Heat Exchange Equipments

In a food processing plant, heating and cooling of foods is conducted in equipment called heat exchangers. As shown in Figure1, heat exchangers can be broadly classified into noncontact and contact types.

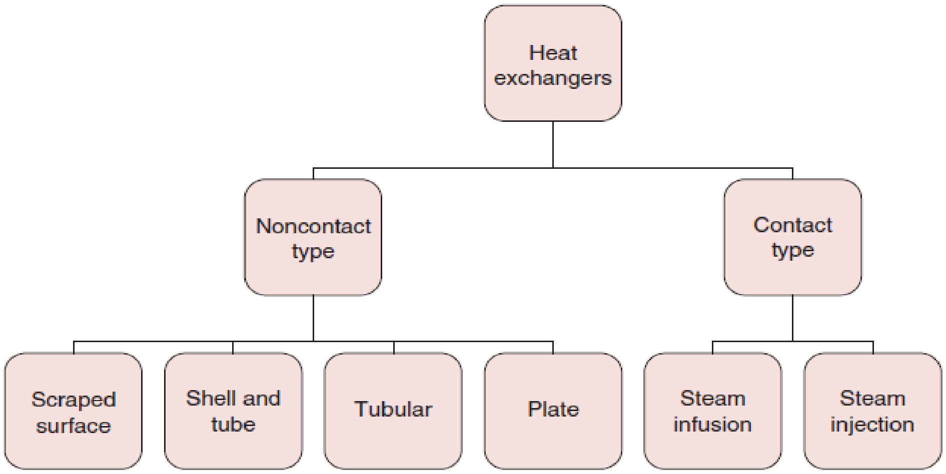

Figure 1. Classification of commonly used heat exchangers.

As the name implies, in noncontact-type heat exchangers, the product and heating or cooling medium are kept physically separated, usually by a thin wall. On the other hand, in contact-type heat exchangers, there is direct physical contact between the product and the heating or cooling streams.

For example, in a steam-injection system, steam is directly injected into the product to be heated. In a plate heat exchanger, a thin metal plate separates the product stream from the heating or cooling stream while allowing heat transfer to take place without mixing. We will discuss some of the commonly used heat exchangers in the food industry in the following subsections.

1. Jacketed pan heater/cooler

In a jacketed pan heater, the food/liquid to be heated is contained in a vessel, which may also be provided with an agitator to keep the food/liquid on the move across the heat-transfer surface, as shown in Figure 2.

The source of heat is commonly steam condensing in the vessel jacket. Practical considerations of importance are:

i. There is the minimum of air with the steam in the jacket.
ii. The steam is not superheated as part of the surface must then be used as a de-superheater over which low gas heat-transfer coefficients apply rather than high condensing coefficients.
iii. Steam trapping to remove condensate and air is adequate.

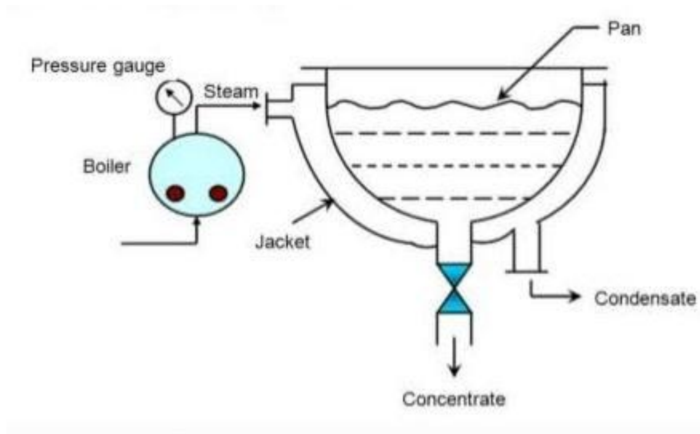

Figure 2. Jacketed pan heater

The action of the agitator and its ability to keep the fluid moved across the heat transfer surface are important. Some overall heat transfer coefficients are shown in Table 1. Save for boiling water, which agitates itself, mechanical agitation is assumed. Where there is no agitation, coefficients may be halved.

The jacketed pan which is used for heating of foods can also be used for cooling of foods (jacketed pan cooler) by using a coolant/refrigerant in place of heating medium (steam).

