EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER CHARACTERISTICS USING SHELL AND TUBE HEAT EXCHANGER EQUIPPED WITH SEGMENTAL AND DOUGHNUT BAFFLES

Dheeraj Joshi
Assistant Professor, Department of Mechanical Engineering,
S R Engineering College, Warangal, Telangana, India

ABSTRACT

Heat exchangers are used in industries & domestic purpose. Heat exchangers are basically convective that is it may be forced or natural convection and in it may be with or without phase change of one or both fluids. Shell and tube heat exchanger can be designed by using different baffles shape but in the present work segmental and doughnut baffles are used. In this paper, an attempt is made to estimate the heat transfer, over-all heat transfer coefficient using shell & tube heat exchanger (STHE). A minor change in the design is segmental and doughnut baffle made to increase the heat transfer in STHE. As compared to theoretical and actual value of overall heat transfer, actual value is closed that of theoretical values.

Keywords: Shell and Tube Heat Exchanger, Baffles, Overall Heat Transfer Coefficient.

http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=10

1. INTRODUCTION

1.1 General

The main objective is to describe most of these heat exchangers in some detail using classification schemes. Starting with a definition, heat exchangers are classified according to transfer processes, number of fluids, and degree of surface compactness, construction features, flow arrangements, and heat transfer mechanisms.
1.2 Heat exchanger

The basic designs for heat exchangers are the shell-and-tube heat exchanger and the plate heat exchanger, although many other configurations have developed. According to the flow layout, heat exchangers are grouped in:

- Spiral heat exchanger
- Shell and tube heat exchanger
- Plate heat exchanger

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact [1].

2. LITERATURE REVIEW

2.1 PROCESS DESIGN OF HEAT EXCHANGER

Process and design of shell and tube heat exchanger condenser and reboiler (nptel). According to TEMA, different parameters and optimized that classification of exchanger are investigated in first phase, while in the next phase of the study is thermal design consideration and process of design procedure. In thermal design, the shell thickness of 3/8 inch for the shell ID of 7-24, the tube length of 6, 8, 12, 16, 20 and 24 Ft. are preferably used. Longer tube reduces shell diameter at the expense of higher shell pressure drop. Brass, copper, bronze and alloys of copper-nickel are the commonly used tube materials. The number of tubes that can be accommodated in a given shell ID is called tube count [2].

The next phase of study is tube passes in this the number of passes is chosen to get the required tube side fluid velocity to obtain greater heat transfer co-efficient and also to reduce scale formation.

Basic Construction of Shell and Tube Heat Exchangers:

From the study, Tubing that is generally used in TEMA sizes is made from low carbon steel, copper, Admiralty, Copper-Nickel, stainless steel, Hast alloy, Inconel, titanium and a few others. It is common to use tubing from 5/8” to 1-1/2” in these designs.

Baffles serve two important functions. They support the tubes during assembly and operation and prevent vibration from flow induced eddies and direct the shell side fluid back and forth across the tube bundle to provide effective velocity and heat transfer rates the cuts areas represent 20-25% of the shell diameter[4]. And we consider the disc and doughnut segmental baffle it is increase the turbulence, if increase the turbulence heat transfer rate increases.


- Design and fundamentals of shell and tube heat exchanger:
- Studied the formulation of shell equivalent and shell side[3]. Nusselt number, Reynolds number, Prandtl number and the overall heat transfer coefficient for the tube-side and shell. Number of tubes and the area of cross sectional of shell and tube side.
- Copper Tube, a handbook given by copper development association, The New York in this book have studied the dimensions of copper tubes and shell. Copper with stand the vibrations and it has high thermal conductivity, less corrosion compare to other material[5].
3. DESIGNING AND FABRICATION

3.1 PROCESS DESIGN AND FABRICATION OF SHELL AND TUBE EXCHANGER FOR TWO PHASE HEAT TRANSFER

In the design process it is necessary to compare disc and donut baffles with segmental baffles from the viewpoint of heat exchanger design where the rate of fluid flow and allowable pressure drop are specified. It was found that when 19 disc and donut baffles were used the pressure drop was the same as when 11 segmental baffles were used, for a given rate of flow; however, the (overall) coefficient of heat transfer obtained with disc and donut baffles was approximately 15% greater than that obtained with segmental baffles. The lower values for the coefficient of heat transfer obtained with segmental baffles seems to indicate that some of the kinetic energy of the fluid is dissipated in eddy motions occurring in the pockets in the flow path.

