EXPERIMENTAL INVESTIGATION ON SHELL AND TUBE HEAT EXCHANGER USING SEGMENTAL AND DISC-DOUGHNUT TYPE BAFFLES

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ABSTRACT

The objective of paper is to conduct experiment and evaluate the performance of shell and tube heat exchangers with two baffles as Segmental and Disc-Doughnut type baffle. We have tested the heat exchanger with two baffles at different hot fluid temperatures and observe its effect on the performance of the heat exchanger with different baffles. By comparing the parameters such as LMTD, effectiveness, and heat transfer coefficient of heat exchangers with Segmental and Disc-Doughnut type baffles and suitable baffles are selected for better heat transfer rate. The results shows that the increase in the LMTD is 19.75%, Effectiveness is 10.8%, NTU is 37.25% using Disc and Doughnut baffle compared to segmental baffle at hot water temperature 38°C.

Keywords: Shell and tube heat exchanger, Segmental and Disc-Doughnut type Baffles, Effectiveness.
1. INTRODUCTION

The performance of various engineering processes such as oil refining, chemical industry, environmental protection, electric power generation, refrigeration etc. depends on the performance of heat exchanger. Heat exchangers are commonly used to transfer the heat from one fluid to the other. In some cases, a solid wall may separate the fluids and prevent them from mixing. In other designs, the fluids may be in direct contact with each other. In the most efficient heat exchangers the surface area and to induce turbulence. There are 3 primary flow arrangements with heat exchangers: counter – flow, parallel flow and cross flow. The most common type of heat exchangers used in the process, the shell on the other hand holds the tube bundle and acts as the conduit for the fluid. The shell assembly houses the shell side connections and is the actual structure into which the tube bundle is placed. Shell and tube heat exchangers (STHX) are used in applications where the pressure and temperature demands are high. The performances of all heat engines, steam power plant, refrigeration, air-conditioning etc. are depended on the performance of heat exchangers. So it is necessary to improve the performance of heat exchangers. The performance of heat exchangers can be increased by change the velocity of the fluid, orientation of flow, geometric shape, extended surface area and surface modification. Master et al. (1) indicated that commonly shell and tube heat exchangers are used due to its robust construction geometry as well as easy maintenance and possible upgrades of STHXs. The heat transfer rate of STHXs can be improved by using different types of baffles. For many years, different types of baffles were designed, for example, the conventional segmental baffles with different arrangements, the
deflecting baffles, the overlap helical baffles, the rod baffles, and others [5–10]. Segmental baffles are most commonly used in conventional STHXs to support tubes and change fluid flow direction. Segmental baffles cause the shell-side fluid to flow in a tortuous, zigzag manner across the tube bundles, which can enhance the heat transfer on the shell side. However, there exist many problems associated with the use of segmental baffles (2–4): (1) high pressure drop on the shell side due to the sudden contraction and expansion of the flow in the shell side, and the fluid impinging on the shell walls caused by segmental baffles; (2) low heat transfer efficiency due to the flow stagnation in the so-called “dead zones,” which are located at the corners between baffles and shell wall; (3) low shell-side mass velocity across the tubes due to the leakage between baffles and shell walls caused by inaccuracy in manufacturing tolerance and installation; (4) short operation time due to the vibration caused by shell-side flow normal to tube banks. When the traditional segmental baffles are used in STHXs, higher pumping power is often needed to offset the higher pressure drop under the same heat load. Therefore, it is essential to develop a new type of STHXs using different type of baffles to have higher heat transfer efficiency and lower pressure drop.

In this work, two different STHXs with Segmental and Disc-Doughnut type baffles were designed and tested their performance.

2. EXPERIMENTAL SETUP
Generally shell and tube heat exchangers contain series of tubes and shell. One fluid passes through the tubes and second fluid flows over the tubes. Then heat is transferred from hot fluid to cold fluid. Two heat exchangers are made using two different type baffles as given below the construction information of heat exchanger.

2.1. Tubes:
Round tubes in various shapes are used in shell and tube heat exchangers. Copper straight tubes used for construct our shell and tube heat exchangers. The diameter of tube is 10 mm and length of tube is 500 mm. The clearance between shell and tube is maintained as 13 mm. Number of tubes used in the heat exchanger are 10.

