The theory behind heat transfer

Plate heat exchangers

Inside view

Heat transfer theory

The natural laws of physics always allow the driving energy in a system to flow until equilibrium is reached. Heat leaves the warmer body or the hottest fluid, as long as there is a temperature difference, and will be transferred to the cold medium.

A heat exchanger follows this principle in its endeavour to reach equalization. With a plate type heat exchanger, the heat penetrates the surface, which separates the hot medium from the cold one very easily. It is therefore possible to heat or cool fluids or gases which have minimal energy levels. The theory of heat transfer from one media to another, or from one fluid to another, is determined by several basic rules.

- Heat will always be transferred from a hot medium to a cold medium.
- There must always be a temperature difference between the media.
- The heat lost by the hot medium is equal to the amount of heat gained by the cold medium, except for losses to the surroundings.

Heat exchangers
A heat exchanger is a piece of equipment that continually transfers heat from one medium to another.

There are two main types of heat exchangers.

- Direct heat exchanger, where both media are in direct contact with each other. It is taken for granted that the media are not mixed together.

An example of this type of heat exchanger is a cooling tower, where water is cooled through direct contact with air.

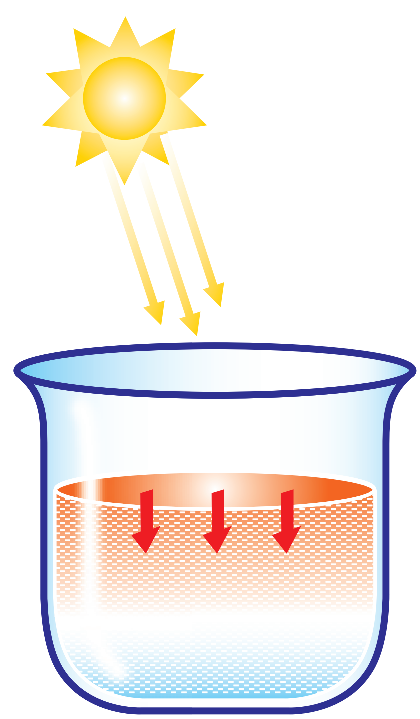
- Indirect heat exchanger, where both media are separated by a wall through which heat is transferred.

Heat transfer theory
Heat can be transferred by three methods.

- **Radiation** – Energy is transferred by electromagnetic radiation. One example is the heating of the earth by the sun.
- **Conduction** – Energy is transferred between solids or stationary fluids by the movement of atoms or molecules.
- **Convection** – Energy is transferred by mixing part of a medium with another part.

a) Natural convection, where the movement of the media depends entirely upon density difference, and temperature differences are evened out.

b) Forced convection, where the movement of the media depends entirely or partly upon the results of an outside influence. One example of this is a pump causing movement in a fluid.



Radiation

Heat exchanger types

In this brochure only indirect heat exchangers are discussed, i.e. those where the media are not mixed, but where the heat is transferred through heat transfer surfaces.

Temperature losses through radiation can be disregarded when considering heat exchangers in this brochure. Indirect heat exchangers are available in several main types (plate, shell-and-tube, spiral etc.) In most cases the plate type is the most efficient heat exchanger. Generally it offers the best solution to thermal problems, giving the widest pressure and temperature limits within the constraint of current equipment. The most notable advantages of a plate heat exchanger are:

- Takes up much less space than a traditional shell-and-tube heat exchanger.

- Thin material for the heat transfer surface – this gives optimum heat transfer, since the heat only has to penetrate thin material.

- High turbulence in the medium – this gives a higher convection, which results in efficient heat transfer between the media. The consequence of this higher heat transfer coefficient per unit area is not only a smaller surface area requirement but also a more efficient operation.

