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SCOPE

This subsection presents a general description along with general design considerations for plate heat exchangers.

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REFERENCES

DESIGN PRACTICES

(Besides other subsections of this section)

[Section II](#) Design Temperature, Design Pressure and Flange Rating

[Section XV](#) Safety in Plant Design

INTERNATIONAL PRACTICES

[IP 3-3-10](#) Strainers for Mechanical Equipment

[IP 14-3-1](#) Fireproofing

OTHER REFERENCES

1. API-662 - Plate Heat Exchangers for General Refinery Services; First Edition, December 1995.
2. HTRI Design Manual D7.1 Plate Heat Exchangers (PHE) - Construction and Operational Principles.
3. HTRI Report No. F-EX-1-8 Plate Heat Exchanger Fouling Study.
4. HTRI Report, Plate Heat Exchangers: Plate Selection and Arrangement, 1990 AIChE meeting in Orlando Florida.
5. "BRRF Plate Heat Exchanger Recommended Gasket Inspection Procedures, Intervals, & Expected Gasket Life," May 1995.
6. HTFS Design Report No. 36 - Plate Heat Exchangers.

ER&E TECHNICAL REPORTS

1. ER&E Technical Report No. EE.127E.92, "Welded Plate Heat Exchanges" (December, 1992).
2. ER&E Technical Report No. EE.47E.87, "Fire Safety of Plate Heat Exchangers" (August, 1987).
3. ER&E Technical Report No. EE.80E.90, "Plate Heat Exchangers: Extending the Range of Applications Within Exxon" (December, 1990).
4. ER&E Technical Report No. EE.18E.95, "A Typical Mechanical Specification and a Guide for the Safe Application of Gasketed Plate and Frame Heat Exchangers" (January 1995).

CHARACTERISTICS OF PLATE HEAT EXCHANGERS

GASKETED PLATE HEAT EXCHANGER

The gasketed plate heat exchanger (PHE), also known as the plate and frame exchanger, is, within the inherent limits of its capabilities, a valid alternative to tubular heat exchangers for many heat transfer processes, especially in no phase change applications. It was originally introduced in the 1930s mainly in the food industry because of the ease of cleaning. Due to the development of more effective plate geometries, frame assemblies, and improved gasket materials in the 1960s, applications for the PHE have broadened considerably. The PHE now successfully competes in areas historically considered to be the domain of tubular exchangers. A more detailed general overview can be found in [Design Practice IX Section A](#).

PARTIALLY OR FULLY WELDED PLATE HEAT EXCHANGERS

A development on the gasketed plate and frame is the partially or fully welded plate heat exchanger. Gaskets on one side of the plate are replaced by a weld in the partially welded PHE. A fully welded PHE has all gaskets replaced with welds. Advantages, disadvantages, and general descriptions of various welded and semi-welded PHE designs can be found in [Design Practice IX Section A](#) and in Technical Report EE.127E.92, "Welded Plate Heat Exchangers." New applications for these exchangers are continuously evolving. For more information and guidance on the use of welded or partially welded PHEs contact the Heat Transfer Equipment Section of ER&E in Florham Park.



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CHARACTERISTICS OF PLATE HEAT EXCHANGERS (Cont)

The remaining sections of this Design Practice were written with gasketed PHEs in mind; however, much of the information can be shared with welded and partially welded PHEs.

OPERATIONAL CHARACTERISTICS AND MAIN ADVANTAGES

1. High thermal efficiency due to: (a) very high film coefficients of heat transfer for both fluids, typically two to three times those for tubular types, (b) the absence of bypassing and leakage streams, and (c) counter-current operation.
2. Flexibility of design through a variety of plate sizes, chevron angles (and their combinations), and pass arrangements.
3. Unique capability of readily permitting changes in configuration to suit altered duty and/or throughput requirements through changes in the number of plates used.
4. In many streams, reduced fouling tendency due to the high induced turbulence, short residence times, and absence of regions of low velocity.
5. PHE design provides for access to all surfaces. Note that the PHE can be fully opened for inspection and maintenance within the confines of the floor area occupied by the assembled unit.
6. Plate failure is the only means of possible fluid cross-contamination, even under gasket failure (positive venting).
7. Very compact (large surface/volume ratio), low weight.
8. Low fluid holdup, faster start-up and response to control functions.
9. Wide range of total surface area up to 15,000 ft² (1395 m²).
10. Only the heat transfer surface and fluid connections need to be constructed in corrosion-resistant materials.