Table 1. Some overall heat transfer coefficients in jacketed pans

Condensing fluid	Heated fluid	Pan material	Heat transfer coefficients (J m^{-2} s^{-1} $°C^{-1}$)
Steam	Thin liquid	Cast-iron	1800
Steam	Thick liquid	Cast-iron	900
Steam	Paste	Stainless steel	300
Steam	Water, boiling	Copper	1800

2. **Plate Heat Exchanger**

The plate heat exchanger invented more than 70 years ago has found wide application in the dairy and food beverage industry. A schematic of a plate heat exchanger is shown in Figure 3. This heat exchanger consists of a series of parallel, closely spaced stainless-steel plates pressed in a frame. Gaskets, made of natural or synthetic rubber, seal the plate edges and ports to prevent intermixing of liquids. These gaskets help to direct the heating or cooling and the product streams into the respective alternate gaps. The direction of the product stream versus the heating/cooling stream can be either parallel flow (same direction) or counterflow (opposite direction) to each other.

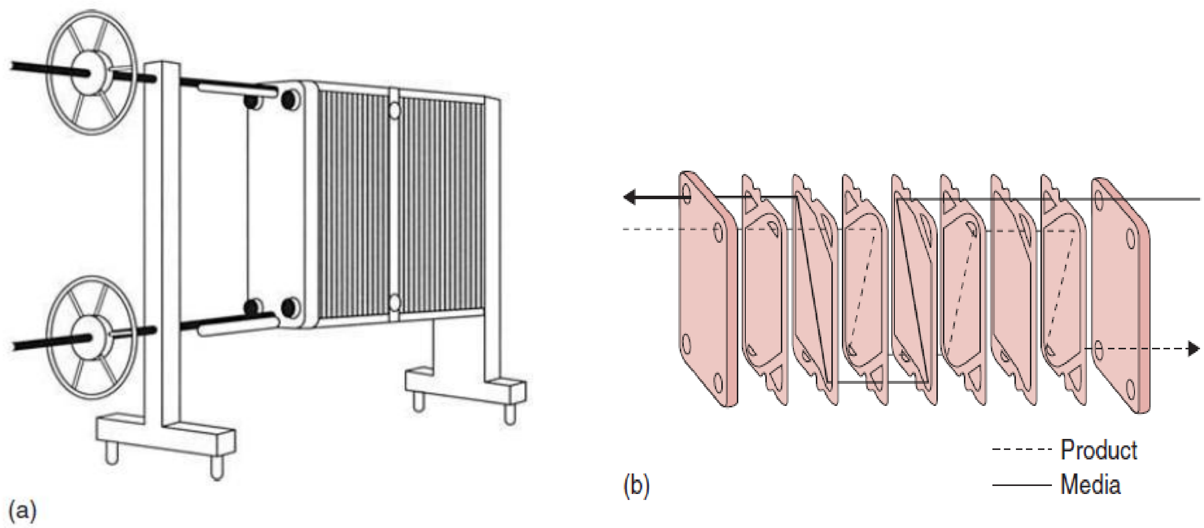

Figure 3. (a) Plate heat exchanger (b) Schematic view of fliuid flow between plates.

The plates used in the plate heat exchanger are constructed from stainless steel: Special patterns are pressed on the plates to cause increased turbulence in the product stream, thus achieving better heat transfer. An example of such a pattern is a shallow herringbone-ribbed design, as shown in Figure 4.

