

# Understand the Capabilities of Plate-and-Frame Heat Exchangers

*Plate exchangers offer high heat transfer, compactness, and cleanability. This overview explains what these devices are and how to apply them to chemical process industries applications.*

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**F**or decades, process heat transfer has been performed in the familiar shell-and-tube heat exchangers. Today, however, an increasing number of heat transfer operations are being performed in plate-and-frame heat exchangers (often called simply plate exchangers).

Plate-and-frame heat exchangers are primarily applied to liquid-liquid heat-transfer duties. They are, however, increasingly being used in condensing and boiling applications, where their compact size and thinner material requirements for wetted parts offer advantages over other types of heat-transfer equipment.

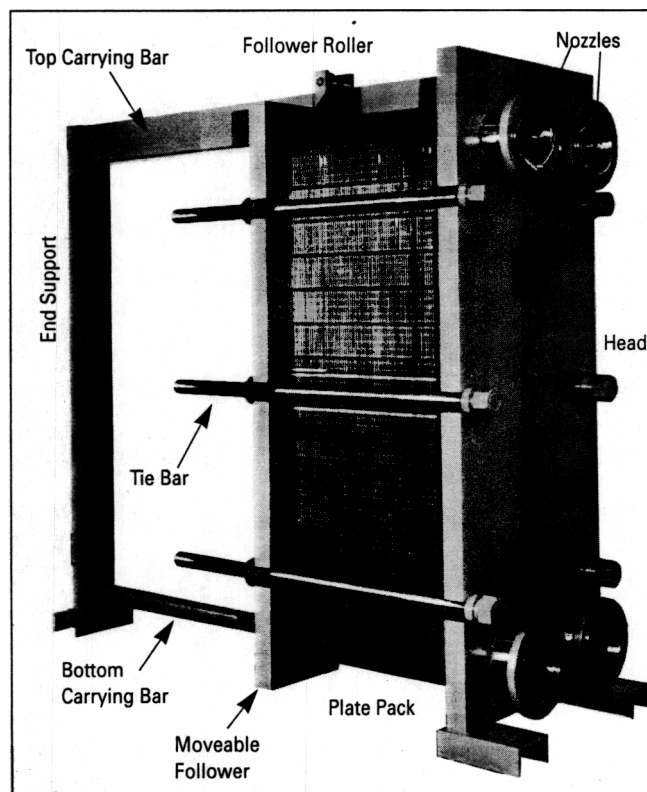
Commercial development of the plate-and-frame heat exchanger was prompted by two basic process objectives — high rates of heat transfer at a low temperature differential and cleanability with full access to both sides of the heat-transfer surface. Both features remain important to users of heat-transfer equipment.

## Exchanger design

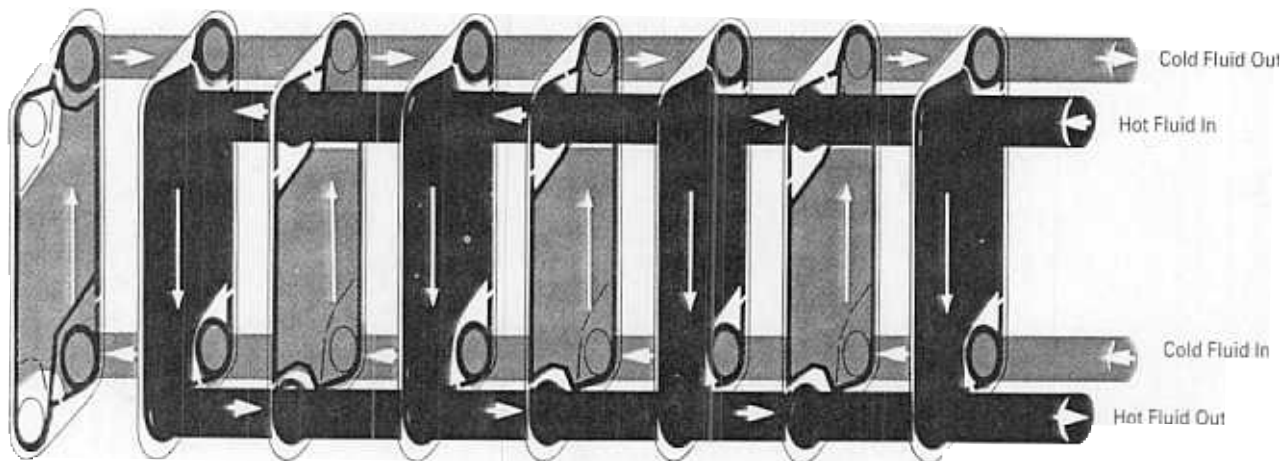
The original idea for the plate-and-frame heat exchanger was patented over a century ago, and the first commercially successful design was introduced in 1923 by the Aluminium Plant and Vessel Company Ltd., now known as

