HEAT EXCHANGERS

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact.

1 Classification according to transfer processes

Heat exchangers are classified according to transfer processes into indirect- and direct contact types.

1.1 Indirect Contact Heat Exchangers

In an indirect-contact heat exchanger, the fluid streams remain separate and the heat transfers continuously through an impervious dividing wall or into and out of a wall in a transient manner. Thus, ideally, there is no direct contact between thermally interacting fluids.

1.1.1 Direct Transfer Type Exchangers.

In this type, heat transfers continuously from the hot fluid to the cold fluid through a dividing wall. Although a simultaneous flow of two (or more) fluids is required in the exchanger, there is no direct mixing of the two (or more) fluids because each fluid flows in separate fluid passages. they are also known as *recuperators*

1.1.2 Storage Type Exchangers

In a storage type exchanger, both fluids flow alternatively through the same flow passages, and hence heat transfer is intermittent. When hot gas flows over the heat transfer surface (through flow passages),the thermal energy from the hot gas is stored in the matrix wall, and thus the hot gas is being cooled during the matrix heating period. As cold gas flows through the same passages later (i.e., during the matrix cooling period), the matrix wall gives up thermal energy, which is absorbed by the cold fluid. This storage type heat exchanger is also referred to as a regenerative heat exchanger, or simply as a *regenerators*.

1.2 Direct-Contact Heat Exchangers

In a direct-contact exchanger, two fluid streams come into direct contact, exchange heat, and are then separated.

1.2.1 Immiscible Fluid Exchangers

In this type, two immiscible fluid streams are brought into direct contact.

1.2.2 Gas Liquid Exchangers

In this type, one fluid is a gas (more commonly, air) and the other a low-pressure liquid (more commonly, water) and are readily separable after the energy exchange.

1.2.3 Liquid Vapor Exchangers

In this type, typically steam is partially or fully condensed using cooling water, or water is heated with waste steam through direct contact in the exchanger.

2 Classification according to number of fluids

Most processes of heating, cooling, heat recovery, and heat rejection involve transfer of heat between two fluids. Hence, two-fluid heat exchangers are the most common. Three fluid heat exchangers are widely used in cryogenics and some chemical processes.

3 Classification according to surface compactness

Heat exchangers are classified as compact and shell and tube type of heat exchangers. compact heat exchangers are characterized by a large heat transfer surface area per unit volume of the exchanger, resulting in reduced space, weight, support structure and footprint, energy requirements and cost, as well as improved process design and plant layout. A heat exchanger is referred to as a compact heat exchanger if it incorporates a heat transfer surface having a surface area density greater than about $700m^2/m^3$

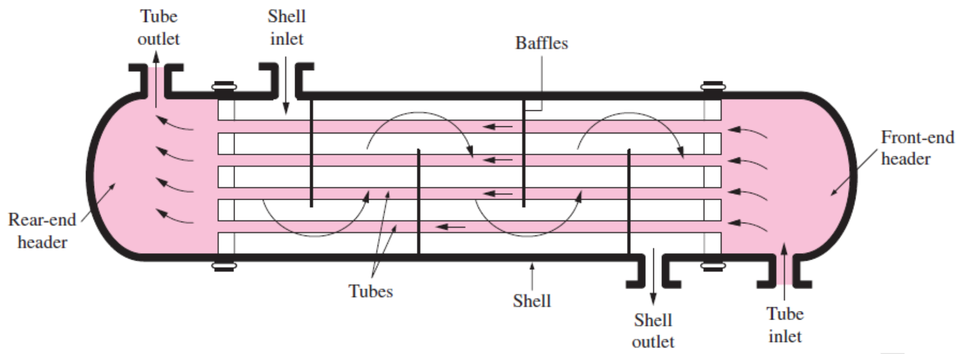

Figure 1: Shell and Tube heat exchanger

4 Classification according to construction features

Heat exchangers are frequently characterized by construction features. Four major construction types are tubular, plate-type, extended surface, and regenerative exchangers.