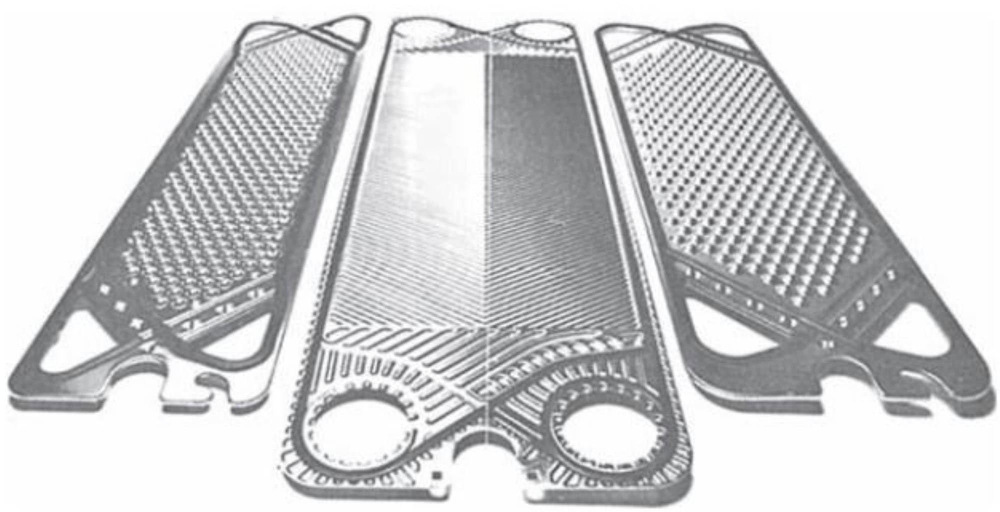

Figure 4. Patterns pressed on plates used on a plate heat exchanger.

Plate heat exchangers are suitable for low-viscosity (<5 Pa s) liquid foods. If suspended solids are present, the equivalent diameter of the particulates should be less than 0.3 cm. Larger particulates can bridge across the plate contact points and “burn on” in the heating section.

In industrial-size plate heat exchangers, product flow rates from 5000 to 20,000 kg/h often are obtained. When using plate heat exchangers, care should be taken to minimize the deposition of solid food material such as milk proteins on the surface of the plates. This deposition, also called *fouling*, will decrease the heat transfer rate from the heating medium to the product; in addition, the pressure drop will increase over a period of time. Eventually, the process is stopped and the plates are cleaned. For dairy products, which require ultra–high temperature applications, the process time is often limited to 3 to 4 h.

Plate heat exchangers offer the following advantages:

- The maintenance of these heat exchangers is simple, and they can be easily and quickly dismantled for product surface inspection.
- The plate heat exchangers have a sanitary design for food applications.
- Their capacity can easily be increased by adding more plates to the frame.
- With plate heat exchangers, we can heat or cool product to within 1°C of the adjacent media temperature, with less capital investment than other noncontact-type heat exchangers.
- Plate heat exchangers offer opportunities for energy conservation by regeneration.

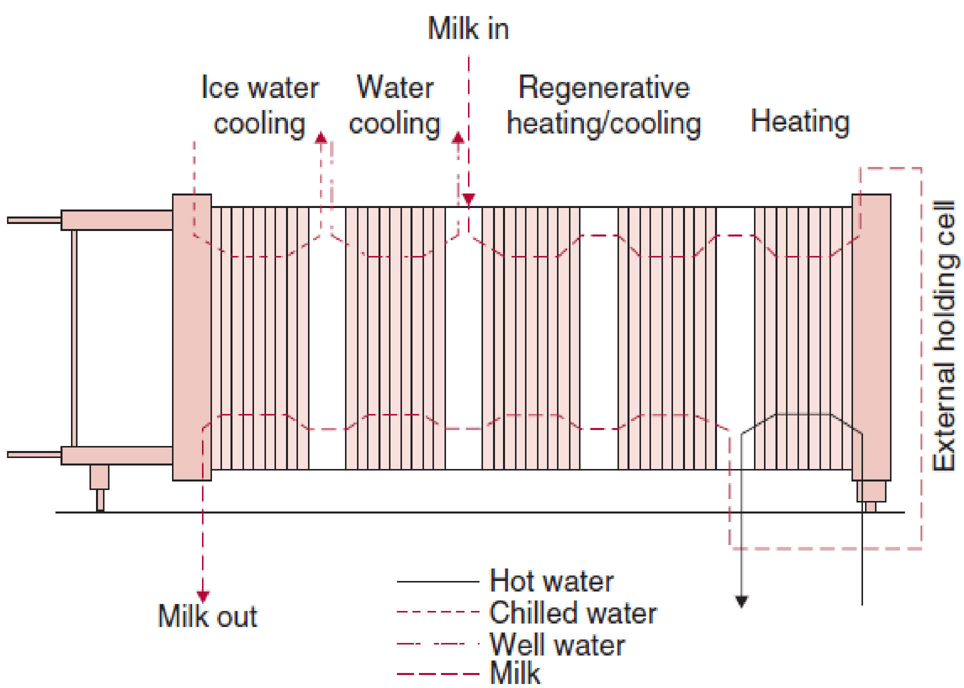

Figure 5. A five-stage plate pasteurizer for processing milk.