2.2. Shell:
The shell is a container for the another fluid and tubes are arranged inside the shell. Generally it is cylindrical in shape with a circular cross section. The material used for shell is steel. The outer diameter of the shell is 142 mm. The inner diameter of the shell is 137 mm. The thickness of the shell is 2.5 m. The length of the shell is 725 mm.

2.3. Front and rear end heads:
These are used for entrance and exit of the fluid passes through the shell and tube in the heat exchanger. The front end head is stationary, while the rear end head could be stationary which depends on the thermal stresses between the shell and tubes. The thickness of head is 6 mm.

2.4. Segmental Baffle:
It is commonly used in the heat exchanger as shown the figure. The diameter of the baffles is 142 mm and thickness is 6 mm.
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2.5. Disc and Doughnut Baffle:
It consists of two plates as Disc and Doughnut as shown in the figure. The diameter of the baffles is 142 mm and thickness is 6 mm.

2.6. Pumps:
Two pumps are used, one for supply the fluid to the shell and another for supply the fluid to the tube.

2.7. Thermocouples:
These are used to measure the inlet and out temperatures of fluid in the shell and tube of heat exchanger.

3. EXPERIMENTAL PROCEDURE:
The experiment is done on shell and tube heat exchanger of Segmental Baffle and Disc and Doughnut Baffle under summer ambient conditions in the period March – April 2017 by following steps.

1) The heat exchangers are connected to two submersible motors to supply the hot and cold water.
2) Connect the motor to 230V, 50Hz power supply.
3) Place the motors into the containers.
4) The motor is pumping the water into shell and tubes of heat exchanger with Segmental baffle.

5) As the hot and cold water flowing through shell and tubes, heat transfer takes place between hot and cold water by different modes like convection and conduction.

6) Collect the water from outlets of shell and tubes.

7) Measure the temperatures of the water at inlet and outlets of shell and tube and also note the time taken to fill 1 litre container.

8) The experiment is repeated at different hot water temperatures

9) The above procedure is carried out for heat exchanger with Disc-Doughnut type baffle and measured temperatures and time are tabulated.

4. THEORETICAL ANALYSIS

In this experiment we have done a counter flow shell and tube heat exchanger to transfer the heat from hot water to cool water using segmental and disc and doughnut baffles. The required parameters are evaluated using following formulae.

The energy balance equation is used to find out the unknown parameter values as follows

\[ Q = m_h c_{ph} (t_{h1} - t_{h2}) = m_c c_{pc} (t_{c2} - t_{c1}) \]  \hspace{1cm} (1)

Then we consider the LMTD expression to find its value as follows

\[ \text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln(\frac{\Delta T_1}{\Delta T_2})} \] \hspace{1cm} (2)

Where, \(\Delta T_1 = (t_{h1} - t_{c2})\) and \(\Delta T_2 = (t_{h2} - t_{c1})\).

Our next step is to calculate the area required of the heat exchanger, number of tubes, tube bundle diameter.

\[ A = \pi d t l n \] \hspace{1cm} (3)

Then calculate the discharge and mass flow rate for both shell and tube from time that is taken to fill the 1 litre bottle. The expressions used are

\[ D = \frac{v}{t} \] \hspace{1cm} (4)

\[ m' = \rho D \]

The overall heat transfer coefficient is calculated by

\[ U = \frac{Q_t}{A \Delta T_{lm}} \] \hspace{1cm} (5)

Following expressions are used to calculate NTU,
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\[
\begin{align*}
C_{shell} &= m_{shell}C_p \\
C_{tube} &= m_{tube}C_p \\
C_{\text{min}}/C_{\text{max}} &= \frac{UA}{C_{\text{min}}} \\
\text{NTU} &= \frac{UA}{C_{\text{min}}}
\end{align*}
\]  

5. RESULTS AND DISCUSSIONS

The experiment is conducted on shell and tube heat exchanger with segmental and disc & doughnut baffle at different heat inputs. The readings are tabulated in the following observation table and required parameters are calculated.