4.1 Tubular Heat Exchangers

These exchangers are generally built of circular tubes, although elliptical, rectangular, or round/flat twisted tubes have also been used in some applications. These exchangers may be classified as shell and tube, double-pipe, and spiral tube exchangers.

4.1.1 Shell and Tube Exchangers

This exchanger, shown in fig. 1, is generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. One fluid flows inside the tubes, the other flows across and along the tubes.

4.1.2 Double-Pipe Heat Exchangers

This exchanger usually consists of two concentric pipes with the inner pipe. This is perhaps the simplest heat exchanger. Flow distribution is no problem, and cleaning is done very easily by dis assembly. This configuration is also suitable where one or both of the fluids is at very high pressure. Double-pipe exchangers are generally used for small-capacity

4.1.3 Spiral Tube Heat Exchangers

These consist of one or more spirally wound coils fitted in a shell. Heat transfer rate associated with a spiral tube is higher than that for a straight tube. In addition, a considerable amount of surface can be accommodated in a given space by spiraling.

4.1.4 Plate-type heat exchangers

Plate-type heat exchangers are usually built of thin plates (all prime surface). The plates are either smooth or have some form of corrugation, and they are either flat or wound in an exchanger. applications

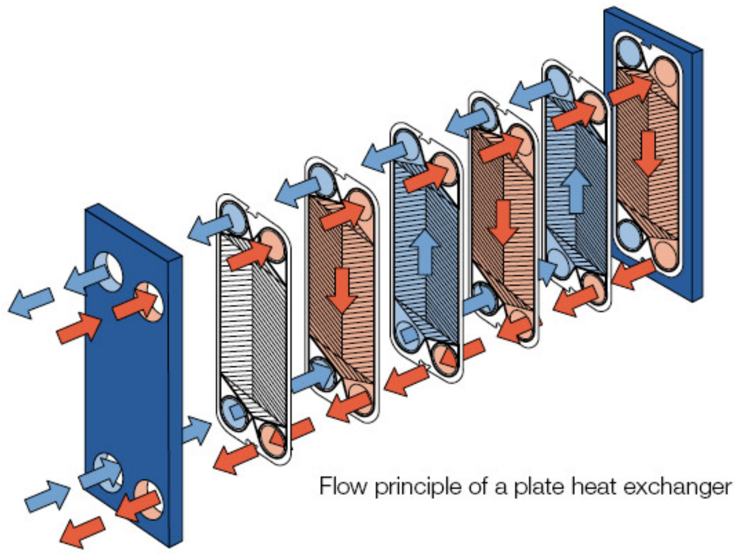

Figure 2: Plate type heat exchanger

5 Classification according to flow arrangements

A fluid is considered to have made one pass if it flows through a section of the heat exchanger through its full length. After flowing through one full length, if the flow direction is reversed and fluid flows through an equal it is considered to have made a second pass. A heat exchanger is considered as a single-pass unit if both fluids make one pass in the exchanger. If the fluid flows in the heat exchangers multiple times over the cross section it is called as multipass heat exchanger.

5.1 Single-Pass Exchangers

5.1.1 Counterflow heat exchanger

In a counterflow heat exchanger the two fluids flow parallel to each other but in opposite directions within the core.

5.1.2 parallelflow heat exchanger

In a parallelflow exchanger, the fluid streams enter together at one end, flow parallel to each other in the same direction, and leave together at the other end.

