GUIDE TO COMPACT HEAT EXCHANGERS

MODULE 2.1

PLATE HEAT EXCHANGER TYPES

This technology module contains a brief introductory description to the exchanger type above, followed by information on construction, construction materials, operating limits and principal applications. Where appropriate, a comparison is made with conventional shell and tube heat exchangers to emphasise size and weight reductions that can be achieved by using compact heat exchangers.

The Module 3 series present further information applicable to all technologies, such as general advantages and limitations of compact exchanger designs, common applications, fouling and how to minimise it, energy efficiency. heat transfer enhancement, exchanger selection, specification and operation, process intensification and software programmes.

Contents

List of Figures

PLATE HEAT EXCHANGER TYPES

2.1.1 Plate and Frame Heat Exchangers

2.1.1.1 Introduction

The plate and frame heat exchanger was one of the first compact exchangers to be used in the UK process industries, being originally introduced in 1923; the first plates were made of gunmetal. It is currently second to the shell and tube heat exchanger in terms of market share.

The most common variant of the plate and frame heat exchanger consists of a number of pressed, corrugated metal plates compressed together into a frame. These plates are provided with gaskets, partly to seal the spaces between adjacent plates and partly to distribute the media between the flow channels. The most common plate material is stainless steel.

Plate and frame heat exchangers were first used in the food and dairy industries, where the ability to access plate surfaces for cleaning is imperative.

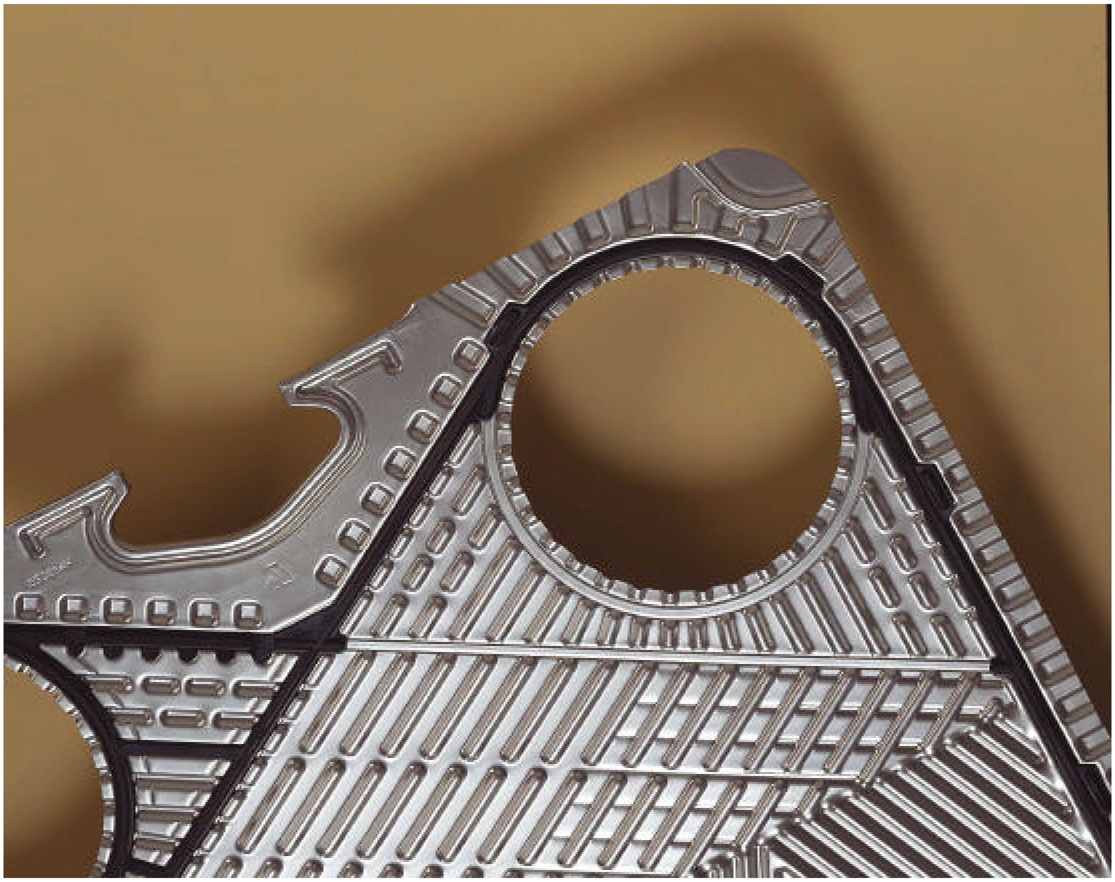

Figure 2.1.1 – Close-up View of a Heat Exchanger Plate
(Courtesy of APV)

There are numerous suppliers of plate and frame heat exchangers. While all manufacturers follow the same basic construction method, the differences in performance claimed tend to be associated with the patterns on the plates that form the flow channels, and the choice of gasket materials. Newer designs can accommodate features such as grossly unequal flow rates on each side of the plate.

2.1.1.2 Construction

Figure 2.1.2 shows an exploded view of a typical plate and frame heat exchanger design.

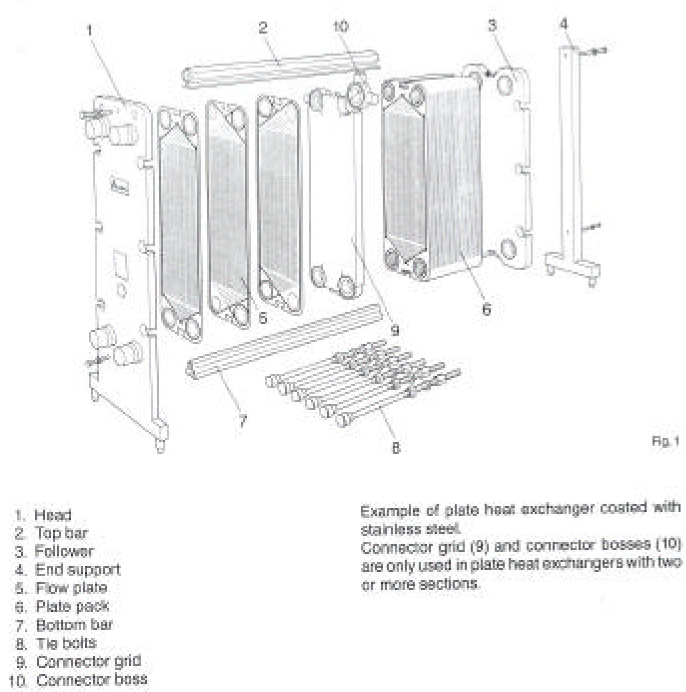

Figure 2.1.2 - Exploded View of a 'Food Style' Plate and Frame Heat Exchanger (Courtesy of APV)

The heat transfer surface consists of a number of thin corrugated plates pressed out of a high grade metal. The pressed pattern on each plate surface induces turbulence and minimises stagnant areas and fouling. Unlike shell and tube heat exchangers, which can be custom-built to meet almost any capacity and operating conditions, the plates for plate and frame heat exchangers are mass-produced using expensive dies and presses. Therefore, all plate and frame heat exchangers are made with what may appear to be a limited range of plate designs.

Although the plate heat exchangers are made from standard parts, each one is custom designed. Variation in the trough angle, flow path or flow gap can alter the N_{TU} of the heat exchanger. The N_{TU}, number of thermal units, is a dimensionless parameter equal to $UA/\dot{M}Cp$. When the trough angle is 90°, the troughs run vertically. The flow passage made of such plates would resemble a collection of vertical tubes with low N_{TU} characteristics.

As the trough angle is reduced from 90^o, the path becomes more tortuous and offers greater hydrodynamic resistance giving rise to high N_{TU} characteristics. A combination of different plates may be used to create an intermediate N_{TU} passage, which can be used to meet a specific N_{TU} requirement.

The plate pack is clamped together in a frame suspended from a carrying bar. Gaskets are fitted to seal the plate channels and interfaces. The frame consists of a fixed frame plate at one end and a moveable pressure plate at the other. The moveable plate facilitates access for cleaning or exchanging the heat transfer surfaces. A feature of this type of heat exchanger is the ability to add or remove surface area as necessary.

The plates are grouped into passes with each fluid being directed evenly between the paralleled passages in each pass. Whenever the thermal duty permits, it is desirable to use single pass, counter flow for an extremely efficient performance. Although plate and frame exchangers can accept more than two streams, this is unusual. Two-pass arrangements are, however, common. Figure 2.1.3 illustrates the flow path in such a unit.

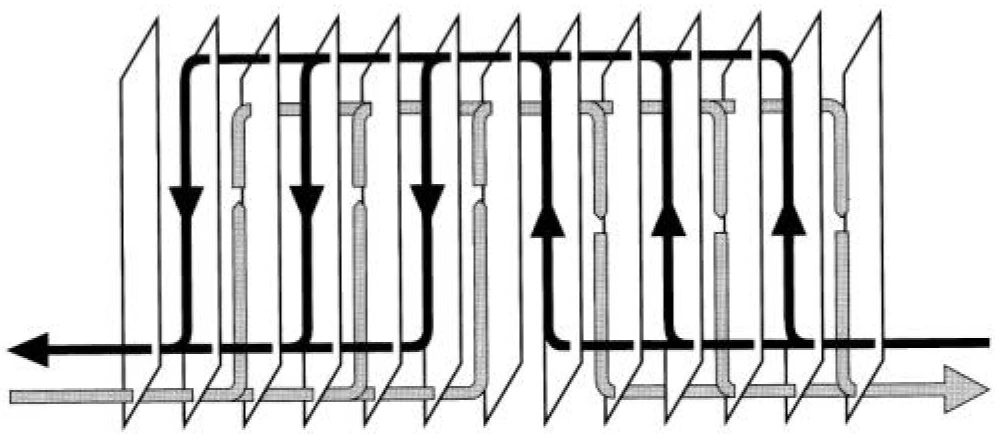

Figure 2.1.3 – A Two-Pass Plate and Frame Flow Arrangement

Plates can be produced from all pressable materials. The most common construction materials are:

- Stainless steel (AISI304, 316).
- Titanium.
- Incoloy.
- Hastelloy.

Where corrosion is a problem, some manufacturers offer plate and frame heat exchangers in non-metallic materials, such as a graphite/fluoroplastic composite or a polymer.

Usually the frame is made of coated mild steel, as it should not, under normal circumstances, come into contact with the process fluids. The surface coatings vary according to the exchanger environment. Frames can be stainless steel or clad with stainless steel as an alternative to mild steel.

Gasket properties have a critical bearing on the capabilities of a plate and frame heat exchanger, in terms of its tolerance to temperature and pressure.

Gaskets are commonly made of:

- Nitrile rubber.
- Hypalon.
- Viton.
- Neoprene.
- EPDM.

Originally, most manufacturers used glue to fix the gaskets to the plates. Several proprietary fixing techniques are available that eliminate the need to use glue, and most manufacturers have adopted these methods. These so-called 'glueless' gaskets are suitable for some heavy-duty industrial applications. The simplified removal and location of such gaskets can be beneficial, as it reduces downtime when on-site changing is necessary.

Care should be taken in locating the gaskets during reassembly, as imperfect sealing is the main disadvantage of the plate and frame heat exchanger.

Double-wall units are another variant catering for specific process situations. Here two special non-welded plates, fitted with a non-glued gasket to seal and hold the plates together, replace the single plate normally separating the two media. Consequently, two walls separate the product and service medium giving additional protection against cross contamination and the occurrence of a hostile reaction. The partially welded plate unit (see Section 2.1.2) is designed for handling aggressive media.

2.1.1.3 Operating Limits

The operating limits of gasketed plate and frame heat exchangers vary slightly from manufacturer to manufacturer. Typically, the operating temperature range of the metal plates is from -35^{o}C to +200^{o}C. Design pressures up to 25 bar can be tolerated, with test pressures to 40 bar.

Heat transfer areas range from 0.02 m^2 to 4.45 m^2 (per plate). Flow rates of up to 3,500 m^3/hour can be accommodated in standard units, rising to 5,000 m^3/hour with a double port entry. Approach temperatures as low as 1^{o}C are feasible with plate and frame heat exchangers.

The surface pattern on the plates tends to induce good mixing and turbulence, and in general this type of heat exchanger has a low propensity for fouling. Fouling resistances of typically 25% of those for shell and tube heat exchangers have been measured by the Heat Transfer Research Incorporated (HTRI) in the USA.

Where fouling is a concern, the gap between the plates can be widened. For example, one manufacturer offers plates with a 13 mm gap and coarse contours for viscous liquids and fluids containing fibres, solids, crystals, pulp, etc.

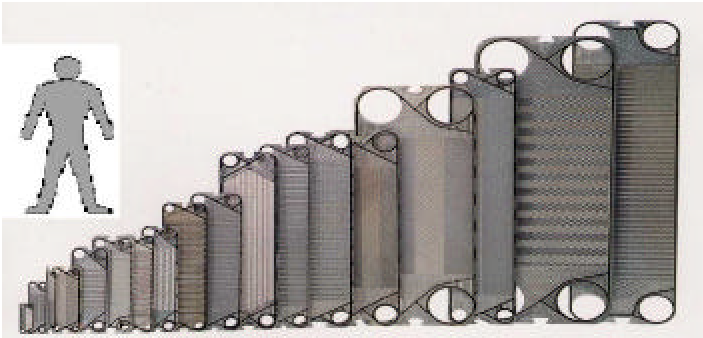

Figure 2.1.4 – Plate Heat Exchanger Plates
(Courtesy of APV)

2.1.1.4 Principal Applications

Gasketed plate and frame heat exchangers have a large range of applications typically classified in terms of the nature of the streams to be heated/cooled as follows:

- Liquid-liquid.
- Condensing duties.
- Evaporating duties.

Gasketed units may be used in refrigeration and heat pump plants (see also Section 2.1.3) and are extensively used in the processing of food and drinks, where the ease of plate cleaning and re-gasketting are important. In the chemicals sector, a substantial list of heating and cooling applications includes cooling isoparaffin, sulphuric acid, salt solutions, hexane and kerosene. Heating glycerine and condensing ethanol are other routine uses. The offshore chemical industry is also a large user in the UK.

There are potential applications for plate heat exchangers on most chemical plants. A typical process installation is shown in Figure 2.1.5.

Figure 2.1.5 – Process Application of a Plate and Frame Heat Exchanger (Courtesy of APV)

2.1.1.5 Comparison with Shell and Tube Heat Exchanger

Figure 2.1.6 shows the comparative sizes of a shell and tube heat exchanger and a gasketed plate and frame unit of comparable duty. In quantitative terms, 200 m^2 of heat transfer surface requires a plate and frame heat exchanger approximately 3 metres long, 2 metres high and 1 metre wide. For a tubular heat exchanger achieving the same effect, some 600 m^2 of surface would be required in a shell 5 metres long and 1.8 metre in diameter, plus the extra length needed for tube bundle removal.

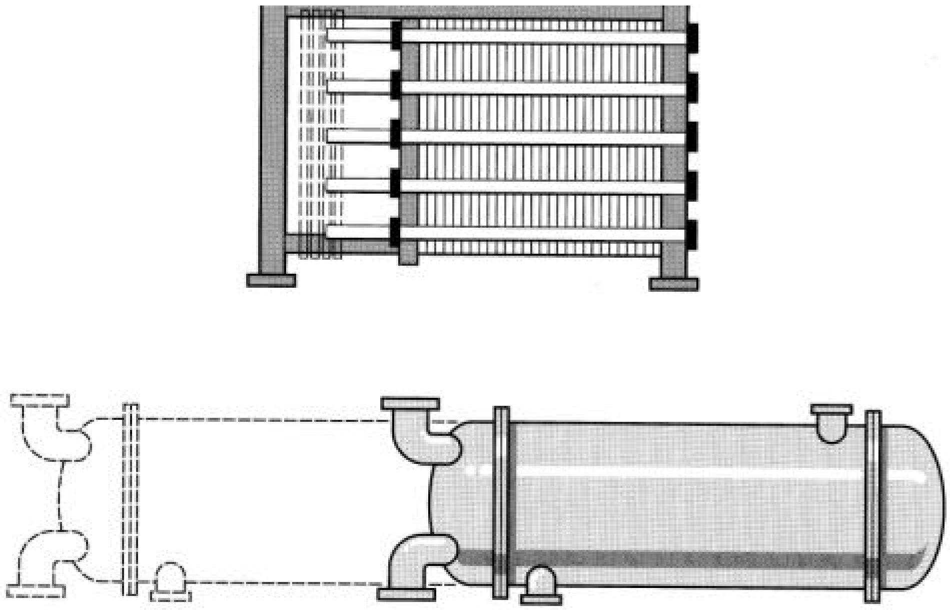

Figure 2.1.6 – Comparison of Shell and Tube and Gasketed Plate and Frame Heat Exchanger Sizes showing Maintenance Space Requirement

For liquid-liquid duties, surface area requirements are typically 25% of those of equivalent shell and tube units. Pressure drops for these duties are, on average, lower.

With regard to weight, the plate and frame unit shown in Figure 2.1.6 has an empty weight of 3.3 tonnes, that increases to 4 tonnes when filled with water. Comparable figures for the shell and tube heat exchanger are 6 tonnes and 11 tonnes respectively.

2.1.2 Partially Welded Plate Heat Exchangers

2.1.2.1 Introduction

Externally, partially welded plate heat exchangers or twin plate heat exchangers resemble a fully-gasketed plate and frame unit. However, the difference is the plate pack has alternating welded channels and gasketed channels as in the arrangement illustrated in Figure 2.1.7.

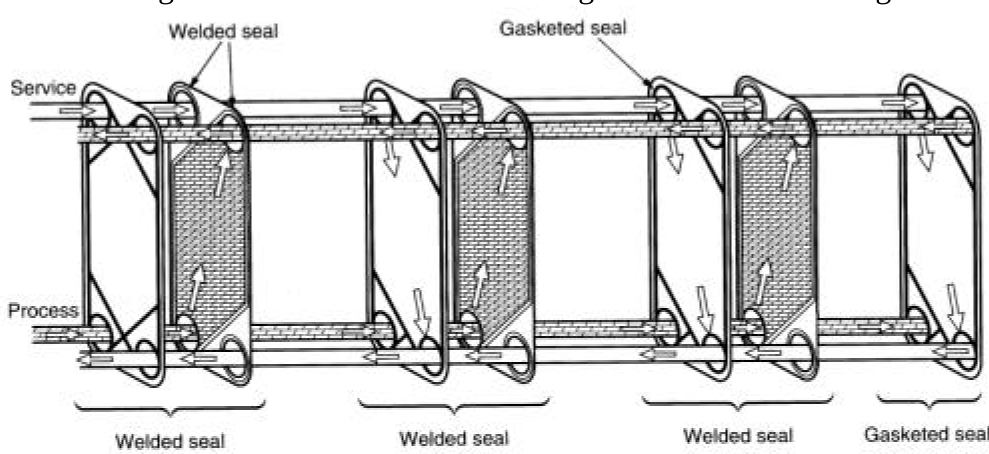

Figure 2.1.7 – Flow Diagram of the LR4 APV Baker Laser-Welded Plate Heat Exchanger (Courtesy of APV)

The advantage of welding the plate pairs is that, except for a small gasket around the ports, other materials are eliminated and corrosion is slightly reduced.