5.1. SEGMENTAL BAFFLE:

Table 1 Experimental Observations

<table>
<thead>
<tr>
<th>Time taken to fill 1 litre bottle(shell) SEC</th>
<th>Time taken to fill 1 litre bottle(tube) SEC</th>
<th>Shell inlet(cold fluid) °c</th>
<th>Shell outlet(cold fluid) °c</th>
<th>Tube inlet (hot fluid) °c</th>
<th>Tube outlet(hot fluid) °c</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>17</td>
<td>22</td>
<td>29</td>
<td>35</td>
<td>26</td>
</tr>
<tr>
<td>13</td>
<td>11</td>
<td>20</td>
<td>22</td>
<td>36</td>
<td>29</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>18</td>
<td>21</td>
<td>38</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>13</td>
<td>18</td>
<td>40</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 2 Result Table

<table>
<thead>
<tr>
<th>(\Delta T_1) °C</th>
<th>(\Delta T_2) °C</th>
<th>LMTD °C</th>
<th>EFFECTIVENESS</th>
<th>(C_{\text{SHLLE}}) w/k</th>
<th>(C_{\text{TUBE}}) w/k</th>
<th>(C_{\text{MIN}}/C_{\text{MAX}})</th>
<th>NTU</th>
<th>OVERALL HEAT TRANSFER CO-EFF W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>5</td>
<td>4.93</td>
<td>0.66</td>
<td>0.2602</td>
<td>0.2448</td>
<td>0.9411</td>
<td>1.824</td>
<td>2.103</td>
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<tr>
<td>14</td>
<td>9</td>
<td>11.31</td>
<td>0.64</td>
<td>0.3208</td>
<td>0.3788</td>
<td>0.846</td>
<td>1.4613</td>
<td>0.8215</td>
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<tr>
<td>17</td>
<td>12</td>
<td>12.35</td>
<td>0.46</td>
<td>0.3476</td>
<td>0.4173</td>
<td>0.8329</td>
<td>0.7723</td>
<td>1.2572</td>
</tr>
<tr>
<td>22</td>
<td>15</td>
<td>18.27</td>
<td>0.45</td>
<td>0.3792</td>
<td>0.4173</td>
<td>0.9086</td>
<td>0.7288</td>
<td>1.1898</td>
</tr>
</tbody>
</table>

5.2. DISC AND DOUGHNUT TYPE BAFFLE:

Table 3 Experimental Observations

<table>
<thead>
<tr>
<th>Time taken to fill 1 litre bottle(shell) SEC</th>
<th>Time taken to fill 1 litre bottle(tube) SEC</th>
<th>Shell inlet(cold fluid) °c</th>
<th>Shell outlet(cold fluid) °c</th>
<th>Tube inlet (hot fluid) °c</th>
<th>Tube outlet(hot fluid) °c</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
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<td>22</td>
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<td>18</td>
<td>14</td>
<td>13</td>
<td>16</td>
<td>40</td>
<td>28</td>
</tr>
</tbody>
</table>
Table 4 Result Table

<table>
<thead>
<tr>
<th>LM TD °C</th>
<th>ΔT1 °C</th>
<th>ΔT2 °C</th>
<th>EFFECTIVENESS</th>
<th>C_SHELL w/k</th>
<th>C_TUBE w/k</th>
<th>C_MIN/C_MA X</th>
<th>NTU</th>
<th>OVERALL HEAT TRANSFER CO-EFF W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.21</td>
<td>10</td>
<td>5</td>
<td>0.96</td>
<td>0.087</td>
<td>0.297</td>
<td>0.2929</td>
<td>3.795</td>
<td>2.8495</td>
</tr>
<tr>
<td>12.43</td>
<td>14</td>
<td>11</td>
<td>0.29</td>
<td>0.26</td>
<td>0.32</td>
<td>0.812</td>
<td>0.496</td>
<td>2.986</td>
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<tr>
<td>14.79</td>
<td>18</td>
<td>12</td>
<td>0.51</td>
<td>0.244</td>
<td>0.32</td>
<td>0.762</td>
<td>1.06</td>
<td>1.7182</td>
</tr>
<tr>
<td>19.14</td>
<td>24</td>
<td>15</td>
<td>0.52</td>
<td>0.232</td>
<td>0.297</td>
<td>0.781</td>
<td>0.9105</td>
<td>1.7459</td>
</tr>
</tbody>
</table>

