PV Newsletter

Monthly Publication from CoDesign Engineering Skills Academy

As indicated in the previous newsletter, the main articles covered in 2013 will relate to the shell-and-tube heat exchangers. Look to the forthcoming newsletters for the following articles throughout this calendar year:

January:	*Introduction to Shell-and-Tube Heat Exchangers*
February:	*Classification of Heat Exchangers*
March:	*Components of Shell-and-Tube heat Exchangers*
April:	*TEMA Designations*
May:	*Thermal Design*
June:	*Tubesheet Design (Part UHX)*
July:	*Fabrication and Inspection of Heat Exchangers*
August:	*Fouling in Heat Exchangers*
September:	*Corrosion in Heat Exchangers*
October:	*Energy Conservation Techniques in Heat Exchangers*
November:	*Controlling Shell-and-Tube Heat Exchangers*
December:	*Shell-and-Tube Heat Exchanger Specifications*

This year, we will also experiment with multiple articles in a newsletter. If you are interested in contributing, please drop us a line.

Introduction to Shell-and-Tube Heat Exchangers

Heat exchangers are the mechanical equipment used for transferring heat from one fluid to another through a separating wall. Shell-and-tube heat exchangers are the most widely used type of heat exchangers in the process industry, conventional and nuclear power stations, steam generating application etc. In such heat exchangers, two fluids of different starting temperatures flow through the heat exchanger. One flows through the tubes (the tube side), and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa.

Shell-and-tube heat exchangers have the capability to transfer large amounts of heat in relatively low cost, serviceable designs. They can provide large amounts of effective tube surface while minimizing the requirements of floor space, liquid volume and weight. They have been used in the industry for over 150 years so the thermal technologies and manufacturing methods are all well-defined.

Heat Exchanger Applications

Because of the many advantages, shell-and-tube heat exchangers are generally used for liquid-to-liquid heat exchange. This does not mean that they are not used in other applications. Shell-and-tube heat exchangers are indeed used in gas-to-gas as well as liquid-to-gas applications as well as those applications which involve a change in phase. The high flow rates and the high heat transfer rates in liquid-to-liquid heat exchangers make shell-and-tube heat exchangers to be suitable for most applications.

Heat exchangers are sometimes named to describe their functions. Heat exchangers with only one phase (liquid or gas) on each side can be called one-phase or single-phase heat exchangers. Two phase heat exchangers can be used to heat a liquid to boil it into gas (vapor), sometimes called boilers, or to cool a vapor to condense it into a liquid (called condensers), with the phase change usually occurring on the shell side.

A chiller cools the liquid flowing through one side by transferring some of its heat to a vaporizing refrigerant flowing through the other side. Reboilers and vaporizers boil or vaporize a liquid by extracting heat from a warmer fluid. Condensers condense a vapor to a liquid by transferring its latent heat to a colder fluid.

Advantages of Shell-and-Tube Heat Exchangers

Here are the main advantages of shell-and-tube heat exchangers:

1. Condensation or boiling heat transfer can be accommodated in either the tubes or the shell, and the orientation can be horizontal or vertical. Of course, single phases can be handled as well.
2. The pressures and pressure drops can be varied over a wide range.
3. Thermal stresses can be accommodated inexpensively.
4. There is substantial flexibility regarding materials of construction to accommodate corrosion and other concerns. The shell and the tubes can be made of different materials.
5. Extended heat transfer surfaces (fins) can be used to enhance heat transfer.
6. Cleaning and repair are relatively straightforward, because the equipment can be dismantled for this purpose.

Major Heat Exchanger Types

There are two distinct types of shell-and-tube heat exchangers, based in part on the shell diameter.

First is the smaller heat exchangers generally up to 12" in shell diameter that feature shell constructions of low cost welded steel, cast end bonnets and copper tubing rolled to the tubesheet. This mass production product had great success with the OEM's of industrial machinery for oil cooling and water-to-water applications. By removing the end bonnets, most plant water-cooled heat exchangers can be readily serviced by mechanically cleaning the interior of the tubes. Failed tubes can be plugged or replaced, depending on the design.