As shown in a simple schematic in Figure 5, a liquid food is heated to pasteurization or other desired temperature in the heating section; the heated fluid then surrenders part of its heat to the incoming raw fluid in the regeneration section. The cold stream is heated to a temperature where it requires little additional energy to bring it up to the desired temperature. For regeneration, additional plates are required; however, the additional capital cost may be recovered quickly by lowered operating costs.

3. Tubular Heat Exchanger

The simplest noncontact-type heat exchanger is a double-pipe heat exchanger, consisting of a pipe located concentrically inside another pipe. The two fluid streams flow in the annular space and in the inner pipe, respectively.

The streams may flow in the same direction (parallel flow) or in the opposite direction (counterflow). Figure 6 is a schematic diagram of a counterflow double-pipe heat exchanger.

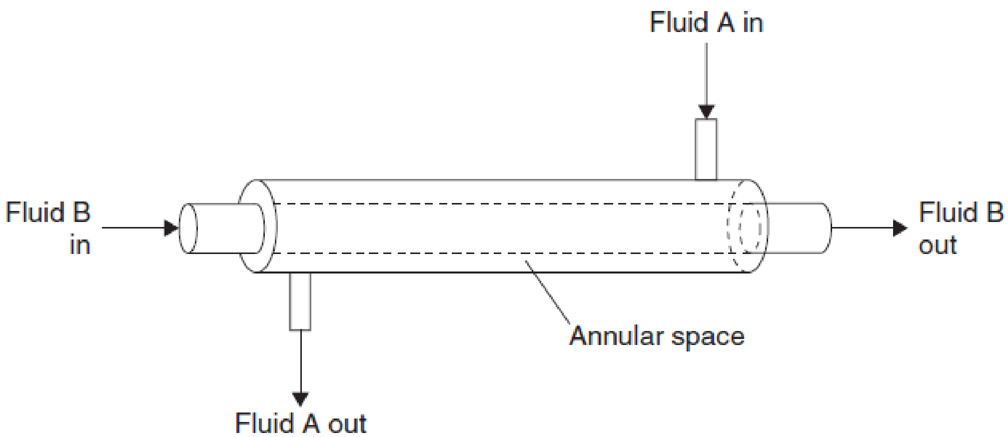

Figure 6. Schematic illustration of a tubular heat exchanger.

A slight variation of a double-pipe heat exchanger is a triple-tube heat exchanger, shown in Figure 7. In this type of heat exchanger, product flows in the inner annular space, whereas the heating/cooling medium flows in the inner tube and outer annular space. The innermost tube may contain specially designed obstructions to create turbulence and better heat transfer. Some specific industrial applications of triple-tube heat exchangers include heating single-strength orange juice from 4 to 93°C and then cooling to 4°C; cooling cottage cheese wash water from 46 to 18°C with chilled water; and cooling ice cream mix from 12 to 0.5°C with ammonia.

