CHAPTER 21
HEAT EXCHANGERS

This chapter will describe the basic operation, construction, configuration and design criteria for heat exchangers (HX) commonly used to heat water and will discuss their advantages, disadvantages and application. Included will be all types of heat exchangers intended to recover waste heat, heat water for domestic purposes and other types of heat transfer purposes.

INTRODUCTION

The basic process behind the heating of all water is heat exchange, where the heat from a hot fluid (the heating medium) is given up to a colder fluid (water). This heat exchange takes place between a heating medium at a higher temperature and another medium, in our case water, at a lower temperature, in a piece of equipment called a heat exchanger specifically manufactured and designed to efficiently and cost effectively transfer the heat from one medium to another. A heat exchanger, if properly selected, installed, and maintained, could be the most trouble free piece of equipment in a water heating system.

Heat exchangers have been used to heat water for domestic and other water heating purposes in commercial and industrial applications for many years. In addition, the ever-increasing cost of energy finds heat exchangers used more and more to extract and conserve energy from hot liquid and gaseous by-products of processes that was previously wasted.

CODES AND STANDARDS

Plumbing Codes

There has been a code interpretation by many plumbing inspectors and local authorities of one section of the Uniform Plumbing Code regarding unlawful connections that affect the construction of water heaters. In a condensed explanation, this section is concerned with the contamination of potable water during normal use or as a result of excess pressure by any fluid while flooded in a tank or heat exchanger. This has led to the introduction of double wall heat exchangers used to generate domestic hot water. Some controversy exists regarding the interruption of this requirement, and it may not be necessary for this requirement to be enforced. Refer to the local AHJ regarding this matter.

Tubular Exchanger Manufacturers Association (TEMA)

TEMA, Tarrytown, N.Y., is an association that has established heat exchanger standards and nomenclature for industrial applications. Every shell-and-tube device has a three-letter designation; the letters refer to the specific type of stationary head at the front end, the shell type, and the rear-end head type, respectively (a fully illustrated description can be found in the TEMA standards).

Heat exchangers used specifically for domestic water heating purposes in plumbing systems are not required to be approved by or comply with TEMA standards.

ASTM B-31.9, CODE FOR PRESSURE PIPING, ASHRAE B-90.1, CONSERVATION OF ENERGY

DEFINITIONS

Heating Medium. A heating medium is any fluid used to heat water or fuel used to heat a fluid to a higher temperature than the raw water to be heated. The only exception is electrical energy, which uses a hot solid wire, or element, to directly transfer heat to the water by contact. Examples of heating mediums are:

1. Steam
2. Water
3. Fuel gas
4. Liquid fuel
5. Electricity
6. Solar energy
7. Geothermal

Approach. The term ‘‘approach’’ is used to describe how close the outlet temperature of the water being heated (the colder fluid) comes to (or approaches) the inlet temperature of a fluid heating medium.

Heat Exchanger. A device specifically constructed and designed to efficiently transfer heat energy from a hot fluid to a colder fluid. In generally accepted usage, the heat exchanger is intended to mean any device used to recover or reclaim waste heat, as compared to a water heater, which is a specific piece of equipment intended to generate hot water.

Countercurrent. A term used when the liquid heating medium in any heat exchanger flows in the opposite direction to that of the liquid being heated.

Temperature Cross. A temperature cross occurs when the liquid being heated has an outlet temperature that falls between the inlet and outlet temperature of the heating medium; this is only possible when flows are 100 percent countercurrent.

GENERAL HEAT EXCHANGER TYPES

General

The two most common types of heat exchangers used for utility type service are the shell and tube and the plate type, also known as plate and frame.

Operating conditions, ease of access for inspection and maintenance, and compatibility with heating medium fluids are just some of the variables engineers must consider when assessing heat exchanger options. Other factors include:

1. Maximum design pressure and temperature
2. Heating or cooling applications
3. Material compatibility with various fluids
4. Cleanliness of the heating medium and liquid to be heated
5. Approach temperature

In recent years, the plate-and-frame has emerged as a viable alternative to the shell-and-tube. Air-cooled exchangers have gained popularity because of their ability to reduce water consumption.

Shell and Tube

The shell-and-tube HX can be found in almost every type of application. Mechanically simple in design and relatively unchanged for more than 60 years, the shell-and-tube HX offers a low-cost method of heat exchange.

This type of HX consists of a number of tubes that can be varied in diameter and flow path encased in an outer manifold or shell pipe. The tubes are fabricated together into an assembly called a tube bundle. A typical shell and tube heat exchanger is illustrated in Fig. 21.1.

Heat is transferred by either having the heating medium flow through the shell and the liquid to be heated flow through the tube or vise versa.

There are many types of shell and tube heat exchangers, distinguished by the head and tubesheet configurations.

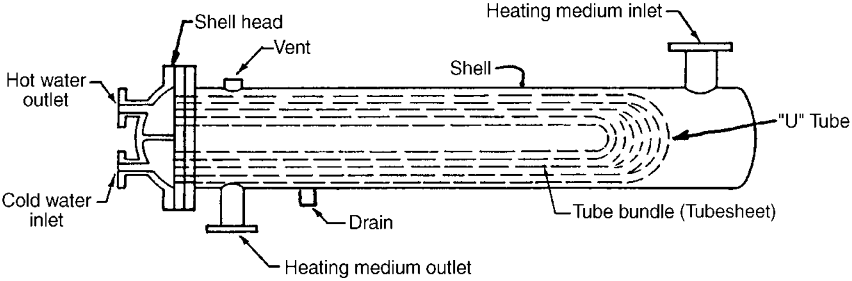


FIGURE 21.1 Typical U-tube heat exchanger.