RANGE OF CAPABILITIES AND LIMITATIONS

Capability boundaries are due to the inherent limitations in the two main construction elements: the gaskets and the plates.

1. The maximum temperature and pressure limits are approximately 450°F and 335 psig (230°C and 2310 kPa). However, Exxon experience indicates that designs operating at less than 300°F and 300 psig (150°C and 2070 kPa) result in the most successful applications, and limits the use of PHEs to these lower limits.
2. Narrow corrugated flow paths (i.e., channels) result in the PHE having high-shear characteristics. Friction factors are generally high for fully developed turbulent flow, but channel lengths are fairly short and nominal velocities are low, so that resulting pressure drops can be maintained within reasonable limits acceptable to most single phase applications.
3. The high-shear characteristics of the PHE may render this type less suitable than others for two-phase duties under conditions of high vapor fraction and low operating pressure and pressure drops. PHEs are, however, successfully applied to the condensation of vapors at moderate pressures and to other selected multiphase duties.
- S 4. The gaskets impose restrictions on operating temperatures and on the nature of the fluids which can be handled. Periodic replacement of the gaskets must be considered. The interval will vary considerably with the application. For severe operating conditions gasket replacement requirements can be a limiting factor.
5. The small channel spacings will restrict the size of entrained particles which can be passed through a PHE. Strainer installation immediately upstream of the PHE inlet nozzles is recommended for all applications.
6. PHEs have a very limited potential for application in vacuum service due to the long gasket periphery.
7. A high flow rate - low heat transfer duty would be accommodated by a small number of relatively large-ported plates. However, the frame cost could be high relative to the total cost, rendering the unit uneconomic. In most cases a PHE will be viable when more than 10 plates are used.
8. While PHEs have proven ease of opening, cleaning, and re-assembly in many non-aggressive services, refining experience has revealed that in services which are aggressive to gasket attack (e.g., swelling and consumption) opening of PHEs is discouraged due to resealing difficulties.
9. PHEs are more vulnerable to damage and loss of containment in a fire than shell and tube heat exchangers.

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CHARACTERISTICS OF PLATE HEAT EXCHANGERS (Cont)

MAIN AREAS OF POTENTIAL USE

The following items describe applications that may benefit from an application of a PHE.

1. Where high thermal effectiveness [close temperature approach $< 15^{\circ}\text{F}$ (-9.4°C) and/or low LMTD $< 25^{\circ}\text{F}$ (-3.9°C)] is required and may be difficult or impossible to achieve in tubular constructions (such as in certain heat recovery situations).
2. Where a temperature cross is required.
3. Where plot space is limited. PHEs provide high surface area density, light weight, and small volume.
4. Where ease and frequency of cleaning is important.
5. For clean and non-aggressive (with respect to the elastomer gaskets) streams.
6. For fouling streams where the fouling rate is a significant function of heat transfer surface shear stress.

GENERAL APPLICATIONS

The PHE is primarily suited for liquid-to-liquid heat transfer. Applications involving gases or vapors (with or without phase-change) are feasible if the operating pressure is not less than atmospheric. Channel pressure drop then becomes a limiting factor due to high specific volumes, whereupon the PHE becomes uneconomic.

The most important phase-change application is where steam is used as the heating medium. Other vapors, including hydrocarbons, may be condensed in PHEs, subject to the same considerations.

The types of liquid successfully handled in PHEs are extremely varied. At one end of the scale are water and other low-viscosity fluids, at the other, such liquids as polymer solutions with an effective viscosity in the order of 10^4 cP.

The number of PHE applications in refineries and chemical plants is growing. Some Exxon applications include high flash product cooling at Bayway Chemical Plant, compressor jacket water cooling services at Baytown and Billings Refineries, and lean/rich solvent exchanger service for gas treating at EUSA's LaBarge facility. PHEs are currently in water cooling service on the sour water condensing towers at the Rotterdam and Baytown Refineries, a PHE has been installed at the Baton Rouge Refinery in DIB subcooling service, and PHEs have been successfully installed as FCC gas compressor interstage condensers in Sriracha. For further information on possible applications please contact the Heat Transfer Equipment Section of ER&E in Florham Park.

PHE COMPONENTS

The two main constructional elements are: a) the "Frame Assembly," and b) the "Plate Pack."

