SHELL AND TUBE HEAT EXCHANGER (STHE) - PART B

A shell and tube heat exchanger (STHE) consist of several different components and each component needs to be evaluated in the selection process for the steam process application. The success or failure of the STHE is insuring that the unit meets the process requirement. The standard main components are as follows:

- Shell
- Tubes
- Tube Sheet
- Front head
- Rear head
- Inlet nozzle
- Outlet nozzle

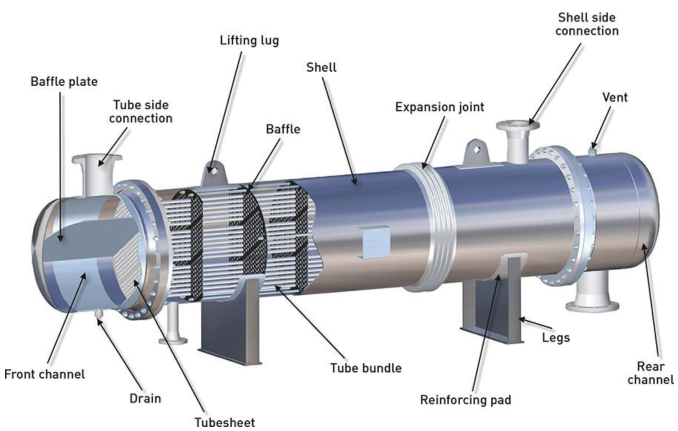

Figure 1: Overview of a shell and tube

STHE SHELL SIDE

The shell is typically manufactured from standard pipe on the smaller designed units and fabricated for the large units. The shell design depends greatly on the pressure and temperature of the steam (steam is typically on the shell side of the unit). As the pressure and temperature increases, the wall thickness of the shell will also increase to accommodate high pressures and temperatures.
An expansion joint is used on the shell side with the straight fix tube bundle design otherwise the expansion and contraction are compensated in the tube bundle. The shell will accommodate the steam inlet and condensate outlet nozzles, air vent and vacuum breaker connections and other drain ports depending on the design of the unit.

STHE TUBES

The internal tubing can be made from many different materials depending on the application. Copper, steel or stainless steel are common materials, but other alloys are used as nickel alloys and a variety of brass materials. The tubes can seamless or welded depending on the plant preferences and process demands. Tube diameter can be in sizes from ¼" to 2" in diameter, which depended on the process application. The larger tube will provide a low pressure drop through the tube bundle which is a parameter that needs to be reviewed on each application.

The tube material used will affect the transfer of energy (thermal conductivity) and materials with lower thermal conductivity will require a larger surface area that increases the size of the unit.

TUBE DIAMETER

Using a small tube diameter can make the heat exchanger both economical and compact. The negative to a small tube diameter are as follows:

- Higher pressure drop
- Faster fouling
- Difficult to clean

Larger diameter will have a lower pressure drop which is major consideration and less acceptability to fouling. Tube diameter is an important consideration when designing a

STHE.

TUBE SHEET

A tube sheet is an important component of a STHE; it is the principal barrier between the shell-side steam and tube-side process fluids. The design of a tube sheet is important for safety and reliability of the STHE. Tube sheets are mostly circular with uniform pattern of drilled holes. Tube sheets are connected to the shell and the channels either by welds (integral) or with bolts (gasketed joints) or with a combination of both.

FRONT/REAR HEAD ASSEMBLIES

The head sections of the STHE can vary from plain standard castings to fabricated assemblies with many special features to accommodate the different passes that the unit can direct the flow of product through the tubes. The cast iron head assembly is the lowest cost for standard STHE designs for non-rigorous applications. When the designs required redirecting the product several times in the tube arrangement, then fabricated heads are required that are most costly to produce. There are many choices that are available to meet the process applications in fabricated head assemblies.