![Figure 1 disc type baffle](image1.jpg)  ![Figure 2 Doughnut baffle](image2.jpg)

A sketch of a typical layout of disc/donut baffles in a shell-and-tube heat exchanger is shown in Figure 2 the flow penetrates the tubular field symmetrically in the radial direction. The pressure drop can be modified by both the baffle spacing and the baffle edge overlap (Dd - Dr). For assembly purposes, the baffle edge overlap must have a minimum of one tube row common to both baffles, but it can be as large as the turnaround at the inner and outer flow passage will permit without causing undue pressure drop. The earlier designs of the disc/donut baffles were usually low pressure drop devices with very small baffle overlaps. The proposed system would not be restricted by this criterion. The characteristics and advantages of the flow in a disc/donut baffle system, as compared to the segmental baffle, are summarized below:

There is no bypass stream between the tube bundle and shell. Only every second ring baffle has a parasitic baffle to shell leakage stream, while the disk baffle has none. The tube field in cross flow is long but shallow; the fore, the pressure drop differential between baffles is small. Accordingly, the driving force that causes the leakage stream between the baffle and shell, and between the tube and baffle whole, is minimized. As a result, the effectiveness of the tube bundle with disk/donut baffles approaches that of an ideal tube bank, unlike the case with segmental baffles, where the effective flow fraction is typically less than 60%.

The fully symmetrical radial flow sweeps the entire tube field uniformly. Avoiding areas of low flow ("dead zones") that arc typical for segmental baffles. This flow uniformly together with the minimum effect of bypass and leakage streams is the main reason for the high effectiveness of pressure drop to heat transfer conversion. The temperature profile distortion is minimized because of the absence of the bypass and leakage streams.
3.1 Materials of Construction

3.1.1 Tube:
Tubing that is generally used in TEMA sizes is made from low carbon steel, copper, Admiralty, Copper-Nickel, Stainless steel, Inconel, titanium and a few others[6].

3.1.2 Copper tubing is most often used for supply of hot and cold tap water and as refrigerant line systems. There are two basic types of copper tubing, soft copper and rigid copper. Copper tubing is joined using flare connection, compression connection,

Common wall-thicknesses of copper tubing in the USA are “Type K”, "Type L", "Type M", and "Type DW"

3.1.3 Tube sheets
Tube sheets are usually made from a round flat piece of metal with holes drilled for the tube ends in a precise location and pattern relative to one another. Tubes are attached to the tube sheet by pneumatic or hydraulic pressure or by roller expansion. Tube holes are typically drilled and then reamed and can be machined with one or more grooves. This greatly increases the strength of the tube joint.

![Image of Front and Rear Tube Sheet](http://www.iaeme.com/IJMET/index.asp)

Figure 3 Front and rear tube sheet

The tube sheet comes in contact with both fluids in the exchanger, therefore it must be made of corrosion resistant materials or allowances appropriate for the fluids and velocities.

3.1.4 Shell assembly and Baffle

![Image of Disassembled Shell and Tube Heat Exchanger](http://www.iaeme.com/IJMET/index.asp)

Figure 4 Disassembly of shell and tube heat exchanger Fig.5 Tubes and Baffles arrangement

The clearance between tube bundle and inner shell wall that depends on a type of exchanger shells. Shell is a container for a fluid and a tube bundle is then placed inside the shell. Shell diameter should be selected in such a way that to give a close fit of a tube bundle. The tube sheet thickness should be greater than the tube outside diameter to make a good seal. Baffles, function in two ways, during assembly they function as tube guides, in operation they...
prevent vibration from flow induced eddies, last but most importantly they direct shell-side fluids across the bundle increasing velocity and turbulence effectively increasing the rate of heat transfer[8].