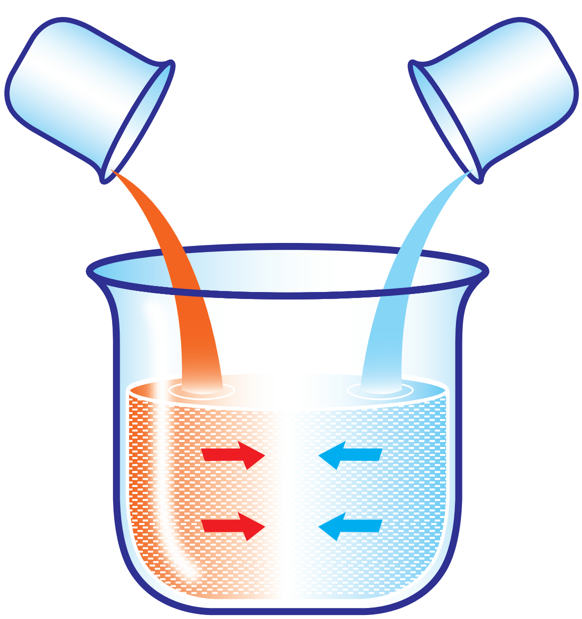
The high turbulence also gives a self-cleaning effect. Therefore, when compared to the traditional shell-and-tube heat exchanger, the fouling of the heat transfer surfaces is considerably reduced. This means that the plate heat exchanger can remain in service far longer between cleaning intervals.

- Flexibility – the plate heat exchanger consists of a framework containing several heat transfer plates. It can easily be extended to increase capacity. Furthermore, it is easy to open for the purpose of cleaning. (This only applies to gasketed heat exchangers, and not to brazed or fusion bonded units.)

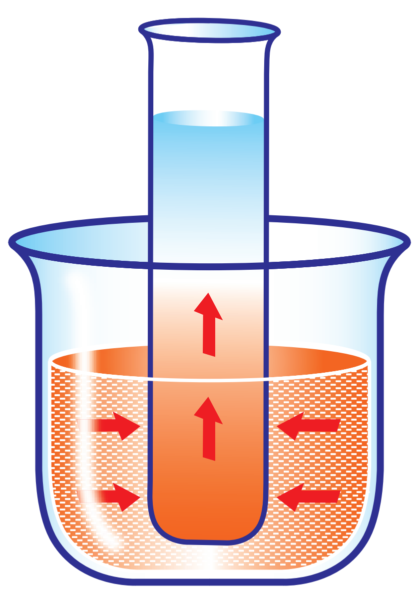
- Variable thermal length – most of the plate heat exchangers manufactured by Alfa Laval are available with two different pressing patterns. When the plate has a narrow pattern, the pressure drop is higher and the heat exchanger is more effective. This type of heat exchanger has a long thermal channel.

When the plate has a wide pattern, the pressure drop is smaller and the heat transfer coefficient is accordingly somewhat smaller. This type of heat exchanger has a short thermal channel.

When two plates of different pressing patterns are placed next to each other, the result is a compromise between long and short channels as well as between pressure drop and effectiveness.