2.1.2.2 Construction

The overall construction is similar to that of the gasketed plate and frame heat exchanger (described in Section 2.1.1), with one important exception: each plate pair is welded together, normally using laser welding. Porthole gaskets fabricated from highly resistant elastomer or non-elastomer materials, are attached using a glueless method.

Plate construction materials are as for the gasketed plate and frame heat exchanger. The plate material is normally selected for its resistance to corrosion.

2.1.2.3 Operating Limits

As for the gasketed plate and frame type, but with the added protection from leaks afforded by the partially welded construction.

2.1.2.4 Principal Applications

As for gasketed plate and frame heat exchanger, but extended to include more aggressive media.

Partially welded plate heat exchangers are used for the evaporation and condensation of refrigerants such as ammonia and hydrochlorofluorocarbons (HCFCs), and for chemical and general process duties involving aggressive liquids.

2.1.2.5 Comparison with Shell and Tube Heat Exchanger

As for gasketed plate and frame units.

2.1.3 Brazed Plate Heat Exchangers

2.1.3.1 Introduction

The brazed plate heat exchanger (see Figure 2.1.8) consists of a pack of pressed plates brazed together, thus completely eliminating the use of gaskets. The frame can also be omitted.

Brazed plate heat exchangers tend to be offered by the principal suppliers of the plate and frame type and tend to be directed at niche markets such as refrigeration. These exchangers have heat transfer capabilities up to 600 kW, depending on the supplier.

The corrugated plates induce a highly turbulent flow such that the scouring action of the turbulence reduces surface deposits in the heat exchanger.

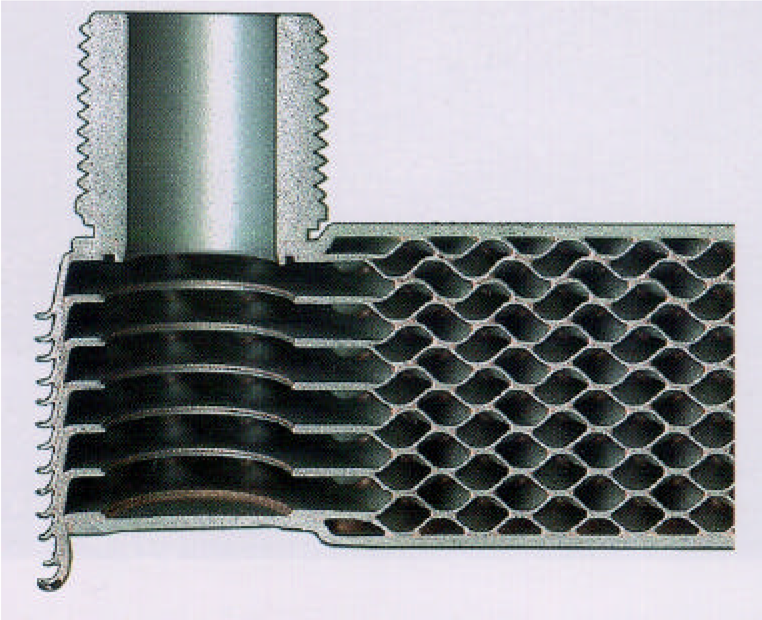

Figure 2.1.8 – Section Through a Brazed Plate Heat Exchanger
(Courtesy of Alfa Laval Thermal Division)

2.1.3.2 Construction

Brazed plate heat exchangers consist of a number of pressed stainless steel plates joined together by brazing. Typically a very high content copper braze is used, and the brazing process is carried out under vacuum. Capillary forces collect the brazing material at the contact points between the plates.

As well as sealing around the periphery of the plates, the internal herringbone contact points are also brazed, permitting higher pressures to be tolerated than in gasketed units.

Stainless steel is usually used as the plate material.

2.1.3.3 Operating Limitations

Copper brazed units are available for temperatures up to 225°C and a maximum operating pressure of 30 bar, but copper braze may produce an incompatibility with some working media. Nickel brazed units are available for temperatures up to 400°C and maximum operating pressures of 16 bar.

2.1.3.4 Principal Applications

The brazed plate unit is aimed at the refrigeration/heat pump market for evaporators and condensers (water-cooled), but it is also suitable for process water heating, heat recovery and district heating systems. Brazed plate heat exchangers can also be used as desuperheaters, subcoolers, economisers and oil coolers.

The introduction of nickel brazed units has allowed brazed units to be used within the process industries, for duties such as de-mineralised water cooling and solvent condensing.

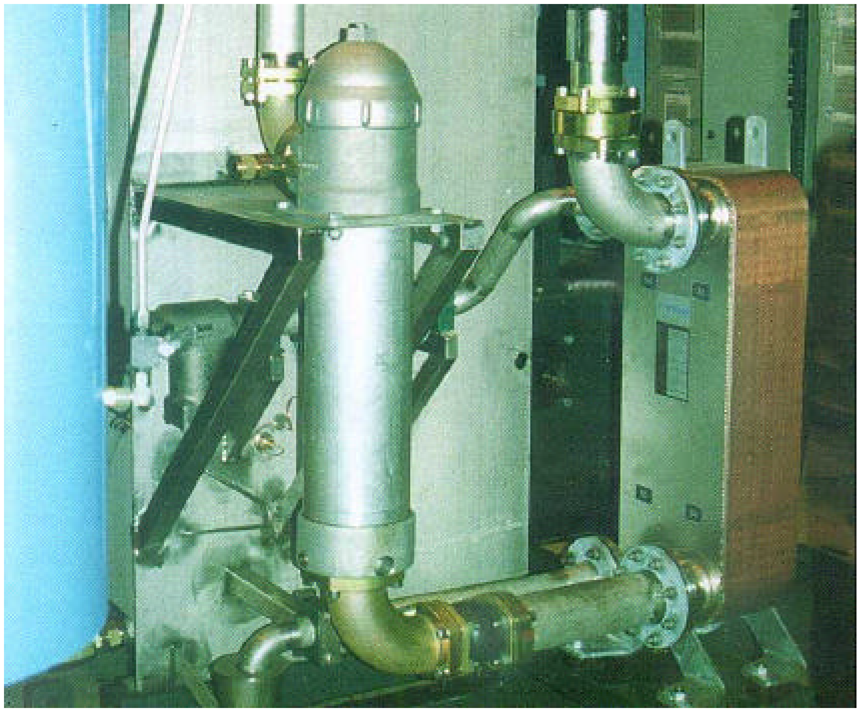

Figure 2.1.9 – A Brazed Plate Heat Exchanger Used as an Oil Cooler
(Courtesy of Alfa Laval Thermal Division)

2.1.3.5 Comparison with Shell and Tube Heat Exchanger

Typically, a brazed plate heat exchanger is about 20-30% of the weight of a shell and tube heat exchanger for the same duty.

For example, a brazed plate heat exchanger, used as a water-cooled refrigerant condenser with a duty of 70 kW, had a weight of 20 kg. Its height and width were 522 mm and 115 mm respectively. A conventional shell and tube condenser of the same duty would be 2,250 mm long, have a diameter of 200 mm, and weigh 130 kg.

2.1.4 The Bavex Hybrid Welded Plate Heat Exchanger

2.1.4.1 Introduction

The Bavex hybrid welded heat exchanger, made in the UK under licence from Bavaria Anlagenbau GmbH, is one of several welded plate units that have found a niche market as an alternative to a shell and tube heat exchanger, particularly where process conditions rule out the plate and frame configuration. The high-pressure capability and wide operating temperature range of the Bavex unit are particularly significant in this respect.

A unique feature of the Bavex design is its internal geometry. As explained below, both 'tube side' and 'plate side' flow paths can be identified.

2.1.4.2 Construction

The construction of a typical Bavex heat exchanger is illustrated in Figure 2.1.10.

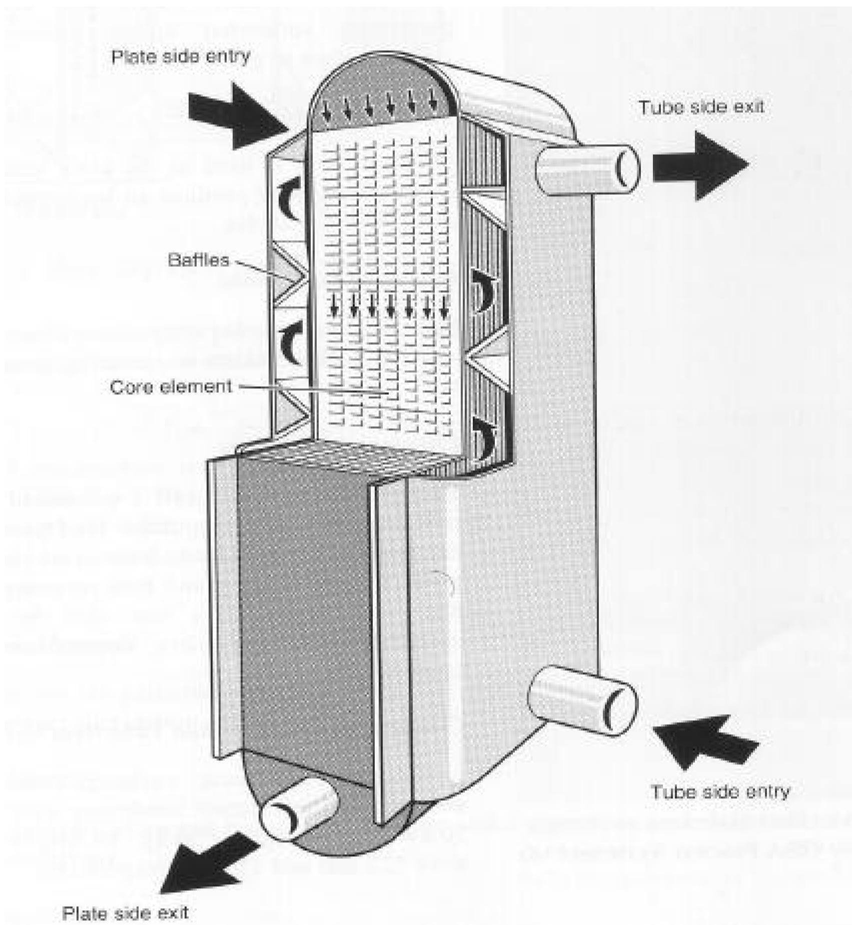

Figure 2.1.10 – Construction of a Bavex Welded Plate Heat Exchanger

The unit in Figure 2.1.10 employs multiple passes on the tube side and a single pass plate configuration. The core assembly is shown in Figure 2.1.11.

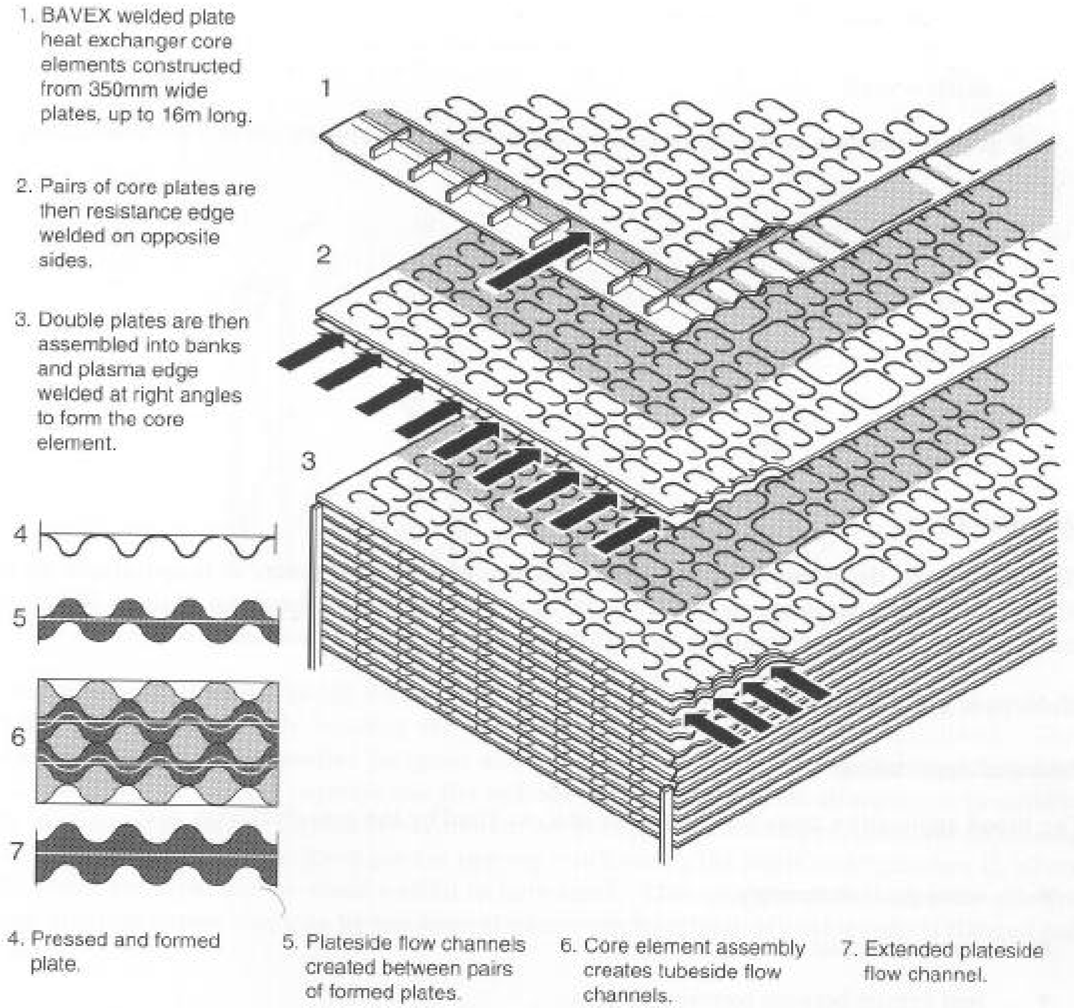

Figure 2.1.11 - Core Structure of a Bavex unit

The plates, 350 mm wide and up to 16 metres long, are resistance edge welded in pairs. The double plates are then assembled into banks and plasma edge welded at right angles to form the core element. The tube is 350 mm long, with up to 8,000 tubes per metre of cross-sectional area being accommodated. Cross-stamping occurs at 37 mm intervals; this induces turbulence in the tubes, while lending strength to the plates.

Plate thickness ranges from 0.2 to 1 mm, while the effective tube diameter ranges from 6.0 to 11.1 mm, depending upon the degree of pressing. The spacing of the plates on the 'plate' side can be varied as a function of the anticipated cleaning requirements.

The vessel containing the core may be of welded or flanged construction, the choice being partly based on the anticipated cleaning requirements.

The heat exchanger core can be made of a wide range of metals, provided that they can be welded and cold-formed (for pressing the plates).

Plate materials include:

- Stainless steel.
- High temperature steels.
- Copper and alloys.
- Nickel and alloys.
- Hastelloy.
- Titanium.
- Incoloy.
- Inconel.

2.1.4.3 Operating Limits

Depending upon the plate metal used, the Bavex heat exchanger can operate at temperatures up to 900°C. Cryogenic applications down to -200°C are also feasible. Pressures of up to 60 bar on the plate side can be tolerated, depending upon the plate thickness and surface form.

Multi-pass designs are feasible.

2.1.4.4 Principal Applications

The broad application areas for the Bavex unit are:

- Waste gas heat recovery.
- Cryogenic applications.
- Heat transfer between corrosive streams.
- Seawater applications.

Typical duties include recuperation (gas-gas) on incineration plant, distillation column condensers and liquid-liquid duties in chemicals and food processing.

2.1.4.5 Comparison with Shell and Tube Heat Exchanger

The Bavex unit is claimed to have typically 40% of the volume of an equivalent shell and tube heat exchanger. Heat transfer coefficients in liquid-liquid duties are about 5,000 W/m^2K.

2.1.5 The Platular Welded Plate Heat Exchanger

2.1.5.1 Introduction

The Platular heat exchanger, manufactured by Barriquand in France, is a welded plate type where standard plate thicknesses are used for the heat transfer surfaces. This gives the strength and integrity of a shell and tube design combined with the heat transfer coefficients of a plate. The plates are welded so no gaskets are necessary.

There are two variants of the design. The basic X type Platular eliminates a shell, while retaining headers and nozzles, by welding the plate elements longitudinally. This overcomes the need to incorporate devices to cope with the differential expansion between the shell and the core. Access is available for inspection and cleaning of the heat transfer surfaces.

In the S type Platular heat exchanger, cores are normally enclosed in a welded plate containment vessel - the 'shell'. Typically, there is no access to the plate pack although a recent innovation is to flange the plate pack to the shell so it is removable. Where both fluids are clean and it is not necessary to inspect the heat transfer surfaces, the plate pack in a shell is more cost competitive.

2.1.5.2 Construction

Three parameters govern the various construction options for the Platular heat exchanger. These are the form of the channels, the fluid flow configuration and whether a shell is used.

A shell design is used when all the fluids are clean. If one or more dirty fluids are anticipated the all-welded construction is used, including appropriate end covers enabling access for mechanical cleaning.

The channels used in the Platular unit can have several configurations, as shown in Figure 2.1.12.