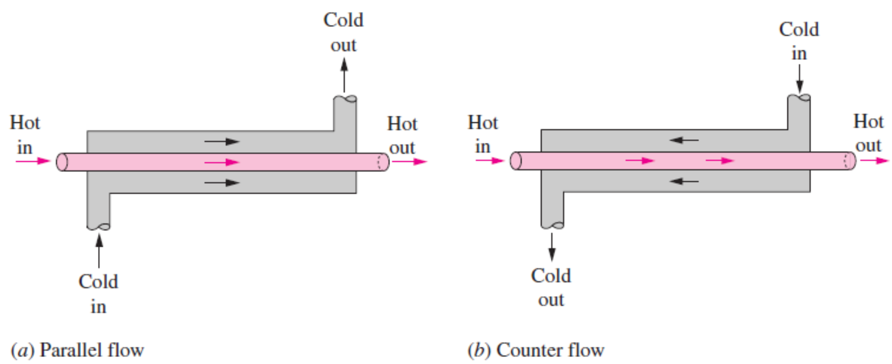

Figure 3: parallel and counter flow arrangment

5.1.3 Crossflow heat exchanger

In this type of exchanger, the two fluids flow in directions normal to each other. In a crossflow arrangement, mixing of either fluid stream may or may not occur, depending on the design.

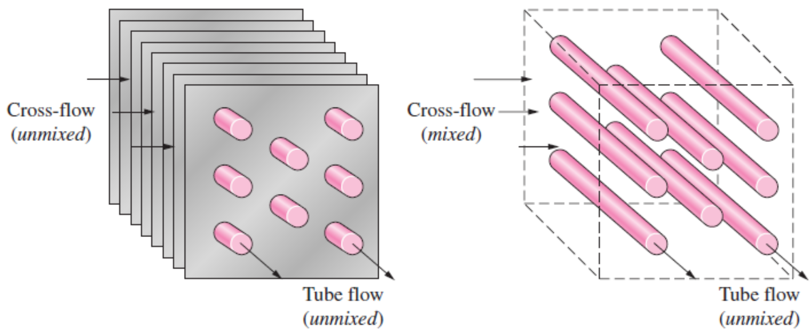

Figure 4: Cross flow heat exchanger

6 Overall heat transfer coefficient

A heat exchanger typically involves two flowing fluids separated by a solid wall. Heat is first transferred from the hot fluid to the wall by convection, through the wall by conduction, and from the wall to the cold fluid again by convection. The thermal resistance network associated with this heat transfer process involves two convection and one conduction resistances, as shown in fig. 5. For a double-pipe heat exchanger, we have $A_i = \pi D_i L$ and $A_O = \pi D_O L$. The total thermal resistance is

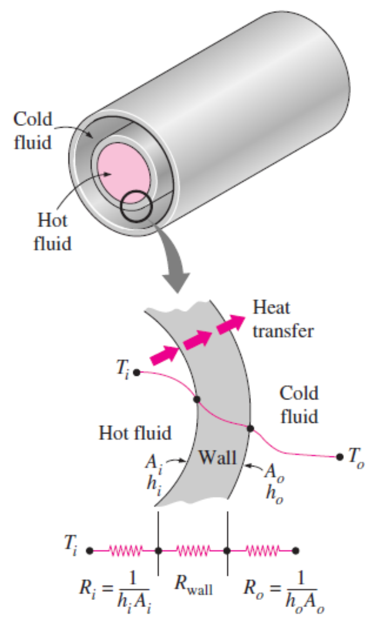

Figure 5: Thermal resistance network

$$\sum R = \frac{1}{h_i\, A_i} + \frac{ln\left(\frac{r_O}{r_i}\right)}{2\pi kL} + \frac{1}{h_O\, A_O}$$

In the analysis of heat exchangers, it is convenient to combine all the thermal resistances in the path of heat flow from the hot fluid to the cold one into a single resistance R, and to express the rate of heat transfer between the two fluids as

$$\dot{Q} = UA\Delta T = U_i A_i \Delta T = U_O A_O \Delta T$$

The overall heat transfer coefficient can be expressed as

$$\sum R_{(thermal)} = \frac{1}{UA} = \frac{1}{U_i A_i} = \frac{1}{U_O A_O}$$

the overall heat transfer coefficient base on outside tube surface can be written as

$$
\begin{aligned}
U_o &= \frac{1}{\sum R_{(thermal)} A_o} \\
&= \frac{1}{\dfrac{A_o}{h_i A_i} + \dfrac{A_o}{2\pi k L} ln\left(\dfrac{r_o}{r_i}\right) + \dfrac{1}{h_o}} \\
&= \frac{1}{\left(\dfrac{r_o}{r_i}\right) h_i + \dfrac{r_o}{k} ln\left(\dfrac{r_o}{r_i}\right) + \dfrac{1}{h_o}}
\end{aligned}
$$

