COMPARATIVE THERMAL ANALYSIS OF CONVENTIONAL TUBULAR HEAT EXCHANGER WITH HELIXCHANGER USING BELL-DELAWARE METHOD

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Abstract
Heat exchangers are important heat & mass transfer apparatus in oil refining, chemical engineering, environmental protection, electric power generation etc. Among different types of heat exchanger, shell-and-tube heat exchangers (STHXs) have been commonly used in Industries. Thermal analysis of helixchanger-a heat exchanger with helical baffles hasn’t been done using Bell-Delaware method. Bell-Delaware method is proven & has been verified by other researchers.

The present work modifies the existing Bell-Delaware method used for conventional heat exchanger, taking into consideration the helical geometry of helixchanger. The thermal analysis of Helixchanger using Bell-Delaware method which gives clear idea that the ratio of heat transfer coefficient per unit pressure drop is maximum in helixchanger as compared to segmental baffle heat exchanger. The Helixchanger eliminates principle shortcomings caused by shell side zigzag flow induced by conventional baffle arrangement. The flow pattern in the shell side of the heat exchanger with continuous helical baffle was forced to rotational & helical due to geometry of continuous helical baffles, which results in significance increase in heat transfer coefficient per unit pressure drop in the heat exchanger.

Keywords: Bell-Delaware method, helical baffles, helix angle, heat transfer coefficient per unit pressure drop, shell & tube heat exchanger.

1) Introduction:

1.1) Introduction
Conventional heat exchangers with segmental baffles in shell side have some shortcomings resulting in the relatively low conversion of pressure drop into a useful heat transfer.

Both hydrodynamic studies and testing of heat transfer and the pressure drop on research facilities and industrial equipment showed much better performance of helically baffled heat exchanger when compared with conventional ones. These results in relatively high value of shell side heat transfer coefficient, low pressure drop, and low shell side fouling1.
1.2) **Desirable Features of Heat Exchangers:**

In order to obtain maximum heat exchanger performance at the lowest possible operating and capital costs without compromising the reliability, the following features are required of an exchange.

1.2.1) **Higher heat transfer coefficient 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.

1.2.2) **Lower pressure drop:**

Pumping costs are dependent on pressure drop within an exchanger. Therefore the lower pressure drop means lower operating costs.

1.3) **Developments in shell and tube exchanger:**

The developments for shell and tube exchangers centre on better conversion of pressure drop into heat transfer by improving the conventional baffle designs. With single segmental baffles, a significant proportion of the overall pressure drop is wasted in changing the direction of flow, this baffle arrangement also leads to other undesirable effects such as dead spots or zones of recirculation which can cause increased fouling, high leakage flow, which bypass the heat transfer surface, and large cross flow. The cross flow not only reduces the mean temperature difference but can also cause potentially damaging tube vibration.

1.3.1) **Helical baffle Heat Exchanger or Helixchanger:**

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.
Compared to the conventional segmental baffled shell and tube exchanger Helixchanger offers the following general advantages:

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

1.3.2) Research aspects

Research on the helixchanger has focused on two principal areas.

- Hydrodynamic studies on the shell side and
- Heat transfer and pressure drop studies on small scale and full industrial scale equipment.

1.3.3) Design aspects:

An optimally designed helical baffle arrangement depends largely on the heat exchanger operating conditions and can be accomplished by appropriate design of helix angle, baffle overlapping, and tube layout.

In the original method an ideal shell-side heat transfer coefficient is multiplied by various correction factors for flow distribution and the non-idealities such as leakage streams, bypass stream etc. for helical baffle geometry it is suggested that some correction factor are not required; at the same time new are introduced by.