APV. Initially a number of cast gun metal plates enclosed in a frame similar to a filter press, the plate-and-frame heat exchanger evolved into its current design with the introduction in the 1930s of plates pressed in thin-gauge stainless steel.

As shown in Figure 1, today's plate-and-



■ *Figure 1. A plate-and-frame heat exchanger, as the name implies, consists of a series of corrugated plates within a structural frame.*



■ **Figure 2.** The process and service fluid flow countercurrently between the plates.

frame heat exchanger consists of a frame that carries a series of closely spaced metal plates that have been pressed with a corrugated trough or pattern. The plates, which are clamped between a fixed head and movable follower, have corner ports to permit the passage of process and service liquids, with elastomeric gaskets around the ports and plate edges to prevent leakage. The plates are grouped into passes within the heat exchanger, and the product and service fluids flow counter-current to each other between the parallel passages in each pass, as illustrated in Figure 2. The gasketing in the through-port area of the plate provides a double seal between the fluid streams and prevents intermixing, as depicted in Figure 3. The space between the seals is vented to the atmosphere so that in the event of leakage of either liquid there is an escape path for the fluid as well as a visual indication of the leak.

A recent development is welded plate pairs. As the name implies, pairs of plates are resistance seam or laser welded together. This forms a metal seal on one flow channel, and the seal between pairs is provided by an elastomer gasket.

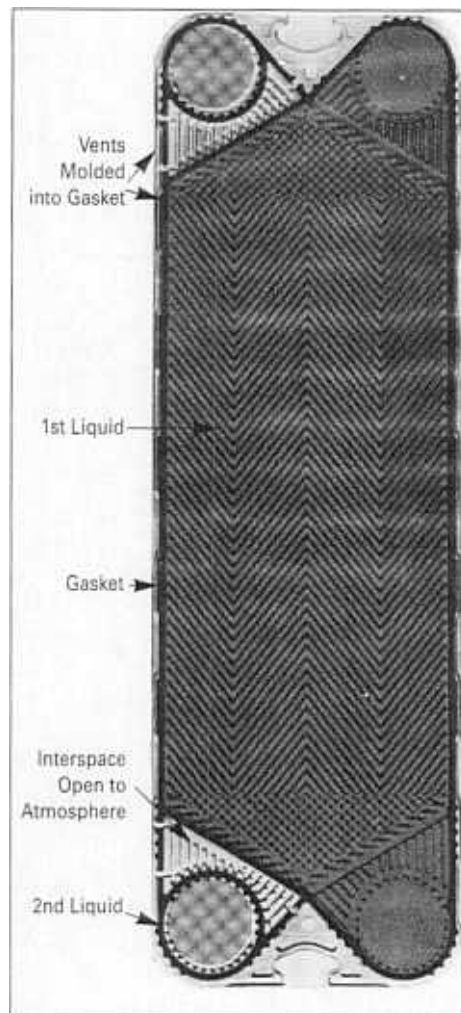
Plate heat exchangers in a variety of metals and gasketing materials are available to handle design pressures to 350 psi. Units presently are available with total heat-transfer surface areas up to 20,000 ft<sup>2</sup> and with ports large enough to handle flows up to 18,000 gal/min.