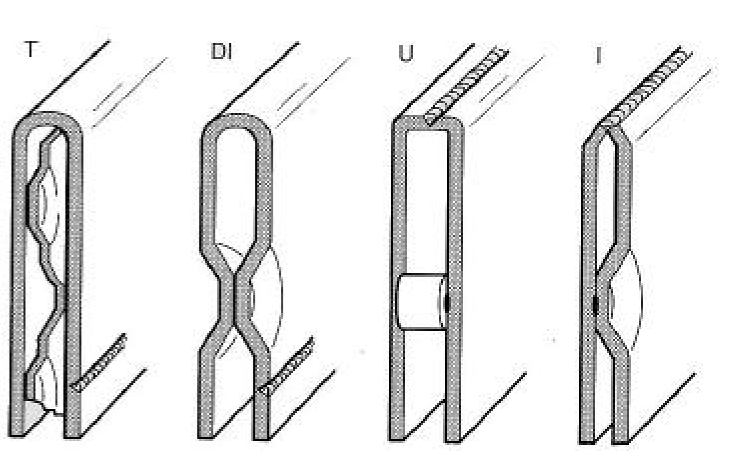

Figure 2.1.12 – Channel Configurations used in the Platular Heat Exchanger (Courtesy of Barriquand Echangeurs)

The four channels shown in Figure 2.1.12 have what are known as 'contact points'. Type T is made by folding and longitudinally welding the plate, through which is inserted a turbulator. This channel design is recommended for gases and viscous fluids.

The rectangular-shaped channel I is made by spot welding together one flat and one stamped plate. This arrangement is suitable for high-pressure duties.

Channel DI is similar, but both plates are stamped, therefore increasing the spacing between them. Even greater spacing is offered by the use of configuration U, where the plates are separated by studs welded to both sides. This configuration is also suitable for high-pressure duties as cleaning by mechanical means can be effectively achieved via flanged end covers.

Where highly contaminated fluids, such as one carrying fibrous material, need to be handled, the manufacturers recommend a channel formed without contact points (see Figure 2.1.13). The spacing of this channel is independent of that employed on other circuits.

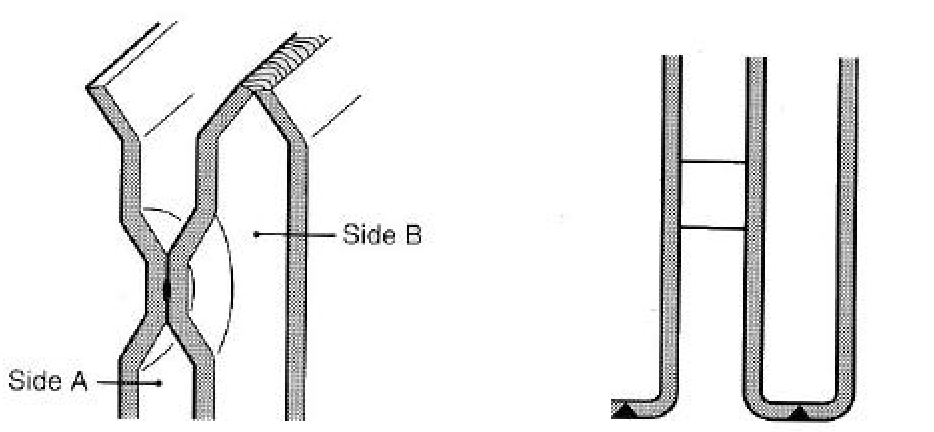

Figure 2.1.13 – Two Typical Channel Pairs
(Courtesy of Barriquand Echangeurs)

The Platular welded plate heat exchanger is available in:

- Most stainless steels.
- Hastelloy.
- Duplex.
- A variety of nickel-based alloys
- Titanium.

2.1.5.3 Operating Limits

Platular heat exchangers are suitable for use at temperatures between –180 and 700°C and at pressures from full vacuum to 40 bar.

Multi-stream units up to a maximum of four streams can be constructed, and a mix of counter-current, co-current and cross-flow configurations can be accommodated. A multi-stream gas-gas unit is illustrated in Figure 2.1.14. Multiple passes can be incorporated at the design stage. Platular heat exchangers can be designed for two or more duties in the same unit, such as combining primary and secondary condensations.

Figure 2.1.14 – A Typical X Type Platular Exchanger Showing Access Doors to the Heat Transfer Surfaces (Courtesy of Barriquand Echangeurs)

A range of units up to those suitable for multi-MW duties is available. The amount of heat transfer surface in a single unit can be up to 1,500 m^2.

Construction can conform to standards such as BS, CODAP, STOOMWEZEN, TUV and ASME, depending on the user's specification.

2.1.5.4 Principal Applications

Generic heat exchange duties for Platular units are:

- Gas-gas.
- Gas-liquid.
- Liquid-liquid.
- Condensers.
- Evaporators.

Platular welded plate heat exchangers are used in the chemical, food and drink, paper, cement, and refrigeration industries.

A typical duty would be heat recovery on a cold box employing a multi-pass, multi-stream configuration. In one such unit at a Rhone-Poulenc plant in France, 336 m^2 of surface was used to simultaneously heat three gas streams - hydrogen, carbon monoxide and methane from 2°C to 32.2°C using gas at 34°C, which was cooled to 6.5°C. Mass flow of gas on the hot side was 6,666 kg/hour and close approach temperatures were achieved.

2.1.5.5 Comparison with Shell and Tube Heat Exchanger

Based on the manufacturer's data, the overall 'U' values are 2 to 4 times those achievable in conventional shell and tube units, resulting in typical volume reductions of 75 - 90%. Therefore, equivalent plant space required is very much less and no additional space is required for tube bundle removal.

Turbulent flow conditions reduce fouling and full counter-current operation can achieve close temperature differences.

2.1.6 The Compabloc Welded Plate Heat Exchanger

2.1.6.1 Introduction

Another version of the welded plate heat exchanger is the Compabloc unit manufactured by Alfa Laval Thermal.

Compabloc heat exchangers are targeted on typical shell and tube, spiral, and plate and frame heat exchanger applications and also applications with gasket compatibility problems. The absence of gaskets enables it to handle high temperature fluids and operate in chemically aggressive environments. Also, the totally bolted design of Compabloc allows quick disassembly of the frame to access the plate-pack for cleaning, maintenance, repair or replacement.

2.1.6.2 Construction

In the Compabloc single-pass design, sets of pressed plates are automatically welded together to give a cross-flow configuration. A multi-pass unit is globally counter-current. The number of plate sets is determined by the required size of the pack. Column liners (see Figure 2.1.15) are then welded on at all four corners and the plate pack is completed by welding top and bottom plate liners. Typically, the gap between the plates is 5 mm.

Four machined columns (see Figure 2.1.15) are welded to the bottom machined head, and the plate pack is slid over the columns. The top plate is then located and welded to each column. Adjustable baffles are installed as required for the desired even number of passes, the baffles also being of the same material as the pack.

The final stage of assembly involves bolting on connections for cover plates, with or without alloy liners, into the columns and heads of the panels.

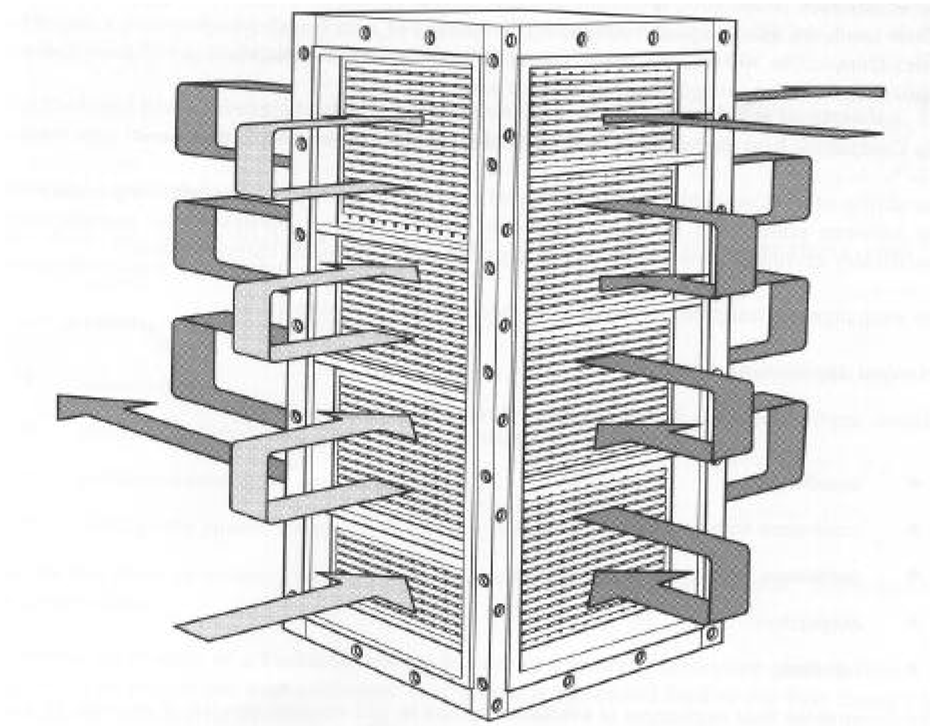

Figure 2.1.15 – Construction of the Compabloc Heat Exchanger
(Courtesy of Alfa Laval Thermal Division)

The Compabloc design is available in the following materials:

- Stainless-steel 3l6L.
- Titanium and titanium plus 0.2% palladium.
- Hastelloy C-276, C-22, B and C.
- Avesta 254 SMO.
- UranusB-6.
- Incoloy 825.
- Monel.
- Tantalum.

Baffle assemblies and panel liners are available in the same material as the plates. Connections are available in steel or alloy materials.

2.1.6.3 Operating Limits.

The Compabloc exchanger is designed to operate at temperatures up to 300°C and working pressures up to 32 bar (with the flanged construction). The amount of heat transfer surface in a Compabloc exchanger varies from 1.5 to 300 m^2, the latter having 500 plates. Approximately 1 m^2 of floor space is required for a unit having 300 m^2 of surface area.

Compabloc heat exchangers are normally designed to handle two fluid streams. In single-pass with cross-flow the Compabloc is capable of handling low N_{TU} duties. N_{TU}, the number of transfer units, is:

$$N_{TU} = \frac{UA}{\left(\dot{M}C_p\right)_{smaller}}$$

In multi-pass with global counter-current flow, temperature-cross is easily achieved.

The ability of the Compabloc design to handle fouled streams is improved by the relatively wide 5 mm gap between plates, and the access through flanged covers. However, the manufacturers specifically exclude its use with heavy sludges or process streams carrying fibres.

Figure 2.1.16 – Compabloc Heat Exchanger (Courtesy of Alfa Laval Thermal Division)

2.1.6.4 Principal Applications

Generic application areas include liquid and two-phase duties such as:

- Liquid-liquid.
- Condensers with or without subcooling.
- Condensers with or without inserts.
- Evaporators.
- Reboilers.

The Compabloc heat exchanger is available for use in full vacuum service; it can also be used with refrigerants.

2.1.7 The Packinox Welded Plate Heat Exchanger

2.1.7.1 Introduction

Packinox is a fully owned subsidiary of Framatome who design, develop and fabricate large, heavy duty welded plate heat exchangers for new units and de-bottlenecking refurbishments in the refining, gas processing and petrochemicals industries.

2.1.7.2 Construction

The Packinox design is based on corrugated stainless steel sheets that are explosion formed underwater. Plates are welded together to form the plate bundle, which is inserted into a pressure vessel.

Depending on the application, Packinox heat exchangers may not require a shell; in this case, the bundle may be inserted directly into a column or placed between heavily bolted panels, as in gasketed plate and frame heat exchangers.

When a shell is fitted, bellows are required to compensate for the differential expansion between the vessel and plate bundle. The bellows are located inside the shell, between the bundle and the pipes connected to the nozzles as shown in Figure 2.1.17. The flow paths are counter-flow.

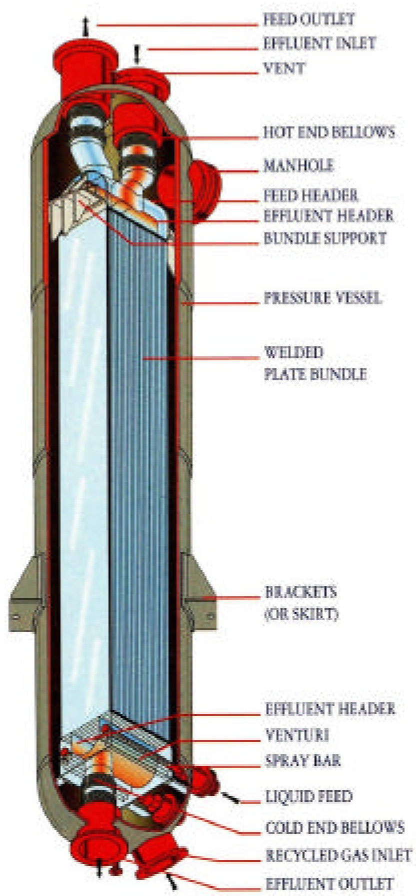

Figure 2.1.17 – Packinox Compact Heat Exchanger (Courtesy of Packinox)

Fabrication materials include:

- All types of austenitic stainless steel.
- Titanium.
- Highly corrosion resistant 6 Mo austenitic stainless steel.

2.1.7.3 Operating Limits

Operating ranges are a function of the plate and shell materials used, but the Packinox can operate at temperatures between -200°C and +700°C. Plate flexibility make these heat exchangers able to withstand large temperature differences between feed and effluent.

Fluid pressure can be extremely high; the only limits on design pressure being the same as those of the containment vessel. Absolute pressures of up to 300 bar can be tolerated normally in the shell.

Substantial differential pressure resistance can be reached due to the multitude of corregation-to-corregation contact points between plates. Differential pressures of up to 60 bar are readily accommodated, with a possible extension to 100 bar.

Packinox heat exchangers normally handle two fluid streams, but can also be multi-fluid.

Homogeneous flow distribution and 100% liquid feed entrainment is ensured for two-phase fluids, even at low operating pressures, either through spray bars or through a patented two-phase fluid distributor, depending on the gas-to-liquid ratio.

The surface area of a single Packinox unit can be as high as 16,000 m^2.

2.1.7.4 Principal Applications

Packinox is the industry standard in catalytic reforming units, and is used in such applications as paraxylene, hydrotreating and isomerization. Packinox heat exchangers operate in a wide variety of chemical processes including linear alkyl benzene, styrene and methanol.

Other applications include combined feed heat exchangers, temperature controlled reactors, multi-fluid exchangers/liquid-vapour separators for gas dew point control and condensate recovery, in-column reflux condensers and stab-in reboilers.

A typical application of a Packinox heat exchanger in a catalytic reforming plant is shown in Figure 2.1.18. The role of the heat exchanger is to pre-heat the mixed feed to the first furnace by cooling the final reactor effluent.

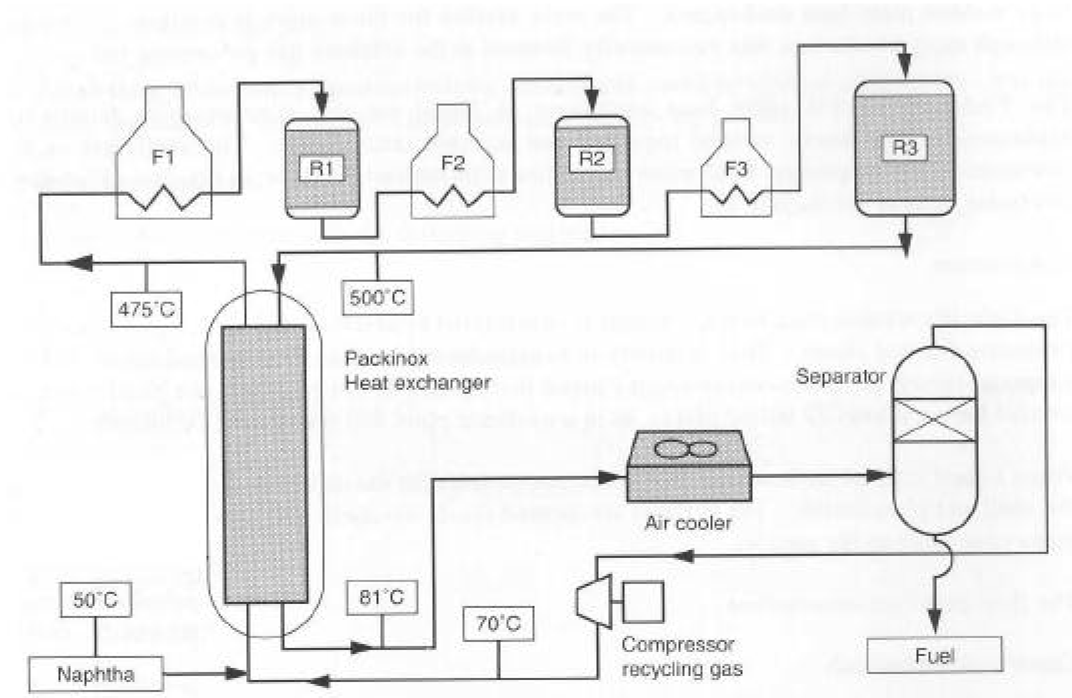

Figure 2.1.18 – A Packinox Plate Heat Exchanger in a Catalytic Reforming Plant (Courtesy of Packinox)

2.1.7.5 Comparison with Shell and Tube Heat Exchanger

For example, in a gas cooling loop handling 1.5 million m^3/day of gas at 39 bar and with the heat exchanger train located downstream of the gas dehydration unit, a shell and tube heat exchanger train would cool the gas to -24°C with a duty of 84 MW. The cold approach would be 14°C and the LMTD 7.4°C.

A shell and tube heat exchanger train would involve eight shells with a total weight of 1,300 tonnes. A Packinox exchanger for the same conditions would require two shells with a total weight of 260 tonnes. The saving on 'footprint' would be 200 m^2.

Another example of how much a welded plate heat exchanger is lighter in weight and more compact than tubular designs for the same duty, as well as offering improved thermal and hydraulic efficiency, is shown in Figure 2.1.19.

