BEST PRACTICE NO. 46

INVENO ENGINEERING LLC

SHELL AND TUBE HEAT EXCHANGER DESIGN "PART A"

STEAM SHELL AND TUBE HEAT EXCHANGERS

The shell and tube heat exchanger (STHE) is the workhorse in the steam world, and it is used in many process steam applications. The design is very flexible to meet the strenuous requirements found in steam and condensate systems. Because of its flexibility, the STHE can be used to heat different process products, CIP systems, water, process fluids, etc. Simply stated, an STHE has two distinct parts: one is a circular vessel or shell, and the other is the tubes in the shell. Typically, steam is delivered to the shell side and transfers the energy from the steam to the process fluids in the tubes without direct contact or mixing the steam with the fluid.

The STHE brings a number of advantages to the steam world, such as the ability to handle different products, high steam pressures, and the high steam temperatures associated with the high steam pressures. Of course, there are always disadvantages too. Here, the primary disadvantage is that the initial cost of the STHE will be higher than the other heat transfer devices that can be used for the process applications. The other disadvantage of the STHE is its size: it is larger than other heat transfer designs, so it requires a greater allotment of installation space, and the allotted area must have enough space to permit removal of the tube bundle.

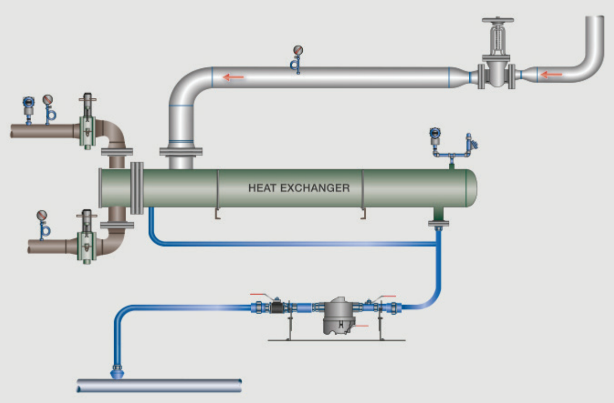

Figure 1: Shell and Tube Heat Exchanger Installation

Certain items need to be taken into account when designing an STHE unit to ensure proper operation and to provide an efficient method to transfer the steam energy to the process fluid. Some applications require even more design consideration, such as when there can be no contamination of the product if a leak were to occur in the STHE unit into the steam side or vice versa.

DESIGNING AN STHE

Several organizations can be of assistance in designing the STHEs. Tubular Exchanger Manufacturer Association (TEMA) and American Petroleum Institute (API) Standard 660 are the most common standards used in the design of STHE units. All plants should select the design standards to follow and institute a program to ensure the standards are followed.

There are different TEMA letters for different services, such as the following:

- TEMA C: Standards for unfired units for moderate conditions
- TEMA B: Standards for unfired units for chemical process
- TEMA R: Standards for unfired units for severe conditions

STHEs do not have to be manufactured according to TEMA design or any other standards, but it is highly suggested for performance and reliable operations. Also, if any requested proposal has designated a recommended guideline, then all manufacturers' quotations should be equal in performance and reliability.

Software systems are available for assisting in design and manufacturing. Many companies perform this work, but here are a few examples:

- Heat Transfer and Fluid Flow Service (HTFS)
- Heat Transfer Research Inc. (HTRI)
- B-JAC International
- Aspen Tech

CODE REQUIREMENTS

An STHE design unit is a pressure vessel that contains a large amount of stored energy. Therefore, it must be designed to meet the pressure vessel code requirements to ensure no failures will occur because of excessive pressure or temperatures. Each country has a governing standard, such as an ASME or ISO standard, that the plant should follow to ensure a safely operating STHE unit.
The STHE unit needs to have a pressure vessel stamped with the same maximum pressure rating as the safety valve set pressure in the system protecting the steam line to the STHE unit. Do not use the steam system operating pressure for the STHE pressure rating, which is lower than the safety set pressure on the steam supply line or the operating boiler.