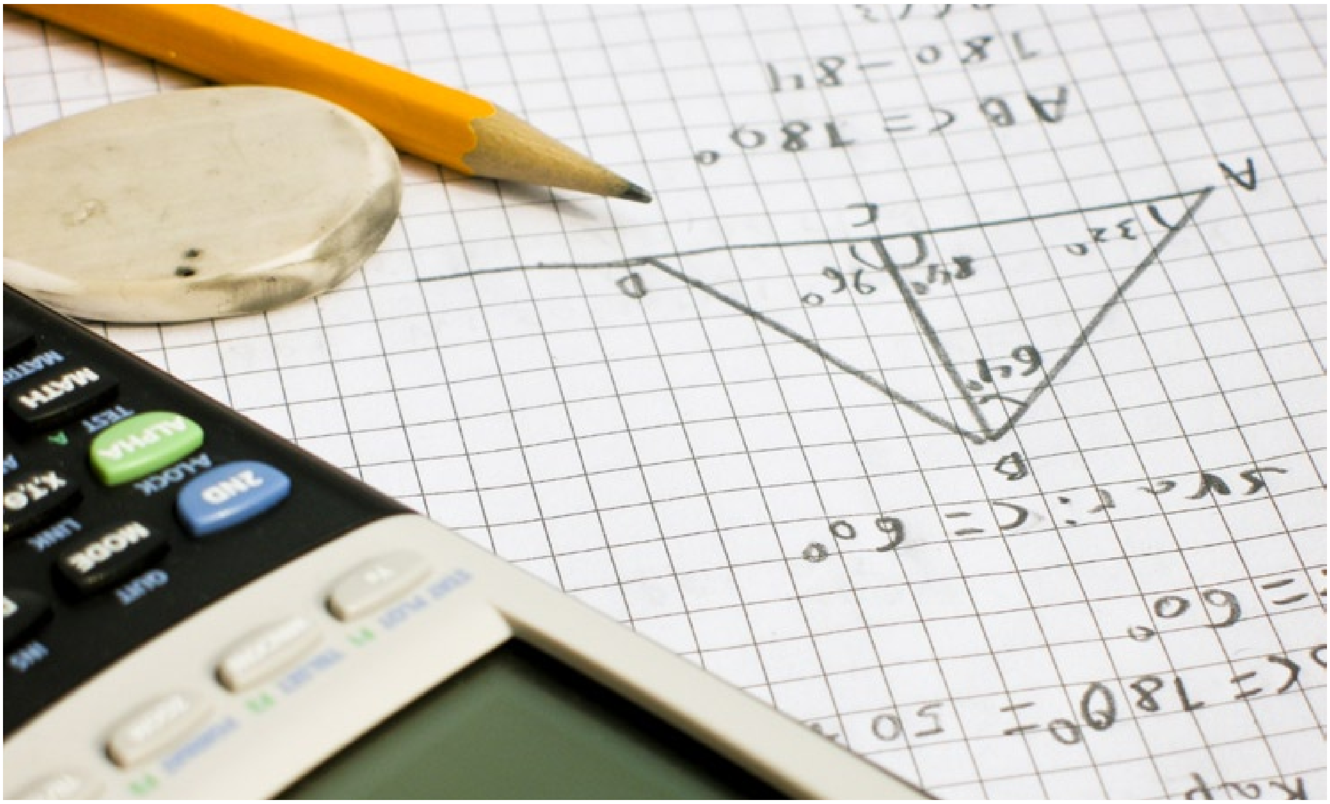


Convection



Conduction

Calculation method



To solve a thermal problem, we must know several parameters. Further data can then be determined. The six most important parameters are as follows:

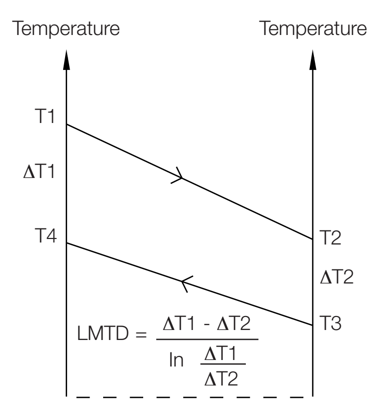
- The amount of heat to be transferred (heat load).
- The inlet and outlet temperatures on the primary and secondary sides.
- The maximum allowable pressure drop on the primary and secondary sides.
- The maximum operating temperature.
- The maximum operating pressure.
- The flowrate on the primary and secondary sides.

If the flow rate, specific heat and temperature difference on one side are known, the heat load can be calculated. See also page 6.

Temperature program
This means the inlet and outlet temperatures of both media in the heat exchanger.

T1 = Inlet temperature – hot side
T2 = Outlet temperature – hot side
T3 = Inlet temperature – cold side
T4 = Outlet temperature – cold side

The temperature program is shown in the diagram below.



Heat load
Disregarding heat losses to the atmosphere, which are negligible, the heat lost (heat load) by one side of a plate heat exchanger is equal to the heat gained by the other. The heat load (P) is expressed in kW or kbtu/h.

Logarithmic mean temperature difference
Logarithmic mean temperature difference (LMTD) is the effective driving force in the heat exchanger. See diagram to the left.

Thermal length
Thermal length (Θ) is the relationship between temperature difference δt on one side and LMTD.

$$\Theta = \frac{\delta t}{LMTD}$$

Thermal length describes how difficult a duty is from a thermal perspective.

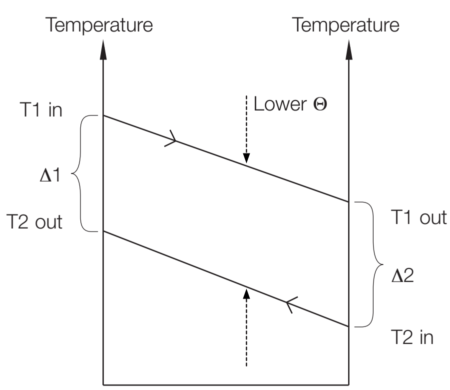
Density
Density (ρ) is the mass per unit volume and is expressed in kg/m^3 or lb/ft^3.