U-tube, Removable Bundle. The U-tube design consists of straight length tubes bent into a U-shape; hence, its name. The U-bend tubes are then mechanically rolled into a common header or tubesheet. Depending on the fluid outside the tubes, the bundle is fitted with either tube supports or flow baffles along its length. The tubesheet, tubes, and tube supports/flow baffles make up the bundle assembly. The bundle assembly is then placed in a shell (a length of pipe that contains inlet and outlet connections and a pipe size flange at one end for insertion of the tube bundle; the other end of the shell is fitted with a cap) to contain the fluid on the outside of the tube bundle. A head assembly (usually a casting that contains the inlet and outlet connections for directing a fluid into the tube bundle) is then bolted to the shell flange to complete the heat exchanger.

The head assembly contains one or more pass partitions for controlling tube velocity and, hence, the tube-side heat transfer coefficient and pressure drop.

Where the presence of a condensing vapor (such as steam) is a possibility, the tube bundle shall have tube supports designed to support the tubes along their length and provide for proper flow and drainage of condensate out of the shell. When a liquid is circulated outside the tube bundle, flow baffles are used to support the tubes and direct flow across the bundle. In this case, the number and spacing of the flow baffles controls the shell-side heat transfer coefficient and its pressure drop.

The U-tube heat exchanger is well suited for large domestic water heating applications using either boiler water or steam as the heating medium. The nature of the U-tube construction allows for large temperature differences between the tube-side and shell-side fluids with the U-tubes expanding or contracting independently of the shell assembly. In addition, the tube bundle assembly is removable for easy and economically replacement of the heat transfer surface should a failure or leak develop in the bundle.

A variation of the single pass tube and shell heat exchanger is the *hairpin* design, often referred to as a "G" fin, double pipe or multitube heat exchanger. This design is a single pass shell and tube unit that has been folded in half, giving it a hairpin appearance. What distinguishes it from the traditional tube and shell exchangers are the end closures, which allow for expansion without expansion joints and removal of the tubes. This design is used when there are solids in the process stream, high pressure is present in tubes, and high flow rate ratios exist between tube and shell fluids.

The U-tube design does have its limitations. First, because of the U-bends, the tube-side fluid always makes multiple passes down the length of the unit. This reduces the economical use of the design on close temperature approaches and eliminates using a single U-tube unit for temperature cross applications such as those found in energy reclamation projects. Also, because of the U-bend, this unit cannot be totally cleaned by mechanical means when the tube-side fluid is dirty or prone to scaling/fouling. The basic U-tube design can be modified to meet a number of special type applications. A typical U-tube is illustrated in Fig. 21.1.

Double-wall Heat Exchangers. Over the last few years, revisions to many plumbing codes have required the use of double-wall protection on potable water systems. The purpose is to warn of a tube failure before cross-contamination can occur between the tube-side and shell-side fluids. A number of manufacturers now produce double-wall units in a U-tube design. Although there are differences in some design features, the basic design is fairly common among double-wall manufacturers.

The double-wall U-tube unit consists of a tube-within-a-tube design. Fins or grooves are used on one of the tubes to create a leak path between the tubes when they are mechanically bonded to enhance heat transfer characteristics. The outside tube is machined back at each end, bent into the U-tube, and either mechanically rolled or brazed into a double-tubesheet arrangement. Should either of the tubes fail, its respective fluid would be channeled through the leak path between the tubes to the space between the tubesheets. The appearance of the fluid from between the tubesheets is evidence of tube failure.

While the double-wall design is very expensive compared to the single-wall unit it replaces, local plumbing codes for the most part are responsible for its growing use. Double-wall exchangers are being used for applications where a failed tube bundle creates a greater loss to the customer than the initial cost of the double-wall unit.

A severe disadvantage is the loss of efficiency in transferring heat from the heating medium to the water.

Straight-tube Designs

This exchanger design is often used to handle heavy fouling fluids or applications where a temperature cross condition may exist.

Because of the straight tubes, the head assemblies can be removed and the tubes can be mechanically cleaned. (This is especially important if the tube-side fluid is prone to heavy fouling/scaling.) In addition to having the capability for multiple tube-side passes, the fixed tubesheet unit can be designed for a single tube-side pass of the fluid through the unit. This means that 100 percent countercurrent flow can be achieved between the tube-side and shell-side fluids.

The fixed tubesheet construction, however, does limit the design's ability to handle large temperature differences between the fluids. Because the tube bundle and the shell assembly are not independent, any differential expansion or contraction between the two will result in stress being transferred to the tube-tubesheet joint. The forces involved can be sufficient to cause a break in the mechanical bond between the tube and tubesheet and, consequently, a failure of the unit. While an expansion joint can be incorporated into the shell to absorb the stresses, this is an expensive alternative subject to fatigue of its own based on the thermal cyclic rate. As a general rule, differences between the average fluid temperatures greater than 75°F should be checked by the heat exchanger manufacturer for excessive stress in the unit. A note of caution, however, even though the difference between average operating temperatures may not indicate a differential expansion problem, the heating up and cooling down from high operating temperatures may, in itself, cause excess stress at the tubesheet interface.

Finally, the bundle assembly is nonremovable. This increases the cost of replacement since the shell must be replaced along with the tube bundle.

Straight Tube, Fixed Tubesheet. The fixed-tubesheet exchanger is the most common used heat exchanger, and typically has the lowest capital cost per square foot of heat-transfer surface area. Fixed-tubesheet exchangers consist of a series of straight tubes sealed between flat, perforated metal tubesheets. The straight tubes are mechanically rolled into a header at each end of the shell pipe. The headers are integral to the shell and act as both a tubesheet and mounting flange for each of the tubeside head assemblies. As a result of its welded design, the fixed tubesheet unit can be designed to accommodate pressures well over 1000 psig.

Because there are neither flanges nor packed or gasketed joints inside the shell, potential leak points are eliminated, making the design suitable for higher-pressure or potentially lethal service. However, because the tube bundle cannot be removed, the shellside of the exchanger (outside the tubes) can only be cleaned by chemical means. The inside surfaces of the individual tubes can be cleaned mechanically, after the channel covers have been removed. The fixed-tubesheet exchanger is limited to applications where the shellside fluid is non-fouling; fouling fluids must be routed through the tubes. The straight tube, fixed tubesheet HX is illustrated in Fig. 21.2.

