
# The PRESSURE DROP

**S. Gavelin, Tranter International AB, Sweden, looks at pressure drop requirements for plate heat exchangers.**

Plate heat exchangers (PHE) contribute to considerable energy savings both upstream and downstream in many different hydrocarbon processes, but whatever the application, there is one characteristic that they nearly all share. Any technical meeting between a process engineer and a heat exchange design specialist is likely to involve a discussion about the value of the pressure drop across the heat exchanger. Process engineers prefer to keep the pressure drop as low as possible to reduce pumping cost and maintain the right suction pressure downstream of the heat exchanger, while heat exchanger designers aim to provide a solution that minimises future operating problems and heat transfer area and that is often only achievable with a relatively high pressure drop.

The heat transfer requirements clearly have to be met in the design of any PHE and the way this is done depends on the relative importance placed on cost, physical size and pressure drop. By forcing the fluids through the heat exchanger at higher flow rates, the overall heat transfer coefficient (U value) might be increased, but this also results in a higher pressure drop through the heat exchanger and correspondingly higher pumping costs. If the surface area of the heat exchanger is increased the U value and hence the pressure drop does not need to be so high; however, there may be limitations on the physical size that can be accommodated and a larger physical size results in a higher cost for the heat exchanger.

## Relation between heat transfer and pressure drop

Reynolds' analogy is based on similarities between heat transfer and fluid friction (which causes the pressure drop). The simple analogy is correct only for fluids with Prandtl numbers equal to one. The Prandtl number expresses the relative magnitude of diffusion of momentum and heat in the fluid and thus a Prandtl number of one is an assumption that the heat and momentum are transported at the same rate. This is not applicable to plate heat exchangers as the flow is generally turbulent with random transportation of heat and momentum. The simple Reynolds analogy may be modified to yield the Colburn (j/f) approach (Equation 1), which gives an approximate rationalisation over a wide range of Prandtl numbers.

$$j = St\,\mathrm{Pr}^{2/3} = \frac{Nu}{\mathrm{Re}\,\mathrm{Pr}^{1/3}} = \frac{f}{2} \tag{1}$$

For this approach the surface performance is assumed to be describable by Colburn (j) factor and Fanning friction factor (f) as functions of Reynolds number. The pressure drop of a fluid through a surface is given in terms of the Fanning friction factor by the definition:

$$\Delta p = \frac{1}{2}\rho u^2 \frac{4L}{d_h} f,\ where\{f = f(\mathrm{Re})\} \tag{2}$$

Inserting this expression in Equation 1 gives:

$$j = \frac{\Delta p d_h}{4\rho u_m^2 L} = \frac{Nu}{\mathrm{Re}\,\mathrm{Pr}^{1/3}} \tag{3}$$

This means that the surface heat transfer coefficient could be estimated from pressure drop measurements. However, the pressure drop in Equation 3 is only referring to the wall friction pressure drop, not the static or the momentum pressure drop. Furthermore the actual relation between heat transfer and pressure drop is in reality far more complicated and a rigorous development of the Reynolds analogy involves considerations beyond the scope of this article. Thus the simple path of reasoning chosen here is for the purpose of indicating the general nature of the physical processes. For calculation purposes, the common relation to use for turbulent flow in a smooth channel is the equation on the form:

$$Nu = C\,\mathrm{Re}^x\,\mathrm{Pr}^y\left(\frac{\mu_{bulk}}{\mu_{wall}}\right)^a \Rightarrow \alpha = C\,\mathrm{Re}^x\,\mathrm{Pr}^y\left(\frac{\mu_{bulk}}{\mu_{wall}}\right)^a \frac{k}{d_h} \tag{4}$$

$$\Delta p = \frac{1}{2}\rho u^2 \frac{4L}{d_h} f\left(\frac{\mu_{wall}}{\mu_{bulk}}\right)^b,\ where\{f = f( \tag{5}$$

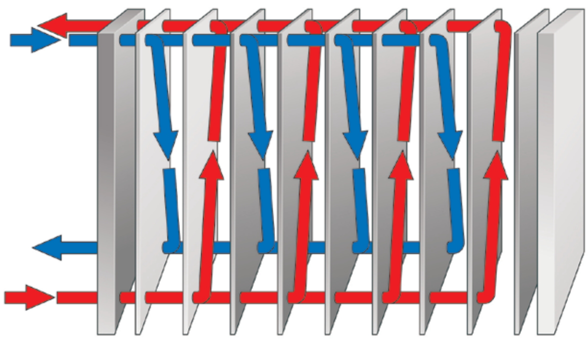


*Figure 1. Manifold pressure and flow distribution (example only).*

Where (a), (b), (x) and (y) are empirical constants specific for a certain plate and a certain Reynolds number range. This specific correlation is recognised as a modification of the well known Dittus-Boelter correlation. It is the most common type of heat transfer correlation for plate heat exchangers found in literature, even though the constants are different, and the exponents on the Prandtl number and the viscosity ratio are often constants. The constants and exponents are fitted to experimental data for each heat exchanger. This is an important point, since all analyses of turbulent flow must eventually rely on experimental data because there is no completely adequate theory to predict turbulent flow behaviour. Here the importance of reliable manufacturer test data cannot be underestimated.