With the corrugated plate patterns inducing liquid turbulence at Reynolds

numbers as low as 150, overall heat-transfer coefficients as high as 1,500 Btu/h•ft<sup>2</sup>•°F may be achieved with a 20-psi pressure drop. In contrast, conventional exchangers require tube side Reynolds numbers of 2,000 or greater to achieve turbulent flow.

**The frame.** The frame, which consists of the head, follower, top and bottom carrying bars, tie bars and nuts, and end support column, forms a rigid structure to hold the plates in alignment and maintain proper gasket compression. A bolted-frame construction is an important consideration for installation in areas with restricted access and for future expansion of the unit in the field.

The head (or fixed cover) forms the stationary end of the frame and generally contains all four product/service-media connections for single-pass design. The follower (or movable cover) forms the movable end, which compresses the plate assembly (called the plate pack) against the head. The follower is suspended from the top carrying bar and is guided by the bottom carrying bar. Liquid connections can be fitted to the follower for multipass plate arrangement. Connections can be flanged nozzles, threaded pipe, grooved pipe, or studded for direct flange connection. The carrying bars



■ **Figure 3.** The gasketed plate provides a double boundary between the fluids and is vented to the atmosphere.

locate and guide the plates and follower. Tie bars bear against opposite sides of the head and follower to compress the plate pack. The carrying bars and tie bars are sized to accommodate the number of plates currently required, and frequently future expansion as well.

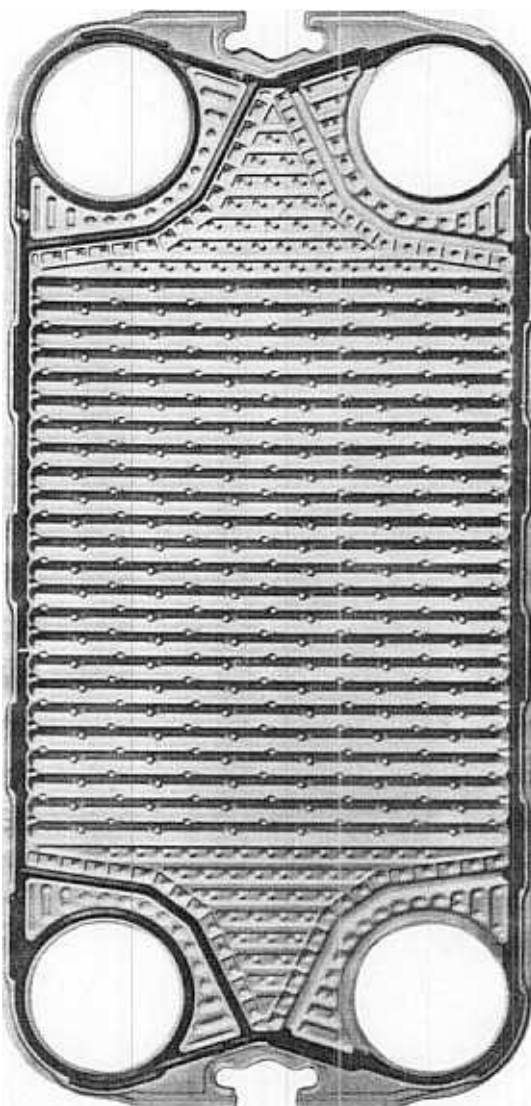
### The plates

The plate pack — the heart of a plate-and-frame heat exchanger — is compressed between the head and follower to form the separate flow paths for the process and service fluids.

The corrugated plates are typically formed from metal 0.5–0.9 mm (0.020–0.036 in.) thick. Proper plate design and material thickness are determined by the manufacturer so that the plate pack can withstand the full design pressure.

Plate corrugation can be of many types. One pattern known as washboard corrugation is illustrated in Figure 4. This design consists of troughs perpendicular to the direction of the liquid flow. These troughs mate with those of the adjacent plate but are kept apart by raised side pips that contact corresponding points on adjacent plates, thus forming flow channels. This results in a ribbon flow path. The gap forming the flow channel typically ranges from 0.150 in. to 0.390 in. depending on plate design.