Cooling

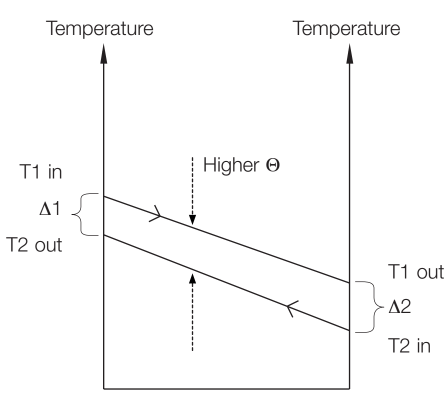
For some duties, cooling applications for example, the temperature program is very tight with close approaches on the different temperatures. This gives what we refer to as high theta duties and requires high theta units. High theta duties are duties that have Θ > 1 and are characterized by:

- Long plate, longer time for the fluid to be cooled
- Low pressing depth that gives less fluid per plate to be cooled

Plate heat exchangers are superior compared to shell-and-tube heat exchangers when it comes to theta values. Shell-and-tube heat exchangers can go up to a maximum value of theta ~1 while plate heat exchangers goes up to theta values of 10 and more. For a shell-and-tube to climb over theta value of 1 or more, several shell-and-tube needs to be put in series.



The diagram shows that large temperature differences give low theta.



The diagram shows that small temperature differences give large theta.

Flow rate

This can be expressed in two different terms, either by weight or by volume. The units of flow by weight are in lb/h or kg/h, the units of flow by volume in m^3/h or gpm. To convert units of volume into units of weight, it is necessary to multiply the volume flow by the density.

The maximum flow rate usually determines which type of heat exchanger is the appropriate one for a specific purpose. Alfa Laval plate heat exchangers can be used for flow rates from 400 lb/hr to 11,110,000 lb/hr. In terms of volume, this equates to 0.8 gpm to 22,000 gpm in a water application. If the flow rate is in excess of this, please consult your local Alfa Laval representative.

Pressure drop

Pressure drop (Δp) is in direct relationship to the size of the plate heat exchanger. If it is possible to increase the allowable pressure drop, and incidentally accept higher pumping costs, then the heat exchanger will be smaller and less expensive. As a guide, allowable pressure drops between 3 and 14.5 psi are accepted as normal for water/water duties.

Specific heat

Specific heat (c_p) is the amount of energy required to raise 1 lb of a substance by one degree fahrenheit. The specific heat of water at 68°F is 1.0 btu/lb °F.

Viscosity

Viscosity is a measure of the ease of flow of a liquid. The lower the viscosity, the more easily it flows.

Viscosity is expressed in centiPoise (cP) or centiStoke (cSt).

Overall heat transfer coefficient

Overall heat transfer coefficient (k) is a measure of the resistance to heat flow, made up of the resistances caused by the plate material, amount of fouling, nature of the fluids and type of exchanger used.

Overall heat transfer coefficient is expressed as W/m^2 °C or Btu/ft^2, h, °F.

$$P = m \times c_p \times \delta t$$

Where;

P = Heat load (btu/h)

m = Mass flow (lb/hr)

c_p = Specific heat (btu/lb °F)

δt = Difference between inlet and outlet temperatures on one side (°F)

Calculation method

The heat load of a heat exchanger can be derived from the following two formulas:

1. Heat load, Theta and LMTD calculation

$$P = m \cdot c_p \cdot \delta t \quad (m = \frac{P}{c_p \cdot \delta t}\ ;\ \delta t = \frac{P}{m \cdot c_p})$$

$$P = k \cdot A \cdot LMTD$$

Where:

P = heat load (btu/h)
m = mass flow rate (lb/h)
c_p = specific heat (btu/lb °F)
δt = temperature difference between inlet and outlet on one side (°F)
k = heat transfer coefficient (btu/ft^2 h °F)
A = heat transfer area (ft^2)
LMTD = log mean temperature difference

$$\Theta = \text{Theta-value} = \frac{\delta t}{LMTD} = \frac{k \cdot A}{m \cdot c_p}$$

