Tech Sheet #141
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Plate Heat Exchanger Fouling

Definition of Heat Exchanger Fouling

Fouling is the degradation in heat transfer over time caused by material deposition on the heat transfer boundary walls of a heat exchanger. As shown in Figure 1, fouling is the reduction in the overall heat transfer coefficient (U value) over time due to this material build-up. The severity of fouling is a function of time and the difference between the clean and fouled overall heat transfer coefficient. Figure 2 shows a cross sectional diagram of a heat transfer boundary wall with fouling. The depositions on the heat transfer walls act as an insulating layer, thus reducing heat transfer. The deposits can be biological, salts, oxides, scales, emulsions, particulates or any combination thereof and are a function of the fluids, the process conditions in the heat exchanger, and the heat exchanger design itself. While fouling is primarily a heat transfer issue, some forms of fouling can also have an impact on heat exchanger pressure drop (hydraulics) by reducing the cross sectional flow area of the flow channel or by increasing the apparent surface roughness of the heat transfer wall. Closely related to fouling is plugging. Plugging is the obstruction of flow into the heat exchanger or plate channels caused by bulk material build-up. Plugging results in higher pressure drops, but not necessarily a reduction in heat transfer coefficients. Plugging is addressed by proper filtration, straining, and heat exchanger design and should be considered in addition to fouling.

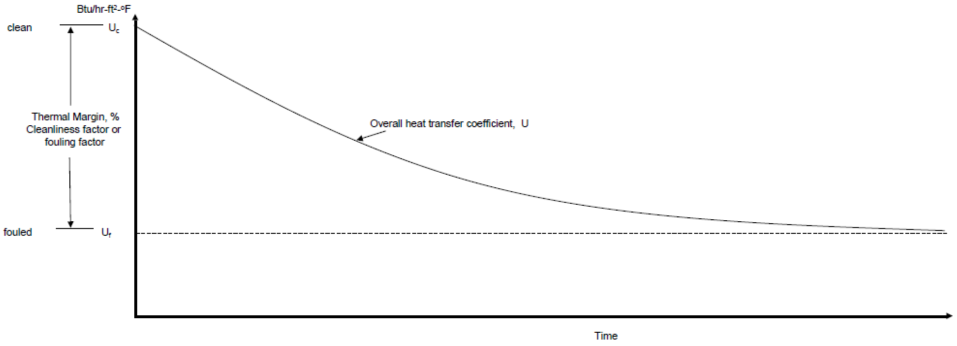

Figure 1. Diagram of fouling

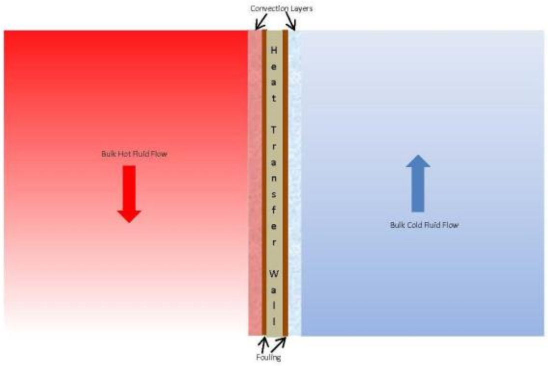

Figure 2. Heat transfer wall with fouling

Designing for Fouling

Once a heat transfer duty (Btu/hr) is defined by the process conditions, a heat exchanger can be designed. Prior to designing a heat exchanger though, many process issues must be considered including but not limited to fouling, type of heat exchanger, metallurgy, allowable pressure drops, corrosion allowance, design pressures, temperatures, and cleaning methodology. To design a heat exchanger, the following equation is used:

$$Q = U_f \times A \times LMTD \qquad \text{(Equation 1)}$$

Where

Q = the heat duty, BTU/hr, as calculated from fluid mass flow rates, specific heat, and temperature change

U_f = the overall fouled heat transfer coefficient, BTU/hr-ft^2-°F
= $1 / 1/U_c + ff$, where ff is the fouling factor and U_c is the clean heat transfer coefficient (Equation 2)
= $U_c/(1 + f_m\%)$, where $f_m\%$ is the fouling margin (also known as excess surface area margin) (Equation 3)
= $U_c \times c_f$, where c_f is the cleanliness factor (Equation 4)

A = heat transfer surface area, ft^2

LMTD = the corrected log mean temperature difference across the heat exchanger, °F.