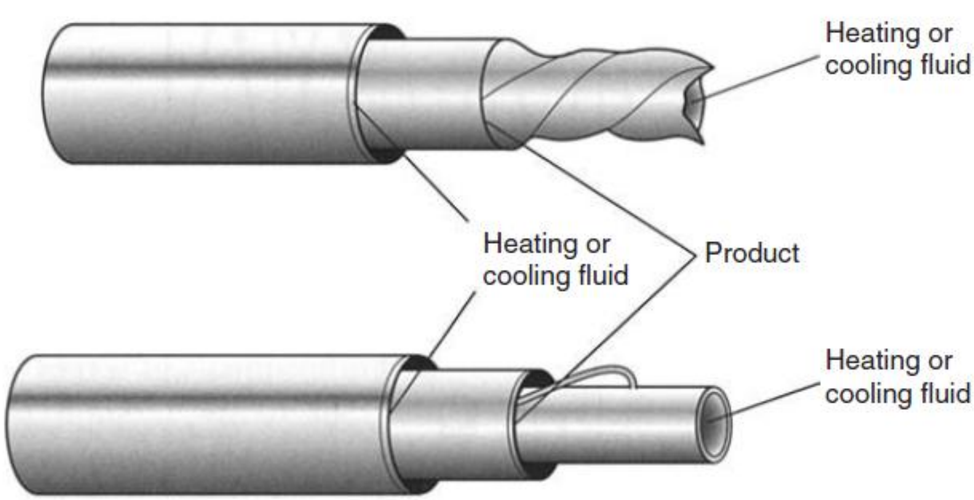

Figure 7. Schematic illustration of a triple-tube heat exchanger

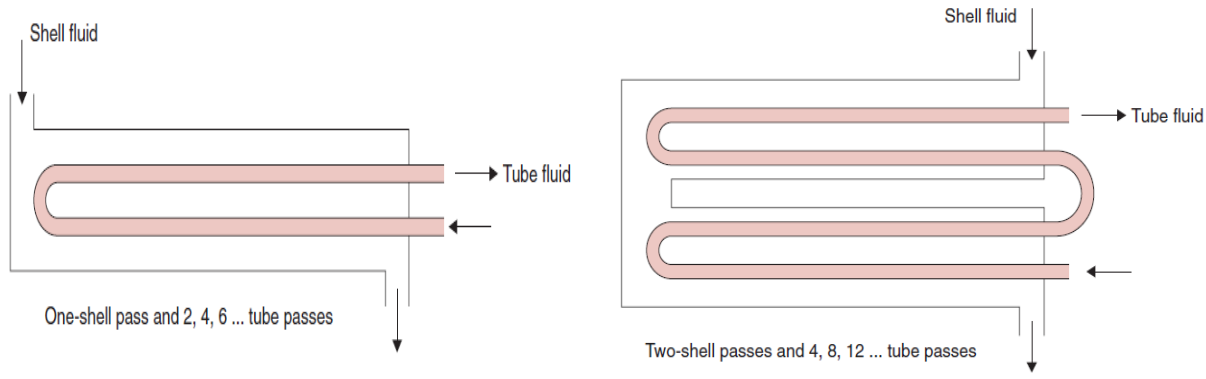

Figure 8. A shell-and-tube heat exchanger.

Another common type of heat exchanger used in the food industry is a shell-and-tube heat exchanger for such applications as heating liquid foods in evaporation systems. As shown in Figure 8, one of the fluid streams flows inside the tube while the other fluid stream is pumped over the tubes through the shell. By maintaining the fluid stream in the shell side to flow over the tubes, rather than parallel to the tubes, we can achieve higher rates of heat transfer. Baffles located in the shell side allow the cross-flow pattern. One or more tube passes can be accomplished, depending on the design. The shell-and-tube heat exchangers shown in Figure 8 are one shell pass with two tube passes, and two shell passes with four tube passes.

4. Scraped-Surface Heat Exchanger

In conventional types of tubular heat exchangers, heat transfer to a fluid stream is affected by hydraulic drag and heat resistance due to film buildup or fouling on the tube wall. This heat resistance can be minimized if the inside surface of the tube wall is scraped continuously by some mechanical means. The scraping action allows rapid heat transfer to a relatively small product volume. A scraped-surface heat exchanger, used in food processing, is shown schematically in Figure 9.

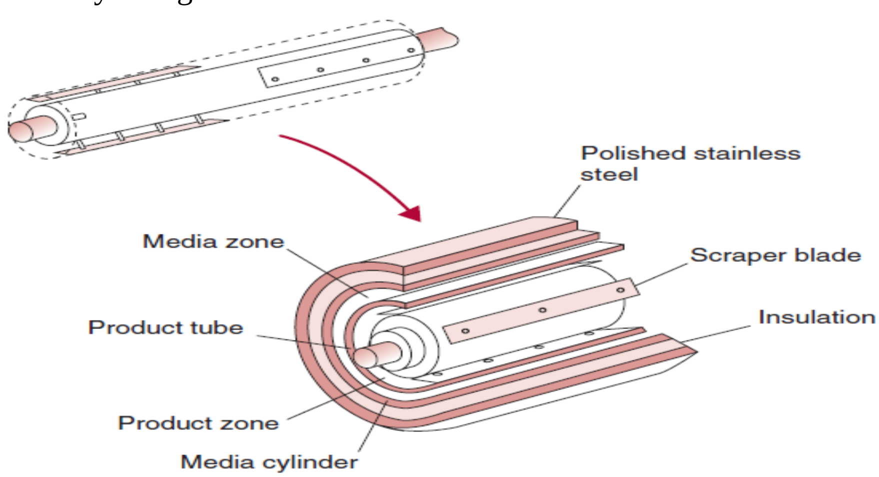

Figure 9. A scraped-surface heat exchanger with a cutaway section illustrating various components.

