IMPROVED PERFORMANCE OF HELIXCHANGER OVER SEGMENTAL BAFFLE HEAT EXCHANGER USING KERN'S METHOD

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ABSTRACT

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. This paper analyses the conventional segmental baffle heat exchanger using the Kern method with varied shell side flow rates. This is a proven method used in design of Heat Exchangers with a baffle cut of 25%. The paper also consists of the thermal analysis of a helixchanger (Continuous Helical baffled Heat Exchanger) using the Kern method, modified to estimate the results for different flow rates at a fixed helical angle of 25˚. The results obtained in this paper show us that the desired properties from a Heat exchanger i.e High Heat Transfer Co-efficient and lower pressure drop are more effectively obtained in a Helixchanger. The shell side zigzag flow induced by the Segmental baffle arrangement is completely eliminated in a Helixchanger. 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. This flow pattern, at a certain fixed helical angle, results in significant increase in the heat transfer coefficient, however at the cost of lower pressure drop.

KEYWORDS: *Kern method, helixchanger, helical angle, increased heat transfer coefficient, reduced pressure drop, shell & tube heat exchanger.*

I. INTRODUCTION

The conventional shell and tube heat exchangers with segmental baffles have low heat transfer co-efficient due to the segmental baffle arrangement that causes high leakage flow, bypassing the heat transfer surface and high pressure drop due to the segmental baffles obstructing the shell side flow completely. This results in higher pumping costs for industries.

The hydrodynamic studies testing the heat transfer (mean temperature difference) and the pressure drop, with the help of research facilities and industrial equipment have shown much better performance of helical baffle heat exchangers as compared to the conventional ones. This results in relatively high value of shell side heat transfer coefficient, low pressure drop, and low shell side fouling.[1]

II. DESIRED FEATURES IN 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, and 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 larger heat transfer surfaces, and 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.

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.

III. 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 cross flow. The cross flow not only reduces the mean temperature difference but can also cause potentially damaging tube vibration.[2]

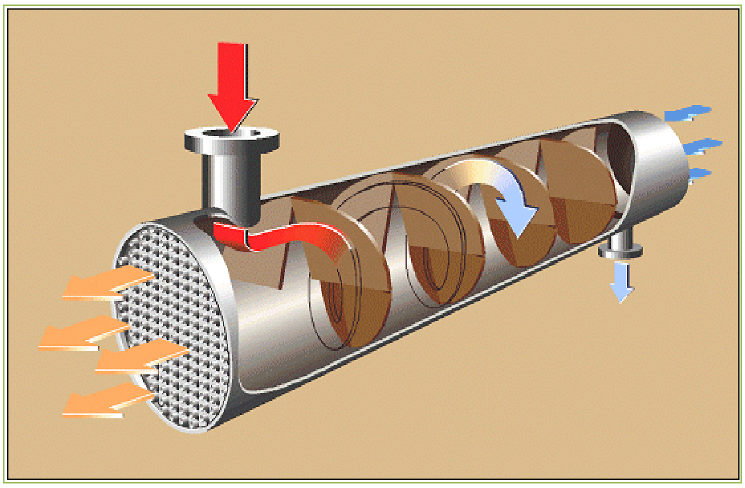


Figure 1. Helical Baffle Heat Exchanger

3.1. 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]

- Increased heat transfer rate/ pressure drop ratio.
- Reduced bypass effects.
- Reduced shell side fouling.
- Prevention of flow induced vibration.
- Reduced maintenance

Figure 2 Helical baffle Heat Exchanger

3.2. Research aspects

Research on the helixchanger has been focussed on two principle areas :

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

3.3. 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-efficient and pressure drop to be carried out and has been successfully used since its inception. [5]

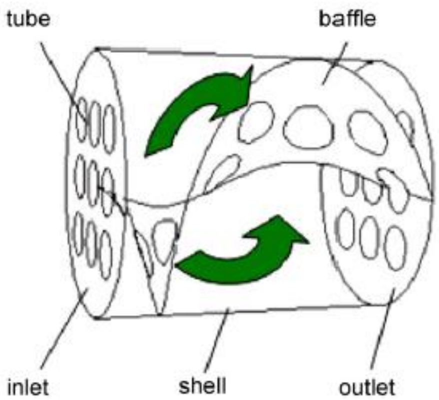


Figure 3 Helical Baffle Heat Exchanger pitch

3.4. Important Parameters

- Pressure Drop (ΔPS)
- Helical Baffle pitch angle (ϕ)
- Baffle spacing (LB)

- Equivalent Diameter (DE)
- 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 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.