4. DESIGNING AND FORMULATIONS

4.1 Process (thermal) design procedure

Shell and tube heat exchanger is designed by trial and error calculations[4]. The main steps of design following the Kern method are summarized as follows:

**Step: 1.** Obtain the required thermo physical properties of hot and cold fluids at the caloric temperature or arithmetic mean temperature. Calculate these properties at the caloric temperature if the variation of viscosity with temperature is large.

**Step: 2.** Perform energy balance and find out the heat duty of the exchanger. \(Q\)

**Step: 3.** Assume a reasonable value of overall heat transfer coefficient \(U_{o,assm}\). The value of \(U_{o,assm}\) with respect to the process hot and cold fluids can be taken from the books

**Step: 4.** Decide tentative number of shell and tube passes \(n_p\). Determine the LMTD and the correction factor \(F_T\) normally should be greater than 0.75 for the steady operation of the exchangers. Otherwise it is required to increase the number of passes to obtain higher \(F_T\) value

**Step: 5.** Calculate heat transfer area \(A\) required: \( A = \frac{Q}{U_{o,assm,\text{LMTD,}F_T}} \) (1.1)

**Step: 6.** Select tube material, decide the tube diameter \((\text{ID}=d_i, \text{OD}=d_o)\), its wall thickness (in terms of BWG or SWG) and tube length \((L)\). Calculate the number of tubes

Required to provide the heat transfer area \(A\): \(n_t=\frac{A}{\pi d_o L} \) (1.2)

Calculate tube side fluid velocity \(u=\frac{4m(n_p/n_t)}{\pi d_o L} \) (1.3)

If \(u<1\) m/s, fix the \(n_p\) so that \(R_e=\frac{4m(n_p/n_t)}{\pi d_o L} \geq 10^4\)

Where, \(m\) mass flow rate, density and viscosity of tube side fluid. However, this is subject to allowable pressure drop in the tube side of the heat exchange

**Step: 7.** Decide type of shell and tube exchanger (fixed tube sheet, U-tube etc.). Select the tube pitch \((P_t)\), determine inside shell diameter \((D_s)\) that can accommodate the calculated number of tubes \((n_t)\). Use the standard tube counts table for this purpose. Tube counts are available in standard text books

**Step: 8.** Assign fluid to shell side or tube side (a general guideline for placing the fluids is summarized in data book. Select the type of baffle (segmental, doughnut etc.), its size (i.e. percentage cut, 25% baffles are widely used), spacing \((B)\) and number. The baffle spacing is usually chosen to be within 0.2 \(D_s\) to \(D_s\).

**Step: 9.** Tube-Side Nusselt Number

Nusselt number is a function of Reynolds number and Prandtl number. However, there are equations developed according to the type of flow. For turbulent flow, the following equation developed by Petukhov-Kirillov can be used.

Predicts the results in the range \(10^4 and R_e \leq 5\times 10^6 and 0.5 < p_r < 200\)

\[ N_u = 1.86 \left( \frac{R_e \rho_d \tau}{2} \right)^{1/3} \] (1.4)

Where \(R_e\) is the Reynolds number for the tube side
4.2 Tube-Side Heat Transfer Coefficient

The heat transfer coefficient for the tube-side is expressed as follows:

\[ h_t = \frac{N_u k}{d_i} \]  

Where \( N_u \) is the Nusselt number for the tube-side, \( k \) is the thermal conductivity of the tube-side fluid, and \( d_i \) is the tube inside diameter.

