Shell & Tube Heat Exchangers

- Shell & tube type heat exchangers are built of tubes (round or rectangular in general) mounted in shells (cylindrical, rectangular or arbitrary shape).
- Many variations of this basic type is available.
  - The differences lie mainly in the detailed features of construction and provisions for differential thermal expansion between the tubes and the shell.

Figure 1.7 A single-pass tube, baffled single-pass shell, shell-and-tube heat exchanger designed to give essentially countercflow conditions. A toroidal expansion joint in the center of the shell accommodates differential thermal expansion between the tubes and the shell, and double header sheets assure that no fluid can leak from one circuit to the other. (Courtesy The Patterson-Kelley Co.)
Shell Types

- TEMA (the Tubular Exchangers Manufacturers Association) publishes standards defining how shell and tube exchangers should be built. They define a naming system that is commonly used.

- Shells are also typically purchased in standard sizes to control costs. Inside the shell, baffles (dividers) are installed to direct the flow around the tubes, increase velocity, and promote cross flow. They also help support the tubes. The baffle cut is the ratio of the baffle window height to the shell diameter. Typically, baffle cut is about 20 percent. It affects both heat transfer and pressure drop. Designers also need to specify the baffle spacing; the maximum spacing depends on how much support the tubes need.
**Tube to Header Plate Connection**

- Tubes are arranged in a **bundle** and held in place by **header plate** (tube sheet).
- The number of tubes that can be placed within a shell depends on
  - Tube layout, tube outside diameter, pitch, number of passes and the shell diameter.
- When the tubes are too close to each other, the header plate becomes too weak.
- Methods of attaching tubes to the header plate

![Diagram of tube to header plate connection]
Baffle Type & Geometry

- Baffles serve two functions:
  - **Support the tubes** for structural rigidity, preventing tube vibration and sagging
  - **Divert the flow** across the bundle to obtain a higher heat transfer coefficient.
The number of tubes in an exchanger depends on the
- Fluid flow rates
- Available pressure drop.

The number of tubes is selected such that the
- **Tube side velocity** for water and similar liquids ranges from 0.9 to 2.4 m/s (3 to 8 ft/sec)
- **Shell-side velocity** from 0.6 to 1.5 m/s (2 to 5 ft/sec).

The lower velocity limit corresponds to limiting the **fouling**, and the upper velocity limit corresponds to limiting the rate of **erosion**.

When sand and silt are present, the velocity is kept high enough to prevent settling.
A pass is when liquid flows all the way across from one end to the other of the exchanger. We will count shell passes and tube passes.

- An exchanger with one shell pass and two tube passes is a 1-2 exchanger. Almost always, the tube passes will be in multiples of two (1-2, 1-4, 2-4, etc.)
- Odd numbers of tube passes have more complicated mechanical stresses, etc. An exception: 1-1 exchangers are sometimes used for vaporizers and condensers.

- A large number of tube passes are used to increase the tube side fluid velocity and heat transfer coefficient and minimize fouling.
  - This can only be done when there is enough pumping power since the increased velocity and additional turns increases the pressure drop significantly.
The number of tube passes depends on the available pressure drop.

- Higher velocities in the tube result in higher heat transfer coefficients, at the expense of increased pressure drop.

Therefore, if a higher pressure drop is acceptable, it is desirable to have fewer but longer tubes (reduced flow area and increased flow length).

- Long tubes are accommodated in a short shell exchanger by multiple tube passes.

The number of tube passes in a shell generally range from 1 to 10.

- The standard design has one, two, or four tube passes.

- An odd number of passes is uncommon and may result in mechanical and thermal problems in fabrication and operation.
Materials selection and compatibility between construction materials and working fluids are important issues, in particular with regard to corrosion and/or operation at elevated temperatures.

Requirement for low cost, light weight, high conductivity, and good joining characteristics often leads to the selection of aluminum for the heat transfer surface.

On the other side, stainless steel is used for food processing or fluids that require corrosion resistance.

In general, one of the selection criteria for exchanger material depends on the corrosiveness of the working fluid.

A summary Table is provided as a reference for corrosive and non-corrosive environments.
Tube Wall Thickness

- The wall thickness of heat exchanger tubes is standardized in terms of Birmingham Wire Gage BWG of the tube.
- Small tube diameters (8 to 15mm) are preferred for greater area to volume density but are limited for the purposes of cleaning.
- Large tube diameters are often required for condensers and boilers.
The most common plain tube sizes have 15.88, 19.05, and 25.40 mm (5/8, ¾, 1 inche) tube outside diameters.

From the heat transfer viewpoint, smaller-diameter tubes yield higher heat transfer coefficients and result in a more compact exchanger.

However, larger-diameter tubes are easier to clean and more rugged.

The foregoing common sizes represent a compromise.
  - For mechanical cleaning, the smallest practical size is 19.05 mm.
  - For chemical cleaning, smaller sizes can be used provided that the tubes never plug completely.
Tube Length

- Tube length affects the cost and operation of heat exchangers.
  - Longer the tube length (for any given surface area),
    - Fewer tubes are needed, requiring less complicated header plate with fewer holes drilled
    - Shell diameter decreases resulting in lower cost

- Typically tubes are employed in 8, 12, 15, and 20 foot lengths. Mechanical cleaning is limited to tubes 20 ft and shorter, although standard exchangers can be built with tubes up to 40 ft.

- There are, like with anything limits of how long the tubes can be.
  - **Shell-diameter-to-tube-length ratio** should be within limits of 1/5 to 1/15

- Maximum tube length is dictated by
  - Architectural layouts
  - Transportation (to about 30m.)
    - The diameter of the two booster rockets is dictated by the smallest highway tunnel size between the location of manufacturer and Florida. Scientific hah!
Tube Layout

- Tube layout is characterized by the included angle between tubes.
  - Two standard types of tube layouts are the **square** and the **equilateral triangle**.
    - Triangular pitch (30° layout) is better for heat transfer and surface area per unit length (greatest tube density.)
    - Square pitch (45° & 90° layouts) is needed for mechanical cleaning.
  - Note that the 30°, 45° and 60° are staggered, and 90° is in line.

- For the identical tube pitch and flow rates, the tube layouts in decreasing order of shell-side heat transfer coefficient and pressure drop are: 30°, 45°, 60°, 90°.
Tube Pitch

- **The selection of tube pitch** is a compromise between a
  - **Close pitch** (small values of $P_t/d_o$) for increased shell-side heat transfer and surface compactness, and an
  - **Open pitch** (large values of $P_t/d_o$) for decreased shell-side plugging and ease in shell-side cleaning.
- Tube pitch $P_T$ is chosen so that the **pitch ratio** is $1.25 < P_T/d_o < 1.5$
  - When the tubes are too close to each other ($P_t/d_o$ less than 1.25), the header plate (tube sheet) becomes too weak for proper rolling of the tubes and cause leaky joints.
- Tube layout and tube locations are standardized for industrial heat exchangers.
  - However, these are general rules of thumb and can be “violated” for custom heat exchanger designs.
Basic Design Procedure

- Heat exchanger must satisfy the
  - Heat transfer requirements (design or process needs)
  - Allowable pressure drop (pumping capacity and cost)

- Steps in designing a heat exchanger can be listed as:
  - Identify the problem
  - Select an heat exchanger type
  - Calculate/Select initial design parameters
  - Rate the initial design
    - Calculate thermal performance and pressure drops for shell and tube side
  - Evaluate the design
    - Is performance and cost acceptable?