![Helixchanger pitch](image)

**Figure 1.3.2 Helixchanger pitch**

1.3.4) Important Parameters:

- Pressure Drop ($\Delta P_s$)
- Baffles pitch (Helix angle) angle ($\alpha$)
- Baffle space ($B$)
- Surface area ($A$)
- Heat transfer coefficient ($h_o$)

In designing of helixchanger’s, pitch angle, baffle’s arrangement, and the space between two baffles with the same position are important parameters. Baffles pitch angle ($\alpha$) is the angle between flow and perpendicular surface on exchanger axis and $B$ is space between two following baffles with the same situation.

Optimum design of helical baffle heat exchangers is depended on operating condition of heat exchanger, and it can be followed and completed by consideration of proper design of pitch angle, overlapping of baffles and tube’s layout. Changing the pitch angle in helical baffle system can create wide range of flow velocities as the baffle space and baffle cut in traditional heat exchangers. Moreover, overlapping of helical baffles is a parameter that can affect significantly on shell side flow pattern.
2) Heat transfer coefficients and pressure drop calculations

Heat transfer coefficients and pressure drop calculations are the main part of design of heat exchangers with a given duty. In traditional approaches such as Kern and Bell–Delaware methods are used to calculate the overall heat transfer coefficient, heat transfer coefficient & pressure drop.

The Kern (1950) 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 leakages. Nevertheless, although the Kern equation is not particularly accurate, it does allow a simple & rapid calculation of shell side coefficients and pressure drop to be carried out and has been successfully used since its inception.

The next stage of development of shell side calculation methods was that commonly described as Bell-Delaware method (Bell-1963). In this method, correction factors for baffle leakage effects, etc., are introduced based on experimental data. This method is widely used and is the basis of the approach recommended, in the Heat exchanger design handbook[5,6,7]

2.1) Thermal analysis of Segmental baffle heat exchanger & Helixchanger

In the present work, Bell Delaware method has been used for comparing the thermal performance of Segmental baffle heat exchanger & Helixchanger. Firstly, thermal parameters have been calculated for Segmental baffle heat exchanger using various steps mentioned by Bell-Delaware. Then, suitable modifications have been carried out in different steps for calculating the thermal parameters of Helixchanger. Then comparative analysis has been done between the two heat exchangers. Following data has been assumed and the geometrical parameters are kept constant for both types of heat exchangers.
Table 2.1 Input Data.

<table>
<thead>
<tr>
<th>Sr.no</th>
<th>Parameter</th>
<th>Shell side</th>
<th>Tube side</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fluid</td>
<td>Water</td>
<td>Water</td>
</tr>
<tr>
<td>2</td>
<td>Volume flow rate ( \dot{Q}_s )</td>
<td>60(lpm)</td>
<td>10(lpm)</td>
</tr>
<tr>
<td>3</td>
<td>Mass flow rate ( \dot{m}_s )</td>
<td>1Kg/s</td>
<td>0.17Kg/s</td>
</tr>
<tr>
<td>4</td>
<td>Shell ID ( \overline{D}_{ls} )</td>
<td>0.153 m</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Shell length</td>
<td>1.123m</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Tube pitch</td>
<td>0.0225 m</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>No of passes</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Baffle cut</td>
<td>25% = 0.25</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Baffle pitch</td>
<td>0.060 m</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Nozzle ID</td>
<td>0.023 m</td>
<td>0.023 m</td>
</tr>
<tr>
<td>11</td>
<td>No of baffles</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Mean Bulk Temperature</td>
<td>35°C</td>
<td>30°C</td>
</tr>
<tr>
<td>13</td>
<td>Tube OD</td>
<td></td>
<td>0.012 m</td>
</tr>
<tr>
<td>14</td>
<td>Tube thickness</td>
<td></td>
<td>0.0014 m</td>
</tr>
<tr>
<td>15</td>
<td>No of tube</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>16</td>
<td>Helix angle</td>
<td>25°</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>No of baffles for Helixchanger</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

Fluid property:

