Fouling Factor

The performance of heat exchangers usually deteriorates with time as a result of accumulation of ***deposits*** on heat transfer surfaces. The layer of deposits represents ***additional resistance*** to heat transfer and causes the ***rate of heat transfer*** in a heat exchanger to ***decrease***. The net effect of these accumulations on heat transfer is representedby a **fouling factor** R_f , which is a measure of the ***thermal resistance*** introduced by fouling.

- The most common type of fouling is the *precipitation* of solid deposits in a fluid on the heat transfer surfaces. To avoid this potential problem, water in power and process plants is extensively treated and its solid contents are removed before it is allowed to circulate through the system.

- The solid ash particles in the flue gases accumulating on the surfaces of air preheaters create similar problems. Another form of fouling, which is common in the chemical process industry, is ***corrosion*** and other ***chemical fouling***.

- The fouling factor is obviously zero for a new heat exchanger and increases with time as the solid deposits build up on the heat exchanger surface. The fouling factor depends on the ***operating temperature*** and the ***velocity*** of the fluids, as well as the ***length of service***.

Fouling increases with ***increasing temperature*** and ***decreasing velocity.***

The overall heat transfer coefficient relation given above is valid for clean surfaces and needs ***to be modified to account for the effects of fouling on both the inner and the outer surfaces of the tube*.** For an unfinned shell-and-tube heat exchanger, it can be expressed as,

$$\frac{1}{UA_s} = \frac{1}{U_iA_i} = \frac{1}{U_oA_o} = R$$

$$= \underbrace{\frac{1}{h_iA_i}}_{\text{conv. in}} + \underbrace{\frac{R_{f,i}}{A_i}}_{\text{fouling in}} + \underbrace{\frac{\ln(D_o/D_i)}{2\pi kL}}_{\text{tube wall resistance}} + \underbrace{\frac{R_{f,o}}{A_o}}_{\text{fouling out}} + \underbrace{\frac{1}{h_oA_o}}_{\text{conv. out}}$$

where $A_i = \pi D_i L$ and $A_o = \pi D_o L$ are the areas of inner and outer surfaces, and $R_{f,i}$ and $R_{f,o}$ are the fouling factors at those surfaces.

Overall Heat Transfer Coefficient (U)

A heat exchanger typically involves two flowing fluids separated by a solid wall. Heat is first transferred from the hot fluid to the wall by ***convection***, through the wall by ***conduction*,** and from the wall to the cold fluid again by ***convection*.** Any ***radiation effects*** are usually ***included in the convection heat transfer coefficients***.

The ***effect of conduction, convection and radiation heat transfer within the heat***

exchangers can be collected in one overall heat transfer coefficient (**U**).

In the analysis of heat exchangers, it is convenient to combine all the ***thermal resistances*** in the path of heat flow from the hot fluid to the cold one into a ***single resistance*** R, and to express the rate of heat transfer between the two fluids as,

$$\dot{Q} = \frac{\Delta T}{R} = UA\Delta T = U_i A_i \Delta T = U_o A_o \Delta T \ , \qquad R = \frac{1}{UA} \quad \text{or:} \quad UA = \frac{1}{R}$$

Where ***U*** is the **overall heat transfer coefficient,** whose unit is W/m2.°C, which is identical to the unit of the ordinary convection coefficient ***h***. Canceling ・ T, get,

$$\frac{1}{UA_s} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = R = \frac{1}{h_i A_i} + R_{\text{wall}} + \frac{1}{h_o A_o}$$

When the ***wall thickness of the tube is small and the thermal conductivity of the tube material is high***, as is usually the case, the thermal resistance of the tube is negligible ($R_{\text{wall}} = 0$) and the inner and outer surfaces of the tube are almost identical (*i o s* $A_o \approx A_i \approx A_s$).

Then the overall heat transfer coefficient simplifies to, $\frac{1}{U} \approx \frac{1}{h_i} + \frac{1}{h_o}$

Where $U \approx U_i \approx U_o$. The individual convection heat transfer coefficients inside and outside the tube, h_i and h_o, are determined using the convection relations.

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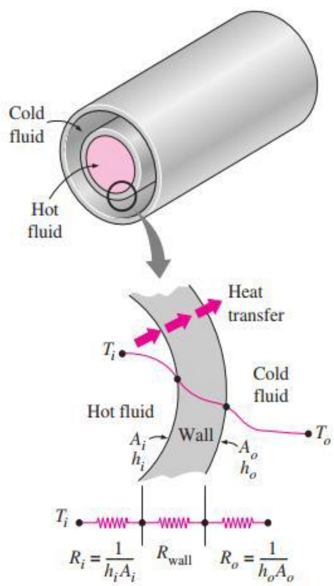

Representative values of the overall heat transfer coefficients in heat exchangers:

Type of heat exchanger	U, W/m² · °C*
Water-to-water	850–1700
Water-to-oil	100–350
Water-to-gasoline or kerosene	300–1000
Feedwater heaters	1000–8500
Steam-to-light fuel oil	200–400
Steam-to-heavy fuel oil	50–200
Steam condenser	1000–6000
Freon condenser (water cooled)	300–1000
Ammonia condenser (water cooled)	800–1400
Alcohol condensers (water cooled)	250–700
Gas-to-gas	10–40
Water-to-air in finned tubes (water in tubes)	30–60†
	400–850†
Steam-to-air in finned tubes (steam in tubes)	30–300†
	400–4000‡

Example :1

Determine the overall heat transfer coefficient U_o based on the outer surface of a D_i=2.5cm, D_o=3.2cm, steel pipe [k=50W/m$_o$C] for the following conditions: The inside and outside heat transfer coefficient are, respectively, h_i=1000W/m$_2$.$_o$C. and h_o=2000W/m$_2$.$_o$C.

Solution; The overall heat transfer based on the outer surface U_o is to be determined, inside heat transfer coefficient h_i=1000W/m2.oC, and the outside heat transfer coefficient h_o=2000W/m2.oC. and D_i=2.5cm, D_o=3.2cm and k=50W/m.oC.

Property: thermal conductivity and heat transfer coefficients are constant

Analysis: To determine the overall heat transfer coefficient based on the outer surface we can use the following equation.

$$U_o = \frac{1}{\frac{r_o}{h_i r_i} + \frac{r_o}{k}\ln\frac{r_o}{r_i} + \frac{1}{h_o}} = \frac{1}{\frac{3.2}{1000 \times 2.5} + \frac{0.032}{50}\ln\frac{3.2}{2.5} + \frac{1}{2000}} = 516 W/m^2.^oC$$