The most widely used plate pattern is the chevron. This design is based on corrugations formed at an angle to the liquid flow which, in combination with plates of opposite or different angles, make contact at the corrugation cross-over points to permit flow between them. This pattern forms a flow path broken into many high-turbulence helical streams. Figure 5 illustrates 50-deg. and 0-deg. chevron angles (as measured from horizontal) as well as the



■ Figure 4. Plates having a washboard corrugation experience a ribbon flow path.

variable length options for a given model. Flow channel gaps on chevron plates typically range from 0.080 in. to 0.250 in.

To provide a quantitative comparison of these two basic corrugation patterns with each other and with tubular exchangers, the term temperature ratio,  $TR$ , is defined as:

$$TR = \Delta T_m / LMTD$$

where  $\Delta T_m$  is the larger temperature change of the two fluids involved and  $LMTD$  is the log mean temperature difference in the exchanger. ( $TR$  is also known as heat-transfer units,

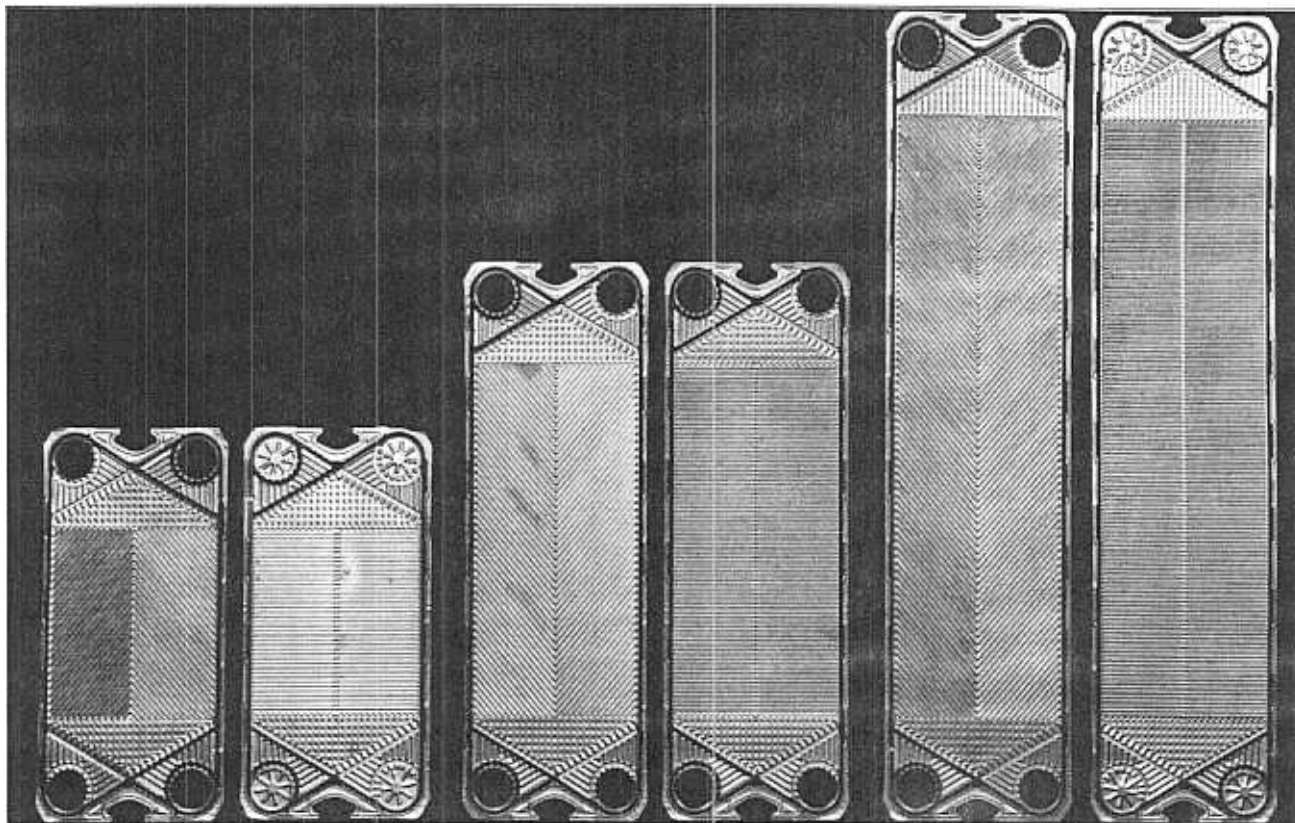
HTU, or number of thermal units, NTU.) For simplicity, only countercurrent flow will be discussed here.