4.3 Thermal Analysis for Shell-Side

4.3.1 Shell Equivalent Diameter

The equivalent diameter is calculated along (instead of across) the long axes of the shell and therefore is taken as four times the net flow area as layout on the tube sheet (for any pitch \( \Delta \))

\[ D_e = \frac{4(p_f^{2/3} \cdot \frac{nd_o}{2})}{nd_o} \]  

Where \( d_o \) is the tube outside diameter

\[ A_S = \frac{D_S}{P_f} \cdot CB \]  

Where \( A_s \) is the bundle cross flow area, \( D_S \) is the inner diameter of the shell, \( C \) is the clearance between adjacent tubes, and \( B \) is the baffle spacing. And the tube clearance is expressed as

\[ C = P_f - d_o \]  

4.3.2 Shell-Side Reynolds Number

Reynolds number for the shell-side is based on the tube diameter and the velocity on the cross flow area at the diameter of the shell:

\[ R_{es} = \left( \frac{M_s}{A_s} \right) \frac{D_e}{\rho_s} \]  

Where \( D_e \) is the equivalent diameter on the shell-side, \( M_s \) is the flow rate of the shell-side fluid, \( \mu_s \) is the viscosity of the shell-side fluid, and \( A_s \) is the cross flow area at the shell diameter.

4.3.3. Shell-Side Heat Transfer Coefficient

The heat transfer coefficient for the shell-side in the Kern Method can be estimated

\[ h_o = \frac{0.36k_s}{D_e} \times R_{es}^{0.55} \times P_f^{\frac{1}{3}} \]  

For \( 2 \times 10^3 < R_{es} = \frac{D_e \cdot \rho_s}{\mu} < 1 \times 10^6 \)

Where \( k_s \) is the thermal conductivity of the shell-side fluid, \( R_{es} \) is the Reynolds number for the shell-side, \( P_f \) is the Prandtl number for the shell-side fluid, and \( D_e \) is the equivalent diameter on the shell-side.
4.4. Overall Heat Transfer Coefficient

The overall heat transfer coefficient for clean surface (U is given by

\[
\frac{1}{U_e} = \frac{1}{h_o} + \frac{1}{h_t} + \frac{d_o}{d_t} + \frac{r_o \ln \left( \frac{r_o}{r_i} \right)}{K}
\]

(1.11)

Where \( h_o \) is the shell-side heat transfer coefficient, \( h_t \) is the tube-side heat transfer coefficient, \( r_o \) is the tube outer radius, \( r_i \) is the tube inner radius, and \( K \) is the thermal conductivity of the tube material.

4.5 Calculation of heat transfer area and tube numbers

The first iteration is started assuming 1 shell pass and 4 tube pass shell and tube exchanger with following dimensions and considerations.

Fixed tube plate

Hot fluid inlet temperature \( T_1 = 54^\circ C \)

Hot fluid outlet temperature \( T_2 = 44^\circ C \)

Cold fluid inlet temperature \( t_1 = 33^\circ C \)

Cold fluid outlet temperature \( t_2 = 40^\circ C \)

Fouling factor of hot fluid \( R_h = 0.0003 \)

Fouling factor of cold fluid \( R_c = 0.001 \)

Shell-Side Heat Transfer Coefficient

The heat transfer coefficient for the shell-side in the Kern Method can be estimated

From \( h_o = \frac{0.36k_s}{d_e} R_e^{0.55} \left( \frac{1}{P_r} \right)^{0.7} \)

\( h_o = \frac{0.36 \times 0.06350}{0.0136} \times 27297.01^{0.55} \times 3.7^{0.7} \)

\( h_o = 715.8 \text{ W/m}^2\text{k} \)

Overall Heat Transfer Coefficient

The overall heat transfer coefficient for clean surface (U is given by

\[
\frac{1}{U_e} = \frac{1}{h_o} + \frac{1}{h_t} + \frac{d_o}{d_t} + \frac{r_o \ln \left( \frac{r_o}{r_i} \right)}{K}
\]

\[
\frac{1}{U_e} = \frac{1}{715} + \frac{1}{996} + 0.0127 + \frac{0.00635 \ln (0.00635)}{386}
\]