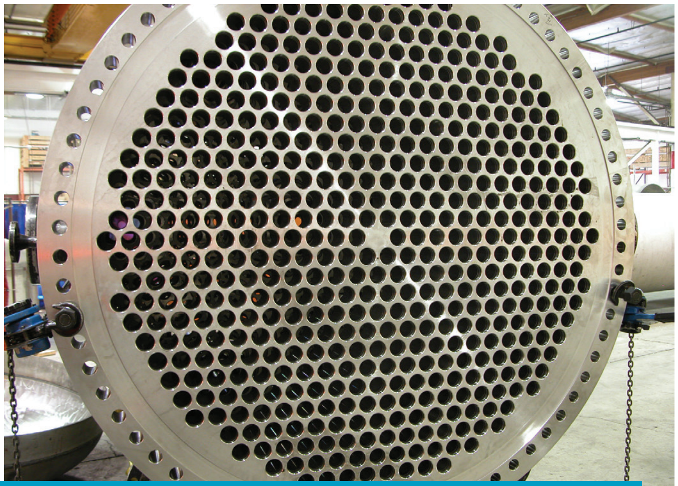

Figure 2. Tube Sheet View

VELOCITIES

For water and similar liquids, the velocity ranges from 3 to 8 ft/sec on the tube side. The shell side; the velocity ranges 2 to 5 ft/sec.

INLET/OUTLET NOZZLE

The steam inlet nozzle will not exceed 5,000 fpm to insure the steam does not erode the tube or cause tube vibration. The outlet nozzle will be sized for 3,000 fpm or less to insure proper condensate removal from the heat exchanger. Remember that condensate is drained from the STHE by gravity; not pressure or velocities.

Figure 3. Example of a Shell and Tube Final Manufactured Unit

MAINTENANCE AND RELIABILITY CONSIDERATIONS

Tube-sheet arrangements are designed to include as many tubes as possible within the shell for maximum heat transfer surface. Sometimes a layout must be selected that also permits access to the tubes for cleaning as required by process conditions.

STHE SELECTION PROCESS

The selection process

1. Temperature of the steam vs. product temperature
The higher the steam pressure/temperature versus the process temperature (larger gradient temperature) will result in a smaller heat exchanger, but will have a higher expansion/contraction and material cost could be higher. A lower temperature gradient will result in larger STHE, but less thermal expansion which will have a longer reliability.

2. Pressure drop
A high allowable pressure drop on both the product side and steam side will result in cost reduction, but a high-pressure drop can cause production issues and

sometimes the pressure drop can shear the product. Low pressure drops will have a higher cost but there will be very little shear factor to the product.

3. Size restrictions
The STHE is typically small in diameter compare to the length due to manufacturing cost. In certain cases, the STHE length cannot be accommodate therefore the unit will a larger diameter versus the length to enable the installation of the unit. In designing the STHE there are many different factors that affect cost and to state that a longer length unit is less costly is not necessarily true all cases.

4. Fouling factor
Product fouling affects the STHE performance and it part of the design of the unit. If the STHE has to operate a certain period without cleaning, then a fouling factor is added to the design, which is simple done by adding more heat transfer area. During the selection process this must be taken into consideration if fouling is going to occur during operation.

5. STHE Output rating
The STHE design will meet the expected output under the specified process conditions. It is up to the consumer to determine if additional capacity if required for possible process increases or product changes. The cost to adding additional capacity is very low and a 5 to 10% additional capacity is typical. The STHE unit cannot have more heat transfer added after the unit is built and delivered to the plant.

6. Product
Product production usually has many variables, such as temperature, pressure, flow rate, viscosity, etc. that can be changed within the maximum design limits. It is important to recognize during the design of the system that changing process conditions do influence the size and cost of heat exchanger.

7. Maintenance of the unit
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STHE HEAT TRANSFER CALCULATIONS

The calculations can very complexed that are required in STHE design for the steam process applications. Some of the calculations can be several separate calculations or very elaborate theoretical work. There are several software systems that are available to assist the companies in the final designs. There are few formulas and concepts that can be used to understand the heat exchanger applications.

The STHE design starts with the product flow rate, product inlet temperature, product outlet temperature and steam pressure/temperature. From this information a certain amount of energy has to be delivered to the product. Most heat exchanger studies begin with a given flow rate and temperature change. A certain amount of heat must be provided to a flow of material or put into it per unit of time. This is the load.

