

Shell and Tube Heat Exchanger

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Abstract — Heat exchangers are one of the most used devices in the industries to regulate efficient transfer heat in industrial process applications. One can realize their importance just by the fact that any process which involves heating, cooling, boiling, condensation or evaporation will require a heat exchanger for these functions. This research paper highlights Shell and Tube Heat Exchangers, their design specifications, thermodynamic aspects and industrial applications.

Keywords — Heat Transfer; Heat Exchangers; Shell and Tube Heat Exchangers.

I. INTRODUCTION

The exchange of energy between thermal systems, or as we know the heat transfer, is a process that we encounter in a lot of common activities and processes in our daily life. From the refrigerators and air conditioners in our home, to melting and freezing processes in nature, the phenomenon of heat transfer is eminent everywhere. One such efficient use of this phenomenon can be used in a device called Heat Exchanger.

Heat exchangers are one of the most used devices in the industries to regulate efficiently transfer heat in industrial process applications. One can realize their importance just by the fact that any process which involves heating, cooling, boiling, condensation or evaporation will require a heat exchanger for these functions. Process fluids, usually are heated or cooled before the process or undergo a phase change. Heat exchangers are commonly used to process liquid or gas cooling, process vapor or steam condensing, process liquid, steam or refrigerant evaporation and many other industrial applications.

The amount of heat transferred using less surface area and pressure drop is a measure of performance and efficiency of the heat exchanger.

Heat exchangers have gone through a lot of modifications over the ages and have become quite efficient

in comparison to their predecessors. They have new designs, new materials and have been customized to meet specific needs.

II. SHELL AND TUBE HEAT EXCHANGERS

Shell and tube heat exchangers are the most common and popular type of heat exchanger due to the flexibility they allow for a wide range of pressure and temperature. They are generally used in chemical process industries, especially in oil refineries which involve heavy volumes of fluids to be processed. Shell and tube exchangers come in many variations to meet process requirements in almost every industry or application. They deliver reliable heat transfer performance by utilizing a high turbulence and counter flow, making one or more passes.

A shell and tube heat exchanger consists of a shell which is a large pressure vessel and a series of tubes of very small diameter inside it. The tubes are positioned in the cylinder (shell) using a tube bundle also known as tube stack. Two fluids, which have different initial temperatures flow through the heat exchanger. One fluid flows through the tubes, which is called the tube side while the other fluid runs over the tubes, but inside the cylinder which is called the shell side. The basic principle on which the shell and tube heat exchanger works is that - heat is transferred from the fluid in tube side to the fluid running in shell side through the tube walls, without the two liquids actually

coming in contact with each other. In other words, it transfers heat without transferring the fluid that carries heat.

III. DESIGN CONSIDERATIONS

There are a lot of variations possible in the shell and tube design. Typically, the ends of each tube are connected to a waterbox called plenum through holes available in tubesheets. The tubes are usually straight or bent in the shape of a U, called U-tubes.

The rates at which hot and cold streams flow, their initial and final temperatures and fluid properties are the major inputs of thermal design of a heat exchanger. Thermal design of a shell and tube heat exchanger normally includes the determination of heat transfer area(A), number of tubes(n), tube layout, number of shell and tube passes, tube length and diameter, type of heat exchanger (fixed tube sheet, removable tube bundle etc.), tube pitch, shell and tube side pressure drop, number of baffles, its type and size, etc.