The food contact areas of a scraped-surface cylinder are fabricated from stainless steel (type 316), pure nickel, hard chromium-plated nickel, or other corrosion-resistant material. The inside rotor contains blades that are covered with plastic laminate or molded plastic (Fig. 9). The rotor speed varies between 150 and 500 rpm. Although higher rotation speed allows better heat transfer, it may affect the quality of the processed product by possible maceration. Thus, we must carefully select the rotor speed and the annular space between the rotor and the cylinder for the product being processed.

As seen in Figure 9, the cylinder containing the product and the rotor is enclosed in an outside jacket. The heating/cooling medium is supplied to this outside jacket. Commonly used media include steam, hot water, brine, or a refrigerant. Typical temperatures used for processing products in scraped-surface heat exchangers range from -35 to 190°C.

The constant blending action accomplished in the scraped-surface heat exchanger is often desirable to enhance the uniformity of product flavor, color, aroma, and textural characteristics. In the food processing industry, the applications of scraped-surface heat exchangers include heating, pasteurizing, sterilizing, whipping, gelling, emulsifying, plasticizing, and crystallizing. Liquids with a wide range of viscosities that can be pumped are processed in these heat exchangers; examples include fruit juices, soups, citrus concentrate, peanut butter, baked beans, tomato paste, and pie fillings.

5. Steam-Infusion Heat Exchanger

A steam-infusion heat exchanger provides a direct contact between steam and the product. As shown in Figure 10, product in liquid state is pumped to the top of the heat exchanger and then allowed to flow in thin sheets in the heating chamber. The viscosity of the liquid determines the size of the spreaders. Products containing particulates, such as diced vegetables, meat chunks, and rice, can be handled by specially designed spreaders. High rates of heat transfer are achieved when steam contacts tiny droplets of the food. The temperature of the product rises very rapidly due to steam condensation. The heated products with condensed steam are released from the chamber at the bottom. A specific amount of liquid is retained in the bottom of the chamber to achieve desired cooking.

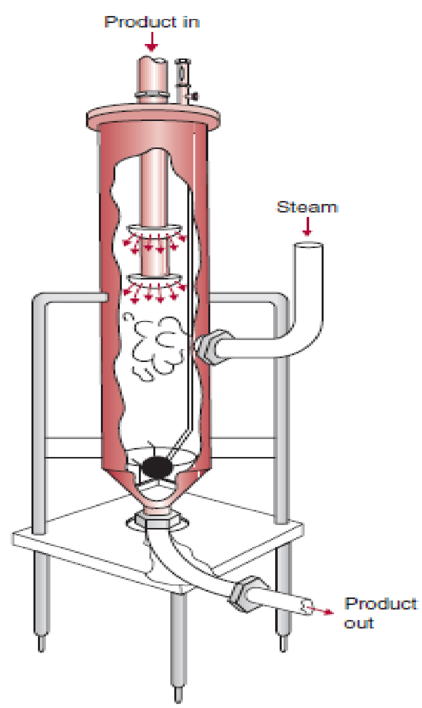

Figure 10. A steam-infusion heat exchanger.

The temperature difference of the product between the inlet and the outlet to the heating chamber may be as low as 5.5°C, such as for deodorizing milk (76.7 to 82.2°C), or as high as 96.7°C, such as for sterilizing puddings for aseptic packaging (48.9 to 145.6°C).

The water added to the product due to steam condensation is sometimes desirable, particularly if the overall process requires addition of water. Otherwise, the added water of condensation can be “flashed off” by pumping the heated liquid into a vacuum cooling system. The amount of water added due to condensation can be computed by measuring the temperature of the product fed to the heat exchanger and the temperature of the product discharged from the vacuum cooler.

This type of heat exchanger has applications in cooking and/or sterilizing a wide variety of products, such as concentrated soups, chocolate, processed cheese, ice cream mixes, puddings, fruit pie fillings, and milk.