TESTING METHODS

The testing methods to determine any leakage that may occur in the STHE or to test the pressure in the STHE are listed below:

- Hydro test
- Pressure decay
- Soap solution
- Gas leak detection
- Plastic wrap
- High frequency ultrasound

To ensure accurate test results, the plant should establish standard operating procedures (SOPs) the proper protocols for testing procedures, and all personnel should be trained on the test methods.

THERMAL EXPANSION AND CONTRACTION

Steam will be at a higher temperature (in the shell) during operation than the process fluid in the tubes; therefore, the STHE design must be able to accommodate the thermal expansion. When the process is in a shutdown mode, contraction will take place in the STHE. The unit's design must be able to accommodate the thermal expansion and contraction. The easiest method of accommodating the thermal expansion and contraction is the U-tube design.

The Steam Tech Paper will review the different designs and explain how they can compensate for expansion and contraction.

PROCESS FLUID

There are different methods to distribute the process fluid into the tubes to ensure the highest energy transfer possible in the unit. The subject of process fluid distribution will be discussed in more detail in Part B of this Steam Tech series.

U-TUBE DESIGN

T he simplest and most cost-effective unit is the U-tube design STHE. In a U-tube STHE, the tubes are bent in a "U" or hairpin shape, the tube firmly fastens to the tube sheet, and the rest of the tubes are allowed to freely move in a back and forth plane to compensate for the expansion and contraction. The advantage of this design is the lower cost in manufacturing the STHE unit. However, the applications of this design are limited to clean fluids that require no tube cleaning.

It is ideal for heating water, CIP, light fuel oils, and other low viscosity products that do not cause any tube fouling that would require tube cleaning. Tube cleaning can only be accomplished by a chemical process, not mechanical cleaning.

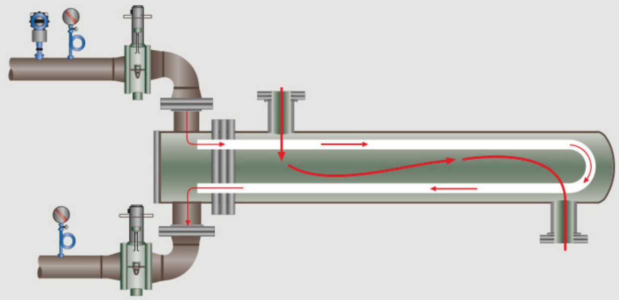

Figure 2. U-Tube STHE

STRAIGHT FIX TUBE SHEET DESIGN

The fixed tube sheet STHE unit incorporates the use of straight tubes firmly attached to tube sheets at both ends of the tubes. The tube sheet is welded to the shell, so it cannot be removed. A shell bellows-type expansion joint will compensate for the thermal expansion and contraction.

The main advantages of the straight tube SHTE design are that its cost is lower than the other straight tube designs, that its tubes can be mechanically cleaned, and that it has a lower shear factor for the process fluid.

The disadvantage of the design is that the tube bundle cannot be removed for repair. If the tube fails, the entire unit must be removed and replaced.

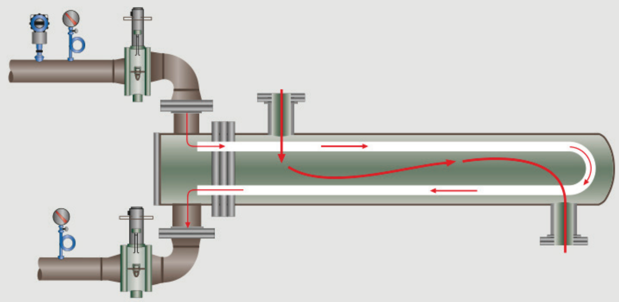

Figure 3. STHE Straight Tube Design

FLOATING HEAD DESIGN WITH STRAIGHT TUBES

The SHTE design incorporates a floating head that has an internal gasket to prevent leakage between the tube side and shell side.