In heat exchanger design, a fouled U value (U_f) is used in the design calculations in lieu of a theoretical clean U value to ensure that the heat exchanger transfers the required amount of heat, even in the dirty condition. U_f is calculated from the theoretical clean U value (U_c) per equations 2, 3 or 4. While different terminologies (fouling factors, fouling margins or cleanliness factors) can be used in industry to account for fouling in heat exchanger design, each fouling design method simply relates U_c to U_f. Designing for fouling ultimately results in using a larger heat exchanger (more heat transfer area than theoretically necessary in a clean condition) to ensure that the same heat exchanger will operate successfully in a dirty condition at some point in the future when the heat exchanger is operating in a fouled condition (operating with a fouled heat transfer coefficient, U_f).

Careful consideration of the fouling is required since it impacts the capital cost, operating cost, maintenance cost, and reliability of the heat exchanger. Fouling factors (or equivalent cleanliness factors or fouling margins) should be based on experience in the specific application, type of heat exchanger, and a reliability analysis. Significant over-surfacing or using excessive fouling factors can result in an uneconomical heat exchanger design, poor process operation and control, and a higher potential for fouling due to lower velocities. For some applications, such as closed cooling water (CCW) heat exchangers, plant thermal margin stack-ups should be evaluated since the CCW heat exchanger duties are a summation of many plant heat exchangers which also have thermal margins.

Fouling Considerations in Plate Heat Exchangers (PHE's)

The rate at which fouling occurs is the difference between the deposition rate (how fast the deposits build up) and the removal rate (how fast the deposit can be removed). While the deposition rate is a function of process conditions, fluid properties, wall temperatures, and heat transfer wall surface roughness, the removal rate of fouling is primarily a function of the wall shear stresses that the fluid exerts on the heat transfer wall. As a fluid flows over the heat transfer wall, it exerts a shear force. This shear force acting over the heat transfer surface area is the wall shear stress and it is directly proportional to the pressure drop taken in the heat exchanger. A high wall shear stress will increase the removal rate of fouling and thus help minimize the potential for fouling in a shear sensitive fouling situation. While all types of fouling may not be shear sensitive, many types of fouling are shear sensitive and can be minimized by increasing the fluid shear stresses in the heat exchanger.

Plate Heat Exchangers (PHE's) use corrugated plates and narrow flow channels to generate turbulence and high wall shear stresses. The wall shear stress in a PHE is calculated as

$$T = \Delta P \text{ x } D \ / \ 2\,L$$

where

T = shear stress on heat transfer wall, psi
ΔP = pressure drop in plate channel, psi
D = channel gap or pressing depth, in
L = flow length of plate, in

For the typical plate geometries with a relatively short channel flow length, PHE's can generate shear stresses generally five times higher than those generated in an equivalent shell and tube heat exchanger [1]. The PHE configuration efficiently uses the pressure drop at the heat transfer surface wall and short flow lengths to maximize the shear stresses. Given this fact, a PHE can often use lower fouling margins or fouling factors than comparable shell and tube heat exchangers. It is important not to use typical TEMA® (Tubular Exchanger Manufacturers Association) fouling factors for PHE designs. The TEMA fouling factors are not applicable to PHE's and can result in excessive surface areas and poor PHE designs.

Practical PHE Fouling Design

Gasketed PHE's are unique in the fact that plates can be added or removed to the frame if needed to vary the heat duty or account for variances in fouling. Since this is the case, many power plant applications use a nominal fouling margin of 5 - 10% (or equivalent cleanliness factor or fouling factor) and use a frame that allows for additional plates if necessary. Very often, frame extension capacities of 30 – 50% are specified to allow for significant increases in the future to account for unexpected fouling, plant up-ratings, or other unanticipated heat loads. This method of accounting for fouling has been used successfully at many power plants and should be considered in lieu of using historical TEMA fouling factors and cleanliness factors.

Since fouling can impact the overall reliability and performance level of a plant, plants often design with redundant heat exchangers. Very often 100 % spare heat exchangers (2 x 100% parallel units) or 50% spares (3 x 50% parallel units) are used to account for heat exchanger downtime due to fouling, maintenance or mechanical downtime. PHE redundancy should be considered when plant uptime and reliability are critical. Redundancy can also be beneficial in plant turndown conditions or where seasonal cooling conditions vary based on ambient temperatures.

The allowable pressure drop across the heat exchanger should also be considered closely. Using a higher pressure drop will increase the operational costs (pumping costs), but the higher pressure drop will also result in higher heat transfer coefficients (U values) and lower fouling potential. The higher U values and lower fouling tendencies will result in a smaller heat exchanger and lower capital costs. An economic analysis of the capital and operational (both operating and maintenance) costs should be completed at various allowable pressure drops across the heat exchanger.

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1. The tube side shear stress in a shell and tube heat exchanger is calculated as $\tau = \Delta P \text{ x } d_t / 4L_t$ where d_t is the tube diameter and L_t is the tube length.