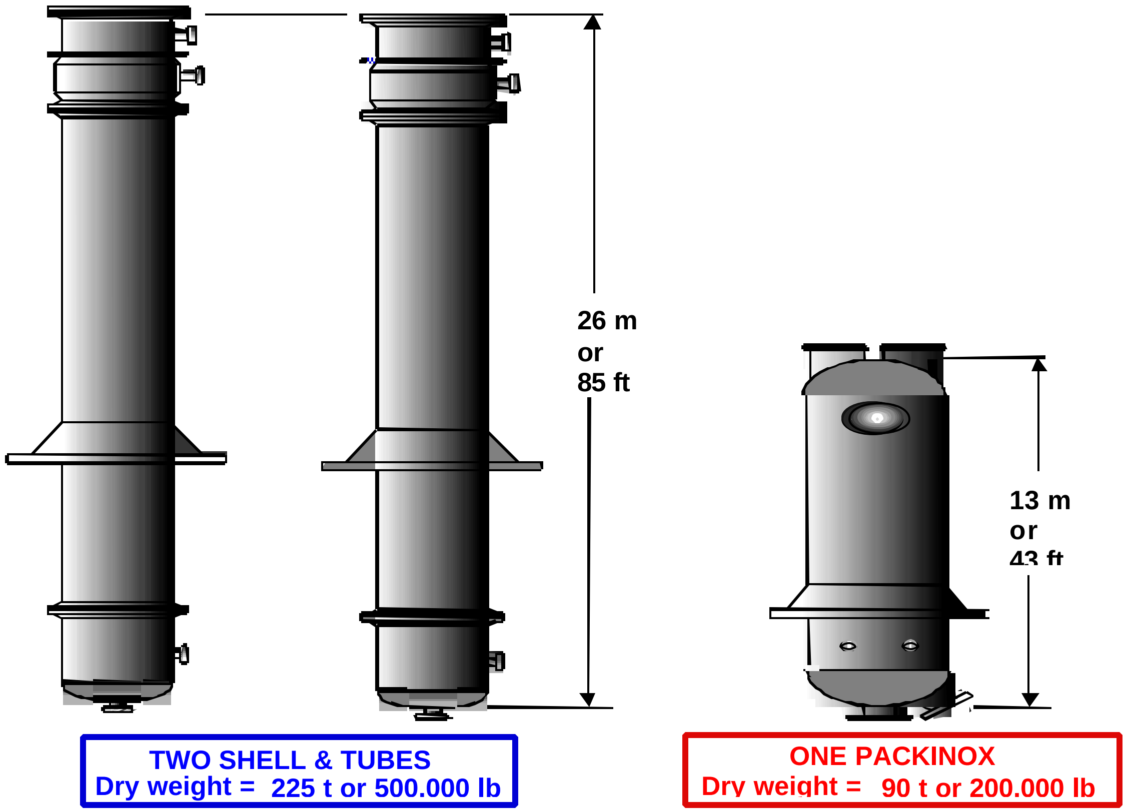

Figure 2.1.19 – Size and Weight Comparison for the Same Duty
(Courtesy of Packinox)

2.1.8 The AlfaRex Welded Plate Heat Exchanger

2.1.8.1 Introduction

The AlfaRex heat exchanger was the first full-size, gasket-free heat exchanger. The herringbone plate design creates channels with high fluid turbulence that increases thermal efficiency and minimises the risk of fouling.

Media flow is counter-current which is optimal for heat transfer, particularly in heat recovery duties. Per unit of surface area, counter current flow achieves 20% higher heat transfer values than cross flow.

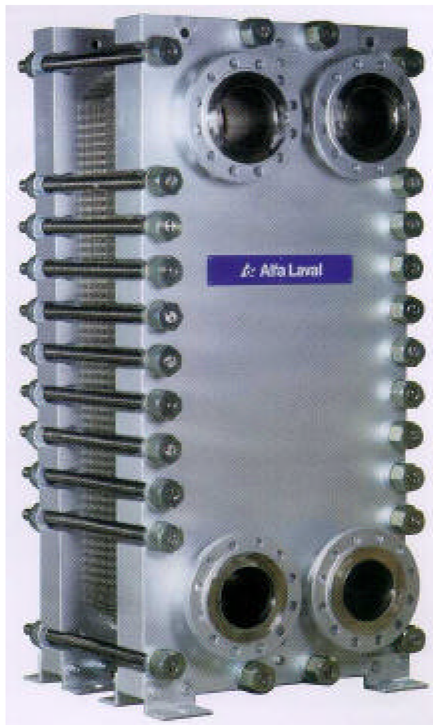

Figure 2.1.20 – AlfaRex Heat Exchanger
(Courtesy of Alfa Laval Thermal Division)

2.1.8.2 Construction

Plates with the traditional herringbone pattern are laser-welded together to form a plate pack in which both media are in full counter-current flow.

Plate materials include:

- AISI 316.
- SMO.
- Titanium.
- Palladium-stabilised Titanium.
- Hastelloy C276.
- Nickel.

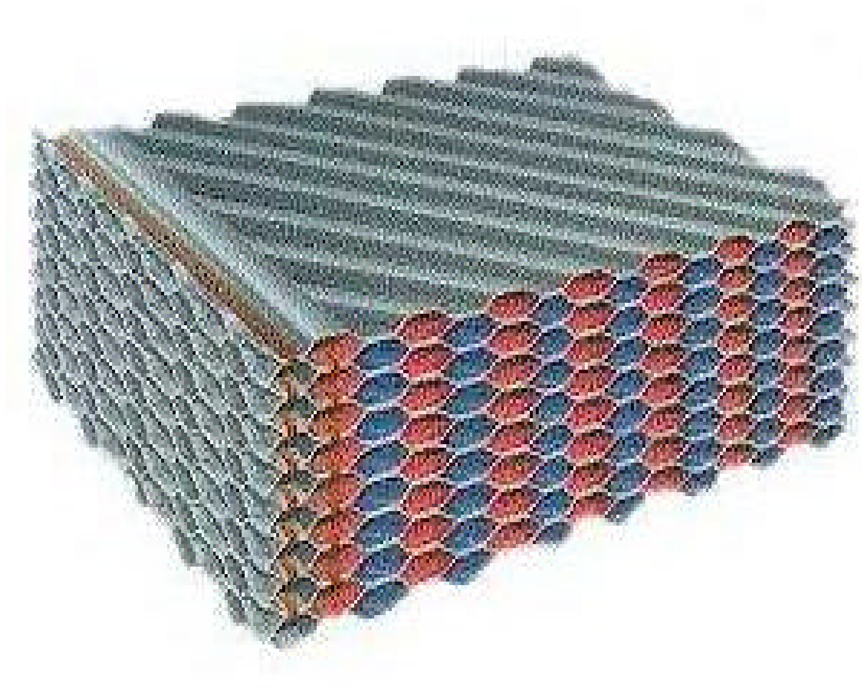

Figure 2.1.21 – Cross-section through AlfaRex Welded Plate Pack
(Courtesy of Alfa Laval Thermal Division)

2.1.8.3 Operating Limits

The AlfaRex design operating temperature range is -50°C to +350°C at pressures up to 40 bar. The exchanger is capable of handling flowrates up to 800 m^3/hour.

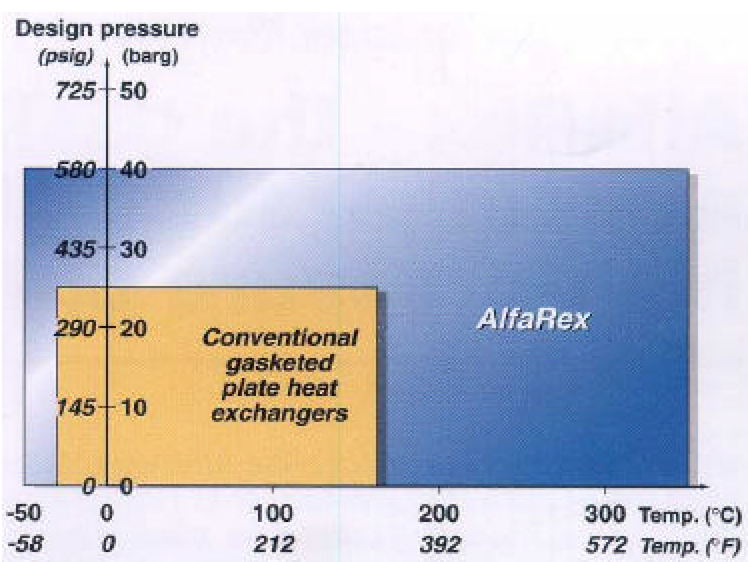

Figure 2.1.22 - Operating Ranges for the AlfaRex and Conventional Gasketed Plate Exchangers (Courtesy of Alfa Laval Thermal Division)

2.1.8.4 Principal Applications

Typical duties for the AlfaRex heat exchanger are:

- Offshore Platforms
  - Cooling of hydrocarbon gas, condensate and crude oil.
  - Heating of condensate and crude oil.
  - TEG interchanging.
- Caustic Soda Production
  - Heating and cooling duties in the evaporation of sodium hydroxide.
- Petrochemical Industries
  - Production of various chemicals, such as caprolactum, ethylene oxide and polyols.
  - Solvent recovery.
  - Reactor temperature control and batch heating.
  - Steam applications.
- Vegetable Oil Refining
  - Interchanging, heating and cooling of high temperature oil in deodorisation and hydrogenation.
- Refrigeration
  - Evaporation and condensing of ammonia or carbon dioxide in heat pump and adsorption systems.
- Power Plants
  - Pre-heating of feedwater.
- District Heating.

2.1.8.5 Comparison with Shell and Tube Heat Exchanger

The AlfaRex heat exchanger uses less than 20% of the floor-space and is only 20% of the weight of the shell and tube heat exchanger for the same duty. Due to the optimal counter-current flow design, the AlfaRex can perform the same heat duty with a reduced transfer area and therefore at less cost.

Also, the reduced hold-up volume allows more accurate process control and improves operational safety when handling hazardous media.

GUIDE TO COMPACT HEAT EXCHANGERS

MODULE 2.2

PLATE-FIN HEAT EXCHANGERS

This technology module contains a brief introductory description to the exchanger type above, followed by information on construction, construction materials, operating limits and principal applications. Where appropriate, a comparison is made with conventional shell and tube heat exchangers to emphasise size and weight reductions that can be achieved by using compact heat exchangers.

The Module 3 series present further information applicable to all technologies, such as general advantages and limitations of compact exchanger designs, common applications, fouling and how to minimise it, energy efficiency. heat transfer enhancement, exchanger selection, specification and operation, process intensification and software programmes.

Contents

List of Tables

List of Figures

PLATE-FIN HEAT EXCHANGERS

2.2.1 Introduction

Plate-fin heat exchangers are a matrix of flat plates and corrugated fins in a sandwich construction.

Brazed aluminium plate-fin heat exchangers exhibit certain features and characteristics that distinguish them from other types of heat exchanger.

These include:

- A very large heat transfer area per unit volume of heat exchanger. This surface area is composed of primary and secondary (finned) surfaces. Typically, the effective surface area is over five times greater than that of a conventional shell and tube heat exchanger. Area densities range from 850 to 1,500 m^2/m^3.
- A single heat exchanger can incorporate several different process streams and the unique plate-fin construction allows these to enter/exit the exchanger at intermediate points along the exchanger length rather than just at the ends.
- Very close temperature approaches between streams (typically 1 to 3^oC) can be accommodated leading to operational cost savings.
- High thermal efficiency, use of aluminium and multi-stream capability combine to form a compact, low-weight structure.
- Usually plate-fin exchangers operate at cryogenic temperatures. Therefore the exchanger is housed in an insulated “cold-box” (typically carbon steel) to preserve the cold. Alternatively, a locally applied exterior insulant may be used.

The versatility of plate-fin heat exchangers, coupled with the ability to manufacture them in a variety of other materials, makes them ideal for a range of process duties outside the cryogenics field.

2.2.2 Brazed Plate-Fin Heat Exchangers

2.2.2.1 Introduction

This section describes brazed plate-fin heat exchangers, an example of which is pictured in Figure 2.2.1.

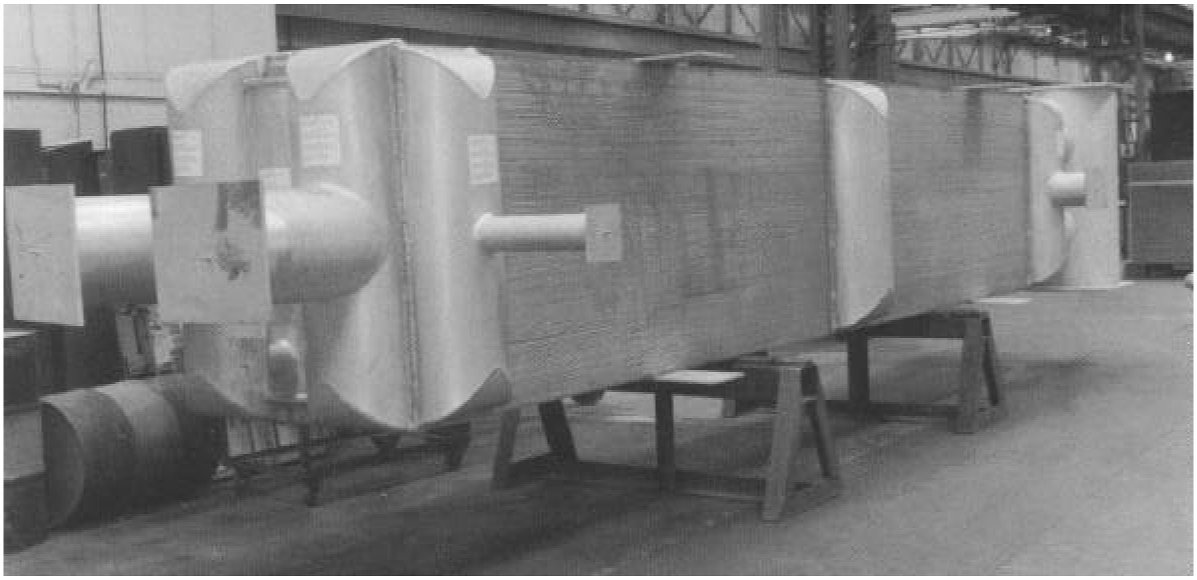

Figure 2.2.1 – Aluminium Plate-Fin Heat Exchanger
(Courtesy of Chart Marston Limited)

2.2.2.2 Construction

The heat exchanger is assembled from a series of flat sheets and corrugated fins in a sandwich construction. Tube plates (i.e. parting sheets) provide the primary heat transfer surface. Tube plates are positioned alternatively with the layers of fins in the stack to form the containment between individual layers. These elements are built into a complete core and then vacuum brazed to form an integral unit. A section through a typical plate-fin heat exchanger core is shown in Figure 2.2.2.

The heat transfer fins provide the secondary heating surface for heat transfer. Fin types, densities and heights can be varied to ensure that exchangers are tailor-made to meet individual customer requirements in terms of heat transfer performance versus pressure drop.

Distributor fins collect and distribute the heat transfer fluid from the header tank to the heat transfer fins at the inlet and reverse the process at the outlet. Distribution fins are taken from the same range as the heat transfer fins, but tend to be less dense.

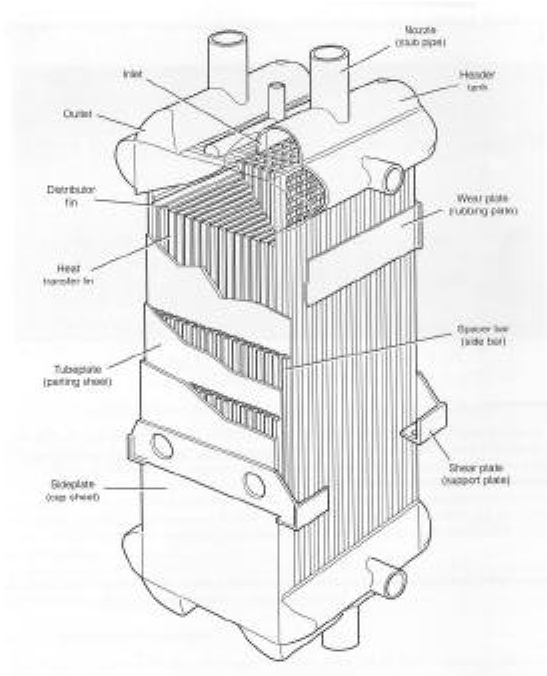

Figure 2.2.2 – Core Structure of a Brazed Aluminium Plate-Fin Heat Exchanger
(Courtesy of Chart Marston Limited)

The heat exchanger core is then encased in a welded structure that incorporates headers, support plates and feed/discharge pipes.

Most plate-fin heat exchangers are made of aluminium, with a vacuum-brazed core. Corrosion-resistant and heat-resistant brazing alloys can be used; for example plate-fin heat exchangers can also be assembled in stainless steel, a variety of nickel-based alloys, and some other specialist alloys. A stainless steel unit is shown in Figure 2.2.3.

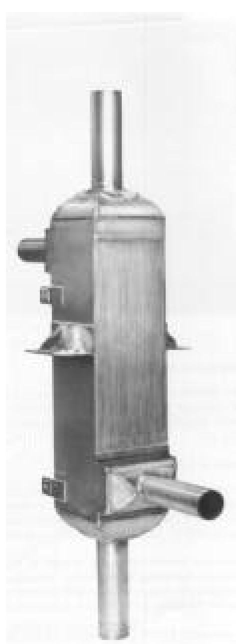

Figure 2.2.3 – Stainless Steel Plate-Fin Heat Exchanger
(Courtesy of Chart Marston Limited)

2.2.2.3 Operating Limits

The maximum operating temperature of a plate-fin heat exchanger is a function of its construction materials. Aluminium brazed plate-fin heat exchangers can be used from cryogenic temperatures (-270°C) up to 200°C, depending on the pipe and header alloys. Stainless steel plate-fin heat exchangers are able to operate at up to 650°C, while titanium units can tolerate temperatures approaching 550°C.

Aluminium brazed units can operate at up to 120 bar, depending on the physical size and the maximum operating temperature. Stainless steel plate-fin heat exchangers are currently limited to 50 bar, with developments expected that will extend the capability to 90 bar. Higher pressures can be tolerated by using a diffusion-bonded structure (see Section 2.2.3).

The size of a plate-fin heat exchanger is a function of the procedure used to assemble the core. In the case of aluminium vacuum-brazed units, modules of 6.25 m x 2.4 m x 1.2 m are available.

When selecting brazed aluminium plate-fin exchangers, the engineer should ensure that:

- All fluids must be clean and dry. Filtration must be used to remove particulate matter over 0.3mm.
- Fluids must be non-corrosive to aluminium. Water is suitable if it is a closed loop and contains corrosion inhibitors.
- Fluids must be in the temperature range –270 to +200°C.
- The maximum design pressure is less than 120 bar.