Straight Tube, Floating Tubesheet. The floating tubesheet design is a removable bundle with a stationary tubesheet at one end of the unit and a floating (pull through) tubesheet at the opposite end.

The floating head design is similar to the floating tubesheet design in that it incorporates both the stationary tubesheet and floating (pull-through) tubesheet. The difference is that an internal head is bolted, with the use of a gasket, to the floating tubesheet. The elimination of the packing removes the associated temperature and pressure limitations.

While the floating head unit provides all the advantages of a straight tube unit without the disadvantages of either the fixed or floating tubesheet designs, the floating head unit is very expensive and rarely used in commercial/HVAC heat exchanger applications.

The floating tube-sheet is a removable bundle design with a stationary tubesheet at one end of the unit and a floating (pull-through) tubesheet at the opposite end. The floating tubesheet is independent of the shell and fits inside the shell pipe and head assembly diameters. To contain the shell-side and tube-side fluids at the floating tubesheet end, packing and a packing retainer are used.

The ability of the tubesheet to move or float within the shell and head means that the unit can handle large temperature differences without creating excessive stresses in the unit. By the same token, the packing is also responsible for the relatively low design pressure and temperature capabilities of the floating tubesheet unit. Generally, these limits are about 800 psi (5500 kPa) and 875°F (466° C). In addition, the packing, as in other packed devices, is a maintenance item and may require periodic replacement. This is especially true when steam is used as the heating medium.

While the floating tube sheet design is available in single-pass on the tube-side and, therefore, capable of handling temperature cross applications, the design is limited to a maximum of two tube-side passes. The reason is that the head assembly does not float with the tubesheet and, therefore, cannot contain any tube-side pass partitions. This, in turn, may limit the design from achieving optimum heat transfer rates in some applications. The floating tubesheet HX is illustrated in Fig. 21.3.

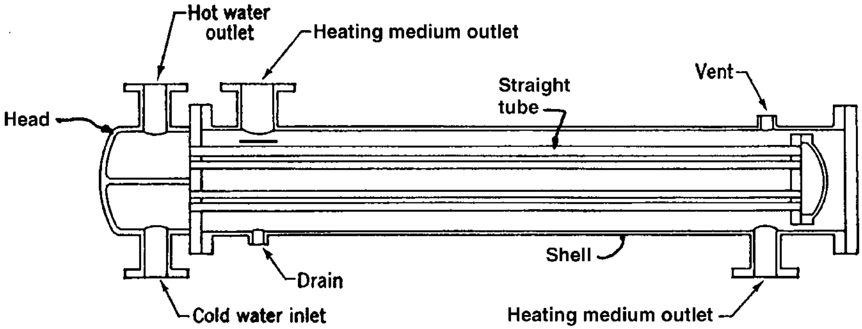


FIGURE 21.2 Typical straight tube, fixed tubesheet heat exchanger.

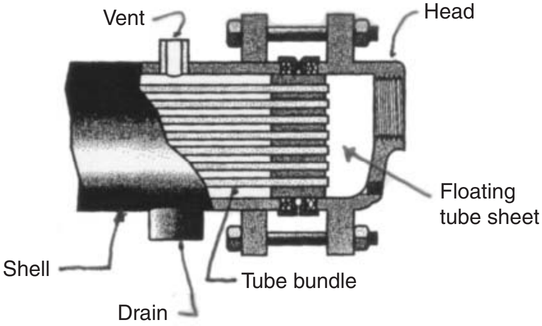


FIGURE 21.3 Straight tube, floating tubesheet.

Removable Bundle, Externally Sealed, Floating Head. Floating-head exchangers are so named because they have one tube-sheet that is fixed relative to the shell, and another that is attached to the tubes, but not to the shell, so it is allowed to ‘‘float’’ within the shell. Unlike fixed tubesheet designs, the dimensions of which are fixed at a given dimension relative to the shell wall, floating-head exchangers are able to compensate for differential expansion and contraction between the shell and the tubes.

Since the entire tube bundle can be removed, maintenance is easy and inexpensive. The shellside surface can be cleaned by either steam or mechanical means. In addition to accommodating differential expansion between the shell and tubes, the floating tubesheet keeps shellside and tubeside process fluids from intermixing.

This exchanger has some design limitations: both shellside and tubeside fluids must be non-volatile or non-toxic, and tubeside arrangements are limited to one or two passes. In addition, the packing used in this exchanger limits design pressure and temperature to 800 psig (5500 kPa) and 300°F (149°C).

Removable Bundle, Outside Packed, Floating Head. This design is especially suited for applications where corrosive liquids, gases or vapors are circulated through the tubes, and for air, gases or vapors in the shell. Its design also allows for easy inspection, cleaning and tube replacement, and provides large bundle entrance areas without the need for domes or vapor belts.

Unlike the previous design, only shellside fluids are exposed to packing, allowing high-pressure, volatile or toxic fluids to be used inside the tubes. The packing in the head does, however, limit design pressure and temperatures.

Removable Bundle, Internal Clamp Ring, Floating Head. This design is useful for applications where high-fouling fluids require frequent inspection and cleaning. And, because the exchanger allows for differential thermal expansion between the shell and tubes, it readily accommodates large temperature differentials between the shellside and tubeside fluids.

This design has added versatility, however, since multi-pass arrangements are possible. However, since the shell cover, clamp ring and floating-head cover must be removed before the tube bundle can be removed, service and maintenance costs are higher than in ‘‘pull through’’ designs.

Removable Bundle, Pull Through, Floating Head. In the pull-through, floating-head design, the floating-head cover is bolted directly to the floating tubesheet. This allows the bundle to be removed from the shell without removing the shell or floating-head covers, and this eases inspection and maintenance.