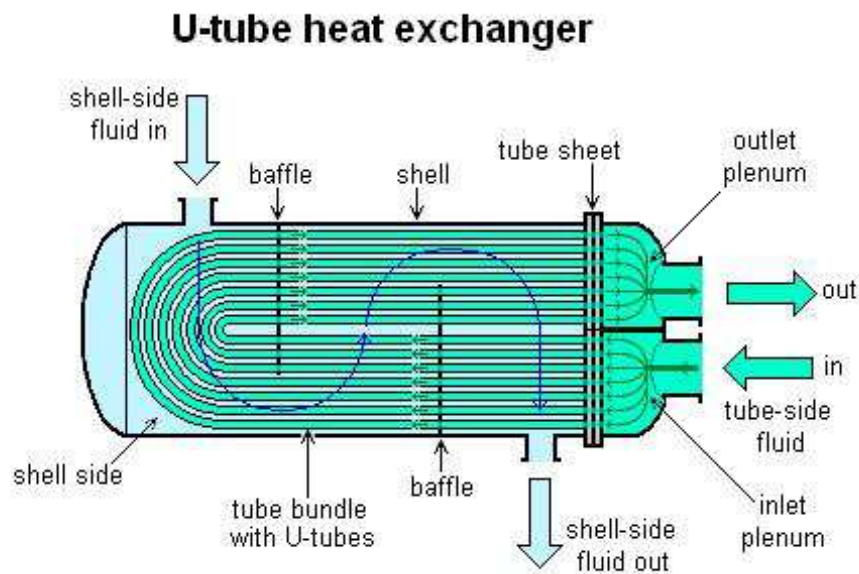


Fig. 1. U-tube Heat exchanger

A. Shell

The shell is the outside cylinder which contains the tube bundle and fluid on the shell side. Shell diameter should be selected in such a way that a close fit of the tube bundle is achieved. The clearance between the tube bundle and the inner shell varies depending on the type of exchanger. Steel pipes are usually used to fabricate shells with satisfactory allowance for corrosion. The shell thickness of 1 cm for the shell inner diameter of 30-60cm can be satisfactorily used up to 2 MPa of operating pressure.

B. Tube

For a compact shell and tube heat exchanger tube diameters of 2-2.5 cm are usually preferred. Increasing the number of tubes is the most efficient condition for heat

transfer as it increases turbulence. The tube thickness should be enough to withstand the internal pressure along with the adequate corrosion allowance. The tube thickness is expressed in terms of BWG (Birmingham Wire Gauge) and true outside diameter (OD). The tube length of 6, 8, 12, 16, 20 and 24 ft are preferably used. Longer tube reduces the shell diameter at the expense of a higher shell pressure drop. Finned tubes are also used when fluid with low heat transfer coefficient flows on the shell side. Stainless steel, admiralty brass, copper, bronze and alloys of copper-nickel are the commonly used tube materials:

C. Tube pitch, tube-layout and tube-count

The shortest distance between the centres of adjacent tubes is called the tube pitch. The tubes normally arranged in square or triangular designs. Tube pitch plays a major

role in reducing the shell side pressure drop and to keep in control the shell side velocity. Tube count is the number of tubes that can be fit inside the shell inner diameter. Various factors such as inner diameter of the shell, tube outer diameter, tube pitch, tube layout, tube passes, type of heat exchanger and design pressure etc. define the tube count. Tube layout is the arrangement of tubes inside the shell.

D. Tube passes

The tubes are arranged in shell and tube exchangers in tube passes. The number of tube passes is defined so as to get the desired tube side velocity to obtain higher heat transfer co-efficient. The tube passes vary from 1 to 16. The tube passes of 1, 2 and 4 are generally common.

E. Tube sheet

The plates or forgings on which holes are drilled through which heat exchanger tubes are inserted are called tubesheets. Its major function is to prevent the mixing of fluids on the tube side and the shell side. It basically acts as a barrier between tube and shell side fluids. In case of straight Shell and tube heat exchanger, a single tubesheet exchanger is required while for the U-tube bundles, a single tubesheet suffices. The tubes are inserted inside through holes made in tubesheets and are held in position either by welding or by hydraulic or mechanical expansion. The thickness of the tube sheets should always be greater than the outside diameter of tube for obtaining a perfect seal.

F. Baffles

Baffles are used to obtain higher transfer coefficient. They divert the flow across the tube bundle thus increasing the fluid velocity. The length between two consecutive baffles is called baffle spacing. Baffles are situated perpendicular to the walls of the shell and force the fluid to flow at 90 degrees to the axis of the tubes. Usually, a baffle spacing of .2 to 1 times of shell inner diameter is used. Holding tubes upright in position, preventing vibrations due to fluid velocity and tube length and directing fluid flow are the major functions of a baffle.

