Overall Heat Transfer Coefficient Analysis in HE

1- Overall Heat Transfer Coefficient in HE

In a heat exchanger in which two fluids are separated by a **plane wall** as shown in the Fig. 1 the overall heat transfer coefficient is given by

$$U = \frac{1}{\frac{1}{h_i} + \frac{L}{k} + \frac{1}{h_o}}$$

If the fluids are separated by a **tubewall** as shown in Fig. 2 the overall heat transfer coefficient is given by,

Inner surface :

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{r_i}{k}\ln(r_o/r_1) + (r_i/r_o) \times \frac{1}{h_o}}$$

Outer surface :

$$U_0 = \frac{1}{(r_o/r_i)\frac{1}{h_c} + \frac{r_o}{k}\ln(r_o/r_i) + \frac{1}{h_o}}$$

where,
$$U_i A_i = U_o A_o$$
$$A_i = 2\pi r_i L; \quad A_o = 2\pi r_o L$$

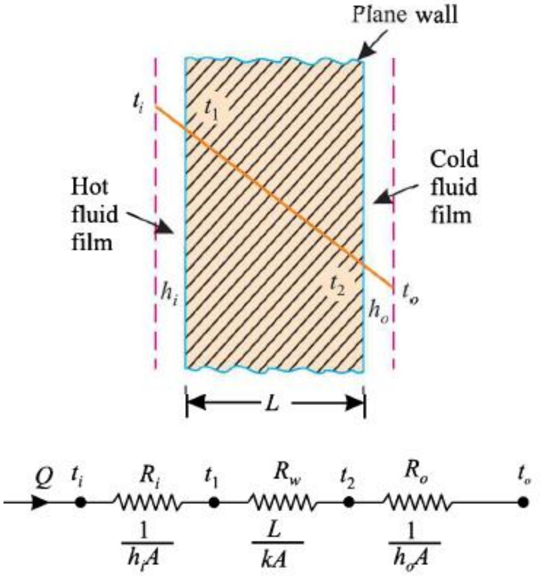

Fig. 1 Overall heat transfer coefficient of two fluids separated by a plane wall.

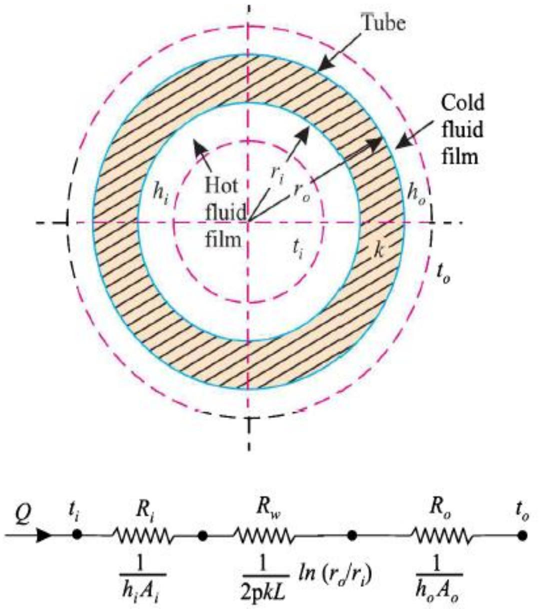

Fig. 2. Overall heat transfer coefficient of two fluids flowing inside and outside a tube.

2- Fouling Factor Consideration.

Material deposits on the surfaces of the heat exchanger tube may add further resistance to heat transfer in addition to those listed above. Such deposits are termed fouling and may significantly affect heat exchanger performance.

☐ Scaling is the most common form of fouling and is associated with inverse solubility salts. Examples of such salts are $CaCO_3$, $CaSO_4$, $Ca_3(PO_4)_2$, $CaSiO_3$, $Ca(OH)_2$, $Mg(OH)_2$, $MgSiO_3$, Na_2SO_4, $LiSO_4$, and Li_2CO_3.

☐ Corrosion fouling is classified as a chemical reaction which involves the heat exchanger tubes. Many metals, copper and aluminum being specific examples, form adherent oxide coatings which serve to passivity the surface and prevent further corrosion.

☐ Chemical reaction fouling involves chemical reactions in the process stream which results in deposition of material on the heat exchanger tubes. When food products are involved this may be termed scorching but a wide range of organic materials are subject to similar problems.

☐ Freezing fouling is said to occur when a portion of the hot stream is cooled to near the freezing point for one of its components. This is most notable in refineries where paraffin frequently solidifies from petroleum products at various stages in the refining process, obstructing both flow and heat transfer.

☐ Biological fouling is common where untreated water is used as a coolant stream. Problems range from algae or other microbes to barnacles.