This is ideal for applications that require frequent cleaning. However, it is among the most expensive designs. And, the pull through design accommodates a smaller number of tubes in a given shell diameter, so it offers less surface area than other removable bundle exchangers.

Removable Bundle, U-tube. In the U-tube exchanger, a bundle of nested tubes, each bent in a series of concentricity tighter U-shapes, is attached to a single tubesheet. Each tube is free to move relative to the shell, and relative to one another, so the design is ideal for situations that accommodate large differential temperatures between the shellside and tube-side fluids during service. Such flexibility makes the U-tube exchanger ideal for applications that are prone to thermal shock or intermittent service.

As with other removable-bundle exchangers, the U-tube bundle can be withdrawn to provide access to the inside of the shell and to the outside of the tubes. However, unlike the straight tube exchanger, whose tube internals can be mechanically cleaned, there is no way to physically access the U-bend region inside each tube, so chemical methods are required for tubeside maintenance. As a rule of thumb, non-fouling fluids should be routed through the tubes, while fouling fluids should be reserved for shellside duty.

This inexpensive exchanger allows for multi-tube pass arrangements. However, because the U-tube cannot be made single pass on the tubeside, true countercurrent flow is not possible.

Tank Suction Heater. A tank suction heater is another variation of the U-tube design. In this application, the portion of the shell opposite the head is removed and a tank mounting flange is welded into the shell near the head of the unit. Tank suction heaters are designed for heating high-viscosity liquids to permit pumping them from their storage tanks. Typical applications include lube oil, heavy fuel oils, tar, road oil, and asphalt. They are also used for preheating oil for oil burners in industrial plants or other large installations.

The main advantage of a tank suction heater over other types of heaters is that it heats the tank fluid on demand and thereby eliminates the loss of energy associated with a system that maintains the entire tank at a temperature above ambient. Flapper plates or valves can be fitted on the open end of the shell to allow maintenance of the bundle without having to drain the entire tank of its contents. A typical tank suction heater is illustrated in Fig. 21.4.

Tank Heater. Replacing the shell assembly with a tank mounting collar allows the U-tube heat exchanger to function as a storage heater. In this application, the tank heater uses hot water for a heating medium that is pumped through the tubes, thus maintaining the tank system water at a set temperature. Steam can also be used as the heating medium when a special head assembly that allows for proper condensate drainage of the unit is installed.

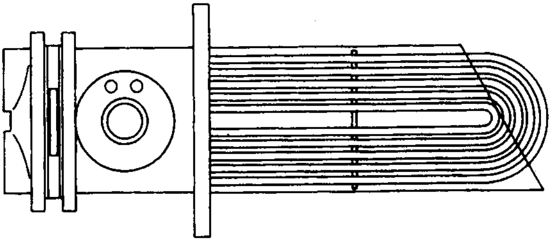


FIGURE 21.4 Typical tank suction heater.

The tank heater uses natural convection for transferring heat to the tank-side system. This is quite different from most other heat exchangers, where pumped or forced convection is used. The significance is that natural convection produces much lower rates of heat transfer. The result is that tank heaters, for a given capacity, require more heat transfer surface area than heat exchangers utilizing forced convection. In addition, it is very important for proper natural convection that the relationship between the size of the tank heater and the size of the tank be within specific limits. The guideline for this relationship is to have the tube bundle extend into the tank from 50 to 75 percent of its length in a horizontal tank or nearly its full diameter if the tank is to be installed vertically.

There are times when a steel tank requires a lining of either cement or epoxy on a domestic water system. When this is done, special consideration must be given by the tank heater manufacturer to insure that the tube bundle fits inside the tank mounting collar. In addition, every tank heater should have adequate support inside the tank to eliminate stress on the tube-tubesheet rolled joint. Inadequate support often leads to leaks of the tube bundle in this area.

A typical tank heater arrangement in a domestic hot water generator is illustrated in Fig. 21.5.

CHOOSING OFF-THE-SHELF SHELL AND TUBE EXCHANGERS

Fixed tubesheet and U-tube shell-and-tube exchangers are the most common types of off-the-shelf heat exchangers available today. Such stock models are typically used as components in vapor condensers, liquid to liquid exchangers, reboilers and gas coolers.

Standard fixed tubesheet units, the most common shell-and tube heat exchangers, range in size from 2 to 8 in dia. Materials of construction include brass or copper, carbon steel, and stainless steel. Even though this exchanger is one of the least expensive available, it is constructed to standards specified by the manufacturer. If

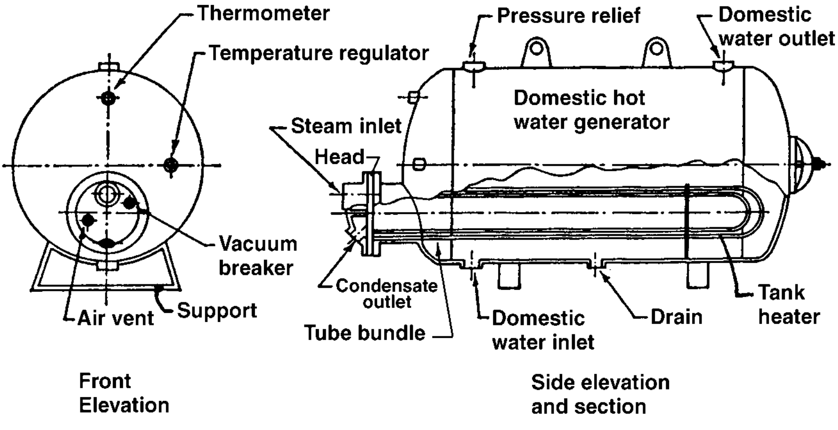


FIGURE 21.5 Tank heater installation.

the user desires, stock exchangers can be constructed to American Society of Mechanical Engineers (ASME) codes.

U-tube heat exchangers are commonly used in steam heating applications, or heating and cooling applications that handle chemical fluids as opposed to water. While the U-tube is generally the lowest-priced heat exchanger available, service and maintenance costs tend to be higher than other exchangers, since the nested, U-bend design makes individual tube replacement difficult.

