flux	M_F	Kg /(m^2 s)

Table2. Properties Of Shell Side

The above table indicates the shell side properties which helps us to determine the heat transfer rate at shell side using kern's method and by carrying out necessary changes same can be applied for helical baffle heat exchanger.

Also a comparative analysis is carried out between the helical and segmental baffle heat exchanger

Heat Exchanger Data at Tubeside:

Sr no	Quantity	Symbol	Value
1	Tube side fluid		Water
2	Volume flow rate	Q_t	40 to 80 LPM
3	Tube side mass flow rate	m_t	0.67 to 1.33 kg/sec
4	Tube OD	D_{ot}	0.153 m
5	Tube thickness		1.123 m
6	Number of tubes		0.0225 m
7	Tube side nozzle ID		1
8	Mean bulk temperature	MBT	30^o C

Table3.Properties of Tubeside

Fluid Properties:

PROPERTY	UNIT	COLD WATER	HOT WATER
Specific heat C_p	KJ/KG.K	4.178	4.178
Thermal conductivity	W/m.K	0.615	0.615
Viscosity	Kg/m.s	0.001	0.001
Prandtl's Number		5.42	5.42
Density	Kg/m^3	996	996

Table4.Fluid Properties

THERMAL ANALYSIS OF HELICAL BAFFLE HEX: (Sunil kumar shinde, 2012)

(Qs) = 40 LPM

1. C' = 0.0105

2. Baffle Spacing (Lb)

Lb = π · Dis · tan ϕ (helix angle = 25˚)

= π · 0.153 · tan 25

= 0.2241

3. Cross-flow Area (AS)

AS = (Dis · C' · LB) / Pt.

= (0.153 · 0.0105 · 0.2241) / 0.0225

= 0.016 m2

4. DE = 0.04171 m.

5. Maximum Velocity (Vmax)

Vmax = ̇s / As

= 6.67 · E-4 / (0.016)

= 0.0416 m/s

6. Reynold's number (Re)

Re = (ρ · Vmax · DE) / μ

= (996 · 0.0416 · 0.04171) / 0.001

= 1728.19

7. Pr = 5.42

8. Heat Transfer Co-efficient (αo)

αo = (0.36 · K · Re0.55 · Pr0.33) / R · DE

= (0.36 · 0.6150 · 1728.190.55 · 5.420.33) / 0.04171

= 559.54 W/m2K

9. No. of Baffles (Nb)

Nb= Ls / (Lb + ΔSB)

$= 1.123 / (0.2241 + 0.005) \approx 5$

10. Pressure Drop (ΔPS)

$\Delta PS = [4 \cdot f \cdot F2 \cdot Dis \cdot (Nb + 1)] / (2 \cdot \rho \cdot DE)$

$= (4 \cdot 0.09 \cdot 41.872 \cdot 0.153 \cdot 6) / (2 \cdot 996 \cdot 0.04171)$

= 6.97 Pa

THERMAL ANALYSIS OF SEGMENTAL BAFFLE HEX:

(Qs) = 40 LPM

1. Tube Clearance (C')

C'= 0.0105

2. Cross-flow Area (AS)

AS = (Dis C' LB) / Pt.

$= (0.153 \cdot 0.0105 \cdot 0.06) / 0.0225$

= 4.284 E-3

3. Equivalent Diameter (DE)

$DE = 4 [(Pt2 - \pi \cdot Dot2 / 4) / (\pi \cdot Dot)$

$= 4 [(0.02252 - \pi \cdot 0.0122 / 4) / (\pi \cdot 0.012)]$

= 0.04171 m.

4. Maximum Velocity (Vmax)

Vmax =Qs / A

$= 6.67 \cdot E\text{-}4 / (\pi/4 \cdot Dis2)$ (since s= 40 lpm = 2400 lph = $6.67 \cdot E\text{-}4$ m3/s)

$= 6.67 \cdot E\text{-}4 / (\pi/4 \cdot 0.1532)$

= 0.0362 m/s

5. Reynold's number (Re)

$Re = (\rho \cdot Vmax \cdot DE) / \mu$

$= (996 \cdot 0.0362 \cdot 0.04171) / 0.001$

6. Prandtl's number (Pr)

Pr = 5.42 (for MBT = 30˚C and water)

7. Heat Transfer Co-efficient (αo)

$\alpha o= (0.36 \cdot K \cdot Re0.55 \cdot Pr0.33) / R \cdot DE$ (Where $R = (\mu/\mu w)\ 0.14 = 1$ for water)

$= (0.36 \cdot 0.6150 \cdot 1507.1360.55 \cdot 5.420.33) / 0.04171$

= 518.968 W/m2K

8. No. of Baffles (Nb)

$Nb= Ls / (Lb + \Delta SB)$

$= 1.123 / (0.06 + 0.005)$

≈ 1

9. Pressure Drop (ΔPS)

$\Delta PS = [4 \cdot f \cdot (F)\ 2 \cdot Dis \cdot (Nb + 1)] / (2 \cdot \rho \cdot DE)$ (f from graph and F = Qs / As)

$= (4 \cdot 0.1 \cdot 156.392 \cdot 0.153 \cdot 18)/ (2 \cdot 996 \cdot 0.04171)$

= 324.298 Pa

The table below gives us the result of various LPM for segmental baffle and helical baffle heat exchanger.

BAFFLE TYPE	LPM	HEAT TRANSFER COEFFICIENT	PRESSURE DROP
HELICAL BAFFLE	40	559.54 W/m²K	6.97 Pa
SEGMENTAL BAFFLE	40	518.96 W/m²K	324.3 Pa

Table5. Comparison between helical and segmental baffle heat exchanger

From the above result, we can conclude that helix changer are far more better than conventional segmental baffle heat exchanger, as pressure drop in Helixchanger is lower compared to segmental baffle HEX. Here, the kern's method is only for segmental baffle HEX but the modified formula gives us the idea about efficiency and effectiveness of Helixchanger.

CONCLUSION

The helix-changer type heat exchangers can save capital cost and additional working and support cost and hence enhances the unwavering quality and accessibility of process plant in a financial way. In this work a model has been created to assess investigation of a Helical and Segmental Baffle Heat Exchanger and also the Comparative examination between the thermal parameters of Segmental and helical baffle has been appeared. From the Numerical Experimentation results it is affirmed that the performance of a Tubular

Heat Exchanger can be enhanced by Helical Baffles rather than Segmental Baffles. Use of Helical Baffles in Heat Exchanger Reduces Shell side Pressure drop, pumping cost, weight, fouling and so on as contrast with Segmental Baffle for another establishment. The Ratio of Heat to build cross stream zone bringing about lesser mass transition all through the shell Transfer Coefficient to Pressure Drop as higher than that of Segmental Baffle.

At bigger stream flow, contrasted with segmental heat exchanger, helical baffle heat exchanger bring down pressure drop with less heat exchange coefficient loss, which patches the disadvantage of segmental heat exchanger.(12)

Flow distribution phenomenon, back flow and mixing flow, non-uniform changes of fluid flow direction at the baffles tips, higher velocity magnitude which all lead to higher pressure drop were noticed for segmental baffles. For the same pressure drop, helical baffles resulted in higher heat transfer. (2)

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