A single-pass conventional tubular exchanger in countercurrent flow service has a practical length limit. This translates to a maximum  $TR$  capability of about 0.3 per shell. To meet a greater  $TR$  duty would, therefore, require multiple shells in series.

The washboard type of plate corrugation typically provides a wider plate gap than the chevron style and has a  $TR$  capability ranging from 0.6 to 2.0 per pass. In this case,  $TR$  capability increases with decreasing flow gap, decreasing corrugation pitch, and increasing plate length. Washboard plates have fewer plate-to-plate contact points and, thus, require thicker and more costly plate material to handle a given pressure compared to chevron plates. However, the wider gap and reduced number of contact points is often an advantage when handling debris-laden streams and slurries.

The chevron type of plate corrugation has a  $TR$  capability ranging from 1.0 to 6.0 per pass, depending on plate gap, corrugation angle, and length. Here, too, the  $TR$  capability increases with decreasing flow gap and with increasing plate length, as well as with decreasing corrugation angle (as measured from horizontal). Combining different corrugation angles with variable length plates allows the thermal and pressure-drop performance to be optimized to the required duty.

Most applications with clean fluids use chevron plates with flow channel gaps in the lower half of the range (0.080 in. to 0.160 in.). At the upper end of the range (near 0.250 in.), modern wide-gap chevron plates often replace the traditional washboard style plates, because chevron plates can achieve greater mechanical strength with reduced plate thickness and, in turn, a lower cost.



■ Figure 5. Mixing and variable-length plates allow the heat-transfer surface to be matched to the thermal duty.

Either type of plate-and-frame exchanger has a higher *TR* capability per pass than a shell-and-tube exchanger. Thus, for a given duty (*TR* requirement), the plate exchanger's fewer passes means less overall pressure loss due to reduced entrance and exit losses. Furthermore, plate-and-frame exchangers can also incorporate multiple passes in full countercurrent flow in a single frame.

In a plate-and-frame exchanger, the geometry of the flow channel is identical on both sides of the plates and is formed to a close and consistent tolerance. Thermal and pressure-drop predictions, therefore, can be made much more accurately than for tubular exchangers. In the latter, practical manufacturing tolerances on the shell side allow flow to bypass through the baffle tube holes and around the baffle perimeter. These bypass streams reduce the film coefficient (and pressure drop) and also the temperature correction over the length of the unit, thus requiring additional heat-transfer surface to correct for these deficiencies.

Furthermore, in a plate exchanger the geometric similarity of the flow channels between the plates and equal access to both sides of the plates eliminates the tubular exchanger dilemma of determining which fluid should be the shell side fluid and which the tube side fluid to allow the unit to be cleaned.

### Materials of construction

To provide corrosion resistance to a wide range of process and service streams, plates are available in such materials as stainless steel, titanium, nickel, and nickel alloys (such as Hastelloys, Incoloy, Inconel, and Monel).

**Table 1. The choice of gasket material depends on the temperature of the application and the fluids being handled.**

	Approximate Maximum Operating Material Temperature	Applications
Nitrile	275°F	General aqueous service, fatty materials, and aliphatic hydrocarbons.
Ethylene-propylene diene monomer	350°F	High-temperature resistance for a wide range of chemicals.
Resin-cured butyl rubber	300°F	Aldehydes, ketones, and some esters.
Fluorocarbon rubber base	350°F	Mineral oils, fuels, vegetable and animal oils.

Gaskets can be of various materials, depending on the temperature and corrosivity of the fluids being handled. Table 1 lists some of the most common gasket materials and their applications.

For welded-plate-pair units, the number of gaskets is reduced by half. This limits gasket exposure to aggressive chemicals and high temperatures and, where necessary, allows the cost-effective use of elastomers having better chemical resistance.