IV. THERMAL ANALYSIS OF SEGMENTAL BAFFLE HEAT EXCHANGER & HELICAL BAFFLE HEAT EXCHANGER

In the current paper, thermal analysis has been carried out using the Kern's method. The thermal parameters necessary to determine the performance of the Heat Exchanger have been calculated for Segmental baffle heat Exchanger following the Kern's method, and suitable modifications made to the method then allow us to apply it for the helical baffle Heat Exchanger which is the subject area of interest. Also, the comparative analysis, between the thermal parameters of the two Heat exchangers has been carried out, that clearly indicates the advantages and disadvantages of the two Heat Exchangers.

4.1 Heat Exchanger data at the shell side

Table 1. Input data – Shell Side [12]

S. No.	Quantity	Symbol	Value
1.	Shell side fluid		Water
2.	Volume flow rate	($\dot{Q}_s$)	40 to 80 lpm.
3.	Shell side Mass flow rate	($\dot{m}_s$)	0.67 to 1.33 kg/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 ˚C
12.	No. of baffles	(N_b)	17
13.	Shell side Mass velocity / mass flux	($\dot{M}_F$)	kg / (m^2s)

4.2 Heat Exchanger data at the tube side

Table 2. Input data – Tube Side

S. No.	Quantity	Symbol	Value
1.	Tube side fluid		Water
2.	Volume flow rate	($\dot{Q}_t$)	40 to 80 lpm.
3.	Tube side Mass flow rate	($\dot{m}_t$)	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 ˚C

4.3 Fluid Properties

Table 3. Properties of the fluid used in the Heat Exchanger. [11]

Property		Unit	Cold Water (Shell side)	Hot Water (Tube side)
Specific Heat	Cp	KJ/kg. K	4.178	4.178
Thermal Conductivity	K	W/m. K	0.6150	0.6150
Viscosity	μ	kg/m. s	0.001	0.001
Prandtl's Number	Pr	-	5.42	5.42
Density	ρ	1 kg/m^3	996	996

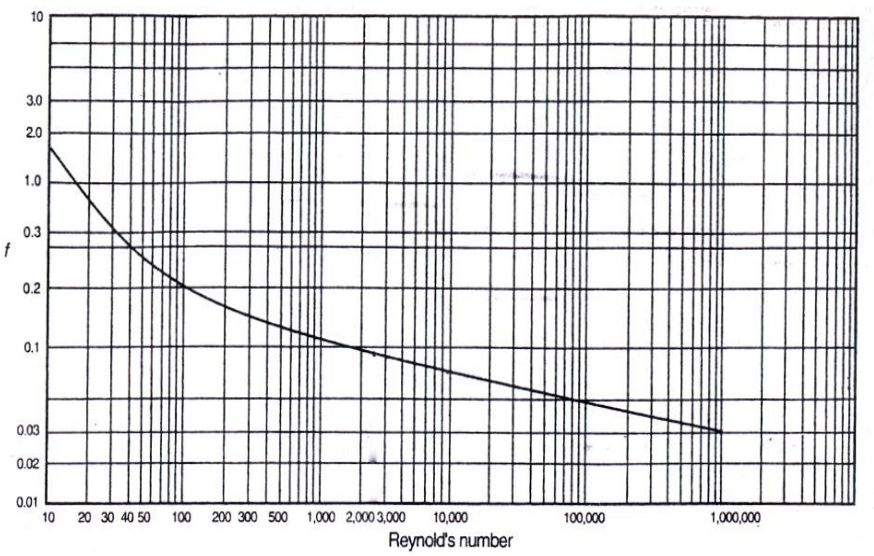


Figure 4. Variation of 'f' with Reynold's number. [5]

4.4. Thermal analysis of Segmental Baffle Heat Exchanger

The thermal analysis has been performed for different flows (LPMs) for the shell side fluid.