Due to these surface deposits the thermal resistance is increased and eventually the performance of the heat exchanger lowers. Since it is difficult to ascertain the thickness and thermal conductivity of the scale deposits, the effect of scale on heat flow is considered by specifying an equivalent *scale heat transfer coefficient* h_s. If h_{si} and h_{so} be the heat transfer coefficients for the scale deposited on the inside and outside surfaces respectively, then the thermal resistances to scale formation on the inside surface (R_{si}) and outside surface (R_{so}) are given by

$$R_{si} = \frac{1}{A_i\, h_{si}}$$

$$R_{so} = \frac{1}{A_o\, h_{so}}$$

The *reciprocal of scale heat transfer coefficient*, h_s is called the *fouling factor*, R_f. Thus

$$R_f = \frac{1}{h_s} \text{ m}^2\,{}^\circ\text{C/W}$$

The heat transfer, considering the thermal resistance due to scale formation, is given by :

$$Q = \frac{(t_i - t_o)}{\frac{1}{A_i\, h_i} + \frac{1}{A_i\, h_{si}} + \frac{1}{2\pi Lk} \ln\,(r_o/r_i) + \frac{1}{A_o\, h_{so}} + \frac{1}{A_o\, h_o}}$$

The overall heat transfer coefficients, U based on the inner and outer surfaces of the inner tube are given by,

$$U_i = \frac{1}{\frac{1}{h_i} + R_{f_i} + \frac{r_i}{k} \ln (r_o/r_i) + (r_i/r_o) R_{f_o} + (r_i/r_o) \frac{1}{h_o}}$$

$$U_o = \frac{1}{(r_o/r_i) \frac{1}{h_i} + (r_o/r_i) R_{fi} + \frac{r_o}{k} \ln (r_o/r_1) + R_{fo} + \frac{1}{h_o}}$$

Points worth noting :

1. The overall heat transfer coefficient depends upon the following *factors* :
   (*i*) The flow rate,
   (*ii*) The properties of the fluid,
   (*iii*) The thickness of material,
   (*iv*) The surface condition of the tubes, and
   (*v*) The geometrical configuration of the heat exchanger.
2. The overall heat transfer coefficient *U* will generally decrease when any of the fluids (e.g. tars, oils or any of the gases) having low values of heat transfer coefficient, *h* flows on one side of the exchanger.
3. The highly conducting liquids such as water and liquid metals give much higher values of heat transfer coefficient, *h* and overall heat transfer coefficient, *U*. In case of boiling and condensation processes also, the values of *U* are high.
4. All the thermal resistances in the heat exchanger must be low for its efficient and effective design.

Representative Fouling Factors

S.No.	**Fluid**	**Fouling factor, $R_f = \frac{1}{h_s}$ (m^2°C/W)**
1.	Sea water	0.0001 (below 50°C) 0.0002 (above 50°C)
2.	Clean river and lake water	0.0002 – 0.0006
3.	Well water	0.0004
4.	Distilled water	0.0001
5.	Treated boiler feed water	0.0001 – 0.0002
6.	Worst water used in heat exchangers	< 0.0002
7.	Fuel oil and crude oil	0.0009
8.	Industrial liquids	0.0002

3- Correction Factors for Multi-Pass Arrangements.

The expression $\theta_m = \dfrac{(\theta_1 - \theta_2)}{ln\ (\theta_1/\theta_2)}$ for *LMTD* is essentially valid for single-pass heat exchangers. The analytical treatment of multiple pass shell and tube heat exchangers and cross-flow heat exchangers is much more difficult than single pass cases; such cases may be analysed by using the following equation :

$$Q = UAF\,\theta_m$$

where *F* is the *correction factor;* the correction factors have been published in the form of charts by Bonman, Mueller and Nagle and by *TEMA*.

Correction factors for several common arrangements have been given in Figs. 10.40 to 10.43 The data is presented as a function of two non-dimensional variables namely the tem (3 to 5) and the capacity ratio *R*.

Temperature ratio, P : It is defined as the *ratio of the rise in temperature of the cold fluid to the difference in the inlet temperatures of the two fluids*. Thus:

$$P = \frac{t_{c2} - t_{c1}}{t_{h1} - t_{c1}}$$

The temperature ratio *P indicates cooling or heating effectiveness* and it can vary from *zero* for a constant temperature of one of the fluids to *unity* for the case when inlet temperature of the hot fluid equals the outlet temperature of the cold fluid.

Capacity ratio R : *The ratio of the products of the mass flow rate times the heat capacity of the fluids is termed as capacity ratio R*. Thus :

$$R = \frac{\dot{m}_c\ .\ c_{pc}}{\dot{m}_h\ .\ c_{ph}}$$

Since, $\dot{m}_c\ .\ c_{pc}\ .\ (t_{c2} - t_{c1}) = \dot{m}_h\ .\ c_{ph}\ .\ (t_{h1} - t_{h2})$

or,

$$R = \frac{\dot{m}_c\ .\ c_{pc}}{\dot{m}_h\ .\ c_{ph}} = \frac{t_{h1} - t_{h2}}{t_{c2} - t_{c1}}$$

$$= \left[\frac{\text{Temperature drop of the hot fluid}}{\text{Temperature rise in the cold fluid}}\right]$$