PLATE TYPE HEAT EXCHANGERS

In recent years, plate type heat exchangers have emerged as an alternative to shell-and-tube heat exchangers. With their ability to optimize thermal performance, they have made possible a number of close approach and temperature cross applications that previously were not economical or practical with a shell-and-tube design. These units are efficient, easy to maintain, less prone to foul and take up little space.

In its most basic form, plate HX consist of corrugated plates compressed in a frame. Plate type heat exchangers are characterized by having heat transfer occur via metal, plastic, glass or ceramic barriers between fluids. One stream heats (or cools) the other by means of conduction (or radiation) through or from the barrier. Inside the heat exchanger the fluids heat by convection. There are two types of plate type units: prime surface and plate and frame. They could be either gasketed or welded. Double-wall heat exchanges could also be provided.

In general, the prime surface units are best suited to small heat loads and batch operations. Because of their very limited use in utility systems, they will only be briefly discussed. The plate and frame units are most efficient when used for larger heat loads and continuous duty.

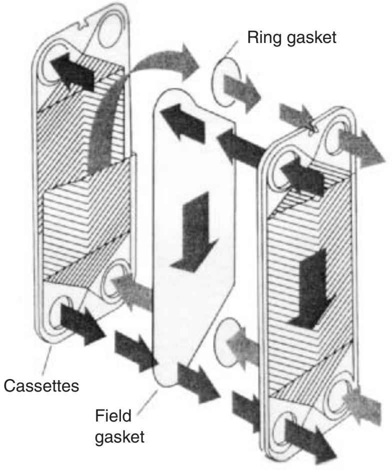
A typical plate and frame heat exchanger is illustrated in Fig. 21.6.

PLATE AND FRAME HEAT EXCHANGERS

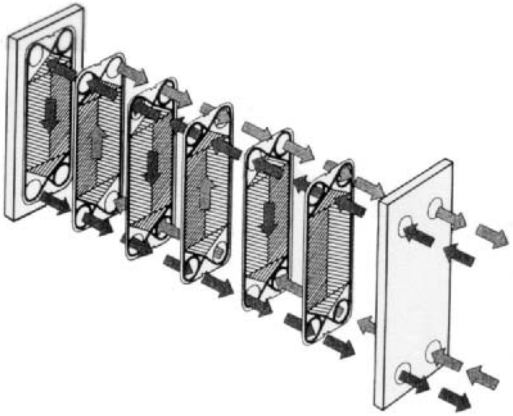
Plate and frame units are fabricated from a series of channel plates that are pressed together to form a plate pack, with the holes at the corners of the plates forming a continuous passage or manifold. This distributes the heat transfer media from the inlet of the heat exchanger into the plate pack for each of the fluids. The media are then distributed into the narrow channels formed by the plates. The gasket arrangement on each plate distributes the hot and cold media into alternating flow channels throughout the plate pack. In all cases, hot and cold media flow countercurrent to each other.

The most common of the plate and frame type heat exchangers is the gasketed plate unit. Heat exchangers of this design include a series of channel plates that are mounted on a frame and clamped together. Each plate is made from pressable materials, such as stainless steel, and is formed with a series of corrugations. The most common pattern of corrugation is the herringbone or chevron. Also included with each plate is an elastomer gasket. This gasket is used for sealing purposes and to distribute the fluids properly in the plate heat exchanger. Spaces between adjacent plates form flow channels for the hot and cold fluids.

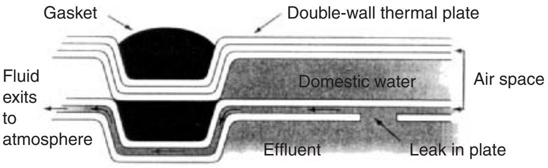
A corrugated herringbone or chevron style pattern is pressed into each plate to produce highly turbulent fluid flows. The high degree of turbulence results in high



Flow Path of Typical Gasketed Plate Heat Exchanger



Flow Path of Typical Welded Plate Heat Exchanger



Double Wall Plate Heat Exchanger

FIGURE 21.6 Plate and frame heat exchangers.

heat transfer coefficients and keeps fouling to a minimum. In addition, the corrugations add rigidity to each channel plate. This allows the use of thinner plate material and improves heat transfer.

The basic design of the gasketed plate exchanger allows for the opening of the frame either to add or remove channel plates to optimize heat exchanger performance or to allow for service and maintenance of the channel plates, all with a minimum of downtime.

Taking into account all the benefits of a plate and frame heat exchanger (100 percent countercurrent flow, high turbulence, and thin plate material), we find it to be a highly efficient device that typically yields heat transfer rates three to five times greater than other types of heat exchangers. As a result, a more compact design is possible for a given application relative to other heat exchanger types. Ideal operating conditions are those involving temperature crosses and close approach temperatures between the hot and cold media.

While gasketed plate and frame heat exchangers can be used in almost any application, there are limitations that must be considered. These limitations are primarily focused on the design pressures and temperatures of the unit. Practical design pressures are limited to 800 psig, while design temperatures are a function of the gasket material used in the exchanger. The most popular and widely applied gasket is nitrile rubber (NR). Its temperature limit is 280 F. NR is followed by EPDM (ethylene propylene diene monomer) with a temperature limit of 820 F. EPDM gaskets can be used as a substitute for NR (for higher temperature ratings) on all applications except those involving oil heating or cooling since EPDM will swell in the presence of most oils. Other gasket materials, such as hypalon and viton, are also available. These gasket materials are more prevalent in industrial applications.

Gasketed exchangers are benefiting from improvements in the quality and diversity of elastomer materials and gasket designs. The use of exchangers with welded connections, rather than gaskets, is also reducing the likelihood of process-fluid escape.