Using common terms, we measure heat in British Thermal Units (BTUs), and we express heat transfer rate on an hourly basis. Then, load—termed "**q**" in the following equations—is expressed in **BTU/hr**.

In heat exchanger design, two flows of materials are involved—one in the tubes and one (steam) on the shell side surrounding the tubes. The calculation assumes that all the heat given up by the steam goes into the fluid in the tube.

EQUATIONS

Useful work represented by the load "q" may thus heating (steam) of a fluid.

For cooling the warmer of two fluids, the load equation is:

$$q = W\,C\,(T1 - T2)$$

Where :

q	= load in BTU/hr.
W	= pounds per hr. of hot fluid
C	= specific heat of hot fluid
T1	= temperature, ºF, of hot fluid in
T2	= temperature, ºF, of hot fluid out

Depending on the fluids; the actual specific heats will enter the calculations. Then, in a liquid-to-liquid situation, the load depends on the weight of fluid handled per hour, its specific heat, and the amount of temperature must be changed. To take care of this load, the product of flow per hour times specific heat times temperature differences of a second fluid must balance out to add or take away that same amount of heat.

If either fluid vaporizes or is condensed from a vapor in the heat exchanging operation, then temperature differences alone do not account for the load. A large amount of heat energy in steam will be latent heat used or given up during this change of state. Neglecting entirely the temperature difference part of the problem, load is then expressed:

$$Q=W\,\Delta\square H$$

Where:

W = pounds per hour of vapors evaporated or condensed

Δ□H = latent heat of vaporization

A Combination of Three Factors Governs Load Capacity
How large a heat exchanger must be to handle a given load depends on the following:

- Overall heat transfer coefficient
- Temperature difference between the two fluids or vapor

The surface of a heat exchanger is its total heat transfer area. Load capacity will be proportionate to this area, but the other two factors can vary so widely that it is most helpful to consider the combination of all factors together.

$$q = U \; MTD \; A$$

Where:

q = load, BTU/hr.

U = design overall heat transfer coefficient, BTU/hr./sq. ft./°F (700–750) steam = 700–750; water = 100 (est.)

MTD = mean temperature difference between ç hot and cold mediums, °F

A = effective outside area of tubes, square feet

This relationship can also be expressed in words, and the equation is then stated: The rate that heat is transferred in a shell and tube heat exchanger is the product of three factors: (1) the overall heat transfer coefficient, (2) the corrected mean temperature difference between the hot and cold fluids, and (3) the effective outside area of tubes and other heating surfaces.

To represent a practical application situation, the equation should be transposed so that A stands alone:

$$A = \frac{q}{U(MTD)}$$

HEAT TRANSFER COEFFICIENT (U) DEPENDS ON MANY VARIABLES

The overall heat transfer coefficient is a measure of performance. It evaluates the ability of the tube in each mechanical arrangement to transmit heat from one fluid to another.

A clearer concept of heat transfer can be gained by considering the reciprocal of heat transfer coefficient, which we may term heat flow resistance. The advantage of this mathematical inversion lies in the fact that overall resistance is the simple sum of five individual resistances. These are the resistances to the flow of heat through the tube-side fluid, tube-side scale, tube metal, shell-side scale, and shell-side fluid.

Usually, the smallest individual resistance to heat transfer is that of the metal tube wall itself.

How the various heat flow resistances affect U, the heat transfer coefficient, can be shown in the equation:

$$\frac{1 = r_t + r_{tf} + r_m + r_{sf} + r_s}{U}$$

Where:

rt = resistance to flow of heat through the tube side fluid film

rtf = resistance to flow of heat through scale deposits inside the tube-fouling resistance

rm = resistance to flow of heat through metal tube wall

rsf = resistance to flow of heat through scale deposits outside the tube-fouling resistance

rs = resistance to flow of heat through shell-side fluid film

The plant should always work with a knowledge engineering firm or vendor in the area heat transfer to ensure a properly sized and efficient shell and tube unit is selected.