Fin Type	**Application**	**Features**	
		Relative Δp	**Relative Heat Transfer**
Plain	General	Lowest	Lowest
Perforated	Boiling streams	Low	Low
Herringbone	Gas streams with low allowable ΔP High pressure streams Gas streams for hydrocarbon and natural gas applications	High	High
Serrated	Gas streams in air separation applications General	Highest	Highest

Table 2.2.1 – Brazed Plate-Fin Types

2.2.2.4 Principal Applications

The plate-fin heat exchanger is suitable for use over a wide range of temperatures and pressures for gas-gas, gas-liquid and multi-phase duties. Typically, these involve:

- Chemical and petrochemical plant:
  - Corrosive and aggressive chemicals.
  - Ammonia and methanol plant.
  - Ethylene and propylene production.
  - Oxygen plant.
  - Inert gas recovery.
  - Hydrogen plant.

- Hydrocarbon off-shore applications:
  - Compressor coolers.
  - Fuel processing and conditioning plant.

- Miscellaneous applications:
  - Fuel cells.
  - Heat recovery plant.
  - Pollution control systems.

In addition to the typical gas/gas applications e.g. in gas liquefaction processes, plate-fin heat exchangers are increasingly used in the following two generic applications:

- Dephlegmators

  A dephlegmator is a refluxing heat exchanger used for partially condensing/purifying fluids in applications such as ethylene recovery and hydrogen purification. The heat exchanger arrangement is shown in Figure 2.2.4.

  The feed stream requiring purification is typically a low molecular weight gas containing small amounts of heavier components. The partially cooled feed stream enters the plate-fin heat exchanger at point A and is cooled by the separate refrigerant stream, and a third process steam (E-F). The plate-fin heat exchanger is mounted vertically, so that the feed gas cools as it flows upwards. The condensate then runs back against the gas flow, where mass transfer (rectification) takes place.

- Compact kettle reboilers

  The use of plate-fin heat exchanger cores as the basis of kettle reboilers, as shown in Figure 2.2.5, permits considerable size reductions compared to conventional shell and tube reboilers. As well as the thermal advantages, the plate-fin heat exchanger-based unit exhibits a lower liquid carry-over, mechanical joints are eliminated, and core removal for repair or replacement is facilitated.

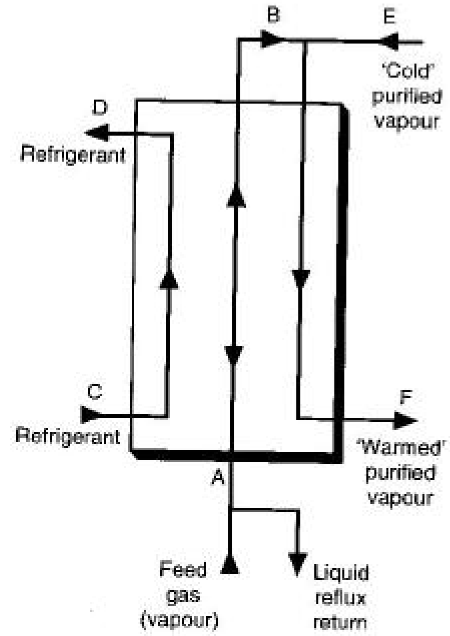

Figure 2.2.4 – Plate-Fin Heat Exchanger Dephlegmator Arrangement

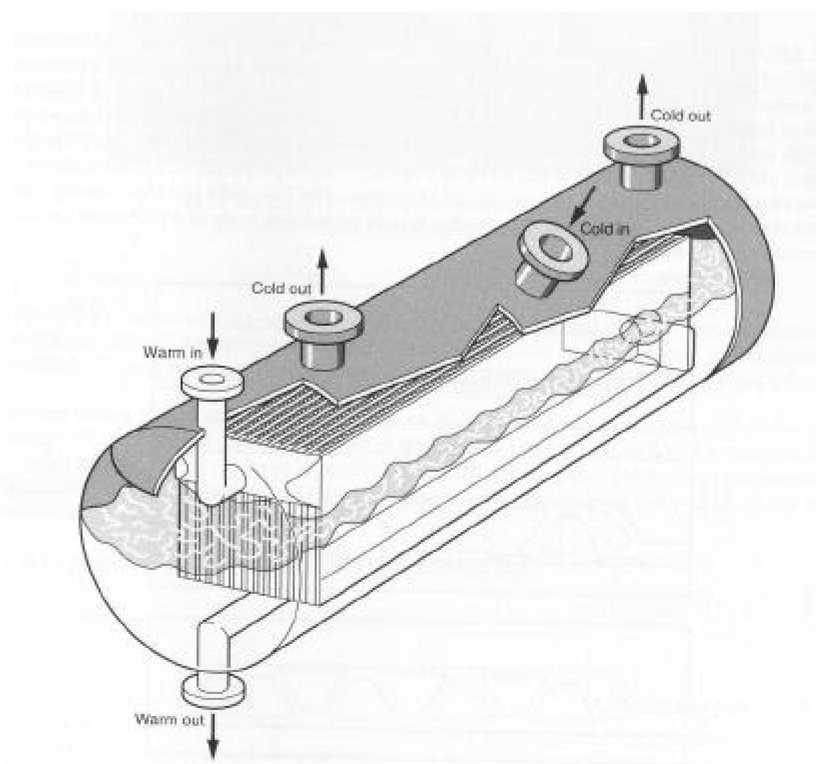

Figure 2.2.5 – The Use of an Aluminium Plate-Fin Heat Exchanger as the Core of a Kettle Reboiler

Plant Types	Products and Fluids	Typical Temperature Range (°c)	Typical Pressure Range (bar.g)
Industrial Gas Production - Air Separation - Liquefaction	Oxygen Nitrogen Argon Rare Gases Carbon Dioxide	-200 to +65	1 to 60
Natural Gas Processing (NGP) - Expander Type - Nitrogen Rejection Unit (NRU) - Liquefied Petroleum Gas (LPG) - Helium Recovery	Methane Ethane Propane Butane Pentane Nitrogen Helium Hydrogen Hexane Carbon Dioxide	-130 to +100	15 to 100
Liquefied Natural Gas (LNG) - Base Load - Peakshaver	Liquefied Natural Gas Multi-component refrigerants	-200 to +65	5 to 75
Petrochemical Production - Ethylene - MTBE - Ammonia - Refinery Off-Gas Purification	Ethylene Propylene Ethane Propane MTBE Ammonia Carbon Monoxide Hydrogen	-200 to +120	1 to 100
Refrigeration Systems - Cascade Cooling - Liquefaction	Helium Freon Propane Ethylene Propylene Nitrogen Hydrogen Multi-component Refrigerants	-270 to +100	15 to 45

Table 2.2.2 – Typical Applications of Brazed Plate-Fin Heat Exchangers

2.2.2.5 Comparison with Shell and Tube Heat Exchanger

A plate-fin heat exchanger with 6 fins/cm provides approximately 1,300 m^2 of surface per m^3 of volume. This heat exchanger would be approximately 10% of the volume of an equivalent shell and tube heat exchanger with 19 mm tubes.

2.2.3 Diffusion-Bonded Plate-Fin Heat Exchangers

2.2.3.1 Introduction

Diffusion bonding has a number of advantages over brazing when assembling a compact heat exchanger. As discussed in Section 2.2.2, most plate-fin heat exchangers still use brazing to assemble the core, with aluminium as the principal core material.

Recently, Rolls Laval Heat Exchangers Ltd applied a technique used for the cost-effective manufacture of aero-engine components -superplastic forming/diffusion bonding (SPF/DB) to the construction of plate-fin heat exchangers. This process permits titanium, and potentially stainless steel, plate-fin heat exchangers of high integrity to be manufactured, giving superior strength characteristics and enhanced corrosion resistance.

2.2.3.2 Construction

The formation of the basic element in the Rolls Laval titanium plate-fin heat exchanger, i.e. two parting sheets separated by the secondary surface, involves several stages. Starting with well-prepared titanium sheets, a bond inhibitor is deposited on the internal surfaces of the parting sheets such that diffusion bonding only occurs where required between the two sheets (as in roll-bonding) and the third sheet, which forms the secondary surface.

The diffusion bonding process is then applied, with the three sheets being held together and subjected to high pressure and temperature. Solid state diffusion bonding takes place between the unmasked surfaces, giving a joint with parent metal properties but without a heat-affected zone or impurities such as flux. The bonded sheets are then placed in a closed die, and controlled internal pressure is applied to superplastically deform the sandwich. The central sheet stretches to provide the secondary surface as shown in Figure 2.2.6. The super-plastic deformation process allows the metal to retain its good mechanical properties. The final stage involves 'ironing' the element to ensure flat surfaces that can conform to their neighbours in the heat exchanger matrix. Examples are shown in Figure 2.2.7.

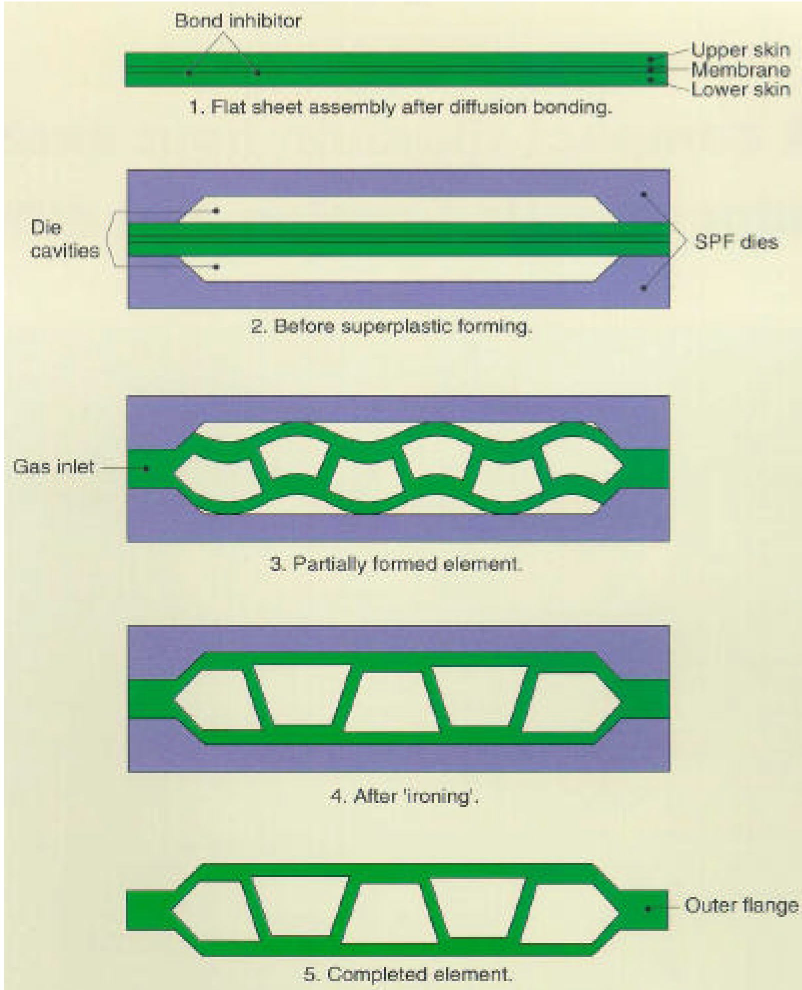

Fig 2.2.6 – Manufacturing the Core of a Diffusion-Bonded Plate-Fin Heat Exchanger (Courtesy of Rolls Laval Heat Exchangers Ltd)

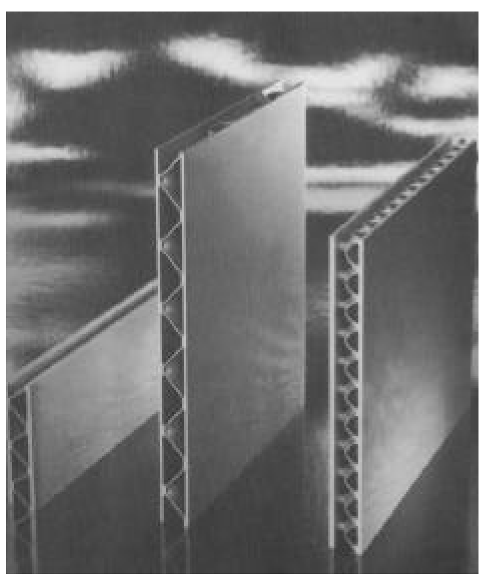

Figure 2.2.7 – Example Elements of Diffusion Bonded Plate-Fin Heat Exchangers (Courtesy of Rolls Laval Heat Exchangers Ltd)

The SPF/DB manufacturing process allows a wide range of internal geometries to be produced, extending beyond conventional finning arrangements such as herringbone and perforated variants. Typical minimum channel heights are about 2 mm, with a maximum of about 5 mm.

Unlike brazed plate-fin heat exchangers, the diffusion-bonded unit does not need edge bars. Flow distributors are integrally incorporated during the sandwich deformation process.

Modules of up to 41 elements are formed by diffusion bonding the parting sheets of adjacent elements. The modules are then joined at the stream inlets and outlets to form an exchanger block of the required size, to which the headers, nozzles and other external features are welded. Figure 2.2.8 shows a completed unit of 8 modules, each of which is 2 m high and 1 m wide.

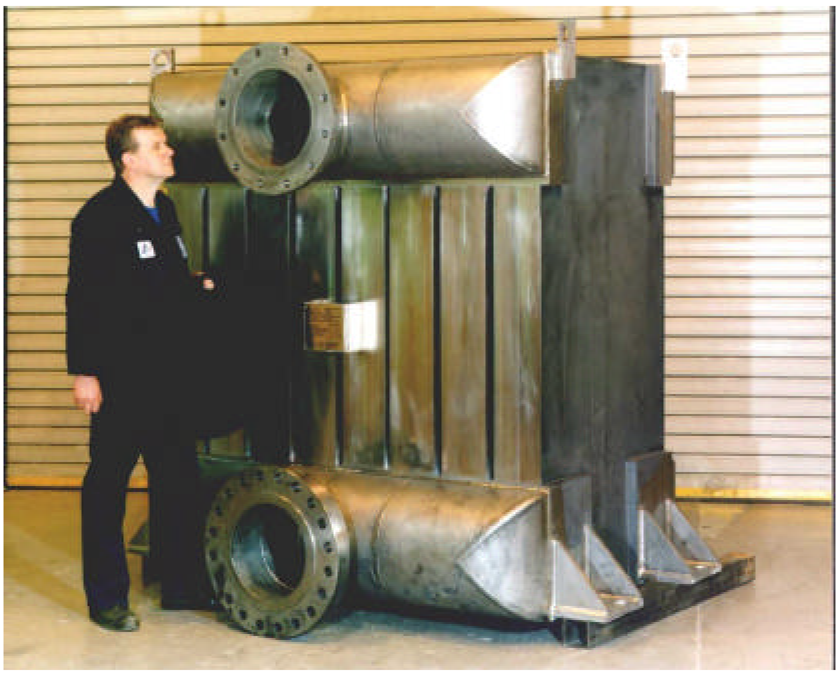

Figure 2.2.8 – A Diffusion-Bonded Titanium Plate-Fin Heat Exchanger
(Courtesy of Rolls Laval Heat Exchangers Ltd)

The diffusion-bonded plate-fin heat exchangers currently available are constructed using titanium. Several other commercially significant alloys exhibit super-plasticity, and the technique can be developed for use with both stainless steel and nickel alloys.

2.2.3.3 Operating Limits

The titanium plate-fin heat exchanger can be designed for pressures in excess of 200 bar and at temperatures up to 400^{o}C.

It is also possible to have exchangers with multi stream capability.

2.2.3.4 Principal Applications

The major application areas for the diffusion-bonded plate-fin heat exchanger are:

- Generic:
  - Gas-gas.
  - Gas-liquid.
  - Two-phase operations.
- Specific:
  - Gas compressor intercoolers.

The manufacturing method makes the unit ideal for duties where stream pressures in excess of 50 bar are likely to be encountered.

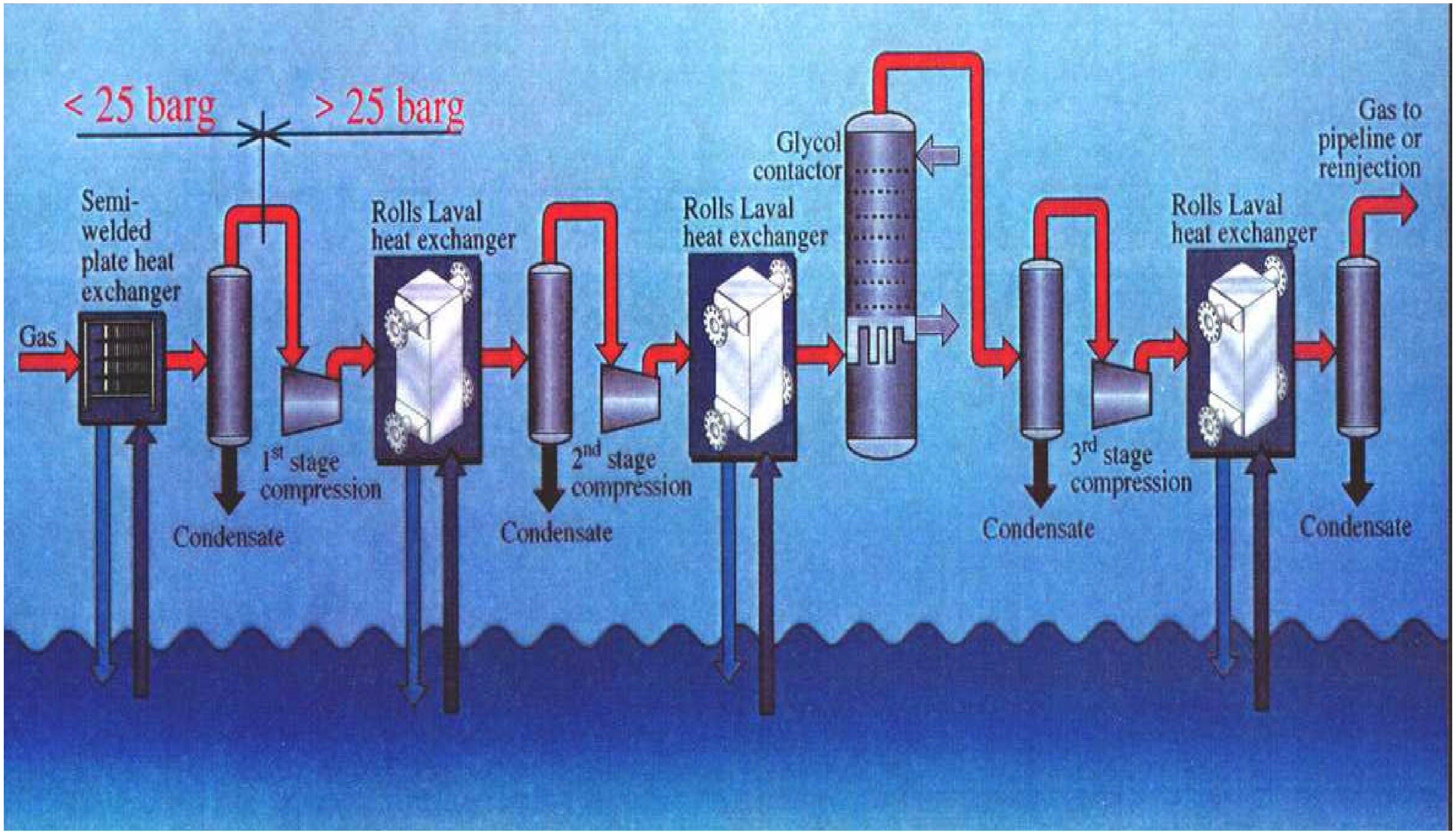

Figure 2.2.9 – Example of Diffusion Bonded Exchanger in Operation
(Courtesy of Rolls-Laval Heat Exchangers Ltd)

2.2.3.5 Comparison with Shell and Tube Heat Exchanger

An indication of the weight benefit associated with a titanium plate-fin heat exchanger compared to an equivalent shell and tube unit is given by the example below.