Figure 4 Hot water Temperature Vs LMTD of Segmental & Disc and Doughnut type

From figure 4, it is observed that if the hot water temperature increases, then LMTD of baffles are increased. The LMTD of Disc and Doughnut baffle is more compared to that of segmental baffle. The LMTD of Disc and Doughnut baffle is 14.79 and that of segmental baffle is 12.35 at hot water temperature 38°C. The increase in the LMTD using Disc and Doughnut baffle is 19.75% compared to segmental baffle at hot water temperature 38°C.

Figure 5 Hot water Temperature Vs Effectiveness of Segmental & Disc and Doughnut type
From the figure 5, it is observed that if the hot water temperature increases. Then effectiveness of Disc and Doughnut first decreases and then baffles are increased. But the effectiveness of Segmental baffle decreases as hot water temperature increases. The Effectiveness of Disc and Doughnut baffle is 0.51 and that of segmental baffle is 0.46 at hot water temperature 38°C. The increase in the Effectiveness using Disc and Doughnut baffle is 10.8% compared to segmental baffle at hot water temperature 38°C.

**Figure 6** Hot water Temperature Vs NTU of Segmental & Disc and Doughnut type

From the figure 6, it is observed that if the hot water temperature increases. Then NTU of Disc and Doughnut first decreases and then baffles are increased. But the NTU of Segmental baffle decreases as hot water temperature increases. The NTU of Disc and Doughnut baffle is 1.06 and that of segmental baffle is 0.7723 at hot water temperature 38°C. The increase in the NTU using Disc and Doughnut baffle is 37.25% compared to segmental baffle at hot water temperature 38°C.

**Figure 7** Hot water Temperature Vs HTC of Segmental & Disc and Doughnut type

From the figure 7, it is observed that if the hot water temperature increases. Then Heat Transfer Co-efficient of Disc and Doughnut first decreases and then baffles are increased. But the Heat Transfer Co-efficient of Segmental baffle decreases as hot water temperature increases. The NTU of Disc and Doughnut baffle is 1.06 and that of segmental baffle is 0.7723 at hot water temperature 38°C. The increase in the NTU using Disc and Doughnut baffle is 36.66% compared to segmental baffle at hot water temperature 38°C.
5. CONCLUSION
By conducting the experiments on shell and tube heat exchangers with two types of baffles at different hot water temperatures. The following points are concluded:

- When testing the heat exchanger under the counter flow with two different baffle (segmental and disc and doughnut type), we have noticed that more heat transfer is observed when the hot water flows in the tubes as compared to the condition in which it has flown through the shell.
- The effectiveness of heat exchanger having disc and doughnut type is more than segmental baffle type, this may be due to increase in the of heat transfer area thereby increase in the rate of cooling.
- The mass flow rate of disc and doughnut type is more than segmental type due to increase in velocity of fluid in disc and doughnut than segmental type.
- The Logarithmic mean temperature difference is also one of the important criteria for evaluating the performance of heat exchanger. It is observed that the LMTD for disc and doughnut type heat exchanger is more when compared with segmental type. This may be due to increase in flow rate of fluid over this tubes, this further increases the heat transfer rate. Higher LMTD means higher heat transfer rate.
- The increase in heat transfer rate is due to the increase in turbulence of fluid. It is seen that more turbulence is created in the flow by disc and doughnut type design when compared to that of Segmental baffles.
- The disc and doughnut type baffles have slightly higher overall heat transfer coefficient than then segmental type baffles for the given shell fluid at given conditions.

From the above points, it is concluded that shell and tube heat exchanger with disc and doughnut type baffles gives better heat transfer rate compared to segmental type baffles

REFERENCES
Experimental Investigation on Shell and Tube Heat Exchanger Using Segmental and Disc-Doughnut Type Baffles