T1 = Temperature inlet – hot side
T2 = Temperature outlet – hot side
T3 = Temperature inlet – cold side
T4 = Temperature outlet – cold side

LMTD can be calculated by using the following formula, where $\Delta T1 = T1–T4$ and $\Delta T2 = T2–T3$

$$LMTD = \frac{\Delta T1 - \Delta T2}{\ln \frac{\Delta T1}{\Delta T2}}$$

2. Heat transfer coefficient and design margin

The total overall heat transfer coefficient k is defined as:

Where: $$\frac{1}{k} = \frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \frac{\delta}{\lambda} + R_f = \frac{1}{k_c} + R_f$$

The design margin (M) is calculated as: $M = \frac{k_c - k}{k}$

α_1 = The heat transfer coefficient between the warm medium and the heat transfer surface (btu/ft^2 h °F)
α_2 = The heat transfer coefficient between the heat transfer surface and the cold medium (btu/ft^2 h °F)
δ = The thickness of the heat transfer surface (ft)
R_f = The fouling factor (ft^2 h °F/btu)
λ = The thermal conductivity of the material separating the medias (btu/ft^2 h °F)
k_c = Clean heat transfer coefficient (R_f=0) (btu/ft^2 h °F)
k = Design heat transfer coefficient (btu/ft^2 h °F)
M = Design Margin (%)

Combination of these two formulas gives: $M = k_c \cdot R_f$

i.e the higher k_c value, the lower R_f-value to achieve the same design margin.

Every parameter in the equation beside can influence the choice of heat exchanger. The choice of materials does not normally influence the efficiency, only the strength and corrosion properties of the unit.

In a plate heat exchanger, we have the advantages of small temperature differences and plate thicknesses of between 0.3 and 0.6 mm. The alpha values are products of the very high turbulence, and the fouling factor is usually very small. This gives a k-value which under favourable circumstances can be in the order of 1,400 btu/ft^2 h °F.

With traditional shell-and-tube heat exchangers, the k-value will be below 440 btu/ft^2 h °F.

Important factors to minimize the heat exchanger cost:

1. Pressure drop
The larger allowed pressure drop the smaller heat exchanger.

2. LMTD
The larger the temperature difference between the medias is, the smaller the heat exchanger will be.

$$\mathrm{LMTD} = \frac{\Delta T1 - \Delta T2}{\ln \frac{\Delta T1}{\Delta T2}}$$

$$\frac{1}{k} = \frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \frac{\delta}{\lambda} + R_f = \frac{1}{k_c} + R_f$$

Construction materials
High quality AISI 316 stainless steel plates are used in most Alfa Laval heat exchangers for water/water applications. When the chloride content as shown in the tables on page 9 does not require AISI 316, the less expensive stainless steel material AISI 304 may sometimes be used. Several other plate materials are also available for various applications. For Alfa Laval brazed and fusion bonded plate heat exchangers AISI 316 is always used. For salt water and brackish water only titanium should be used.

Pressure and temperature limitations
The maximum allowed temperature and pressure influence the cost of the heat exchanger. As a general rule, the lower the maximum temperature and maximum pressure are, the lower the cost of the heat exchanger will be.

Fouling and fouling factors
Fouling allowance can be expressed either as a design margin (M), i.e. an additional percentage of heat transfer area, or as a fouling factor (R_f) expressed in the units m^2 °C/W or ft^2 h °F/btu. R_f should be much lower for a plate heat exchanger than for a shell-and-tube exchanger. There are two main reasons for this.

1. Higher k-values means lower fouling factors.
The design of plate heat exchangers gives much higher turbulence, and thereby thermal effeciency, than a shell-and-tube exchanger. A typical k-value (water/water) for a plate heat exchanger is 1050-1300 btu/ft^2 h °F while a typical shell-and-tube exchanger gives only 350-440 btu/ft^2 h °F. A typical R_f-value used for shell-and-tube exchangers is 5.68 ft^2 h °F/btu. With k-values 350-440 btu/ft^2 h °F this gives a Margin of 20-25%. ($M = k_c \times R_f$). To achieve M = 20-25% in the plate heat exchanger with 1050-1300 btu/ft^2 h °F the R_f-value should only be 1.87×10^{-4} ft^2 h °F/btu.