The second type of shell-and-tube heat exchangers are those with shell diameters above 12". Commonly available steel pipe is generally used up to 24" in diameter. Above 24" diameter, manufacturers prefer rolled and welded steel plate. Heat exchangers of this type are commonly manufactured to the standards established by TEMA, the Tubular Exchangers Manufacturer's Association (discussed later in the article).

There are other ways to classify heat exchangers. Heat exchangers used in heating, ventilating, air-conditioning and refrigeration, petroleum refining, chemical and petrochemical processing, and general industrial manufacturing are categorized as *process heat exchangers*. Auxiliary shell and tube heat exchangers used in power generation are called *power plant heat exchangers*. Specialized units used to heat boiler feedwater with turbine extraction steam are called *closed feedwater heaters* but may be termed as *feedwater heaters* or simply *heaters*.

Shell-and-Tube Heat Exchanger Design

Figure 1 shows the design of a standard shell-and-tube heat exchanger. It consists of a shell on the outside and tubes placed inside the shell. Tubes are mechanically attached on the front and rear ends to tubesheets, and are supported by baffles which also serve to redirect the shell fluid past the tubes to enhance heat transfer. Shell-and-tube heat exchangers are designed to prevent fluid flowing inside the tubes from mixing with the fluids outside the tubes. Tubesheets can be fixed to the shell or allowed to expand and contract with thermal stresses by having one tubesheet float inside the shell, or by using expansion bellows in the shell.

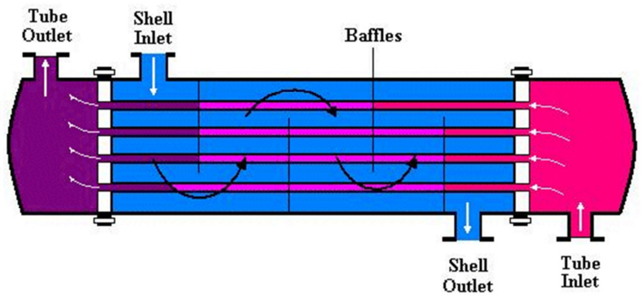

Figure 1: Standard Shell and Tube Heat Exchanger

Differences in the types of shell-and-tube heat exchangers are based on flows inside the shell and inside the tubes. In Figure 1 above, a heat exchanger with one shell flow pass and one tube flow pass can be seen. The baffles lead the shell flow in such a way along the tubes that this type is a cross-flow device. So, it could be classified as a *Shell-and-tube heat Exchanger with One Shell Pass and One Tube Pass; Cross-Counterflow Operation*".

Table 1 shows the range of dimensions of several parts of a shell-and-tube heat exchanger. One can clearly see the many possibilities with the shell-and-tube heat exchanger. The key to such flexibility is the wide range of materials of construction, forming and joining methods, and design features that can be built into these heat exchangers. Because of this flexibility, the shell-and-tube heat exchanger is frequently used in installation of all sizes of heat exchangers.

Table 1: Range of Dimensions for Shell-and-Tube Heat Exchanger

	Metric Units	US Units
Heat Transfer Area	0.1 - 100,000 m^2	1.0 - 1,000,000 ft^2
Pressure	Vacuum - over 1000 bar	Vacuum - over 15,000 psi
Temperature	0 - 1400 K	0 - 2500 R
Diameter of Tubes	6.35 - 50.8 mm	¼ - 2 in
Diameter of Shell	50 mm - 3.05 m	2 - 120 in
Number of Tubes Used	20 - 1000	20 - 1000

Shell-and-Tube Heat Exchanger Standards

Tubular Exchanger Manufacturer's Association (TEMA):

To get a better overview of possibilities for designers, a set of standards has been introduced in the 1940's. These define the heat exchanger style, machining and assembly tolerances to be employed in the manufacture of a given exchanger. TEMA makes and controls these standards. The New York based association was formed by a group of heat exchanger manufacturers, and their specifications comprise industry standards that directly relate to recognized quality practices for manufacturing.

Process heat exchanger nomenclature is based upon the standards of TEMA. These standards also have systems for describing process exchanger types and for designating sizes and operating positions. With some modifications, these systems are used worldwide.