Table 2.2 Fluid properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Cold Water (Shell Side)</th>
<th>Hot Water (Tube Side)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cp</td>
<td>kJ/kg.K</td>
<td>4.178</td>
<td>4.178</td>
</tr>
<tr>
<td>K</td>
<td>W/m.K</td>
<td>0.6150</td>
<td>0.6150</td>
</tr>
<tr>
<td>( \mu )</td>
<td>Kg.s/m²</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Sp Gr.</td>
<td>Kg/s/m³</td>
<td>0.996</td>
<td>0.996</td>
</tr>
<tr>
<td>Pr</td>
<td></td>
<td>5.42</td>
<td>5.42</td>
</tr>
<tr>
<td>( \rho )</td>
<td>Kg/m³</td>
<td>996</td>
<td>996</td>
</tr>
</tbody>
</table>
Leakage and bypass clearances:

i) Tube to baffle clearance ($\delta_{bt}$) = 0.0004 m.

ii) Baffle to shell clearance ($\delta_{bs}$) = 0.001 m

iii) Shell to bundle clearance ($\delta_{su}$) = 0.01428 m.

iv) Shell outer tube limit ($D_{ott}$) = 0.1387 m

v) Shell central tube limit ($D_{cct}$) = (0.1387 - 0.012) = 0.1267 m

1) Cross flow area: Area between central baffle spaces

$$S_m = D \left[ (D_s - D ot l) + \frac{(Botl - Do) (Po - Do)}{Pref} \right]$$

2.1.1

$$S_m = 0.004405 \text{m}^2$$

2) Reynolds number

$$Re = \frac{\rho V_{max} D_e}{\mu}$$

2.1.2

$$Re = 2725$$

3) Heat transfer coefficient:

$$h_o = h_{ideal} (J_1, J_2, J_3)$$

2.1.3

$$h_o = 2570.82 \text{W/m}^2\text{k}$$

4) Window flow area: Area between the baffle cut & shell wall.

$$S_w = D_s^2 \left[ \cos^{-1} \left( \frac{D_r - 2\delta_b}{D_s} \right) - \frac{(D_r - 2\delta_b)}{D_s} \sqrt{1 - \left( \frac{(D_r - 2\delta_b)}{D_s} \right)^2} \right] \frac{1}{4} - nt (1 - F_c) \frac{n \rho_\alpha D_e^2}{2}$$

2.1.4

$$= 0.003139 \text{m}^2$$

5) Shell side pressure drop

$$\Delta P_s = \left[ (n_d - 1) \times \Delta P_\alpha \times R_\alpha + n_b \Delta P_w \right] R_2 + 2\Delta P_\alpha (1 + N_{cw}/N_c) R_2$$

2.1.5

$$= 2209.6P_\alpha$$
2.2) Thermal analysis of Helixchanger

1) Cross flow area:

\[ S_{in} = \frac{D_{o}}{2} \left[ (D_{s} - D_{o} t) + \frac{(D_{o} t - D_{o})}{D_{s} - D_{o}} (F_{c} - D_{o}) \right] \]

\[ = 0.008224 m^{2} \]

In helixchanger baffles covers half of the shell diameter so cross flow area reduces to half.

2) Reynolds number:

\[ Re = \frac{\rho V_{max} D_{o}}{\mu} \]

\[ = 1459 \]

3) Heat transfer coefficient:

\[ h_{o} = h_{ideal} (J_{c} J_{e} J_{o}) \]

\[ = 1639.65 W/m^{2} \]

4) Window flow area:

As the helical baffle runs over the diameter window area does not exists.

From geometry Window flow area,

\[ S_{w} = 0 \]