FRAME ASSEMBLY

The main components of a typical PHE are shown in **Figure 1**. Effort has been made to standardize PHE nomenclature by the publication of API-662, however, you may still encounter alternative names used by the various PHE manufacturers.

A typical PHE consists of two rectangular metal head plates or end covers which, coupled with tie bolts, clamp together a number of thin corrugated plates, each sealed by a peripheral gasket. Plates and the movable part of the frame are suspended from the upper carrier bar and guided at their lower ends by a guide bar. The carrier and guide bars are bolted to the fixed part of the frame and, on all but the smaller types, are attached to the end support. The plates are arranged so that the hot and cold fluids flow on alternating plates. Plates are spaced very close together to maximize velocity and turbulence, which in turn enhances heat transfer and reduces surface fouling.

THE PLATE AND PLATE PACK

The plate pack corresponds to the tube bundle in shell-and-tube exchangers, with the important difference that the two sides of a PHE are normally of identical hydrodynamic characteristics, i.e., there is no difference between "tubeside" and "shellside" flows. The basic element of the plate pack is the plate, a sheet of metal, precision pressed into a corrugated pattern as shown in **Figure 2**. The pattern of the corrugations (depth, shape of the groove, and chevron angle) is always a proprietary design and determines the effectiveness of any given plate with respect to heat transfer and pressure drop characteristics.

Of particular importance is also the design of the flow distribution region between the ports and the main body of the plate, which should assure that the fluid is equally distributed over the full width of the plate. Poor design of the distribution region can severely affect the plate performance.

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PHE COMPONENTS (Cont)

Although most modern PHEs are of the chevron type, to give improved mechanical strength, a number of commercial plates have a surface corrugation pattern called "nesting" or "washboard." Because of major variations in individual corrugation patterns of this plate type, heat transfer and pressure drop correlations similar to chevron plates are not possible. However, such plates are not thermally inferior and are still in wide use in many industries.

Every pair of two adjoining plates forms a flow channel which is analogous to a tube in tubular exchangers. The fact that the plates can be closely spaced, typically channel width is between 0.05 and 0.625 in. (1.3 to 16 mm), is one reason for the high heat transfer effectiveness. This high heat transfer effectiveness corresponds to the use of small tube diameters which is usually not practical in tubular exchangers. The plate corrugations produce an effect which is similar to that of turbulence promoters in tubular devices.

The fluid flow through the plate pack is illustrated schematically in **Figure 3** for the simplest case of a U-arrangement, which has flow inlets and outlets of both fluids located at the same end plate.

Separation of the two fluids depends on accurately molded gaskets, tailored for the grooves, pressed into the periphery of the plates and around the ports. However, fluid intermixing is prevented, even in the event of gasket failure, due to "vents" open to the atmosphere.

OPERATING PRINCIPLES AND CONSTRUCTION

A number of constructional and design related items and concepts are defined and described below.

PLATES AND PLATE CHARACTERISTICS

Refer to **Figures 2 and 4** which are schematic sketches of a plate with all pertinent dimensions. Modern efficient plates are pressed from sheet metal blanks into a corrugated pattern with a characteristic angle β which is referred to as "herringbone" or "chevron" angle.

Some manufacturers use the chevron angle definition shown as β , while others prefer the included angle β_i . The user should be aware of these differences. In this text the β definition is used preferentially.

The herringbone plates are inserted into the "plate pack" with the corrugation pattern pointing in alternate directions, so that when tightened to metallic contact, the corrugations "cross and abut." Because of the many support points of contact, the plates can be made from very thin material, but not less than 0.024 in. (0.6 mm).

The chevron angle β varies between the extremes of about 65° and 25° ($\beta_i = 50^\circ$ and 130°) and determines the pressure drop and the heat transfer characteristics of the plate. Low values of β (obtuse corrugation angles) produce high heat transfer and high pressure drop and are referred to as "high NTU" plates, while "low NTU" plates have the opposite characteristics. NTU is the commonly used expression for "number of transfer units," derived from the heat balance and rate equations as:

$$NTU_{\text{required}} = (T_i - T_o) / LMTD \quad \text{Eq. (1)}$$

$$NTU_{\text{actual}} = (U A_e) / (W C_p) \quad \text{Eq. (2)}$$

where:

A_e	=	Total effective plate area, ft ² (m ²)
C_p	=	Specific heat, Btu/lb (J/Kg)
LMTD	=	Log mean temperature difference, °F (°C)
NTU_{actual}	=	Actual number of transfer units
NTU_{required}	=	Required number of transfer units
T_i	=	Inlet temperature, °F (°C)
T_o	=	Outlet temperature, °F (°C)
U	=	Overall heat transfer coefficient, Btu/hr ft ² °F (W/m ² °C)
W	=	Flow rate, lb/hr (Kg/s)

Note that NTU_{required} is the ratio of the temperature change from inlet (T_i) to outlet (T_o) of a plate to the log mean temperature difference. The NTU_{actual} represents the capability of a plate to obtain such a temperature change and is therefore related to a given flow rate W , overall coefficient U , and an effective plate area A_e . Thus, there is no general meaning to a specific NTU value, except as a convenient designation as: (a) "low NTU" ($NTU < 1.0$) plates with $\beta = 65^\circ$ or $\beta_i = 50^\circ$, which produce lower heat transfer coefficients but also require lower pressure drops, and (b) "high NTU" ($NTU > 1$) plates, with $\beta = 25^\circ$ or $\beta_i = 130^\circ$, which have the opposite characteristics.

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OPERATING PRINCIPLES AND CONSTRUCTION (Cont)

PLATE MIXING OR COMPOSITE CHANNELS

The significance of the low and high NTU plates becomes especially apparent in "composite channels" which are created by plates of different β value being assembled alternately within a plate pack, this arrangement being consistent throughout the plate pack. As an example, plates 1, 3, 5, etc., might have chevron angle $\beta = 30^\circ$, and plates 2, 4, 6, etc., have a chevron angle $\beta = 60^\circ$. In this arrangement, *each* channel for *both* fluids is bounded by a plate of each type, and *all* channels have the same heat transfer and pressure drop characteristics.

Thus with only two plate patterns, H (high NTU plate) with $\beta = 30^\circ$ and L (low NTU plate) with $\beta = 60^\circ$, the manufacturer can create at least three different NTU characteristics, HH, LL and HL. With all L-plates, more plates are needed to produce the required Q, and thus flow velocity is decreased. With all H-plates, plates must be added to accommodate maximum pressure drop. For each level of pressure drop, there will be an optimum solution of mixed H and L plates.

As an approximation, the characteristics of composite channels may be taken as being the same as would be obtained in channels formed by plates having the arithmetic mean of the two chevron angles; in the above example, the same characteristics would be achieved from plates all having $\beta = 45^\circ$.

CHANNEL MIXING

Further extension of the composite channel concept leads to "channel mixing." In this case the plate pack is divided into two "sections," each containing channels of different heat transfer and pressure drop characteristics. One section may be (but not necessarily) composed of composite channels, while the other may be composed of channels formed from plates of identical chevron angle.

A simple system of this type involves the use of two plate patterns X and Y, forming XX or YY channels and a "composite" channel XY. Part of the flow for each fluid is through channels of type XX, and the remainder through channels of type XY. Since these two channel types have different pressure drop characteristics, the flow per channel in each type will adjust to result in the same pressure drop since the channels are connected in parallel. The outlet temperatures for a given fluid from each channel type will be different. By proper selection of the appropriate numbers of each type, the desired overall mix temperature will be achieved at an optimum utilization of pressure drop.

Mixed channels can be compared to two dissimilar heat exchangers (of any type) which are connected in parallel on both sides; flows will distribute so as to achieve equal pressure drop, and the overall outlet temperatures will be those obtained by the mixing of the two streams of each fluid emerging from the two exchangers.

MATERIALS OF CONSTRUCTION AND DESIGN CODES

PLATES

Various pressing patterns are used, normally employing precision cold-pressing techniques. The entire plate pattern is pressed in a single operation to ensure accuracy, leaving punching the ports, guide bar cutouts, etc. as subsequent operations. In principle, any metal that can be cold-pressed may be used, but in practice, plates are readily available in:

MATERIAL	THERMAL CONDUCTIVITY	
	Btu/hr ft °F	W/m °K
Stainless Steel (Type 316)	9.5	16.5
Titanium	11.6	20.0
Incoloy 825	7.2	12.5
Hastelloy C-276	6.1	10.6
Monel 400	38.1	66.0

Note that carbon steel is not used since PHEs are designed using a thin gauge metal with zero corrosion allowance requiring the use of higher alloy metals.