4.4.1 ($\dot{Q}_s$) = 40 lpm

1. Tube Clearance (C')
   $C' = P_t - D_{ot}$
   $= 0.0225 - 0.012$
   $= 0.0105$
2. Cross-flow Area (A_S)
   $A_S = (D_{is}\ C'\ L_B) / P_t$
   $= (0.153 \cdot 0.0105 \cdot 0.06) / 0.0225$
   $= 4.284$ E-3
3. Equivalent Diameter (DE)
   $D_E = 4 [(P_t^2 - \pi \cdot D_{ot}^2 / 4) / (\pi \cdot D^{ot})$
   $= 4 [(0.02252 - \pi \cdot 0.0122 / 4) / (\pi \cdot 0.012)]$
   $= 0.04171$ m.
4. Maximum Velocity (V_{max})
   $V_{max} = \dot{Q}_s / A$
   $= 6.67 \cdot E{-4} / (\pi/4 \cdot D_{is}^2)$ …(since $\dot{Q}_s$= 40 lpm = 2400 lph = $6.67 \cdot E{-4}\ m^3/s$)
   $= 6.67 \cdot E{-4} / (\pi/4 \cdot 0.1532)$
   $= 0.0362$ m/s
5. Reynold's number (Re)
   $Re = (\rho \cdot V_{max} \cdot D_E) / \mu$
   $= (996 \cdot 0.0362 \cdot 0.04171) / 0.001$

= 1507.136

6. Prandtl's number (Pr)
   Pr = 5.42
   …(for MBT = 30˚C and water as the medium)
7. Heat Transfer Co-efficient (αo)
   $\alpha_o = (0.36 \cdot K \cdot Re^{0.55} \cdot Pr^{0.33}) / R \cdot D_E$
   …(where $R = (\mu/\mu w)^{0.14} = 1$ for water as medium)
   = (0.36 ·0.6150 · 1507.1360.55 · 5.420.33) / 0.04171
   = 518.968 W/m²K
8. No. of Baffles (N_b)
   $N_b = L_s / (L_b + \Delta SB)$
   = 1.123 / (0.06 + 0.005)
   ≈ 17
9. Pressure Drop (ΔPS)
   $\Delta P_S = [4 \cdot f \cdot (\dot{M}_F)^2 \cdot D_{is} \cdot (N_b + 1)] / (2 \cdot \rho \cdot D_E)$ …(f from graph and $\dot{M}_F = \dot{m}_s / A_s$)
   = (4 ·0.1 ·156.392 ·0.153 ·18)/(2 · 996 ·0.04171)
   = 324.298 Pa
   = 0.3243 KPa

4.4.2 ($\dot{Q}_s$) = 60 lpm

1. Tube Clearance (C')
   C' = 0.0105
2. Cross-flow Area (A_S)
   $A_S = 4.284\ E^{-3}$
3. Equivalent Diameter (D_E)
   D_E = 0.04171 m.
4. Maximum Velocity (V_{max})
   $V_{max} = \dot{Q}_s / A$
   $= 0.001 / (\frac{\pi}{4} \cdot D_{is}^2)$ …(since $\dot{Q}_s$ = 60 lpm = 3600 lph = 0.001 m³/s)
   $= 0.001 / (\frac{\pi}{4} \cdot 0.153^2)$
   = 0.0544 m/s
5. Reynold's number (Re)
   $Re = (\rho \cdot V_{max} \cdot D_E) / \mu$
   = (996 · 0.0544 · 0.04171) / 0.001
   = 2259.948
6. Prandtl's number (Pr)
   Pr = 5.42
7. Heat Transfer Co-efficient (α_o)
   $\alpha_o = (0.36 \cdot K \cdot Re^{0.55} \cdot Pr^{0.33}) / R \cdot D_E$
   $= (0.36 \cdot 0.6150 \cdot 2259.948^{0.55} \cdot 5.42^{0.33}) / 0.04171$
   = 648.352 W/m²K
8. No. of Baffles (N_b)
   $N_b \approx 17$
9. Pressure Drop (Δ_{PS})
   $\Delta P_S = [4 \cdot f \cdot (\dot{M}_F)^2 \cdot D_{is} \cdot (N_b + 1)] / (2 \cdot \rho \cdot D_E)$ …(f from graph and $\dot{M}_F = \dot{m}_s / A_s$)
   $= (4 \cdot 0.09 \cdot 233.42^2 \cdot 0.153 \cdot 18)/(2 \cdot 996 \cdot 0.04171)$
   = 650.15 Pa
   = 0.65 KPa

