Δ T HEAT EXCHANGERS
Phone: (519)471-2800
Fax: (519)471-8494
E-mail: sales@deltathx.com
1674 Hyde Park Rd., Suite 206, London, ON, Canada N6H 5L7

Fouling In Heat Exchangers

One of the most common operational challenges encountered with heat exchangers is fouling. Fouling is the buildup of sediments and debris on the surface area of a heat exchanger that inhibits heat transfer. Fouling will reduce heat transfer, impede fluid flow, and increase the pressure drop across the heat exchanger. As with many operational concerns, proper planning at the design stage can minimize the effects of fouling down the road.

Designers use fouling factors to maximize the lifespan, runtime and efficiency of a heat exchanger by accounting for the amount of fouling an exchanger will sustain over a period of time. This often results in increasing the surface area of a heat exchanger, so that fouling will not have as much of an effect. In many applications, such as refineries, heat exchangers will have to perform for several years without a cleaning. This means that the heat exchanger must be able to function efficiently for long periods of time. Compensating for fouling by enlarging surface area allows heat exchangers to function with years of fouling.

Types of Fouling

There are several types of fouling, each forming depending on the type of fluid and conditions. The following are some of the more common fouling mechanisms;

Crystallization is one of the most common type of fouling. Certain salts commonly present in natural waters have a lower solubility in warm water than cold. Therefore, when cooling water is heated during the cooling process (particularly at the tube wall) these dissolved salts will crystallize on the surface in the form of scale. [Common Solution: reducing the temperature of the heat transfer surface often softens the deposits]

Sedimentation, the depositing of dirt, sand, rust, and other small matter is also common when fresh water is used. This can be controlled to a degree by the heat exchanger design. [Common Solution: velocity control]

Biological Organic growth material occurs from chemical reactions, and can cause considerable damage when built up. [Common Solution: material selection]

Chemical Reaction Coking appears where hydrocarbon deposits in a high temperature application. [Common Solution: reducing the temperature between the fluid and the heat transfer surface]

Corrosion can destroy surface areas of the heat exchangers, creating costly damage. Fouling will slow down heat transfer and damage equipment unless it is dealt with accordingly. [Common Solution: material selection]

Freezing Fouling results from overcooling at the heat transfer surface causing solidification of some of the fluid stream components. [Common Solution: reducing the temperature gradient between the fluid and the heat transfer surface.]

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Fouling factor

The most common way to account for the effects of fouling in a tubular heat exchanger is the application of a *fouling factor*. The fouling factor is a predetermined number that represents the amount of fouling a particular heat exchanger transferring a particular fluid will sustain. In the heat transfer equation the fouling factor is added to the other thermal resistances to calculate the *Total Thermal Resistance* which is the reciprocal of U_{clean}. There is no direct calculation to determine the appropriate fouling factor to use for a given fluid in a particular application, however guidelines do exist to help determine an appropriate fouling factor. The most common compilation of fouling factors, to be used for a variety of fluid in various applications, is supplied by Tubular Exchanger Manufacturers Association (TEMA). The below table is a list of general fouling factors used for shell and tube heat exchangers and common fluids and applications.

Fluid	Fouling Resistance (ft^2-°F-hr/BTU)
Transformer Oil	0.001
Steam	0.0005
Compressed Air	0.001
Hydraulic Fluid	0.001
Glycol Solutions	0.002
Refined Lube Oil	0.001
Sea Water	0.0005 (up to 125°F) 0.001 (over 125°F)
Cooling Tower Water	0.001 (up to 125°F) 0.002 (over 125°F)
River Water (minimum) (tube velocity ≤ 3 fps)	0.002 (up to 125°F) 0.003 (over 125°F)
River Water (minimum) (tube velocity > 3 fps)	0.001 (up to 125°F) 0.002 (over 125°F)
River Water (average) (tube velocity ≤ 3 fps)	0.003 (up to 125°F) 0.004 (over 125°F)
River Water (average) (tube velocity > 3 fps)	0.002 (up to 125°F) 0.003 (over 125°F)
River Water (muddy or silty) (tube velocity ≤ 3 fps)	0.003 (up to 125°F) 0.004 (over 125°F)
River Water (muddy or silty) (tube velocity > 3 fps)	0.002 (up to 125°F) 0.003 (over 125°F)

Fouling and Plate Heat Exchangers

The manner in which fouling and fouling factors apply to plate exchangers is different from tubular heat exchangers. There is a high degree of turbulence in a plate heat exchanger which increases the rate of foulant removal and, in effect, make the plate heat exchanger less prone to fouling. In addition, there is a more uniform velocity profile in a plate heat exchanger than in most shell and tube heat exchanger designs eliminating zones of low velocity which are particularly prone to fouling.

Plate heat exchangers typically have a higher U factor than shell and tube heat exchangers and often significantly higher. It was previously described that in the heat transfer equation the Total Thermal Resistance is the reciprocal of U_{clean}, therefore the Total Thermal Resistance in a plate heat exchanger is often significantly less than the same application of a shell and tube heat exchanger. Applying a typical fouling factor developed for a shell and tube heat exchanger to a plate and frame design therefore will have a greater proportional effect on the U factor resulting in a greater overdesign of the exchanger. On the downside, due to the higher U factor and lower surface area, the development of fouling affects plate heat exchangers more significantly so controlling the development of fouling is very important in plate heat exchangers.

In most plate heat exchanger applications specifying a percent of excess surface is more practical than specifying the TEMA fouling factors described above.

Minimizing fouling

Fouling depends on the type of heat exchanger, and the kind of fluids being transferred. Due to different designs, composition, and transfer fluid, each type of heat exchanger will suffer fouling in unique ways. The tube side of a shell and tube heat exchanger is usually easy to clean but the shell side can be more difficult to access. Plate heat exchangers can be taken apart for cleaning on both sides. Some heat exchangers can be cleaned every night when the equipment is not in use, while others can only be cleaned every few months or years. In order to reduce the amount of fouling in a heat exchanger, equipment should be cleaned as often as possible.

If a plate heat exchanger were to suffer from the effects of fouling, extra plates can be added to re-gain performance if the space permits in the frame.

Design Considerations to Decrease Effects of Fouling

There are a number of accommodations a designer may use once they have figured out how much fouling to expect in a particular unit.

- A high level of turbulence keeps sediments from settling on the surface of the heat exchanger, and also helps clean off any fouling so it is important to ensure that the design velocities are high enough to mitigate fouling but not too high to promote erosion.

- Try to keep a uniformly high velocity throughout the entire exchanger, so that sediments are not able to settle. Keep the amount of low velocity turns and 'dead' spots to a minimum, so that fouling will not accumulate.

- Consider how often the unit needs to be cleaned, and provide easy access to make this process easier.

- For a plate heat exchanger, select a frame size that will accommodate additional plates in the case that more surface is needed because of a loss of performance due to the effects of fouling.

Excessive Fouling Factors

It seems that proper planning for the future and good design practice would result in the specification of a higher than required fouling factor for safety sake. Anticipating fouling is good practice, over-designing significantly however can actually facilitate fouling. Specifying too large a fouling factor will often result in more flow area that can result in lower velocities in the exchanger and actually promote fouling. Another risk is that an oversized exchanger operating clean will overperform and a possible reaction would be to reduce the cooling water flow which would reduce the velocity - promoting fouling. It is important with all heat exchangers to operate as close to the design flow conditions as possible.