2. Difference in how margin is added.
In a shell-and-tube heat exchanger margin is often added by increasing the tube length, keeping the same flow through each tube. In a plate heat exchanger however, margin is added by adding parallell channels, i.e. lowering the flow per channel resulting in lower turbulence/efficiency, increasing the risk for fouling. A too high fouling factor can result in increased fouling!

For a plate heat exchanger in a water/water duty a margin of 0-15% depending on water quality is normally enough.

Product range

The plate heat exchangers in this brochure are suitable for the majority of relatively uncomplicated heat transfer jobs using water, oil or glycol as the media. When it comes to the effectiveness of heat transfer and economical operation, the plate heat exchanger is unsurpassed in HVAC, refrigeration, sanitary water heating as well as industrial heating and cooling applications.

The Alfa Laval product range of plate heat exchangers is extensive. From the largest units with maximum surfaces up to 32,300 ft^2 and flow rates of approximately 22,000 gpm to smaller units with maximum heat transfer areas of less than 11 ft^2 and flow rates from 0.8 gpm.

Every single heat exchanger in the catalogue can perform a range of duties. Applications include the heating and cooling of different fluids in factories, HVAC applications, process cooling, components in air conditioning equipment etc. The list of applications is considerable. Not all types of our plate heat exchangers are included in this brochure. If you require more information, please do not hesitate to contact us.

Gasketed plate heat exchangers

Brazed plate heat exchangers

Fusion-bonded plate heat exchangers

Applications

Although the principle of heat transfer is the same irrespective of the medium used, we must differentiate the applications from each other. Most duties fall into three main applications:

Water/Water

The largest part of our production of heat exchangers is used for water/water duties, i.e. water heated or cooled with water. This can be achieved by different methods:

Water must be cooled
Here, water with a lower temperature is used, for example from a cooling tower, lake, river or sea.

Water must be heated
Here, water with a higher temperature is used, for example district heating, boiler or hot process water.

Some typical uses of plate heat exchangers

- District heating/cooling
- Tap water heating
- Swimming pool heating
- Heat recovery (engine cooling)
- Temperature control of fish farms
- Steel industry – furnace cooling
- Power industry – central cooling
- Chemical industry – process cooling

Plate material	Maximum temperature °F			
Chloride content (ppm)	140°F	176°F	212°F	248°F
10 ppm	304	304	304	316
25 ppm	304	304	316	316
50 ppm	316	316	316	Ti
80 ppm	316	316	316	Ti
150 ppm	316	Ti	Ti	Ti
300 ppm	Ti	Ti	Ti	Ti
Gasket material	Nitrile	Nitrile	Nitrile	
	EPDM	EPDM	EPDM	EPDM

Water/Oil

In some industries, oil has to be cooled using water. This water can then be connected to a heat recovery system recovering the heat from the oil to various usages, such as tap water heating etc.

Some typical uses of plate heat exchangers

- Hydraulic oil cooling
- Quench oil cooling
- Cooling of motor oil in engine test beds

With synthetic oil it may be necessary to use special gaskets. Please contact Alfa Laval for these applications.

Plate heat exchangers can function with oils having viscosities as high as 2,500 centiPoise. Emulsions can also be used in plate heat exchangers, and can be treated like water when concentrations are below 5%.

Plate material	Maximum temperature °F			
Chloride content (ppm)	140°F	176°F	212°F	248°F
10 ppm	304	304	304	316
25 ppm	304	304	316	316
50 ppm	316	316	316	Ti
80 ppm	316	316	316	Ti
150 ppm	316	Ti	Ti	Ti
300 ppm	Ti	Ti	Ti	Ti
Gasket material	Nitrile	Nitrile	Nitrile	

Water/Glycol

When there is a risk of freezing, add glycol to the water.

Glycol has a different heat capacity from water and therefore needs a somewhat larger heat transfer area to perform the same duty. On the other hand, the physical properties of the various glycols are much the same. Examples of glycols are:

- Ethylene glycol (mono, di or tri)
- Propylene glycol.