5) Shell side pressure drop:

\[ \Delta P_{s} = \left[ \left( \frac{n_{2} - 1}{n_{2}} \right) \times \Delta P_{c} \times R_{s} + n_{2} \Delta P_{w} \right] R_{s} + 2 \Delta P_{c} \left( 1 + N_{w} / N_{c} \right) R_{s} \]

\[ = 420.5 \]
### Table 2.3

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Parameter</th>
<th>Segmental baffle Heat Exchanger</th>
<th>Helixchanger (25 deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$S_{mb}(m^2)$</td>
<td>0.004405</td>
<td>0.008224</td>
</tr>
<tr>
<td>2</td>
<td>$S_{sb}(m^2)$</td>
<td>0.00032</td>
<td>0.00016</td>
</tr>
<tr>
<td>3</td>
<td>$S_{tb}(m^2)$</td>
<td>0.0003012</td>
<td>0.00027143</td>
</tr>
<tr>
<td>4</td>
<td>$F_{bp}(m^2)$</td>
<td>0.195</td>
<td>0.1947</td>
</tr>
<tr>
<td>5</td>
<td>$R_s$</td>
<td>2725</td>
<td>1459</td>
</tr>
<tr>
<td>6</td>
<td>$h_0(W/m_2.k)$</td>
<td>2570.82</td>
<td>1639.65</td>
</tr>
<tr>
<td>7</td>
<td>$\Delta P_\ell(Pa)$</td>
<td>112.22</td>
<td>95.83</td>
</tr>
<tr>
<td>8</td>
<td>$\Delta P_w(Pa)$</td>
<td>102.24</td>
<td>0.1719</td>
</tr>
<tr>
<td>9</td>
<td>$\Delta P_s(Pa)$</td>
<td>2209.6</td>
<td>420.5</td>
</tr>
<tr>
<td>10</td>
<td>$h_0/\Delta P_s$</td>
<td>1.16</td>
<td>3.90</td>
</tr>
</tbody>
</table>

### Table 2.4

<table>
<thead>
<tr>
<th>$m$ Kg/s</th>
<th>$\Delta P_s$ (Seg.)</th>
<th>$\Delta P_s$ (Helix.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.333</td>
<td>171.04</td>
<td>50.21</td>
</tr>
<tr>
<td>0.667</td>
<td>642.59</td>
<td>82.32</td>
</tr>
<tr>
<td>1</td>
<td>2209.59</td>
<td>420</td>
</tr>
<tr>
<td>1.33</td>
<td>3395.37</td>
<td>500.25</td>
</tr>
<tr>
<td>1.667</td>
<td>4951.12</td>
<td>600.01</td>
</tr>
</tbody>
</table>

### Graph 2.1

**$\Delta P_s$ Vs $m$**

- **Segmental baffle**
- **25 degree helix angle**

**Shell side pressure drop $\Delta P_s$ (Pa)**

- **Mass flow rate $m$ Kg/s**
- **Graph 2.1**
### Table 2.5

<table>
<thead>
<tr>
<th>$m$ Kg/s</th>
<th>$h_o$(Seg.)</th>
<th>$h_o$(Helix.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.333</td>
<td>1256.313654</td>
<td>848.0710607</td>
</tr>
<tr>
<td>0.667</td>
<td>1974.66215</td>
<td>1332.990228</td>
</tr>
<tr>
<td>1</td>
<td>2570.318155</td>
<td>1735.086168</td>
</tr>
<tr>
<td>1.33</td>
<td>3094.669695</td>
<td>2089.048227</td>
</tr>
<tr>
<td>1.667</td>
<td>3584.816743</td>
<td>2419.920637</td>
</tr>
</tbody>
</table>

### Table 2.6

<table>
<thead>
<tr>
<th>$m$ Kg/s</th>
<th>$h_o$/$\Delta P$s(Seg.)</th>
<th>$h_o$/$\Delta P$s(Helix.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.333</td>
<td>7.345017281</td>
<td>98.19264199</td>
</tr>
<tr>
<td>0.667</td>
<td>3.072939033</td>
<td>55.21283866</td>
</tr>
<tr>
<td>1</td>
<td>1.163255249</td>
<td>4.131157544</td>
</tr>
<tr>
<td>1.33</td>
<td>0.911435811</td>
<td>4.85825169</td>
</tr>
<tr>
<td>1.667</td>
<td>0.724041466</td>
<td>5.287808639</td>
</tr>
</tbody>
</table>
4) Conclusion

- The pressure drop in window flow region for helical baffle STHX reduces drastically as compared to conventional due to negligible window flow area.