\( U_e = 377.05 \text{ W/m}^2\text{k} \)

---

**Figure 1** 3D design of baffles and tubes arrangement

**Table 1** specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube Material</td>
<td>Copper</td>
</tr>
<tr>
<td>Tube outside diameter</td>
<td>0.0127 m</td>
</tr>
<tr>
<td>Tube Wall Thickness</td>
<td>0.0001 m</td>
</tr>
<tr>
<td>Number of tubes in bundle</td>
<td>12</td>
</tr>
<tr>
<td>Effective length of tube bundle</td>
<td>0.457</td>
</tr>
<tr>
<td>Effective heat transfer area</td>
<td>0.0105 m²</td>
</tr>
<tr>
<td>Shell Material</td>
<td>Mild steel</td>
</tr>
<tr>
<td>Shell Inside Diameter</td>
<td>0.179</td>
</tr>
<tr>
<td>Shell Wall Thickness</td>
<td>0.002 m</td>
</tr>
<tr>
<td>Number of baffles</td>
<td>4</td>
</tr>
</tbody>
</table>

http://www.iaeme.com/IJMET/index.asp
OBSERVATIONS
Flow Direction: Counter-flow
Direction: Counter-flow

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>T1(°C)</th>
<th>T2(°C)</th>
<th>T3(°C)</th>
<th>T4(°C)</th>
<th>Vhot (G/sec)</th>
<th>Vcold (G/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54</td>
<td>44</td>
<td>33</td>
<td>40</td>
<td>0.033</td>
<td>0.033</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>37</td>
<td>28</td>
<td>32</td>
<td>0.083</td>
<td>0.033</td>
</tr>
<tr>
<td>3</td>
<td>41</td>
<td>33</td>
<td>28</td>
<td>31</td>
<td>0.086</td>
<td>0.156</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
<td>32</td>
<td>28</td>
<td>34</td>
<td>0.113</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 3 Observations

Calculation
Hence the power emitted from the hot fluid

\[ Q = m \cdot c_p (T_1 - T_2) \]

\[ Q_1 = 0.57 \times 4.18(54-44) = 23.93 \text{Watts.} \]

Power emitted from the hot fluid

\[ Q_2 = m \cdot c_p (T_1 - T_2) \]

\[ Q_2 = 0.086 \times 992 \times 0.0175 \times (41-33) \]

\[ Q_2 = 30.66 \text{ watts.} \]

Power emitted from the hot fluid

\[ Q_3 = m \cdot c_p (T_1 - T_2) \]

\[ Q_3 = 0.113 \times 0.0175 \times 9954.18 \times (39-32) = 57.5 \text{Watts} \]

5. RESULTS AND DISCUSSIONS:

5.1 RESULT:
Shell and tube heat exchanger is designed by trial and error calculations.

The main steps of design following the KERN METHOD
We got the following values and compared to theoretical overall heat transfer coefficient.
The first iteration is started assuming 1 shell four tube pass shell and tube exchanger with
following dimensions and considerations.
Hot fluid inlet temperature = 54°C.
Hot fluid outlet temperature = 44°C.
Cold fluid inlet temperature = 33°C.
Cold fluid outlet temperature = 40°C.
Fouling factor of hot fluid = 0.0003.
Fouling factor of cold fluid = 0.001.
Caloric temperature of hot fluid = 50°C.
Caloric temperature of cold fluid = 36.5°C.
0.0127 OD tubes on triangular pitch
Outer diameter of the tube = 0.0127m.
Tube length = 0.4772m.