Some typical uses of plate heat exchangers

- As an intercooler in a heat pump
- Chilled water production in food factories
- Cooling of air conditioning circuits
- Solar heating systems

Plate material	Maximum temperature °F			
Chloride content (ppm)	140°F	176°F	212°F	248°F
10 ppm	304	304	304	316
25 ppm	304	304	316	316
50 ppm	316	316	316	Ti
80 ppm	316	316	316	Ti
150 ppm	316	Ti	Ti	Ti
300 ppm	Ti	Ti	Ti	Ti
Gasket material	Nitrile	Nitrile	Nitrile	
	EPDM	EPDM	EPDM	EPDM

Plate heat exchanger construction

A plate heat exchanger consists of a number of heat transfer plates which are held in place between a fixed plate and a loose pressure plate to form a complete unit. Each heat transfer plate has a gasket arrangement which provides two separate channel systems.

The arrangement of the gaskets (field and ring gaskets) results in through flow in single channels, so that the primary and secondary media are in counter-current flow. The media cannot be mixed because of the gasket design.

The plates are corrugated, which creates turbulence in the fluids as they flow through the unit. This turbulence, in association with the ratio of the volume of the media to the size of heat exchanger, gives an effective heat transfer coefficient.

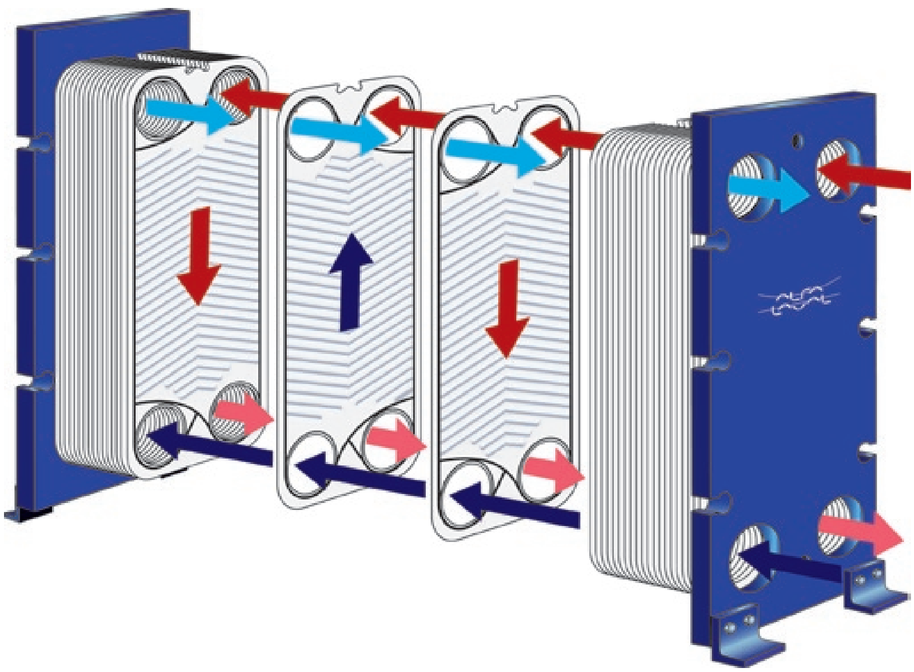


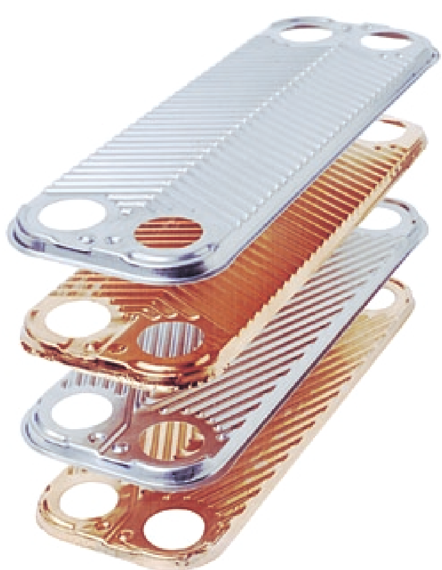
Plate heat exchanger components
The components consist of a fixed end plate, connections and a loose pressure plate, with carrier bars mounted between them. The plates are hung from the top carrier bar. The carrier bars also serve to position the heat transfer plates. The single plates are pulled together to form a plate pack by means of tightening bolts.

Gasketed plate heat exchangers are available in standard sizes or can be individually prepared.