- The pressure drop in cross flow region for helical baffle STHX decreases appreciably as compared to conventional due to baffle geometry.

- Helical baffle heat exchanger has better heat transfer coefficient per unit pressure drop as compared to segmental baffle heat exchanger.

- Bell Delaware method available in the literature is only for the segmental baffle heat exchanger since helical baffle heat exchanger is the recent development.

- Suitable modifications in Bell Delaware method can give the preliminary results.

- Suitable helix angle can be selected based upon the requirement and industrial applications.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Area (m²)</td>
</tr>
<tr>
<td>B</td>
<td>Baffle spacing (m)</td>
</tr>
<tr>
<td>Bc</td>
<td>Baffle cut (%)</td>
</tr>
<tr>
<td>Cp</td>
<td>Heat capacity at constant pressure (kJ/kg k)</td>
</tr>
<tr>
<td>Dctl</td>
<td>Central tube limit diameter (m)</td>
</tr>
<tr>
<td>Do</td>
<td>Outside diameter of tube (m)</td>
</tr>
<tr>
<td>Dotl</td>
<td>Outer tube limit diameter (m)</td>
</tr>
<tr>
<td>Ds</td>
<td>Inside diameter of shell (m)</td>
</tr>
<tr>
<td>Fe</td>
<td>Fraction of tubes in cross flow between baffle tips</td>
</tr>
<tr>
<td>H</td>
<td>Heat-transfer coefficient (W/m².k)</td>
</tr>
<tr>
<td>ho</td>
<td>Shell-side heat-transfer coefficient (W/m².k)</td>
</tr>
<tr>
<td>hideal</td>
<td>Ideal tube bank heat-transfer coefficient (W/m².k)</td>
</tr>
<tr>
<td>Jh</td>
<td>Heat-transfer correction factor for bundle bypass effects</td>
</tr>
</tbody>
</table>
\( J_C \)  
Heat-transfer correction factor for effect of baffle window flow

\( J_L \)  
Heat-transfer correction factor for baffle leakage effects

\( N_c \)  
Number of tube rows crossed in flow between two baffle tips

\( N_{cw} \)  
Effective number of tube rows crossed in flow through one baffle window

\( N_{ss} \)  
Number of pairs of sealing strips

\( n_b \)  
Number of baffles

\( n_t \)  
Number of tubes in bundle

\( m \)  
Mass flow rate (Kg/s)

\( P \)  
Pressure (kg/m²)

\( Pr \)  
Prandtl number

\( P_T \)  
Tube pitch (m)

\( P'_T \)  
Tube pitch parallel to flow direction (m)

\( R_B \)  
Pressure-drop correction factor for bundle bypass effects

\( Re \)  
Shell-side Reynolds number

\( R_L \)  
Pressure-drop correction factor for baffle leakage effects

\( F_{bp} \)  
Bundle bypass flow area (m²)

\( S_m \)  
Cross-flow area (m²)

\( S_{sb} \)  
Shell-to-baffle leakage area (m²)

\( S_{tb} \)  
Tube-to-baffle leakage area (m²)

\( S_w \)  
Window flow area (m²)

**Greek Letters**

\( \Delta P_C \)  
Cross flow pressure drop (Pa)

\( \Delta P_e (\Delta P_s) \)  
Total shell-side pressure drop (Pa)

\( \Delta P_w \)  
Pressure drop in one baffle window, uncorrected for baffle leakage effects (Pa)

\( \delta_{sb} \)  
Shell-to-baffle clearance (m)

\( \delta_{tb} \)  
Tube-to-baffle clearance (m)

\( \mu \)  
Viscosity (kg.s/m²)

\( \rho \)  
Fluid density (kg/m³)

\( V_{max} \)  
Maximum intertube velocity (m/s)

\( \alpha \)  
Helix angle (degree)

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References