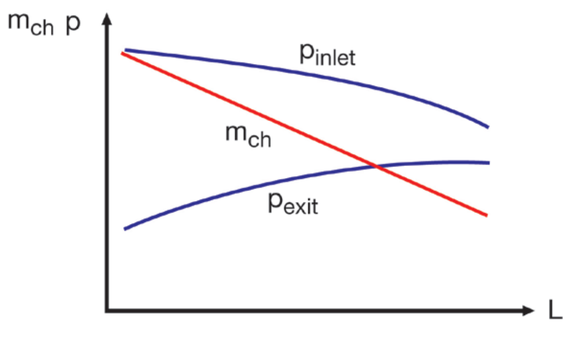
## Relation between fouling and pressure drop

After a period of operation, the heat transfer surfaces for a plate heat exchanger might become coated with various deposits present in the process fluids. The coating represents an additional resistance to the heat transfer, and thus results in decreased performance which can lead to troubles in meeting the process requirements. The overall effect is usually represented by a fouling factor, which is added to the other thermal resistances making up the overall heat transfer coefficient. Fouling factors must rely on experiments which aim to determine the values of U for both clean and dirty conditions in the heat exchanger. The fouling factor can thus be defined on the form shown in Equation 6.

$$R_f = \frac{1}{U_{dirty}} - \frac{1}{U_{clean}} \tag{6}$$

Very often there is confusion among process engineers as to exactly what fouling factors should be used for plate heat exchangers. The fouling factors developed for shell and tube heat exchangers are therefore often specified. However, investigations have shown that these values do not give good results in plate heat exchangers since they often result in highly over sized units, which will result in premature fouling. Bear in mind that regardless of fluid type, a plate heat exchanger will have a corrugated pattern that facilitates higher turbulence, yielding more efficiency and will always clean more easily than a shell and tube unit. It is therefore recommended to size the unit with a certain shear rate (Equation 7) rather than applying fouling factors.

$$f = \frac{2\tau_0}{\rho u_m^2} \Rightarrow \{f = eq.2\} \Rightarrow \tau_0 = \frac{\Delta p d_h}{4L} \tag{7}$$



It is not recommended to size a unit with a shear rate below 50 Pa but, as indicated in Equation 7, it is not possible to achieve this without the corresponding pressure drop. With further increased risk for fouling or when fouling must be avoided, the shear stress value should be increased to at least 100 Pa or higher. If the pressure drops corresponding to these shear rates are not available, it is recommended to follow the guidelines in API 662, which recommends a minimum 10% fouling margin based on the ratio between $U_{clean}$ and $U_{dirty}$ defined in Equation 6. The actual fouling factors can of course be specified directly, but experience has shown that it is very hard to predict them in an accurate way.

The heat exchanger performance has a strong impact on the pump operation efficiency and the following example aims to describe this in terms of degree of fouling. A pump is usually designed to operate at its best efficiency point and the heat exchanger performance has a great impact on this point. The operating point is the intersection of the pump characteristic curve and the load curve, which in this case is assumed to be just determined by the heat exchanger. If fouling is encountered, the operating point will move along the pump curve and might go beyond the region of best efficiency which will increase the amount of energy needed to operate the whole system and thereby increase the operational cost.

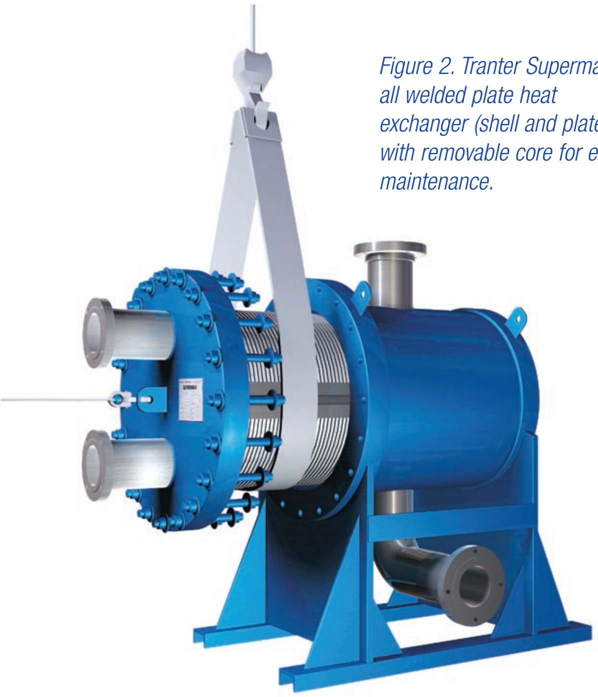


*Figure 2. Tranter Supermax all welded plate heat exchanger (shell and plate) with removable core for easy maintenance.*