American Petroleum Institute Standard 660:

API 660 Shell and Tube Heat Exchangers for General Refinery Services is intended for shell-and-tube heat exchangers used in the petroleum, petrochemical and natural gas industries. It specifies requirements and gives recommendations for the mechanical design, material selection, fabrication, inspection, testing and preparation for shipment of shell-and-tube heat exchangers. This international standard is applicable to following types of heat exchangers: heaters, condensers, coolers and reboilers (excludes vacuum operated steam surface condensers and feedwater heaters). This standard incorporates the TEMA nomenclature and terminology by incorporating *TEMA Mechanical Standards*, Class R, by reference.

Heat Exchange Institute (HEI):

HEI has developed standards for power plant heat exchangers, closed feedwater heaters, steam surface condensers and air-cooled condensers used in power generation, and shell-and-tube heat exchangers.

ASME Boiler & Pressure Vessel, Section VIII, Division 1

This Division of ASME Section VIII provides requirements applicable to the design, fabrication, inspection, testing, and certification of shell-and-tube heat exchangers. In addition to the rules for components that are common to other pressure vessels, this code also contains Part UHX that provides rules for tubesheets used in the shell-and-tube heat exchangers.

Shell-and-Tube Heat Exchanger Costs

Cost is always an important consideration in designing a heat exchanger. Cost can be broken into two principal components - capital cost and operating cost. In addition, maintenance costs are incurred during operation - they tend to be more or less independent of the size of heat exchanger.

The capital cost for heat exchangers increases with increase in heat transfer area. It is evaluated by using values known from 1957-1959, and applying a multiplicative factor known as the “Cost Index”. This index is published in each issue of *Chemical Engineering*, and uses 100 as basis for the cost in 1957-1959.

Operating cost is primarily pumping cost. The pumps must provide work to overcome the pressure drops on the tube side and on the shell side. It is typical to conservatively assume the overall pump efficiency to be 0.6. Normally, 24-hour operation per day for 350 days a year is assumed; the remaining days being nominal maintenance shutdown days.

The three main relevant factors that have the greatest effect on operating cost are pressure drop, log mean temperature difference (LMTD) and fouling factors.

Pressure Drop

If unrealistically low allowable pressure drops are imposed, the designer is forced to use lower fluid velocities to stay within the pressure drop limitations. Low velocities can result in large heat exchangers and high capital cost. Higher allowable pressure drops permit high velocities resulting in smaller heat exchangers; but increased pump work is needed to maintain high fluid velocities which results in high operating costs. Only by considering the relationship between operating costs and capital costs can the economical pressure drops be determined.

LMTD

The size, or surface area, of the heat exchanger is inversely proportional to the overall heat transfer coefficient and the corrected LMTD.

Fouling Factors

Fouling factor reduces the heat transfer coefficient resulting in increase of the heating surface area. The reduction of the heat transfer coefficient is more severe in heat exchangers with high heat transfer coefficient in the unfouled condition.

Figure 2 shows the relationship between the surface area of a single shell heat exchanger and the costs in dollars per square feet. As one can see, the costs are going down exponentially with the increase of the surface area. So the larger shell-and-tube heat exchangers are cheaper per square feet than the smaller ones.

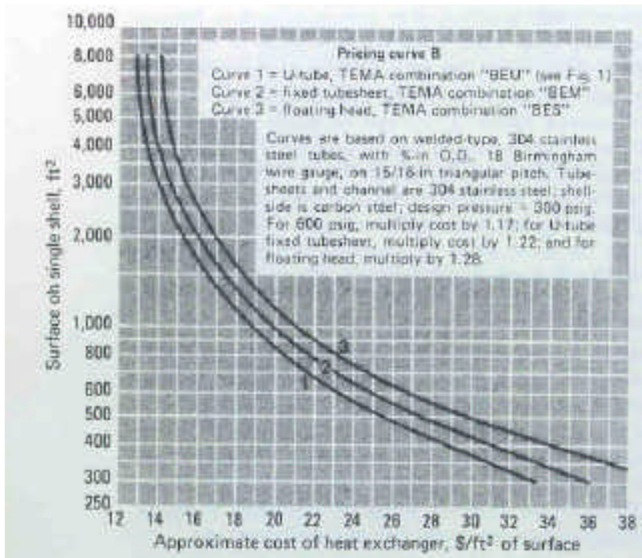

Figure 2: Relation between Heat Exchanger Surface Area and Costs

Fluid Stream Allocations

There are a number of practical guidelines which can lead to the optimum design of a given heat exchanger. There are trade-offs in fluid allocations in heat transfer coefficients, available pressure drop, fouling tendencies and operating pressure.