   Similarly,
   50 lpm→ α_o = 585.28 W/m²K, ΔP_s = 0.482 KPa.
   70 lpm→ α_o = 705.92 W/m²K, ΔP_s = 0.885 KPa.
   80 lpm→ α_o = 758.56 W/m²K, ΔP_s = 1.150KPa.

4.5. Thermal analysis of Helical Baffle Heat Exchanger

The thermal analysis of the helical baffle Heat Exchanger will be carried out using the Kern's method which has been modified to suit the changed geometry of the Heat exchanger and hence get comparable results to the above analysis.

4.5.1 ($\dot{Q}_s$) = 40 lpm

1. C' = 0.0105
2. Baffle Spacing (L_b)
   $L_b = \pi \cdot D_{is} \cdot \tan \phi$ …(where ϕ is the helix angle = 25°)
   $= \pi \cdot 0.153 \cdot \tan 25$
   $= 0.2241$
3. Cross-flow Area (A_S)
   $A_S = (D_{is} \cdot C' \cdot L_B) / P_t$
   $= (0.153 \cdot 0.0105 \cdot 0.2241) / 0.0225$
   $= 0.016\ m^2$
4. $D_E = 0.04171$ m.
5. Maximum Velocity (V_{max})
   $V_{max} = \dot{Q}_s / A_s$
   $= 6.67 \cdot E\text{-}4 / (0.016)$
   $= 0.0416$ m/s
6. Reynold's number (Re)
   $Re = (\rho \cdot V_{max} \cdot D_E) / \mu$
   $= (996 \cdot 0.0416 \cdot 0.04171) / 0.001$
   $= 1728.19$
7. Pr = 5.42
8. Heat Transfer Co-efficient (α_o)
   $\alpha_o = (0.36 \cdot K \cdot Re^{0.55} \cdot Pr^{0.33}) / R \cdot D_E$
   $= (0.36 \cdot 0.6150 \cdot 1728.19^{0.55} \cdot 5.42^{0.33}) / 0.04171$
   = 559.54 W/m²K
9. No. of Baffles (N_b)
   $N_b = L_s / (L_b + \Delta_{SB})$
   $= 1.123 / (0.2241 + 0.005)$
   ≈ 5
10. Pressure Drop (ΔP_S)
    $\Delta P_S = [4 \cdot f \cdot \dot{M}_F^{\,2} \cdot D_{is} \cdot (N_b + 1)] / (2 \cdot \rho \cdot D_E)$
    $= (4 \cdot 0.09 \cdot 41.87^2 \cdot 0.153 \cdot 6) / (2 \cdot 996 \cdot 0.04171)$
    = 6.97 Pa

4.5.2 ($\dot{Q}_s$) = 60lpm

1. C' = 0.0105
2. Baffle Spacing (L_b)
   $L_b = 0.2241$
3. Cross-flow Area (A_S)
   $A_S = 0.016\ m^2$
4. Equivalent Diameter
   $D_E = 0.04171$ m.
5. Maximum Velocity (V_{max})
   $V_{max} = \dot{Q}_s / A_s$
   $= (1 \cdot E\text{-}3) / 0.016$
   $= 0.0625$ m/s
6. Reynold's number (Re)
   $Re = (\rho \cdot V_{max} \cdot D_E) / \mu$
   $= (996 \cdot 0.0625 \cdot 0.04171) / 0.001$