the overall heat transfer coefficient base on inside tube surface can be written as

$$
\begin{aligned}
U_i &= \frac{1}{\sum R_{(thermal)} A_i} \\
&= \frac{1}{\dfrac{1}{h_i} + \dfrac{A_i}{2\pi k L} ln\left(\dfrac{r_o}{r_i}\right) + \dfrac{A_i}{A_o h_o}} \\
&= \frac{1}{\dfrac{1}{h_i} + \dfrac{r_i}{k} ln\left(\dfrac{r_o}{r_i}\right) + \left(\dfrac{r_i}{r_o}\right) h_o}
\end{aligned}
$$

When the wall thickness of the tube is small and the thermal conductivity of the tube material is high, as is usually the case, the thermal resistance of the tube is negligible ($Rwall \approx 0$) and the inner and outer surfaces of the tube are almost identical ($A_i \approx A_o$). Then Equation for the overall heat transfer coefficient simplifies to

$$
U = \frac{1}{\dfrac{1}{h_i} + \dfrac{1}{h_o}}
$$

7 Fouling Factor

The performance of heat exchangers usually deteriorates with time as a result of accumulation of deposits on heat transfer surfaces. The layer of deposits represents additional resistance to heat transfer and causes the rate of heat transfer in a heat exchanger to decrease. The net effect of these accumulations on heat transfer is represented by a fouling factor R_f , which is a measure of the thermal resistance introduced by fouling.

The most common type of fouling is the precipitation of solid deposits in a fluid on the heat transfer surfaces. This is especially the case in areas where the water is hard. The scales of such deposits come off by scratching, and the surfaces can be cleaned of such deposits by chemical treatment. Another form of fouling, which is common in the chemical process industry, is corrosion and other chemical fouling. In this case, the surfaces are fouled by the accumulation of the products of chemical reactions on the surfaces. This form of fouling can be avoided by coating metal pipes with glass or using plastic pipes instead of metal ones. Heat exchangers may also be fouled by the growth of algae in warm fluids. This type of fouling is called biological fouling and can be prevented by chemical treatment.

The fouling factor is obviously zero for a new heat exchanger and increases with time as the solid deposits build up on the heat exchanger surface. The fouling factor depends on the operating temperature and the velocity of the fluids, as well as the length of service. Fouling increases with increasing temperature and decreasing velocity. The overall heat transfer coefficient relation given above is valid for clean surfaces and needs to be modified to account for the effects of fouling on both the inner and the outer surfaces of the tube.

$$\sum R_{(thermal)} = \frac{1}{h_i\, A_i} + \frac{R_{f,i}}{A_i} + \frac{ln\left(\frac{r_o}{r_i}\right)}{2\pi k L} + \frac{R_{f,o}}{A_o} + \frac{1}{h_o\, A_o}$$

the overall heat transfer coefficent considering fouling will be

$$U_o = \frac{1}{\left(\frac{r_o}{r_i}\right)\frac{1}{h_i} + \frac{r_o}{k} ln\left(\frac{r_o}{r_i}\right) + \frac{1}{h_o} + \left(\frac{r_o}{r_i}\right) R_{fi} + R_{fo}}$$

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{r_i}{k} ln\left(\frac{r_o}{r_i}\right) + \left(\frac{r_i}{r_o}\right)\frac{1}{h_o} + R_{fi} + \left(\frac{r_i}{r_o}\right) R_{fo}}$$

where R_f and R_i are fouling factors based on inner and outer surfaces.

References

[1] Shah, R. K. and Sekulic, D. P., *Fundamentals of Heat Exchanger Design*, John Wiley & Sons, Inc, 2003.

[2] Yunus Cengel, *Heat and Mass Transfer*, Tata Mcgraw-Hill Companies, 2012.