1. The higher pressure fluid normally goes through the tube side. With their small diameter and nominal wall thickness, they are easily able to accept higher pressures and avoid more expensive, large diameter components to be designed for the high pressure. If it is necessary to put the higher pressure stream in the shell, it should be placed in a smaller diameter and longer shell.
2. Corrosive fluids should be placed on the tube side - other items being equal. Corrosion is resisted by using special alloys and it is much less expensive than using special alloy shell materials.
3. Higher fouling fluids should be placed on the tube side. Tubes are easier to clean using common mechanical methods.
4. Because of wide variety of designs and configurations available for the shell circuits, such as tube pitch, baffle cut and spacing and multiple nozzles, it is best to put fluids requiring low pressure drops in the shell circuit.
5. The fluid with the lower heat transfer coefficient normally goes in the shell circuit. This allows the use of low-fin tubing to offset the low heat transfer rate by providing increased available surface.

In heat exchanger, the fluid does not follow the idealized path anticipated from the elementary conditions. This departure from ideality can result in the fluid behaving very differently from what is expected. The major cause of such departure from expected behavior is the unequal flow distribution on the shell-side. It can be generally reduced by improving the baffle arrangement, and proper design and placement of inlet and outlet shell-side nozzles.

Performance Degradation

Degradation is an inevitable process for every heat exchanger, and is generally attributed to fouling and corrosion.

In fouling, there is accumulation of deposits that increase the thermal resistance to heat transfer. This diminishes the heat transfer while simultaneously increasing the compressor and the pump work because of partial blockage of fluid conduit. Fouling may be overcome by cleaning, with the potential for restoration of heat exchanger to its original performance.

Corrosion of heat exchanger materials progressively weakens the element to the point where failure is imminent.

Sources:

1. Basic Construction of Shell-and-Tube heat Exchangers *by* Ketema
2. A Working Guide to Shell-and-Tube Heat Exchangers *by* Stanley Yokell
3. Article "Shell and Tube Heat Exchangers" *by* R. Shankar Subramanian

***** E N D O F T H E A R T I C L E *****

About CoDesign Engineering:

CoDesign Engineering specializes in the core business of providing training and consultancy for design and fabrication of ASME code pressure vessels, and the ecosystem that includes piping, welding, valves, geometric dimensioning and tolerancing, process improvement, and engineering management. Some of the training courses (lasting from two days to five days) that we provide include:

- Design and Fabrication of ASME Section VIII, Div. 1 Pressure Vessels
- Design and Fabrication of ASME Section VIII, Div. 2 Pressure Vessels
- Shell & Tube Heat Exchangers - Thermal and Mechanical Design
- ASME Section IX - Welding Technology
- Engineering Management

We also provide several one-day workshops:

- Know Your Power Piping
- Know Your Process Piping
- Know Your ASME Section VIII Pressure Vessel Code
- Know Your Shell & Tube Heat Exchangers
- A to Z of Pressure Vessels
- Transitioning to ASME Section VIII, Div. 2

Our trainings can be offered at most cities in India and in US.

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Ramesh Tiwari holds a Master's degree in Mechanical Engineering from Clemson University in South Carolina, and is a registered Professional Engineer from the state of Maryland in the United States. He has over 22 years of experience designing pressure vessels, heat exchangers and tanks. Ramesh is a member of ASME Section VIII Subgroup on Heat Transfer Equipment, and member of ASME B31.1 IWG for Power Piping. He is also an approved pressure vessel instructor at National Thermal Power Corporation (NTPC), a premier thermal power generating company in India.