= 2596.44

7. Pr = 5.42
8. Heat Transfer Co-efficient (α_o)
$\alpha_o = (0.36 \cdot K \cdot Re^{0.55} \cdot Pr^{0.33}) / R \cdot D_E$
$= (0.36 \cdot 0.6150 \cdot 2596.44^{0.55} \cdot 5.42^{0.33}) / 0.04171$
= 699.94 W/m^{2}K
9. No. of Baffles (N_b)
$N_b \approx 5$
10. Pressure Drop (ΔP_S)
$\Delta P_S = [4 \cdot f \cdot \dot{M}_F{}^2 \cdot D_{is} \cdot (N_b + 1)] / (2 \cdot \rho \cdot D_E)$
$= (4 \cdot 0.08 \cdot 62.5^2 \cdot 0.153 \cdot 6) / (2 \cdot 996 \cdot 0.04171)$
= **13.81 Pa**
Similarly,
50 lpm→ α_o = 633.05 W/m^{2}K, ΔP_s = 9.59 Pa.
70 lpm→ α_o = 780.15 W/m^{2}K, ΔP_s = 17.62 Pa.
80 lpm→ α_o = 819.82 W/m^{2}K, ΔP_s = 21.48Pa.

V. RESULTS

The table below gives the results at various LPMs for the Segmental Baffle Heat Exchanger. These results have been calculated above.

Table 4.

LPM	H.T Co-efficient (W/m^{2}K)	Pressure drop (Pa)	$\alpha_o/\Delta P_s$
40	518.96	324.3	1.6
50	585.28	482	1.2142
60	648.35	650	0.9974
70	705.92	885	0.7976
80	758.56	1150	0.6596

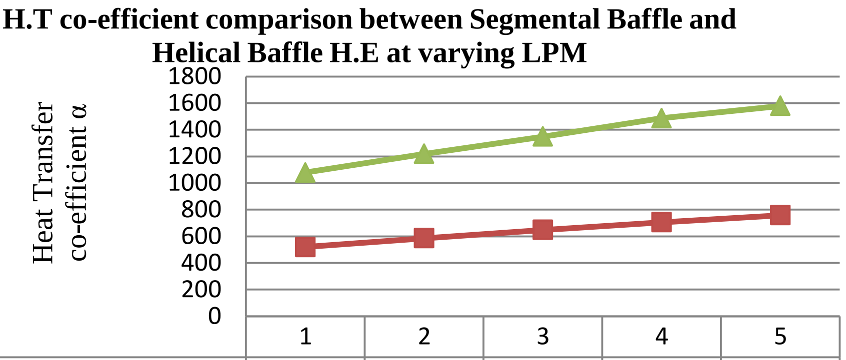
The table below gives the results at various LPMs for the Segmental Baffle Heat Exchanger. These results have been calculated above.

Table 5.

LPM	H.T Co-efficient (W/m^{2}K)	Pressure drop (Pa)	$\alpha_o/\Delta P_s$
40	559.54	6.97	80.27
50	633.05	9.59	66.01
60	699.94	13.81	50.68
70	780.15	17.62	44.27
80	819.82	21.48	38.16

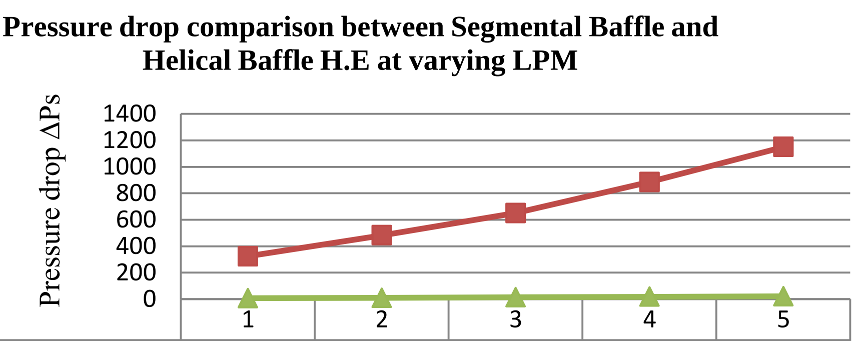
5.1 Graph Plots

The below graphs have been plotted with the help of the results obtained above. They clearly indicate that the use of Helixchanger in place of a Segmental baffle Heat Exchanger results in higher Heat Transfer co-efficient that is required ideally from a Heat Exchanger.
The graphs have been plotted using MS Excel and various colours have been used to clearly distinguish between Helical Baffled Heat Exchanger and Segmental baffled Heat Exchanger.
The points plotted are at **40, 50, 60, 70 and 80 LPM** respectively. These points indicate the Heat Transfer co-efficient and Pressure drop at these inlet Volume flow rates.