One advantage of the floating head design STHE unit is that its tubes can be used with products that do have a fouling factor that require mechanical cleaning.

The other major advantage is that the tube bundle can be replaced if it fails. Another advantage to a floating head design is the elimination of the need for a bellows expansion device to compensate for the expansion and contraction. If the bellow expansion joint fails, it can release high-pressure steam into the work area, thus presenting a safety risk. The floating head is allowed to move to compensate for the thermal expansion and contraction. The disadvantages are the limited number of passes that can be accomplished with this design (two maximum on the tubes) and the limits on the pressure and temperature ratings.

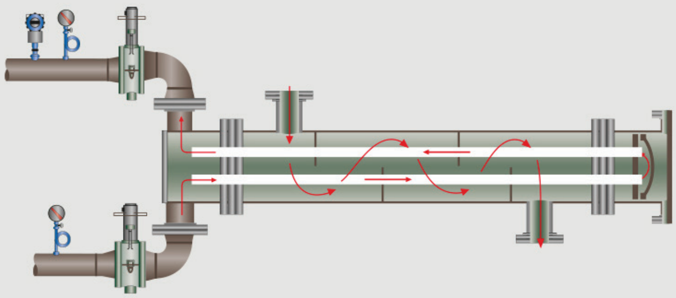

Figure 4. Floating Head Design STHE

FLOATING HEAD SPLIT BACKING RING

The floating head split backing ring unit is bolted to the split backing ring. The tube bundle is allowed to move freely against the seal and compensate for the thermal expansion. These units are often used in the petroleum industry for moderate operating pressures and temperatures.

There are other types of floating head STHEs: the outside lantern ring, split backing ring, and outside packed stuffing box type. All designs have their advantages and disadvantages, and each application needs to be analyzed so the correct STHE unit is selected for the process.

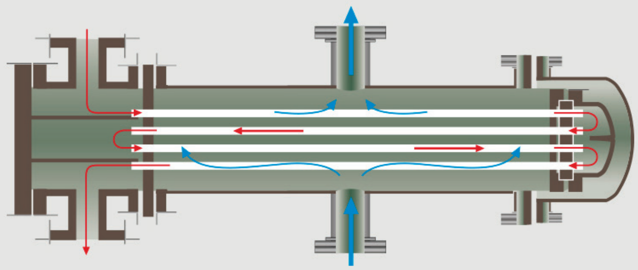

Figure 5. Checking All Steam Components

Cross-Contamination

If the steam could get into the process fluid and cause a problem, or if the process product could get into the steam/condensate system and cause a problem, then a double tube sheet construction is used to eliminate this problem. The construction is a tube sheet with a second tube sheet installed inside the main tube sheet with a small distance between the tube sheets. Typically, a weep hole is installed between the tube sheets to allow indication of a tube failure.

The advantage of the double tube sheet construction is that no cross-contamination can occur. The disadvantages are that it drives up the cost of the STHE unit and that the thermal conductivity can be reduced by the gap between the steam and the process fluid that is caused by the tube within a tube.

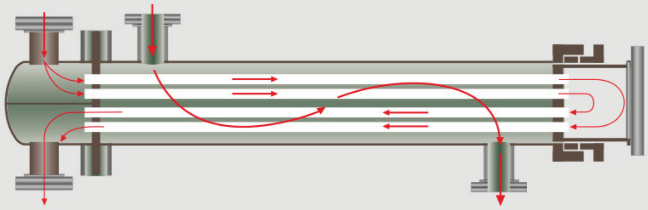

Figure 6. Floating Head Outside Packed Stuffing Box

SHTE INTERNAL COMPONENTS

Tube Baffles

Typically, the steam flow is in the shell side of the unit, and there are methods in the shell that distribute steam to ensure even energy transfer throughout the unit.