Other limitations are due to the narrow channels between adjacent plates. If a fluid entering the plate heat exchanger has suspended solids or is susceptible to depositing large amounts of scale on the plate surfaces, careful consideration should be given to the free channel space between the plates. Also, the narrow channels and resultant high turbulence of the fluid flows produce high-pressure drops, making the plate exchanger incompatible with low-pressure applications.

Until recently, a major limitation to the gasketed plate heat exchanger was the method used to attach the gaskets to the channel plates. In the past, gaskets were glued to the channel plates. Since gaskets are a replaceable part, removal and reinstallation of the new gaskets was a very time consuming and labor intensive procedure. Most manufacturers now use a glueless gasket design. Clip-type and snap-type are the two most common forms off glue-less gasket. Both simplify the regasketing procedure, making it possible for on-site service and thus reducing service downtime.

Recent advances in plate design and technology have produced two variations to gasketed plate and frame heat exchangers: double-wall and welded plate.

Double Wall Plate and Fame Exchangers. In double-wall plate and frame exchangers, two standard channel plates are welded together at the four corner ports to form one assembly. An air space or leak path is created between the plates for the passage of a fluid should a plate fail. The appearance of this fluid is evidence of plate failure.

The purpose of the double-wall plate and frame exchanger, like that of the double-wall shell-and-tube heat exchanger, is to warn of a plate failure before cross contamination can occur between the heating medium and the colder water.

Welded Plate and Frame Exchangers. In welded plate and frame exchangers, two standard channel plates are welded together at the periphery of the plates. In this design, the two welded plates (usually called a cassette) form a flow channel where the elastomer gasket has been replaced by the welded joint. This configuration may be necessary when there is no elastomeric gasket compatible with the fluid or more positive containment is required. Typical applications include refrigerant evaporators/condensers, ammonia refrigeration, and wherever aggressive or corrosive fluids are present.

Brazed Plate and Frame Exchangers. The latest addition to the plate and frame type exchanger line is the brazed plate exchanger. This type of unit shares the same features, benefits, and method of operation as the gasketed plate and frame exchanger. What it does not share are the gaskets and heavy frame components.

In this design, the elastomer gaskets are replaced with a brazed material (copper or nickel) that greatly increases its pressure and temperature capabilities. The brazed plate design is typically rated at pressures up to 450 psig with temperatures up to 500 F.

Most brazed plate exchangers are very compact in size and are lightweight. They are suitable for most OEM applications where package size is a major consideration or, for that matter, any application where space consideration is a factor. Typical applications include water heating/cooling, refrigerant evaporators/condensers, heat recovery systems, steam applications, district heating systems, oil cooling, and air drying.

The limitations of a brazed plate have to do with the size of plate that can be successfully and reliably brazed. Currently, flow rates top out at about 850 gpm in a single unit. In addition, the brazed plate design is a sealed unit and not serviceable, as such, and it should be considered a throw-away unit in the event the unit becomes fouled or fails altogether.

Wide Gap Plate Exchangers. Compared with traditional plate and frame exchangers, this design relies on a more loosely corrugated chevron pattern, which provides exceptional resistance to clogging. The plates are designed with few, if any, contact points between adjacent plates to trap fibers or solids. Some styles of this exchanger use wide gap plates on the process side and conventional chevron patterns on the coolant side, to enhance heat transfer.

Prime Surface

These units are fabricated from two die-formed sheets welded together. One or both sheets are die or pressure formed (cold formed) to create a series of well defined passages through which the heating (or cooling) medium flows. Most common metals that could be cold worked and resistance welded are used, the most common being carbon steel, stainless steels, monel, titanium and Hasteloy. They are a single circuit design and could be used as shelves, immersed, clamped on or built into tanks and otherwise used where plate and frame exchangers are not suitable even when the media are the same. Maximum operating parameters are generally limited to a temperature of 650°F (343°C) and a pressure of 500 psig (3450 kPa).

IMMERSION HEAT EXCHANGERS

An immersion heat exchanger consists of a tube bundle (coil) containing fluid to be heated and an atmospheric basin or tank in which the tube bundle is immersed that contains the heating medium, which could be any liquid. The heat is transferred directly from the heating medium to the water in the coil. A typical immersion heater installation is shown in Fig. 21.7.

AIR-COOLED EXCHANGERS

In the air-cooled exchanger, a motor and fan assembly forces ambient air over a series of tubes, to cool or condense the fluids carried within. The tubes are typically assembled in a coiled configuration.

Air is cheap and abundant, but it is a relatively poor heat transfer medium. To increase the heat transfer rates of the system, the tubes in air-cooled exchangers are typically given fins, which extend the surface area, increase heat transfer, and give such systems the nickname fin-tube coils.

The diameter and materials specified for the tubes and fins depend on system requirements. The fins are commonly made from aluminum or copper, but may be fabricated of stainless or carbon steel. Tubes are generally copper, but can be made from most any material, and they range in size from 5/8 in to 1/4 in outer diameter. The design of the air-cooled exchanger is such that individual coils can be removed independently for easy cleaning and maintenance.

Aluminum Brazed-fin Exchangers

In this design, corrugated plates and fins are added to a brazed-composite core, to create alternating air and fluid passages. This compact, lightweight design is considered to most cost-effective air-cooled unit available. Turbulence created in the fluid channels boosts efficiency.

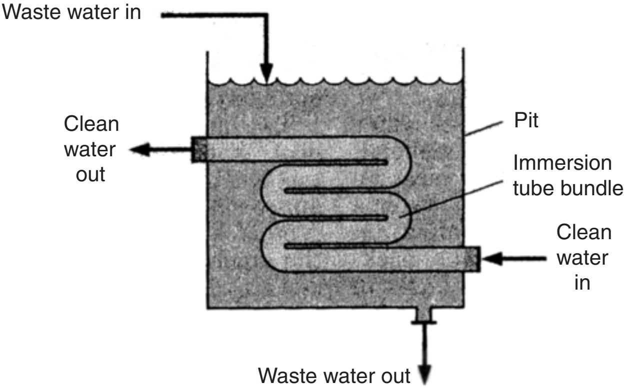


FIGURE 21.7 Immersion heat exchanger.