Gaskets

Materials available

Nitrile rubber	general purpose, oil resistant
EPDM	general purpose, elevated temperatures
HeatSealF™	for high temperatures, specially heating by steam



Brazed plate heat exchangers
A brazed plate heat exchanger is small, light and compact. It does not need gaskets. Instead, it is brazed together using copper to give a strong, compact construction.

This heat exchanger is especially suitable for pressures up to 725 psi and temperatures from -320°F to 1022°F.

Fusion-bonded plate heat exchanger
AlfaNova is a new type of plate heat exchanger constructed of 100% stainless steel using AlfaFusion. A unique bonding technology that provides high temperature resistance (up to 1022°F) and an exceptional level of hygiene. Copper-free, AlfaNova offers unmatched corrosion resistance.

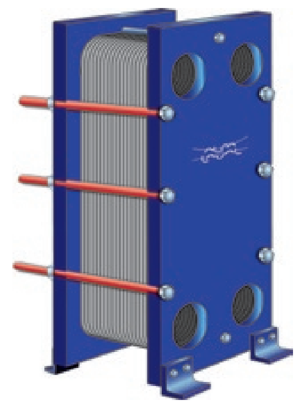
Assembly

Alfa Laval delivers your heat exchanger assembled and pressure tested. Gasketed heat exchangers can easily be opened for inspection and cleaning. Should the capacity requirements change in the future, additional plates can easily be hung in the frame on site.

The following sketches show assembly step by step:

1. The frame is put together. It consists of frame and pressure plates, top and bottom carrying bars and connections. The end plate is the first plate to be hung in the frame.

2. Then the plates corresponding to the platage specification are positioned in the frame.



3. The tightening bolts are fitted and the plate pack is tightened by means of a spanner or any other suitable tool to a set measure (specified in the platage specification).

Installation

All the heat exchangers in this brochure have the connections in the frame plate. They are referred to as S1, S2, S3 and S4.

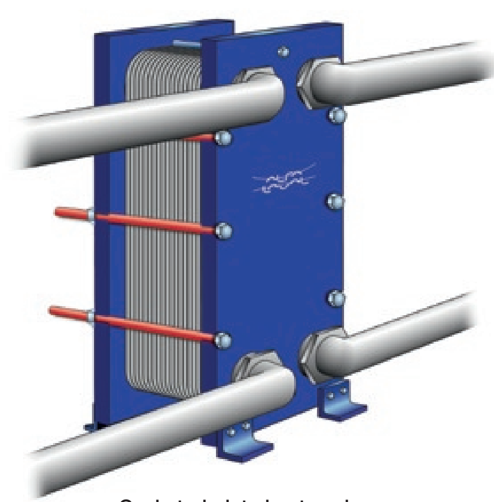
The gasketed heat exchanger can be placed directly on the floor. When possible, it is always safer to secure the unit with foundation bolts. The plate heat exchanger is noted for occupying less space than traditional heat exchangers. When planning the space recommended, it is necessary to leave space on one side of the heat exchanger only. The pipe connections can be either screwed or flanged, depending on the type of heat exchanger selected.

The brazed plate heat exchanger will normally be built into the pipework, or mounted into a small console.

The inlet of one medium is next to the outlet of the other. If S1 is the inlet for medium 1, then S4 is the outlet for medium 2. Every heat exchanger delivered is accompanied by instructions as to which inlet and outlet to use.

Depending upon the type of connection selected, prepare the pipework with screwed thread ends, fit flanges or prepare for welding.

Some of the accessories available for the Alfa Laval plate heat exchangers are insulation, drip trays and protection sheets.



Gasketed plate heat exchanger standing directly on the floor.

Alfa Laval in brief

Alfa Laval is a leading global provider of specialized products and engineered solutions.

Our equipment, systems and services are dedicated to helping customers to optimize the performance of their processes. Time and time again.

We help our customers to heat, cool, separate and transport products such as oil, water, chemicals, beverages, foodstuffs, starch and pharmaceuticals.

Our worldwide organization works closely with customers in almost 100 countries to help them stay ahead.

How to contact Alfa Laval

Up-to-date Alfa Laval contact details for all countries are always available on our website at www.alfalaval.com

ECF00250EN 1009