### Advantages of plate exchangers

The gasketed plate exchanger offers six key advantages:

**High heat transfer.** Film coefficients three to five times higher and the lower thermal resistance of the plates (due to thinner material) combine to provide high heat-transfer rates compared to tubular or spiral-plate designs. In combination with fully countercurrent arrangement of the plates, this allows heat recovery or regeneration of 90–95% in many processes.

**Compactness.** As a direct result of its high heat-transfer capability, the plate heat exchanger may be

installed in one-fourth to one-tenth the floor space required by other types of heat-transfer equipment, often performing at a higher heat load.

**Cleanability.** The efficient use of heat-transfer surface eliminates areas of little or no flow, thus preventing the buildup of dirt or debris. This also allows for effective "cleaning in place" (CIP) to remove chemical film or scaling deposits.

**Accessibility.** The gasketed plate exchanger provides full access to both sides of the heat-transfer surface for inspection, maintenance, and cleaning in cases where the unit has been allowed to foul beyond the capabilities of chemical cleaning. This access is readily accomplished within the installed space of the unit.

**Flexibility.** Many processes are not at their optimum as designed and require equipment changes and modifications after startup to achieve maximum throughput. This fine-tuning is readily achieved with the plate heat exchanger by adding, removing, or rearranging plates as required to meet actual process conditions. Similar adjustments can also be made to accommodate future process

or plant expansions or modifications.

Welded plate exchangers do not enjoy the same degree of accessibility and flexibility as gasketed plate exchangers. Welded plate pair units can only be disassembled and reconfigured in pairs.

**Economy.** The high heat-transfer capability reduces surface area requirements and, thus, the initial cost of the equipment. Additional cost savings carry through as the result of reduced installation space, ease of maintenance, high energy recovery, and reduced service fluid requirements.

### Exchanger sizing

While generic programs for sizing plate-and-frame heat exchangers are available through membership in professional groups involved in heat-transfer research, thermal sizing or rating is usually best done on a case-by-case basis by the manufacturer, who has full knowledge of the parameters for the company's specific plates. To work most effectively with the equipment manufacturer, the user should provide the information outlined in Table 2.

**Table 2. To obtain a sizing and cost estimate from a plate exchanger manufacturer, provide the following information.**

	Hot Fluid	Cold Fluid
Description and chemical composition		
Flow rate (gal/min)		
Inlet temperature (°F)		
Outlet temperature (°F)		
Maximum permissible pressure drop (psi)		
Maximum working pressure (psi)		
Specific gravity		
Specific heat at mean temperature (Btu/lb)		
Thermal conductivity at mean temperature (Btu/h-ft <sup>2</sup> ·°F/ft)		
Mean temperature (°F)		
Viscosity at several temperatures in the operating range (cP @ °F)		
Undissolved solids content (%)		
Nature of solids (i.e., fibrous, powder, size)		
Flow fluctuations, if any		
Preferred materials of construction		
Plates		
Gaskets		
Future expansion requirements		