Aluminum Plate-fin Exchangers

This type of exchanger is constructed with traditional heat exchanger tubing. Stacked, die-formed aluminum plates extend the surface to maximum air-side heat transfer. Like the brazed-fix exchanger, this unit is also used for oil and glycol cooling, but its higher flow-rate expands its capabilities. Built from standard components, aluminum-fin exchangers are designed with a more solid construction than their brazed-fin counterparts.

Fin-tube Exchangers

In this design, one continuous fin is wrapped spirally around a series of individual tubes. Often referred to as a ‘‘heavy duty coil,’’ this air exchanger has fin-tube attachments that can be built either to ASME and API standards, or to customer specifications. Often used in air-heating applications, the heavy-duty coil is available with several different fin variations, including the tapered fin, footed ‘‘L’’ fin overlapped-footed fin and the embedded fin, which describe the geometry at the fin-tube interface. The method of attaching the fin to the tube is critical, since the loosening os this bond may hinder heat exchange.

HEAT EXCHANGER SELECTION

One of the most asked questions when it comes to selecting a type of heat exchanger for a particular application is ‘‘Which is the most appropriate- shell-and-tube or plate type?’’ Assuming that the application is within the pressure and temperature limits of both designs, the issue usually centers around initial cost, maintenance cost, and future operating conditions.

The shell-and-tube heat exchanger has the following advantages:

1. Greatest flexibility of design and configuration
2. Large choice of shell and tubes material
3. High temperature and pressure limitations and specific design features
4. Ability to handle high levels of particulate material
5. All-welded construction and the absence of gaskets contribute to a longer exchanger life.

The plate and frame heat exchanger has the following advantages:

1. The highly efficient heat-transfer surface and pure countercurrent flow yield smaller and less costly heat exchangers that require less space.
2. All heat transfer surfaces can be easily opened and mechanically cleaned on a unit with gaskets.
3. All-bolted construction allows for easy maintenance.

Initial cost is usually dictated by the approach temperatures of the application. Close approach temperatures and temperature crosses favor the plate heat exchanger, while wide temperature approaches favor the shell and tube. Materials of construction can influence this relationship, especially if the application requires the use of stainless steel. With the extensive use of computerized selection programs, it requires little effort to obtain prices for each types of unit and be able to compare initial cost quickly.

With respect to maintenance cost, much depends on the properties of the fluids involved. If the fluid has a tendency to foul, the plate heat exchanger offers somewhat easier and direct access to the heat transfer surface for the purpose of cleaning. In addition, because of the high turbulence in plate units, they have less of a tendency to scale or foul compared to the shell-and-tube design.

If a plate and frame type heat exchanger has a weakness compared to the shell-and-tube, it lies in the amount of gasketing in the unit. Compared to the shell-and-tube, the amount of gasketing is magnitudes larger, and therefore the potential for leakage is much higher. In addition, the gaskets are elastomers, which means they do have a service life. On average, the life of a gasket on a plate and frame heat exchanger is approximately 6 to 7 years with operating temperatures having a significant effect on the average. Units operating close to the temperature limit of the gasket will experience shorter gasket life. There is one other aspect of an elastomer gasket that must be considered: the phenomenon of cold leakage. Cold leakage is due to the cooling down of a plate heat exchanger from high operating temperatures when there is differential pressure between the hot and cold media in the unit. The plate and frame unit has a tendency to weep through the gasket interface. The weeping normally stops after the gaskets reset or the unit is brought back up to operating temperatures. Basically, if the application requires a high probability against leakage, the better choice is a prime surface or shell-and-tube design rather than plate and frame.

While gaskets may be a weakness in a plate and frame unit, the ability to expand its thermal capacity by merely adding channel plates to the existing unit is one of its major strengths. If it is known that a particular application needs to be expanded in the future, a plate unit is by far the easiest and most economical design for such an expansion.

Certain exchanger designs operate better at different approach temperatures. Plate-and-frame exchangers, for example, work well at a very close approach, on the order of 2°F (1°C). For shell-and-tube exchangers, however, the lowest possible approach is on the order of 10°F (6°C).

As for cleanliness, shell-and-tube exchangers have tube diameters that can accommodate a certain amount of particular matter without clogging or fouling. Plate-and-frame exchangers, however, have narrow passageways, making them more susceptible to damage from precipitation or particulate fouling.

HEAT EXCHANGER DESIGN

SHELL AND TUBE HEAT EXCHANGERS

Shell and tube HX use tubes arranged inside a shell in such a way that one fluid, known as the tube fluid, flows within the tubes while the other fluid, known as the shell fluid, flows outside the tubes and within the shell. Heat is transferred through the tube wall.

The shell fluid enters one of the shell nozzles, passes around the tubes, follows the path formed by the shell baffles and finally leaves through the other tube nozzle. The tube fluid enters one of the tube nozzles at one end, generally flows in only one direction and leaves through the other tube nozzle. This is called a single pass because the fluid passes through the tube only once. By adding partitions, the tube fluid could have additional passes.

This section will discuss a simplified method of calculating the area of the tube bundle for only single pass HX units. The heat transfer rate depends on the basic flowpath of each stream. HX design depends on the overall heat transfer coefficient, flow rate of the heating medium, the size and length of the tube bundle and the difference in temperature between the tube fluid and the shell fluid.