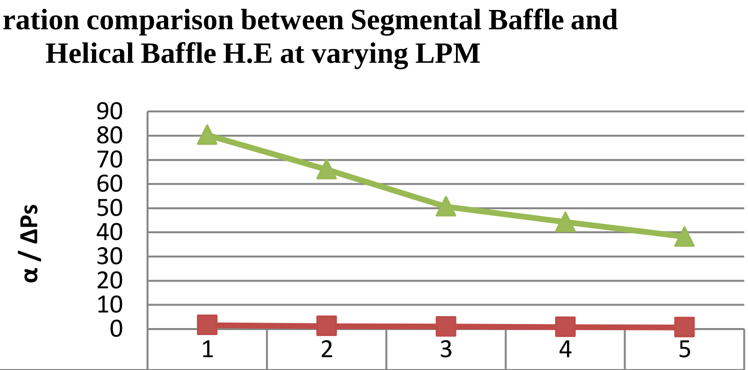
	1	2	3	4	5
Heat Transfer for Helical baffle	559.54	633.05	699.94	780.15	819.82
Heat Transfer for Segmental baffle	518.96	585.28	648.35	705.92	758.56

Figure 5. Heat Transfer co-efficient $\alpha_o$for Segmental and Helical Baffle Heat Exchanger.



	1	2	3	4	5
Pressure drop for Segmental baffle	324.3	482	650	885	1150
Pressure drop for Helical baffle	6.97	9.59	13.81	17.62	21.48

Figure 6. Pressure Drop ΔPs for Segmental and Helical Baffle Heat Exchanger.



	1	2	3	4	5
α / ΔPs for segmental baffle	1.6	1.2142	0.9974	0.7976	0.6596
α / ΔPs for Helical baffle	80.27	66.01	50.68	44.27	38.16

Figure 7.α / ΔPs for Segmental and Helical Baffle Heat Exchanger.

VI. CONCLUSIONS

a) The above results give us a clear idea that the Helical baffle heat exchanger has far more better Heat transfer coefficient than the conventional segmental Heat Exchanger, in all cases of varying LPM.[Graph 1]

b) The above results also indicate that the pressure drop ΔP_s in a helical baffle heat exchanger is appreciably lesser as compared to Segmental baffle heat Exchanger [Graph 2], due to increased cross-flow area, resulting in lesser mass flux throughout the shell.

c) The ratio of Heat Transfer co-efficient to the pressure drop is higher as compared to segmental baffle heat exchanger. This kind of ratio is**most desired in Industries, especially the one obtained at 60LPM**.[Graph 3]
This helps reduce the pumping power and in turn enhance the effectiveness of the heat exchanger in a well-balanced way.

d) The Kern method available in the literature is only for the conventional segmental baffle heat exchanger, but the modified formula used to approximate the thermal performance of Helical baffle Heat Exchangers give us a clear idea of their efficiency and effectiveness.

e) The ratio of Heat transfer co-efficient to the Pressure drop is around 50 for Volume flow rate of 60 LPM amongst all the other varying flow rates. This is the most desired result for industrial Heat Exchangers as it creates a perfect balance between the Heat transfer co-efficient and shell side pressure drop in a heat exchange.

NOMENCLATURE

Symbol	Quantity	Units
A_s	Shell Area	m^2
L_B	Baffle Spacing	m
C_p	Specific Heat	kJ/kgK
D_{ot}	Tube Outer Diameter	m
D_{is}	Shell Inner Diameter	m
D_E	Equivalent Diameter	m
α_o	Heat Transfer Co-efficient	$\frac{W}{m2 \cdot K}$
N_b	Number of Baffles	-
Pr	Prandtl's No.	-
P_T	Tube Pitch	m
Re	Reynold's Number	-
ΔP_S	Total shell side pressure drop	Pa
μ	Dynamic viscosity	$Kg \cdot s/m^2$
ρ	Fluid Density	kg/m^3
V_{max}	Maximum Tube Velocity	m/s
ϕ	Helix Angle	-

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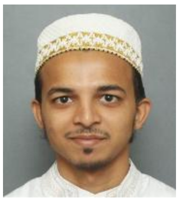

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