For a 250 bar duty, a shell and tube unit with titanium tubes and a titanium-clad shell would weigh 9.5 tonnes. The equivalent plate-fin heat exchanger would weigh 1 tonne.

A rule-of-thumb calculation suggests that, for a given duty, a shell and tube unit will be 5 to 10 times heavier.

The weight benefit is coupled with significant volume reductions.

Table 2.2.3 and Figure 2.2.10 illustrate an example gas cooler on a North Sea platform with a design pressure of 64 bar. It should be noted that for constrained space installations, the "space cost" may be substantially higher than the purchase cost of the heat exchanger.

Specification	**Rolls Laval Plate-Fin Heat Exchanger**	**Shell and Tube Heat Exchanger**
Material	Titanium	Titanium
Length, metres	1.1	10.0
Width, metres	1.0	1.3
Empty Weight, tonnes	3.7	18.0
Operating Weight, tonnes	4.0	28.0

Table 2.2.3 – Benefits of Compactness

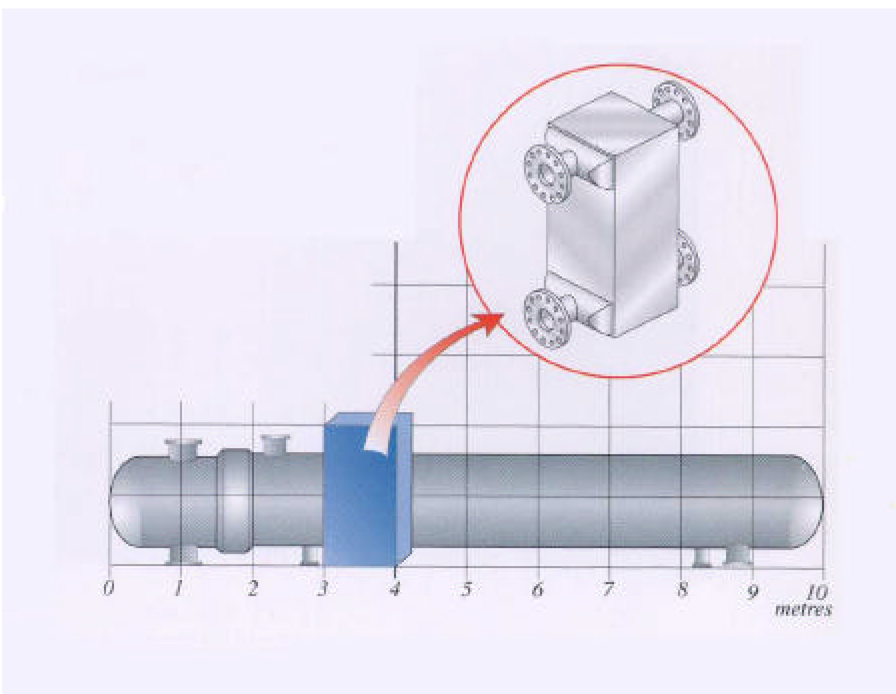

Figure 2.2.10 – Size difference for Gas Cooling Heat Exchanger on a North Sea Platform (Courtesy of Rolls Laval Heat Exchangers Ltd)

GUIDE TO COMPACT HEAT EXCHANGERS

MODULE 2.3

SPIRAL HEAT EXCHANGERS

This technology module contains a brief introductory description to the exchanger type above, followed by information on construction, construction materials, operating limits and principal applications. Where appropriate, a comparison is made with conventional shell and tube heat exchangers to emphasise size and weight reductions that can be achieved by using compact heat exchangers.

The Module 3 series present further information applicable to all technologies, such as general advantages and limitations of compact exchanger designs, common applications, fouling and how to minimise it, energy efficiency. heat transfer enhancement, exchanger selection, specification and operation, process intensification and software programmes.

Contents

List of Figures

SPIRAL HEAT EXCHANGERS

2.3.1 Introduction

Spiral heat exchanger design approaches the ideal in heat transfer equipment by obtaining identical flow characteristics for both media. The classic design of a spiral heat exchanger is simple; the basic spiral element is constructed of two metal strips rolled around a central core forming two concentric spiral channels. Normally these channels are alternately welded, ensuring that the hot and cold fluids cannot intermix.

The heat exchanger can be optimised for the process concerned by using different channel widths. Channel width is normally in the range 5 to 30 millimetres.

Plate width along the exchanger axis may be 2 m, as can the exchanger diameter, giving heat transfer areas up to 600 m^2.

Figure 2.3.1 – Spiral Heat Exchanger With End-Cap Removed (Giving Access to One Spiral Channel) (Courtesy of GEA Process Technology)

Gasketed flat covers are fitted to the open side of each channel resulting in easy access and reduced maintenance costs.

Spiral heat exchangers tend to be self-cleaning. The smooth and curved channels result in a lower fouling tendency with difficult fluids. Each fluid has only one channel and any localised fouling will result in a reduction in the channel cross sectional area causing a velocity increase to scour the fouling layer. This self-cleaning effect results in reduced operating costs particularly when the unit is horizontally mounted.

Horizontal mounting is essential when handling fibrous, high viscosity, particle-laden or clogging media since all particles potentially settle to the bottom of the channel curvature.

2.3.2 Construction

The spiral heat exchanger can be tailor-made to perform in a wide variety of duties in all metals that can be cold-formed and welded, such as carbon steel, stainless steel and titanium. High-grade alloys are routinely used for excellent resistance to corrosion and erosion.

In some cases double spacing may be used, produced by simultaneously winding four strips to form two channels for each fluid. These double channel systems are used when there is a large flowrate or small pressure drop, but should not be used for fouling media or media containing solids.

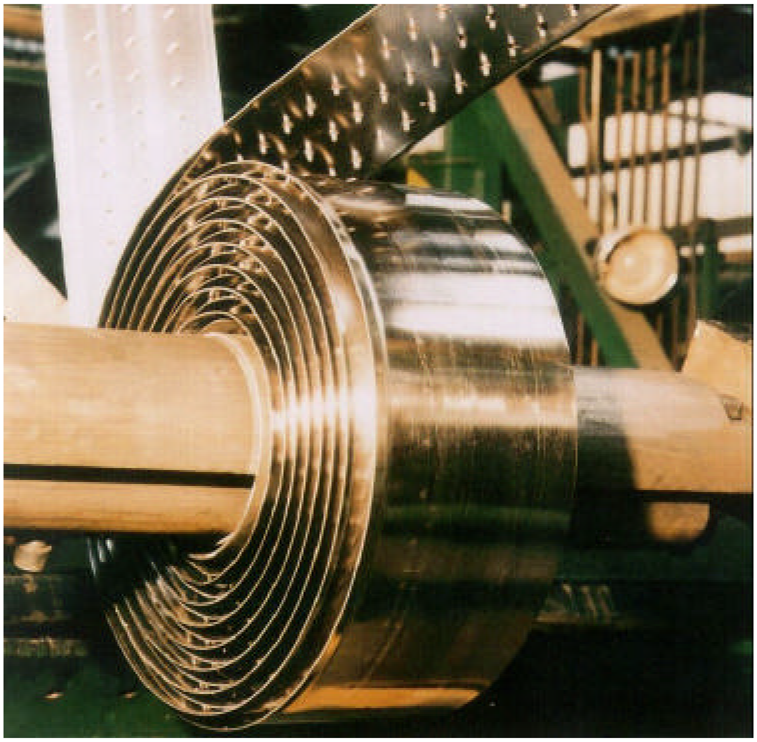

Figure 2.3.2 – Spiral Heat Exchanger Manufacture
(Courtesy of GEA Process Technology)

The use of spiral heat exchangers is not limited to liquid-liquid services. Variations to the basic design give exchangers that are suitable for liquid-vapour or liquid-gas services.

Typically spiral heat exchangers are available in three configurations:

- Type 1 – Media in full counter-current flow.

  The hot fluid enters at the centre of the unit and flows from the inside outward. The cold fluid enters at the periphery and flows towards the centre.

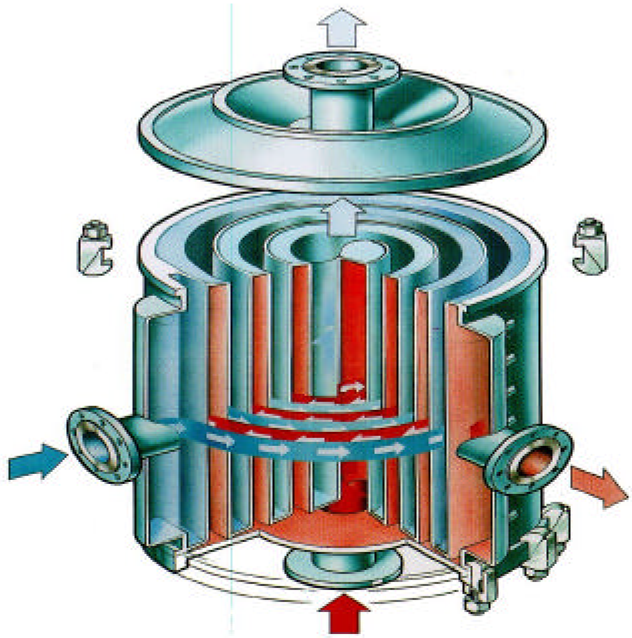

Figure 2.3.3 – Type 1 - Spiral Flow-Spiral Flow Heat Exchanger
(Courtesy of Alfa Laval Thermal Division)

- Type 2 – One medium in cross flow whilst the other is in spiral flow.

The medium in crossflow passes through the open channels of the spiral usually in a vertical direction. The service fluid spiral flows through the other channel, welded shut, with side wall inlet and central outlet fed through the side wall as shown in Figure 2.3.4. This design can be used as either a condenser or vaporiser.

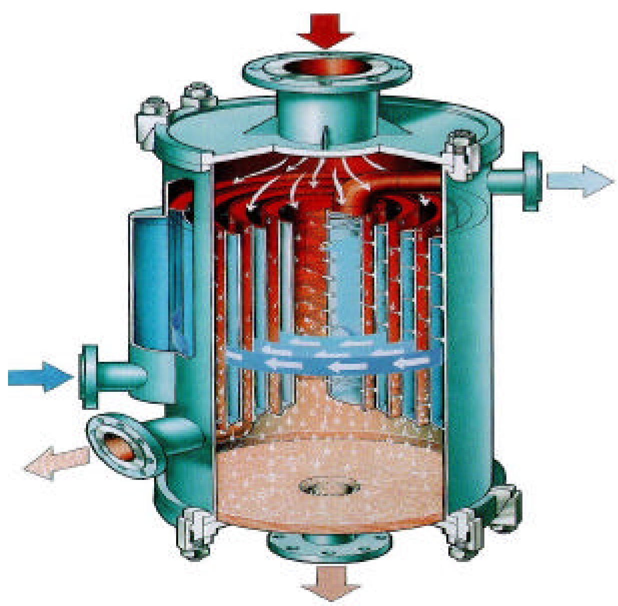

Figure 2.3.4 – Type 2 - Cross Flow-Spiral Flow Heat Exchanger
(Courtesy of Alfa Laval Thermal Division)

- Type 3 – Combination design.

  A gas or vapour mixture to liquid exchanger combines the above two designs; the hot stream enters at the top and flows tangentially through the exchanger exiting at the side.

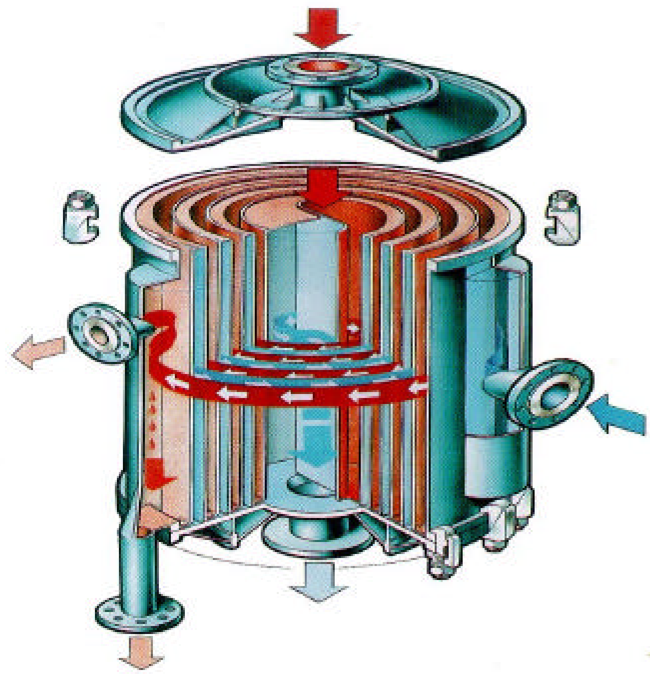

Figure 2.3.5 – Type 3 - Combination Cross-Flow and Spiral Flow-Spiral Flow (Courtesy of Alfa Laval Thermal Division)

2.3.3 Operating Limits

Typically, the maximum design temperature is 400°C set by the limits of the gasket material. Special designs without gaskets can operate with temperatures up to 850°C. Maximum design pressure is usually 15 bar, with pressures up to 30 bar attainable with special designs.

2.3.4 Principal Applications

The design is ideal for fluids prone to fouling, or polluted with particles as a result of the relatively large channel width. Hence, it is ideal for use in the food industry (sauces, slush and slurry) as well as in brewing and wine making.

Spiral heat exchangers have many applications in the chemical industry including $TiCl_4$ cooling, PVC slurry duties, oleum processing and heat recovery from many industrial effluents.

Spiral heat exchangers also provide temperature control of sewage sludge digesters plus other public and industrial waste plants.

Spiral heat exchangers have perfect counter-current flow paths that permit the best possible overlap of exit temperatures. As such, they can maximise the heat recovery on large-scale cogeneration projects although they may be more expensive than plate designs.

Spiral exchangers can be mounted directly onto the head of distillation columns acting in a condensing or reflux role. Specific advantages are ease of installation, low pressure drop and large flow cross-section. Consequently, there are many condensing applications in all process industries particularly for condensing under vacuum.

2.3.5 Comparison with Shell and Tube Heat Exchanger

Spiral designs have a number of advantages compared to shell and tube heat exchangers:

- Optimum flow conditions on both sides of the exchanger.
- An even velocity distribution, with no dead-spots.
- An even temperature distribution, with no hot or cold-spots.
- More thermally efficient with higher heat transfer coefficients.
- Copes with exit temperature overlap, or crossover, whereas shell and tube units require multi-shells in series to handle temperature crossover.
- Small hold up times and volumes.
- Removal of one cover exposes the total surface area of one channel providing easy inspection cleaning and maintenance.

For the same duty, a spiral heat exchanger heat transfer area would be 90m^2 compared to 60m^2 for a plate and frame design or 125m^2 for a shell and tube design. The physical size comparison is shown in Figure 2.3.6

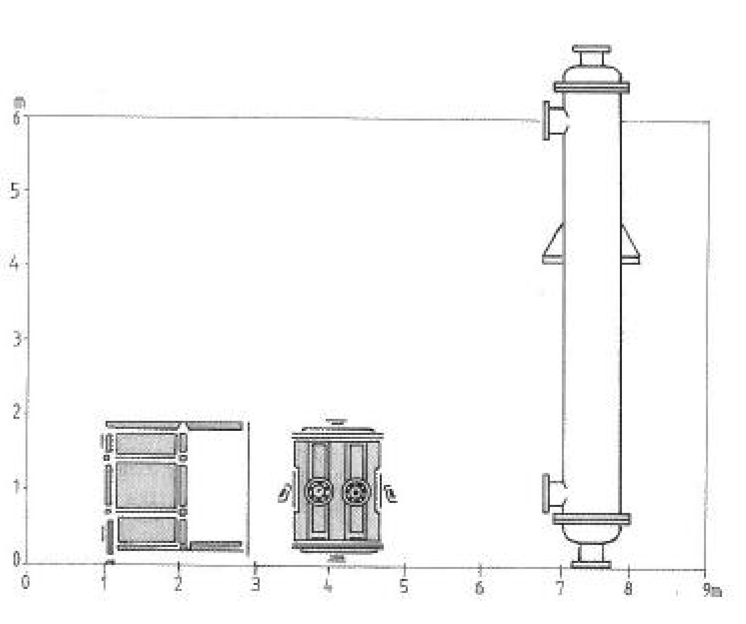

Figure 2.3.6 – Heat Exchanger Size Comparison for Plate, Spiral, and Shell and Tube Heat Exchangers (Courtesy of GEA Process Technology)

GUIDE TO COMPACT HEAT EXCHANGERS

MODULE 2.4

PRINTED CIRCUIT HEAT EXCHANGERS

This technology module contains a brief introductory description to the exchanger type above, followed by information on construction, construction materials, operating limits and principal applications. Where appropriate, a comparison is made with conventional shell and tube heat exchangers to emphasise size and weight reductions that can be achieved by using compact heat exchangers.

The Module 3 series present further information applicable to all technologies, such as general advantages and limitations of compact exchanger designs, common applications, fouling and how to minimise it, energy efficiency. heat transfer enhancement, exchanger selection, specification and operation, process intensification and software programmes.