To calculate the inside area of coils for heating water use the following formula, where the heating medium is inside the HX shell:

$$A = \frac{Q \times 8.33 \times (t2 - t)}{U \times DT} \tag{21.1}$$

where: A = surface area of coil, sq. ft.
Q = quantity of water, gph
T2 = outlet temperature of tube fluid, °F
T1 = Inlet temperature of tube fluid, °F
U = Heat transfer coefficient, (overall conductance in btu/hr)
DT = mean temperature difference between shell fluid and tube fluid
TS = Temperature of shell fluid

$$DT = TS - \frac{(T2 - T1)}{2} \tag{21.2}$$

Design Considerations for Tube Bundles

1. Table 21.1 gives the area (A) and other properties for often used copper tubes.
2. “U”, the heat transfer coefficient, is found in Table 21.2.
3. The heat transfer coefficient is reduced by a fouling factor that reduces the amount of heat transferred between the tube bundle and the shell fluid. Typical fouling factors vary depending on the fluid can be found in Table 21.3.

The basic water heating rate for conventional storage type domestic water heaters used by many manufacturers is 20 gallons per hour per square ft of bundle outside area when heating water from 40°F to 180°F with saturated steam condensing inside the coils at 0 psig (212°F). The heat transfer rate therefore, is 280 BTU/h/sq.ft coil/°F.

TABLE 21.1 Properties of Copper Tube

Nominal or standard size, inches	Nominal dimensions, inches		Calculated values (based on nominal dimension)	
	Outside diameter	Wall thickness	Cross sectional area of bore, sq inches	External surface, sq ft per linear ft
⅛	.125	.030	.00332	.0327
3⁄16	.187	.030	.0127	.0490
¼	.250	.030	.0284	.0654
5⁄16	.312	.032	.0483	.0817
⅜	.375	.032	.076	.0982
	.375	.030	.078	.0982
½	.500	.032	.149	.131
	.500	.035	.145	.131
⅝	.625	.035	.242	.164
	.625	.040	.233	.164
¾	.750	.035	.363	.196
	.750	.042	.348	.196
	.750	.042	.348	.196
⅞	.875	.045	.484	.229
	.875	.045	.484	.229
1⅛	1.125	.050	.825	.295
	1.125	.050	.825	.295
1⅜	1.375	.055	1.26	.360
	1.375	.055	1.26	.360
1⅝	1.625	.060	1.78	.425
	1.625	.060	1.78	.425
2⅛	2.125	.070	3.09	.556
2⅝	2.625	.080	4.77	.687
3⅛	3.125	.090	6.81	.818
3⅝	3.625	.100	9.21	.949
4⅛	4.125	.110	12.0	1.08

TABLE 21.2 Typical Heat Transfer Coefficients

Controlling fluid and apparatus	Type of exchanger	U free convection	U forced convection
Air-flat plates	Gas to gas[a]	0.6–2	2–6
Air-bare pipes	Steam to air[a]	1–2	2–10
Air-fin coil	Air to water[a]	1–3	2–10
Air-HW radiator	Water to air[a]	1–3	2–10
Oil-preheater	Liquid to liquid	5–10	20–50
Oil-preheater	Steam to liquid	10–30	25–60
Brine-flooded chiller	Brine to R12, R22		30–90
Brine-flooded chiller	Brine to NH_3		45–100
Brine-double pipe	Brine to NH_3		50–125
Water-double pipe	Water to NH_3		50–150
Water-Baudelott cooler	Water to R12, R22		60–150
Brine-DX chiller	Brine to R12, R22, NH_3		60–140
Brine-DX chiller	E glycol to R12, R22		100–170
Water-DX Baudelot	Water to R12, R22, R502		100–200
Water-DX shell & tube	Water to R12, R22, NH_3		130–190
Water-shell & int finned tube	Water to R12, R22		160–250
Water-shell & tube	Water to water		150–300
Water-shell & tube	Condensing vapor to water		150–800

Notes: U factor = Btu/h − ft^2 • °F
Liquid velocities 3 ft/sec or higher
a At atmospheric pressure
b At 100 psig
Values shown are for commercially clean equipment.
Adapted from "Numbers", Bill Holladay and Cy Otterhelm, 1985.

An important consideration in the design of tube fluid when it is water is the effect of buildup of scale on the inside of the coil if it is copper. See Fig. 21.8.

SIZING PRESSURE AND TEMPERATURE RELIEF VALVE

The purpose of the temperature relief valve is to prevent the water in a heater from reaching 210°F (99°C). The temperature rating equals the maximum heat rate from heat input to the heater on which thee valve is installed. It shall be water rated on the basis of 1250 BTU for each gallon per hour discharge at 30 psi (210 kPa). The formula is:

$$\text{BTU capacity of valve} = \frac{\text{Heated GPH} \times 8.33 \times \text{Temp. rise}}{0.8} \qquad (21.3)$$

The purpose of the pressure relief valve is prevent the pressure in the heater from rising higher than 10 percent in excess of the set opening pressure of the valve. It shall be set at a pressure not exceeding the working pressure of the tank or heater. Water shall be discharged to a safe location.

TABLE 21.3 Typical Fouling Factors

Recommended minimum fouling allowances for water flowing at 3 ft/sec* or higher:		
Distilled water		0.0005
Water, closed system		0.0005
Water, open system		0.0010
Inhibited cooling tower		0.0015
Engine jacket		0.0015
Treated boiler feed (212°F)		0.0015
Hard well water		0.0030
Untreated cooling tower		0.0033
Steam:		
Dry, clean and oil free		0.0003
Wet, clean and oil free		0.0005
Exhaust from turbine		0.0010
Brines:	**Non-ferrous tubes**	**Ferrous tubes**
Methylene chloride	none	none
Inhibited salts	0.0005	0.0010
Non-inhibited salts	0.0010	0.0020
Inhibited glycois	0.0010	0.0020
Vapors and gases:		
Refrigerant vapors		none
Solvent vapors		0.0008
Air, (clean) centrifugal comp		0.0015
Air, reciprocating compressor		0.0030
Other liquids:		
Organic solvents (clean)		0.0001
Vegetable oils		0.0040
Quenching oils (filtered)		0.0050
Fuel oils		0.0060
Sea water		0.0005

* Lower velocities require higher f values.

Adapted from ''Numbers,'' Bill Holladay and Cy Otterhelm, 1985.

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