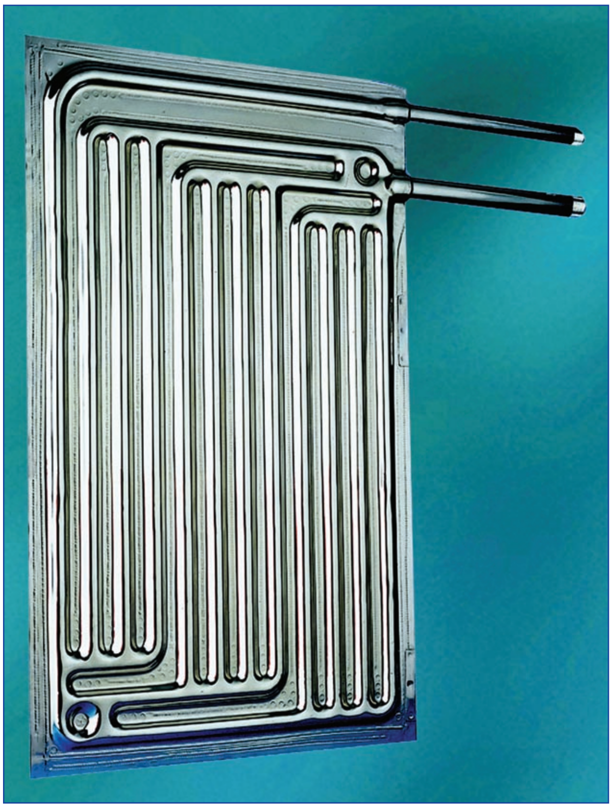


*Figure 3. Tranter plate coil all welded heat exchanger suitable for bunker oil heating.*

## Relation between maldistribution and pressure drop

The flow distribution between the plates in a plate heat exchanger is highly dependent on the relative magnitude of port pressure drop and total pressure drop through the heat exchanger. The port pressure drop is said to be dependent on two things: fluid friction in the manifolds and the momentum changes occurring when the fluid is entering the manifolds from the corrugated channels and vice versa. The port pressure drop can be expressed in terms of the Reynolds number and thereby it is also important to bear in mind that the manifold velocities cannot be too high, as this will contribute to a higher degree of maldistribution. Figure 1 illustrates how the port pressure drop may influence the flow distribution.

A general rule of thumb for a proper design of the PHE, with acceptable maldistribution, is that the pressure drop over the port connection should not be greater than approximately 25% of the total pressure drop. If the heat exchanger is very tall, it is also necessary to take into account the pressure drop due to change in elevation when calculating the total pressure drop. With knowledge of the coupling between heat transfer and pressure drop, it is clear that the port pressure drop does not contribute to higher heat transfer coefficients; this pressure loss does not occur due to fluid friction in the plate channels. Therefore a high port pressure drop must also be avoided in order to decrease the surface area of the heat exchanger.

## Recent product developments and applications

Plate heat exchanger manufacturers offer a wide range of products and all of them have different characteristics in terms of pressure drop and heat transfer performance. Tranter has several in house plate heat exchanger sizing programmes for single phase and a range of specific two phase applications. The thermal and hydraulic performance predictions of these programmes are based on laboratory test results of each plate design. The laboratory also carries out thermal and mechanical fatigue testing and burst testing of all new products. The importance of reliable manufacturer test data has been described in the text and the following is a brief summary of the recent product/application development for plate heat exchangers.

Even though the general working principle is the same, constant product/application development is enabling a wider use of plate heat exchangers in hydrocarbon processes. The applications for gasketed units are well known so the area of

*Figure 4. Tranter Supermax shell and plate heat exchanger mounted in a propane recovery skid.*

focus for many manufacturers is the development of welded plate heat exchangers. These units have proven to withstand challenging process conditions with liquids, gases, steam and two phase mixtures, including aggressive media and organic solvents. Especially two applications, gas suction cooling and bunker oil heating are two areas where all welded plate heat exchangers could contribute to higher process efficiency and lower investment cost.

Tranter shell and plate unit is a fully welded design with excellent resistance to thermal and pressure fatigue. In addition, the footprint and weight is often several times smaller than other types of heat exchanger such as shell and tube units. The shell and plate design offers full maintainability with an option for removable plate-pack core via a bolted cover on one end of the shell. This allows the entire heat transfer surface to be changed out in a single maintenance shift. The core can be immersed in a chemical cleaning solution to recondition for future reinstallation. These features have shown to be advantageous in gas suction cooling duties onboard offshore platforms where the pressure/temperature are high and cyclic and space/weight is limited.

Tranter plate coil is also a welded design with the same working principle as a radiator. These die formed and resistance seam welded prime surface panels are frequently immersed in tanks and vessels with the heating or cooling medium passing through the cavity within the panel. The robust construction of Platecoil enables internal operating pressures up to 28 barg and external operating pressures to 70 bar. When used in tanks, the heat transfer is achieved by natural convection driven by density differences in the tank. Compared to conventional pipe technology this is very cost efficient considering cost for labour, maintenance and material. Space and weight is also significantly lower than any other type of equipment used for the duty.

As their advantages become more known, all welded plate heat exchangers are likely to take on additional duties in the hydrocarbon industry. Tranter works closely with engineering, procurement and construction (EPC) contractors to ensure that process parameters are selected to obtain the best performance of the PHE. Tranter's success has resulted in many installations in crude oil processing plants around the world.