Internally, the steam flow from the inlet nozzle to the outlet nozzle could be a laminar flow and reduce the efficiency of the STHE, as shown in Figure 7.
Internal tube supports can have some effect on the shell-side steam flow (distributing the flow pattern), but the main reason for the supports is to support the tubes in a bundle.

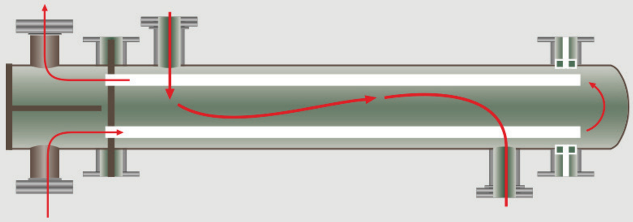

Figure 7. Laminar Flow: No Baffles

Therefore, the SHTE design incorporates internal baffles engineered to transform the laminar steam flow to a wiping steam flow path, as shown in Figure 8.

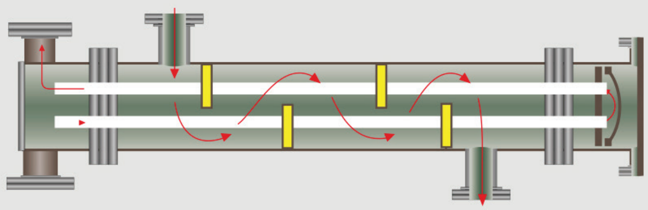

Figure 8. STHE Internal Baffles

This wiping steam flow path around the tubes increases the steam flow velocity in the tube bundle, which results in a higher transfer coefficient.

The distance between adjacent baffles is referred to as the baffle spacing. An internal baffle spacing of 0.2 to 1 times of the inside shell diameter is commonly used in steam system applications. Closer baffle spacing creates a greater transfer coefficient by inducing higher turbulence in the steam flow pattern. The disadvantage of the baffles is that they cause a high pressure drop on the steam side.

There are various types of baffles, such as the cut-segmental baffle, where a segment (called baffle cut) is removed to form the baffle expressed as a percentage of the baffle diameter. Baffle cuts from 15 to 45% are normally used. A baffle cut of 20 to 25% provides a good heat transfer with a reasonable pressure drop.

Tube Supports

In the long shell design of STHE, the tubes are not able to support themselves; therefore, internal support is added to ensure the tube bundle does not sag, vibrate, or experience strain.

The supports assist in distributing the steam flow from the laminar flow to increase the SHTE efficiency.

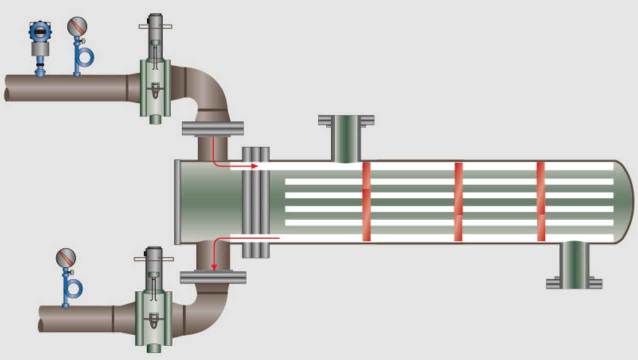

Figure 9. STHE Tube Supports

Impingement Plates

If the velocity of the steam entering the tube bundle area cannot be lowered to acceptable limits by the inlet nozzle sizing, then an impingement plate is installed to protect the tubes from the steam velocities or and potential erosion.

The impingement plate diverts the steam flow around the tube area and allows the steam to decrease its velocity.

Figure 10. Impingement Plate

The impingement plate can be of solid construction or a perforated plate design; both accomplish the goal of protecting the tubes and providing reliable operation. The disadvantage of using the impingement plate is the loss of tube rows for the installation of the plate mechanism.

CONCLUSION

Always have all the required information for any application in a well-defined request for quotation. There are many choices in selecting an STHE, and each choice will have plusses and minuses. So long as the plant evaluates all parameters in the selection process, there will be a positive result.