Contents

List of Figures

PRINTED CIRCUIT HEAT EXCHANGERS

2.4.1 Introduction

Printed circuit heat exchangers are highly compact, corrosion resistant heat exchangers capable of operating at pressures of several hundred atmospheres and temperatures ranging from cryogenic to several hundred degrees Celsius.

The printed circuit heat exchanger design offers a unique combination of innovative manufacturing technology and potential breadth of application. In common with some other compact heat exchangers, it is potentially more than just a compact plate heat exchanger; the structure has applications in a variety of other unit operations, including reactors, mass transfer and mixers.

Printed circuit heat exchangers are constructed from flat alloy plates with fluid flow passages photo-chemically machined (etched) into them. This process is similar to manufacturing electronic printed circuit boards, and gives rise to the name of the exchangers. An example of a plate showing a 'herringbone' pattern of flow paths is shown in Figure 2.4.1.

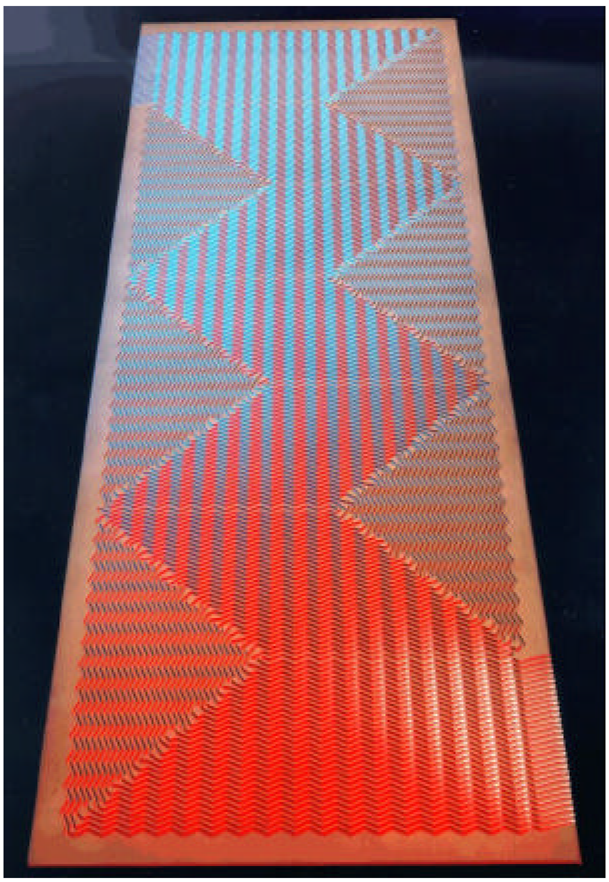

Figure 2.4.1 – Fluid Flow Paths on a Typical Printed Circuit Heat Exchanger Etched Plate (Courtesy of Heatric Ltd)

Heatric originally developed printed circuit heat exchangers in Australia, where this type of heat exchanger first became commercially available for refrigeration and process applications in 1985. In 1990, Heatric moved to the UK and has supplied printed circuit exchangers into the offshore and process sectors, both in the UK and overseas.

2.4.2 Construction

The standard manufacturing process involves chemically milling (etching) the fluid flow passages into the plates. This allows enormous flexibility in thermal/hydraulic design, as complex new plate patterns require only minimal re-tooling costs.

This plate/channel forming technique can produce a wide range of flow path sizes, the channels varying typically from 0.5 to 2.0 mm in depth.

Stacks of etched plates, carrying flow passage designs tailored for each fluid, are diffusion bonded together to form a compact, strong, all-metal heat exchanger core. A cross-section through a typical core sample is shown in Figure 2.4.2. No gaskets or brazing materials are required for the assembly. Diffusion bonding allows the plates to be joined so that the bond acquires the same strength as the parent metal. The thermal capacity of the exchanger is built to the required level by welding together diffusion bonded blocks to form the complete heat exchanger core. Finally, fluid headers and nozzles are welded to the cores, in order to direct the fluids to the appropriate sets of passages. Figure 2.4.3 shows a completed heat exchanger unit.

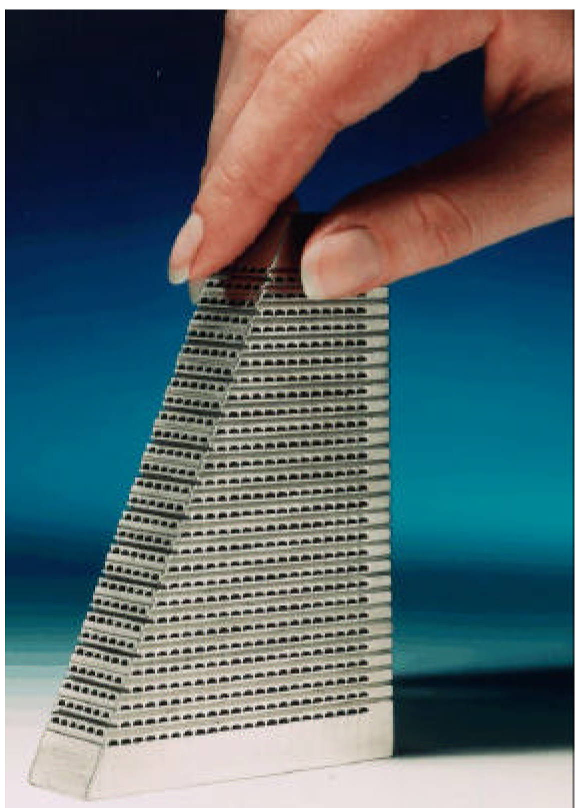

Figure 2.4.2 – Cross-section Through a Typical Printed Circuit Heat Exchanger Core (Courtesy of Heatric Ltd)

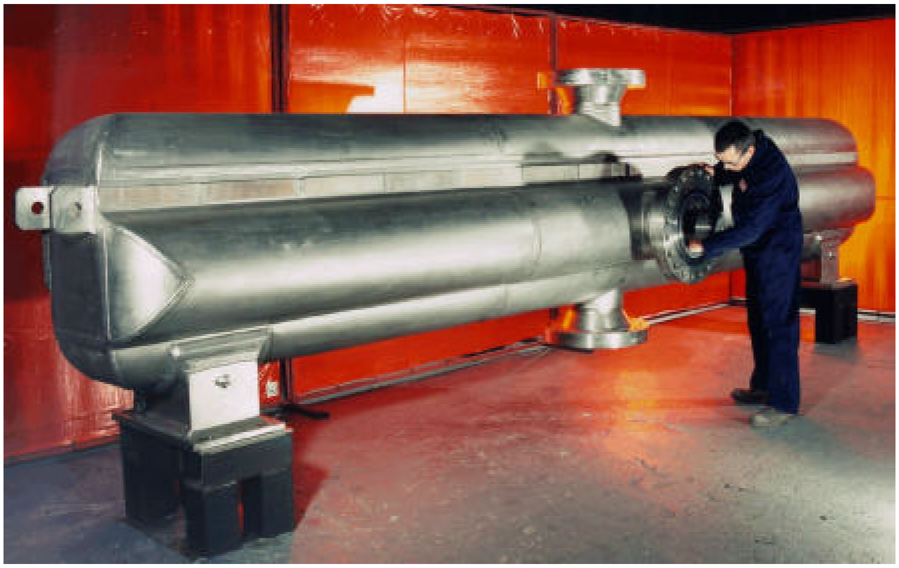

Figure 2.4.3 – Gas Dew Point Control Printed Circuit Heat Exchanger
(Courtesy of Heatric Ltd)

Materials of construction include stainless steel (SS 300 series) and titanium as standard, with nickel and nickel alloys also being commonly used. A copper variant is being developed.

2.4.3 Operating Limits

Mechanical design is flexible; etching patterns can be adjusted to provide high pressure containment where required. Due to its construction, the printed circuit heat exchanger is able to withstand substantial pressures. Pressures as high as 200 bar are routine, with values in the range 300 - 500 bar being possible.

The all welded construction is compatible with very high temperature operation, and the use of austenitic steel allows cryogenic operation. Operating temperature ranges from -200^{o}C to +900^{o}C, the upper limits depending on the metal selected and the pressure duty.

Passages are typically of the order of 2 mm semi-circular cross-section (i.e. 2 mm across and 1 mm deep) for reasonably clean applications, although there is no absolute limit on passage size.

Prime heat transfer surface densities, expressed in terms of effective heat transfer area per unit volume, can be up to 2500 m^2/m^3. This is higher than prime surface densities in gasketed plate exchangers, and an order of magnitude higher than normal prime surface densities in shell and tube exchangers.

2.4.4 Operation

Printed circuit heat exchangers are all welded so there is no braze material employed in construction, and no gaskets are required. Hence the potential for leakage and fluid compatibility difficulties are reduced and the high level of constructional integrity renders the designs exceptionally well suited to critical high pressure applications, such as gas compression cooling exchangers on offshore platforms.

The thermal design of printed circuit heat exchangers is subject to very few constraints. Fluids may be liquid, gas or two-phase, multi-stream and multi-pass configurations can be assembled and flow arrangements can be truly counter-current, co-current or cross-flow, or a combination of these, at any required pressure drop.

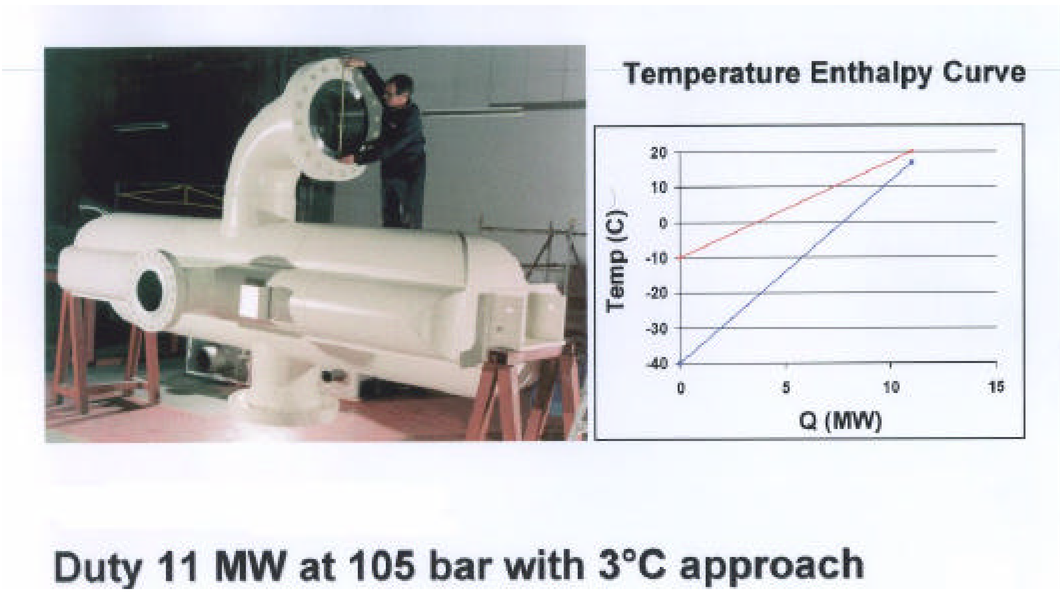

Figure 2.4.4 - Application Showing Close Temperature Approach
(Courtesy of Heatric Ltd)

Where required high heat exchange effectiveness (over 98%) can be achieved through very close temperature approaches in counter-flow. To simplify control, or to further maximise energy efficiency, more than two fluids can exchange heat in a single core. Heat loads can vary from a few watts to many megawatts, in exchangers weighing from a few kilograms to thousands of kilograms.

Flow induced vibration, an important source of failure in shell and tube exchangers, is absent from printed circuit heat exchangers.

A simple strainer upstream of the unit will remove outsize particles, while the corrosion resistant materials of construction for printed circuit heat exchangers, the high wall shear stresses, and the absence of dead spots assist in resisting fouling deposition.

2.4.5 Design

Detailed thermal design of printed circuit heat exchangers is supported by proprietary design software developed by the manufacturer that allows infinite geometric variation to passage arrangements during design optimisation. Variations to passage geometry have negligible production cost impact since the only tooling required for each variation is a photographic transparency for the photo-chemical machining process.

Although the scope of printed circuit heat exchanger capabilities is much wider, as a sizing guide it is safe to assume that channel patterns can be developed to mimic any j- and f- factor characteristics (found in publications such as "Compact Heat Exchangers" by Kays and London) for aluminium surfaces, or data presented by gasketed plate manufacturers.

It is rarely necessary to apply a correction factor substantially less than 1 to the LMTD calculated for an heat exchange, no matter how high the effectiveness required, because of the printed circuit heat exchanger counter-flow capabilities. Pressure drops can be specified at will, however as with all heat exchangers, lower allowable pressure drops will result in lower heat transfer coefficients and hence larger exchangers.

2.4.6 Principal Applications

Printed circuit heat exchangers extend the benefits of compact heat exchangers into applications where pressure, temperature or corrosion prevents the use of conventional plate exchangers.

As mentioned above, the printed circuit heat exchanger can handle gases, liquids and two-phase flows. The manufacturer cites four main application areas, as listed below:

- Fuels processing:
  - Gas processing e.g. compressor cooling, liquids recovery.
  - Dehydration.
  - Synthetic fuels production e.g. methanol.
  - Reactor feed/effluent exchange.

- Chemical processing:
  - Acids e.g. nitric, phosphoric.
  - Alkalis e.g. caustic soda, caustic potash.
  - Fertilisers e.g. ammonia, urea.
  - Petrochemicals e.g. ethylene, ethylene oxide, propylene.
  - Pharmaceuticals.
  - Plastics e.g. formaldehyde, phenol.

- Power and energy:
  - Feedwater heating.
  - Geothermal generation.
  - Chemical heat pumps.

- Refrigeration:
  - Chillers and condensers.
  - Cascade condensers.
  - Absorption cycles.

Figure 2.4.5 - Typical Compression Cooling Printed Circuit Heat Exchanger (Courtesy of Heatric Ltd)

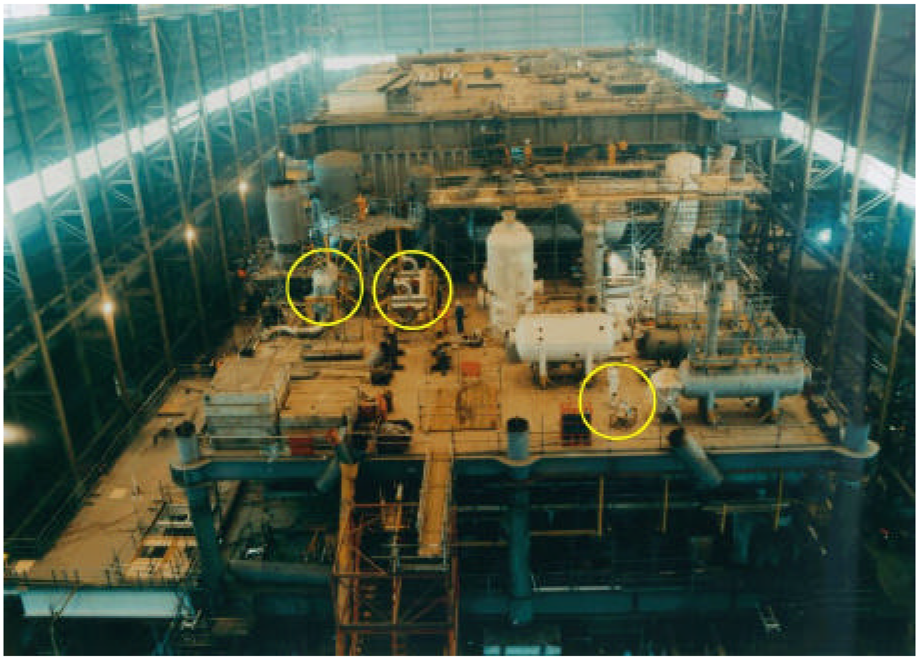

Figure 2.4.6 – Compression Cooling Printed Circuit Heat Exchangers Installed on a Gas Platform (Courtesy of Heatric Ltd)

The printed circuit heat exchanger pictured in Figure 2.4.7 is a multi-stream unit. Such a unit cools high pressure feed gas with a combination of cold separator gas, cold separator liquid and refrigerated triethylene glycol (TEG) solution.

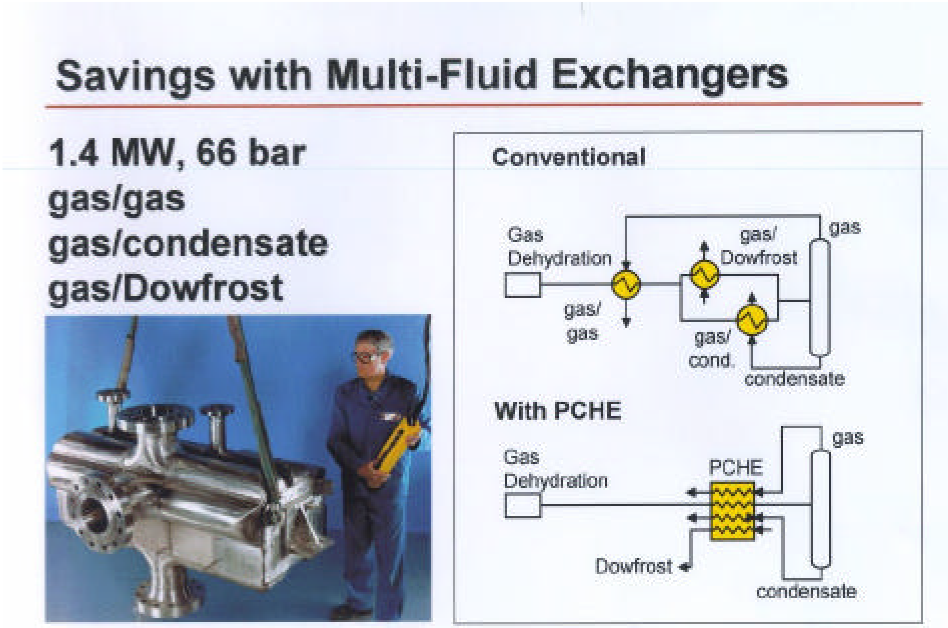

Figure 2.4.7 – Multi-stream Printed Circuit Heat Exchanger Replacing Three Shell and Tube Units (Courtesy of Heatric Ltd)

2.4.7 Comparison with Shell and Tube Heat Exchanger

Figure 2.4.8 illustrates the size difference between a comparable printed circuit heat exchanger and stack of three series shell and tube units used for gas dew point control. The duty is 2,350 kW across a 4^{o}C LMTD.