G. Fouling considerations

In the majority of cases the fluids flowing in the tube and shell foul the surface of heat transfer. The materials which get deposited on the surface reduce the heat transfer rate due to comparatively low heat conductivity. Due to fouling there is an increase in the cost of (i) construction

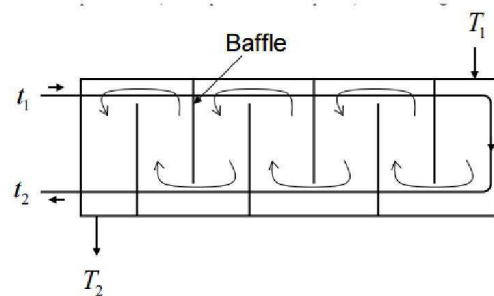
due to oversizing, (ii) additional energy due to poor exchanger performance and (iii) cleaning to remove deposited materials. It is always recommended to have a spare heat exchanger so that the first exchanger could be timely cleaned. Shell and tube side fouling resistances are considered before designing a heat exchanger. As the fouling resistance increases, the heat coefficient decreases.

IV. THERMODYNAMIC ASPECTS

According to energy balance equation and rate equation,

$$Q = m_{hot} C_{p,hot} (T_{hot,in} - T_{hot,out}) = m_{cold} C_{p,cold} (T_{cold,out} - T_{cold,in})$$

$$Q = UA F \Delta T_{lm}$$



The symbols have the usual meanings in these equations.

The normal symbol convention followed is :

ΔT_{lm} : log mean temperature difference

F : log mean temperature correction factor

T1 : inlet temperature of shell side fluid

T2 : exit temperature of shell side fluid

t1 : inlet temperature of tube side fluid

t2 : exit temperature of tube side fluid

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \left[\frac{T_1 - t_2}{T_2 - t_1} \right]}$$

F is calculated experimentally by plotting graphs and depends on 2 parameters namely, P and R where?

$$P = \frac{t_2 - t_1}{T_1 - t_1} \text{ and } R = \frac{T_1 - T_2}{t_2 - t_1}$$

$$F_{1-2} = \frac{\left[\frac{\sqrt{R^2 + 1}}{R - 1} \right] \ln \left(\frac{1 - P}{1 - PR} \right)}{\ln \left[\frac{A + \sqrt{R^2 + 1}}{A - \sqrt{R^2 + 1}} \right]}$$

$$F_{2-4} = \frac{\left[\frac{\sqrt{R^2 + 1}}{2(R - 1)} \right] \ln \left(\frac{1 - P}{1 - PR} \right)}{\ln \left[\frac{A + B + \sqrt{R^2 + 1}}{A + B - \sqrt{R^2 + 1}} \right]}$$

$$\text{where } A = \frac{2}{P} - 1 - R, \quad B = \frac{2}{P} \sqrt{(1 - P)(1 - PR)}$$

Here, subscripts on F corresponds to number of shell and tube passes respectively.

V. HEAT TRANSFER COEFFICIENT

Heat transfer coefficient evaluation is an important part of shell and tube heat exchanger analysis. Achieving a high heat transfer coefficient is desired.

The following is the generic heat transfer coefficient (U_o) equation neglecting the fouling resistances.

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{\Delta r}{k} \left(\frac{A_o}{A_{lm}} \right) + \frac{1}{h_i} \left(\frac{A_o}{A_i} \right)$$

Where,

h_o = heat transfer coefficient for shell side fluid

h_i = heat transfer coefficient for tube side fluid

A_o = outer surface area of the tube

A_i = inside surface area of the tube

A_{lm} = log mean area.

VI. APPLICATIONS OF SHELL AND TUBE HEAT EXCHANGERS

Shell and tube heat exchangers are used in almost all the industries wherever heat transfer is required.

A. Food and Beverage industry

In food and beverage industry, it is used in ovens, cookers, food processing & pre-heating, milk pasteurization, beer cooling and pasteurization, cooling or chilling the final product to desired temperatures etc.

B. Petroleum industry

In the petroleum industry, it is used for brine cooling, crude oil preheating, acid gas condenser, heat recovery etc.

C. Hydro Carbon Processing

In Hydrocarbon Processing, it is used in the preheating of methanol, liquid hydrocarbon product cooling, recovery and removal of Carbon-dioxide etc.

D. Polymer industry

In polymer industry, it is used in production of polypropylene, reactor jacket cooling for the production of polyvinyl chloride.

E. Pharmaceutical industry

In the pharmaceutical industry, it is used in purification of water and steam.

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