http://www.iaeme.com/IJMET/index.asp
editor@iaeme.com
Tube ID = 0.0102m.
The log mean temperature correction factor for 1-4 shell and tube heat exchanger. \( F_t = 0.8 \) cm. \( R = 1.42, S = 0.33 \)
Logarithm mean temperature difference = 9.12.
Tube material = copper.
Tube outside diameter = 0.0127m.
Tube wall thickness = 0.0001m.
Number of tubes in bundle = 12.
Effective length of tube bundle = 0.457m.
Effective heat transfer area = 0.105m.
Shell material = mild steel.
Shell inside diameter = 0.179m.
Shell wall thickness = 0.002m.
Number of baffles = 4.
The overall heat transfer coefficient of hot and cold fluid of heat exchanger 300 is assumed to initiate the design calculation.
The approximate range of overall heat transfer of hot and cold fluid of heat exchanger = \( A = 0.0505\text{m}^2 \).
Number of tubes \( t = 12 \) is taken corresponding to the closest standard shell ID of 0.1778m for fixed tube sheet, 1-shell and 4-tube pass exchanger with 0.0127 tube, triangular pitch.
Nusselt number = 1.86.
Tube side heat transfer coefficient = 996 w/ m\(^2\)k.
Shell side heat transfer coefficient = 715.81 w/ m\(^2\)k.
The overall heat transfer coefficient for clean surface = 377.05 w/ m\(^2\)k.
Heat transfer from the hot fluid = 673 watts.
Heat absorb by cold fluid = 252.96 watts.
The experimental value, we got has high \( U \) and thus the rate of heat transfer is increased by using segmental and doughnut baffles.

5.1.1 The observed value of log mean temperature difference value and overall heat transfer
Table 2 represents the LMTD increased the overall heat transfer (U) decreased. Because of the LMTD and overall heat transfer (U) are inversely proportional to each other.

<table>
<thead>
<tr>
<th>S.NO.</th>
<th>LMTD</th>
<th>Overall heat transfer (U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.48</td>
<td>446</td>
</tr>
<tr>
<td>2</td>
<td>7.5</td>
<td>421</td>
</tr>
<tr>
<td>3</td>
<td>9.1</td>
<td>377</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>209</td>
</tr>
</tbody>
</table>
5.1.2 The changing value of velocity and heat transfer rate:
The below table is represented that flow rate vs heat transfer rate in this we observed that the flow rate increases, heat transfer rate is gradually increased.

6. CONCLUSIONS
The following conclusions are arrived from the heat transfer of shell and tube heat exchangers for water.

- Compared the result of concentric tube heat exchanger & shell - tube heat exchanger, from the experiment carried out it improved the overall heat transfer coefficient of the heat exchanger by using segmental and doughnut type baffles shell & tube heat exchanger.
- It was observed that the rate of heat transfer increases with increase in overall heat transfer coefficient when compare to other heat exchangers.
- From the data arrived it is concluded that as Reynolds number increases, Nusselt number increases.
- It was observed that number of baffles increases then there will be increase in turbulence.
- It was concluded that as Compared to the double segmental, segmental baffles and disc and doughnut in that the disc and doughnut baffle gives the less pressure drop and high heat transfer rate.
- The number of tubes will increase heat transfer rate and overall heat transfer rate also increases.
- Compared to other heat exchanger it is concluded that shell and tube heat exchanger of 4 tubes passes shell will increase the heat transfer rate because of the fluid covered area increases.
- It was observed that compared to square pitch, triangular pitch gives the better heat transfer rate.
- It is considered that the baffle spacing is 0.2 to 1 time of shell inside diameter gives the best result.
- It is a fixed type of heat exchanger so that to prevent the leakages.

Water is mainly preferred in this process due to easily available, nonflammable, less toxic in nature, no environmental impact, when compared to other resources.

Future Scope: This type of segmental and doughnut baffle shell and tube heat exchanger is used to increase the rate of heat transfer. By varying flow rate, input temperature of hot fluids & other parameters, compare the results of heat exchanger using different fluids.

REFERENCES