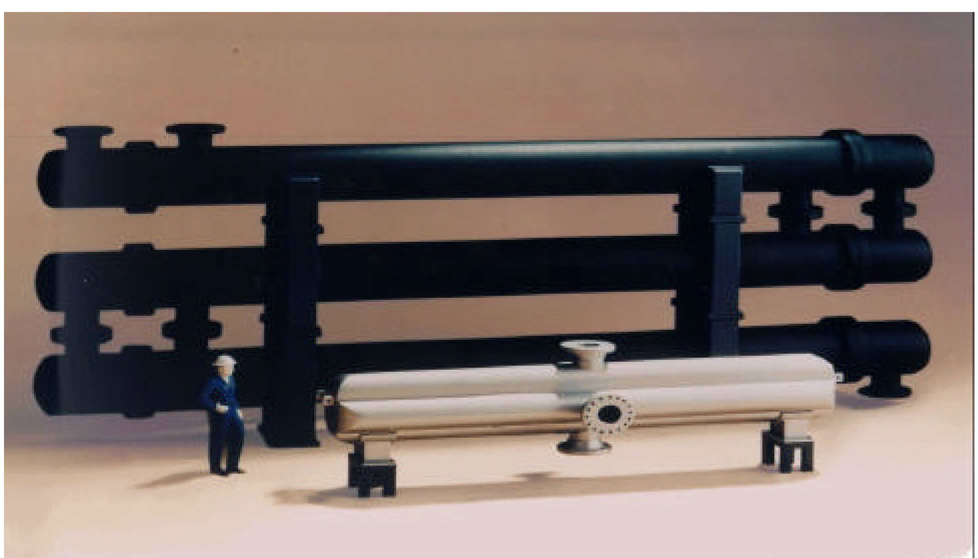

Figure 2.4.8 – Comparison of Printed Circuit Heat Exchanger and Shell and Tube Heat Exchangers of Equivalent Capacity (Courtesy of Heatric Ltd)

The printed circuit heat exchanger illustrated in Figure 2.4.8 has 600 m^2 of surface and a design pressure of 124 bar. Its weight is 15 tonnes, compared to 105 tonnes for equivalent shell and tube heat exchangers.

Printed circuit heat exchanger cores are typically 5 to 10 times smaller than shell and tube exchangers tube bundles of equivalent performance.

GUIDE TO COMPACT HEAT EXCHANGERS

MODULE 2.5

PLATE AND SHELL HEAT EXCHANGERS

This technology module contains a brief introductory description to the exchanger type above, followed by information on construction, construction materials, operating limits and principal applications. Where appropriate, a comparison is made with conventional shell and tube heat exchangers to emphasise size and weight reductions that can be achieved by using compact heat exchangers.

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Contents

List of Figures

PLATE AND SHELL HEAT EXCHANGERS

2.5.1 Introduction

The plate and shell heat exchanger combines the merits of shell and tube with plate heat exchangers, while externally resembling the former in some respects.

Plate and shell heat exchangers feature an outer shell enclosing circular plates welded into pairs. The cooling medium flows on the shell side between the pairs of plates. As a plate is more thermally efficient than a tube, this achieves a significantly higher level of heat transfer.

2.5.2 Construction

The construction of a plate and shell heat exchanger involves welding together, in pairs, circular plates of a similar surface form and material to those of plate and frame heat exchangers. The plates are then located inside a shell, as shown in Figure 2.5.1.

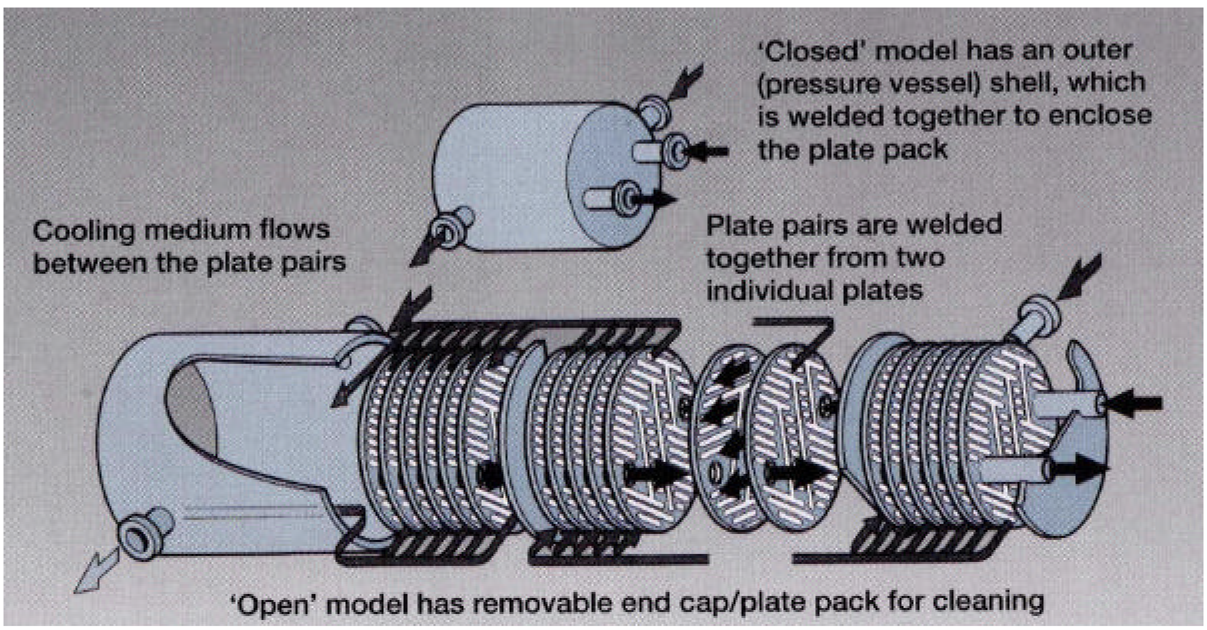

Figure 2.5.1 – General Arrangement of a Plate and Shell Heat Exchanger
(Courtesy of APV)

A 'closed' model has a welded shell or an 'open' model has a removable end flange to facilitate shell-side cleaning.

Generally the hot fluid is passed through the plate side, while the cooling fluid is directed on the shell side. The shell side fluid is routed through individual passes via a baffle plate similar to the shell in the tubular type heat exchanger. Multi-pass arrangements are possible, flow directors on both the shell and plate side adjust the flow paths.

Figure 2.5.2 – Closed Plate and Shell Heat Exchangers
(Courtesy of APV)

Current plate and shell heat exchanger models accommodate up to 600 plates in a shell 2.5 m long with a 1 m diameter. Plate and shell heat exchangers are available with a heat transfer surface area of up to 500m^2.

Standard plate materials are Titanium B265, Avesta 254 SMO and AISI 316. The shell can be made of St 35.8 or AISI 316 or other materials, such as Hastelloy or nickel, if necessary.

2.5.3 Operating Limits

The maximum operating temperature of a plate and shell heat exchanger is 900^{o}C, and maximum working pressure is 100 bar. Single units, which can be operated in parallel for higher throughputs, can currently handle flow rates of 11 litres per second on the shell side.

2.5.4 Principal Applications

Plate and shell heat exchangers can work with aggressive media and acids, which cannot be handled by conventional gasketed plate heat exchangers. They can also withstand extreme temperature shocks and pressure shocks due to their rigid and compact construction.

The principal applications for plate and shell heat exchangers are:

- Heating including district heating.
- Cooling including cryogenic applications.
- Heat recovery.
- Combined exchanger/reactors vessels.
- Condensation/evaporation.

A variety of fluids can be handled including:

- Water.
- Thermal oil.
- Solvents.
- Steam.
- Hydrocarbons and organic chemicals.
- Refrigerants.

2.5.5 Comparison with Shell and Tube Heat Exchanger

Data that directly compares the shell and plate unit with a shell and tube heat exchanger are not available, but shell and plate heat exchangers have been compared with brazed plate heat exchangers. Like brazed plate heat exchangers, plate and shell heat exchangers reach very close approach temperatures. Furthermore due to the flexible layout of flow path configurations, overlapping or crossover of exit temperature is possible.

For heat exchangers of equivalent area and capacity, plate and shell designs are smaller due to the higher ratio of heat transfer area and specific volume. It is claimed that the plate and shell heat exchanger will occupy only 20 to 30% of the footprint of equivalent capacity shell and tube types. The maximum operating pressure of the plate and shell unit will also be higher.

GUIDE TO COMPACT HEAT EXCHANGERS

MODULE 2.6

POLYMER HEAT EXCHANGERS

This technology module contains a brief introductory description to the exchanger type above, followed by information on construction, construction materials, operating limits and principal applications. Where appropriate, a comparison is made with conventional shell and tube heat exchangers to emphasise size and weight reductions that can be achieved by using compact heat exchangers.

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Contents

List of Figures

POLYMER HEAT EXCHANGERS

2.6.1 Introduction

While most of the heat exchangers used in the process industries are metallic, other materials are available. Carbon, for example, is used for sulphuric acid, TEFLON and glass are occasionally used where extensive corrosion may occur. Ceramic units are available for use at high temperatures.

Polymer heat exchangers are available for heating, ventilating and air conditioning duties. The application of polymers in process heat exchangers, often stimulated by the need to protect against corrosion, can have other benefits that extend into the area of compact heat exchangers.

2.6.2 TEFLON Heat Exchangers

2.6.2.1 Construction

Heat exchangers incorporating TEFLON were first introduced for corrosive or abrasive applications in chemical plants.

As plastics have a relatively low thermal conductivity, small-bore tubes with thin wall sections were used. Typically 2.5 mm o/d tubes were used with a wall thickness of 10% of the outside diameter.

TEFLON heat exchangers are available as shell and tube designs, or as immersion coils.

TEFLON "Q" is a resin development that increases the temperature capability up to 200^{o}C and has approximately twice the thermal conductivity of normal TEFLON. In addition, this resin is tougher and more abrasion resistant.

Tube diameters have been introduced from 2.5 to 9.5 mm to increase flexibility.

2.6.2.2 Shell and Tube Units

Polymer shell and tube units tend to be single pass, counter-current designs incorporating flexible tubes of TEFLON FEP or TEFLON "Q" fused at both ends to form a honeycomb structure. Shell-side baffles promote cross-flow and optimise thermal efficiency. All surfaces exposed to the process stream are made of TEFLON to resist fouling and corrosion.

The small bore tubes produce a large surface area for a given volume; for example 1000 tubes of 4.45 mm o/d inside a 10 inch shell gives a heat transfer area of 275 m^2/m^3.

Usually the shell is carbon steel although other shell materials are available. In the case of heat exchange between two corrosive streams, the shell can be TEFLON lined. Shell diameters range from 76 to 355 mm in lengths from 0.6 to 7.3 m.

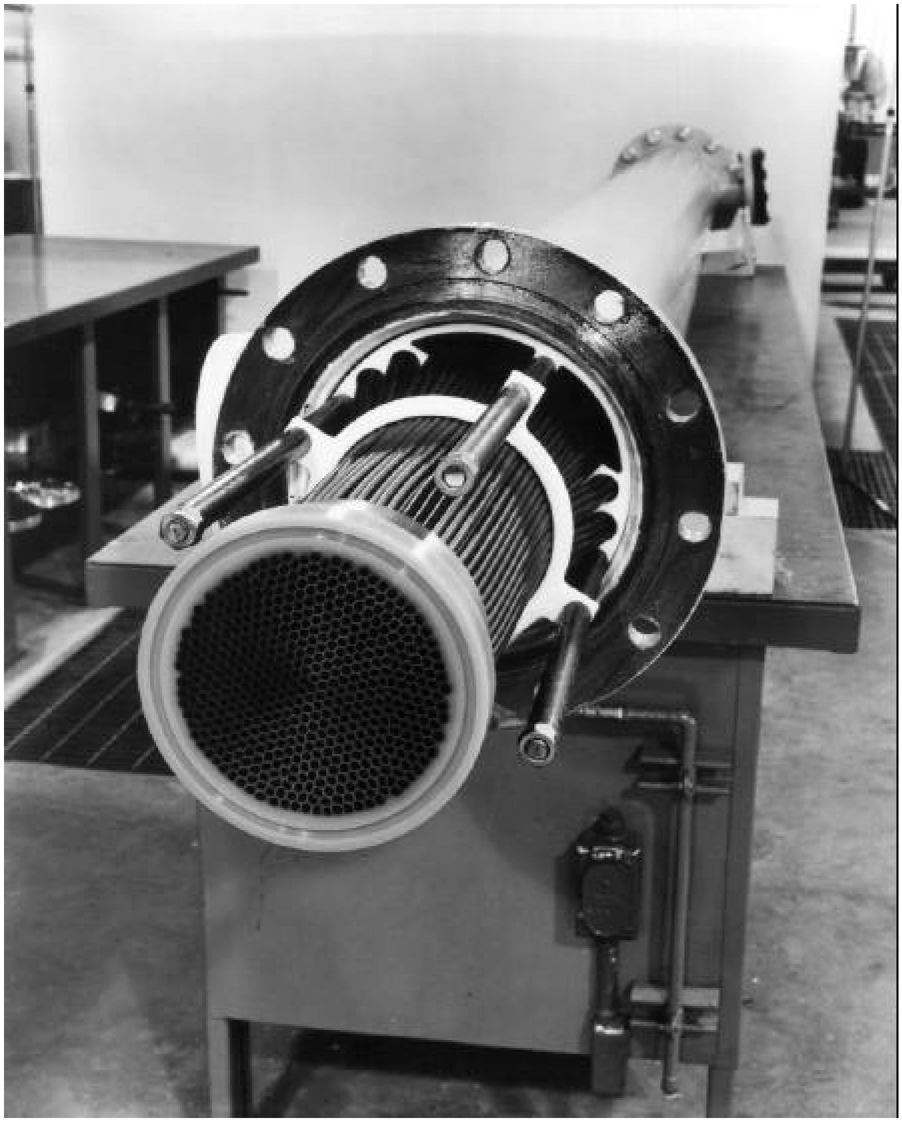

Figure 2.6.1 – TEFLON Shell and Tube Heat Exchanger
(Courtesy of Ametek)

2.6.2.3 Immersion Coils

Slimline coils are used in medium and large process tanks for heating or cooling purposes. Typically 300 tubes of 3 mm diameter give 166 m^2/m^3.

Units are available in lengths from 1.22 to 4.9 m with surface areas from 3.2 to 23.7 m^2.

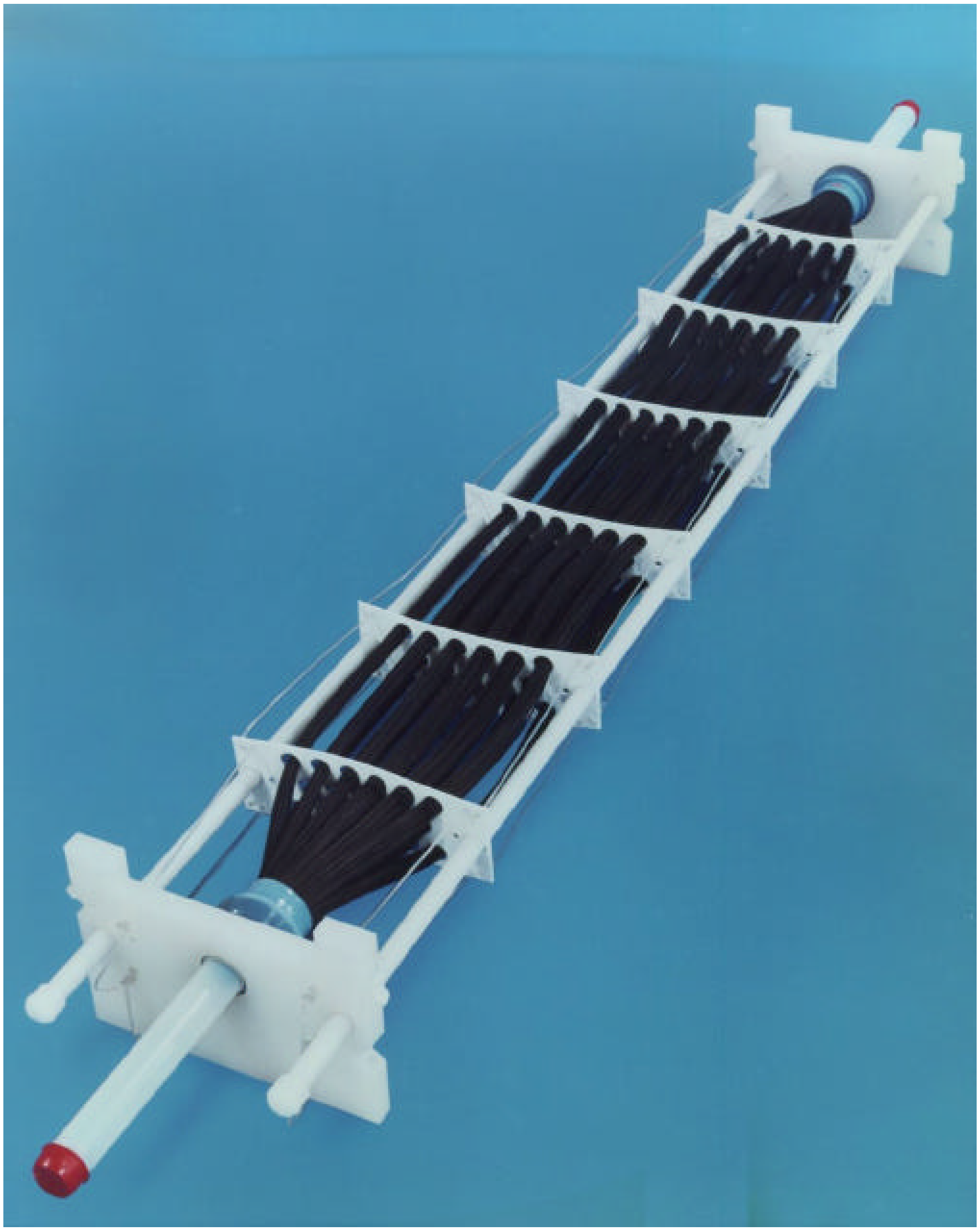

Figure 2.6.2 – TEFLON Heating Coil
(Courtesy of Ametek)

2.6.2.4 Operating Limits

Process stream temperatures are restricted to less than 200°C

2.6.2.5 Applications

These specialist exchangers are used for corrosive process streams, such as hydrochloric acid, or for abrasive process streams.