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## Typical applications

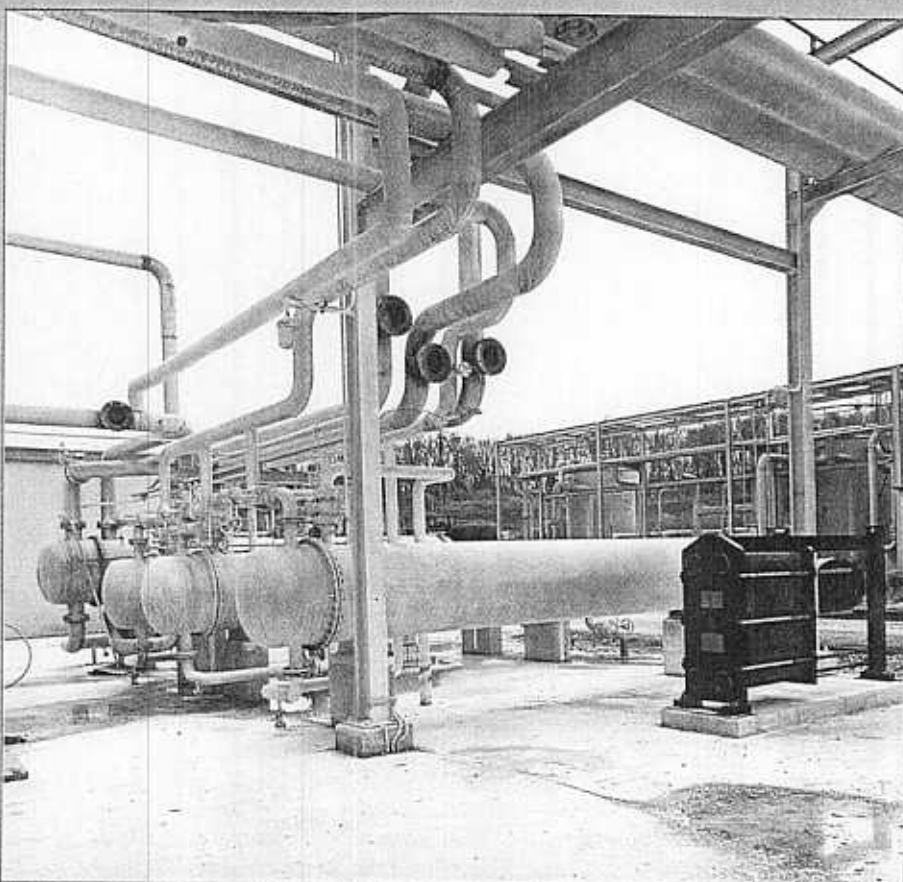
**Heat recovery.** A major Texas utility uses a plate-and-frame exchanger as part of its effluent control system to recover 46 million Btu/h. At \$6/million Btu, this recovered heat represents a return of \$276/h. The initial cost of the unit, \$89,000, was paid back in two weeks.

**Corrosion resistance.** An ammonia-urea fertilizer complex operates a central cooling system and distributes fresh cooling water in a closed circuit throughout the plant. This closed-circuit fresh water is cooled in a plate heat exchanger with seawater. The exchanger plates and seawater connections are made of titanium to resist the corrosive effects of the seawater.

**Water conservation.** Faced with a severe limit on production due to a cooling-water distribution system of fixed capacity, a large soda ash plant replaced its existing tubular exchangers with 16 plate-and-frame exchangers. This reduced water consumption by some 18 million gal/d, which allowed further expansion of overall plant capacity.

**Environmental protection.** Increasing restrictions on plant emissions and demand for higher plant production forced a copper smelter to install a new wet scrubbing system to remove sulfur oxides from the converter off-gas. Since water conservation was also a primary concern, a closed-loop arrangement uses three large plate heat exchangers to cool the weak (1%) sulfuric acid circulating through the scrubber.

**High viscosity.** Consistent quality in urethane foam production is assured with close temperature control of the two reactants, toluene diisocyanate (TDI) and polyester



■ Figure 6. This exchanger with 241 plates cools 1,000 gal/min of deionized water and needs only half the space as a tubular unit for the same duty.

resin. The TDI, with a viscosity similar to water, would present little problem to any heat exchanger. The polyester resins, however, have viscosities up to 30,000 cP at the foaming temperature. These are readily handled by plate-and-frame exchangers.

**Compactness.** As mentioned previously, the plate heat exchanger will be smaller and require far less floor space than a tubular exchanger. At one plant, a plate-and-frame heat exchanger cools 1,000 gal/min of deionized water (Figure 6); the comparable tubular units need twice the amount of space for the identical duty. In addition, full access to the plate pack for inspection and maintenance within the installed length of

the unit was another plus in this installation.

**Flexibility.** As part of the continuing modernization of the U.S. steel industry, one steel manufacturer installed a pair of electric-arc furnaces with closed-circuit cooling water for the furnace and transformer, furnace wall and roof panel, and emission duct. The once-through river water used in these circuits is cooled in plate heat exchangers. After operating experience indicated a need to revise the furnace wall and roof panel system for improved cooling and extended panel life, the resulting increased heat load was readily accommodated by adding heat-transfer surface to the existing plate heat exchanger simply by adding more plates.