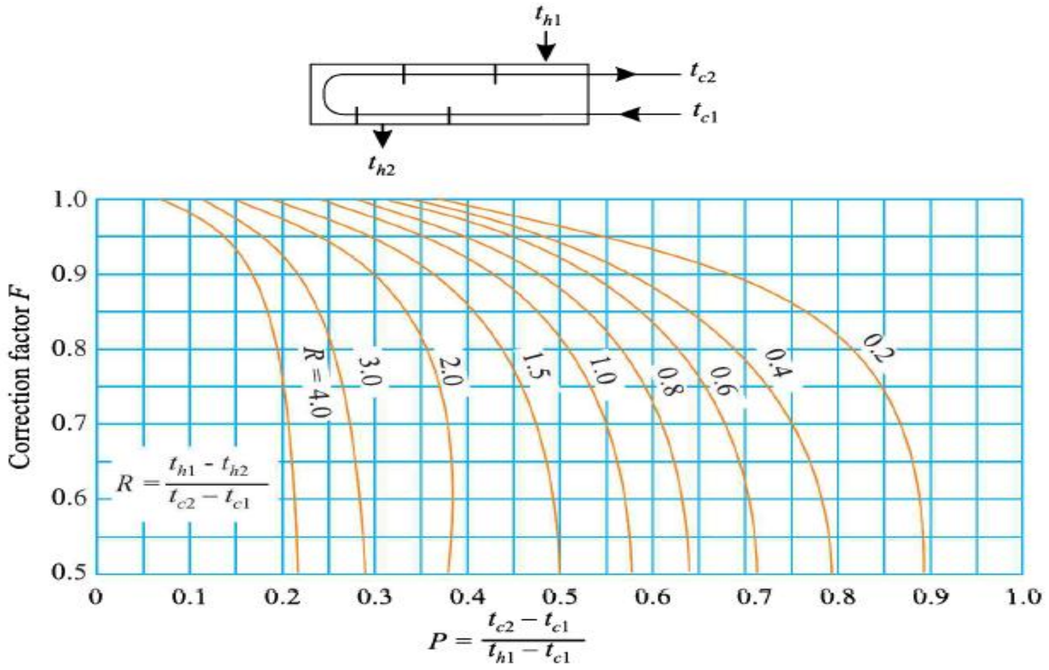

Figure 1: Correction factor plot for heat exchanger with one shell pass and two, four or any multiple of tube passes.

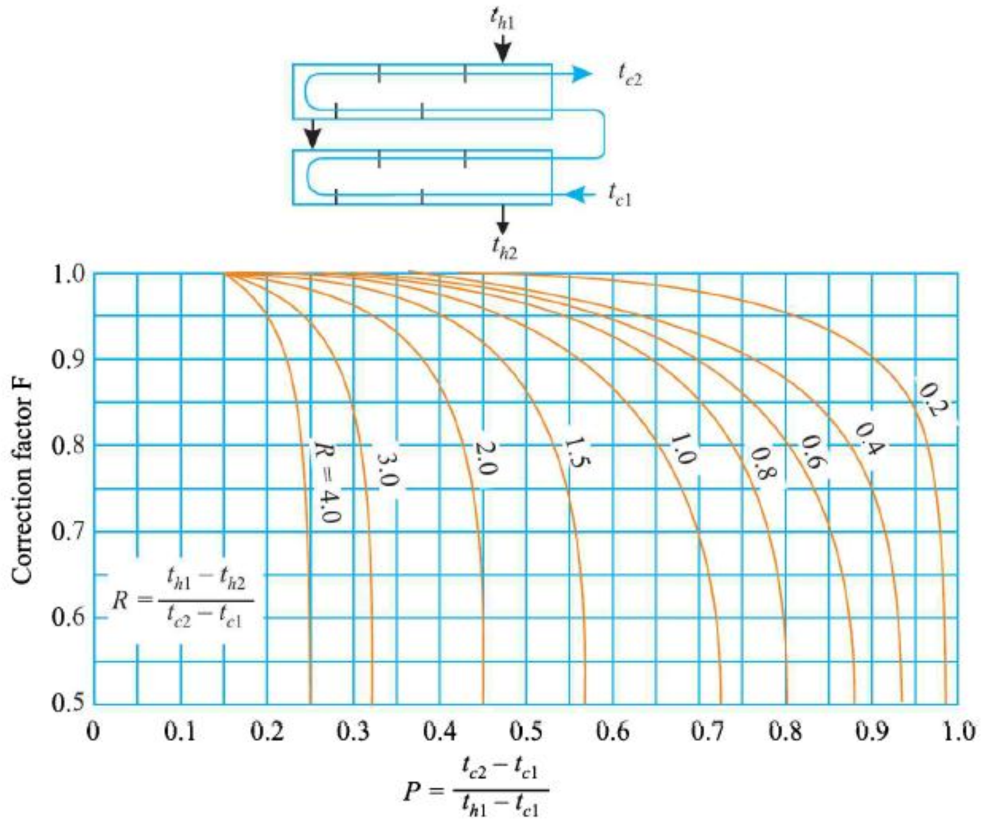

Figure 2: Correction factor plot for heat exchanger with two shell passes and two, four, eight or any multiple of tube passes.

in condensation or boiling (evaporation), the fluid normally remains at essentially constant temperature and the relations are simplified. For this condition, P or R becomes zero and we obtain

$$F = 1.0 \qquad \text{for boiling or condensation}$$

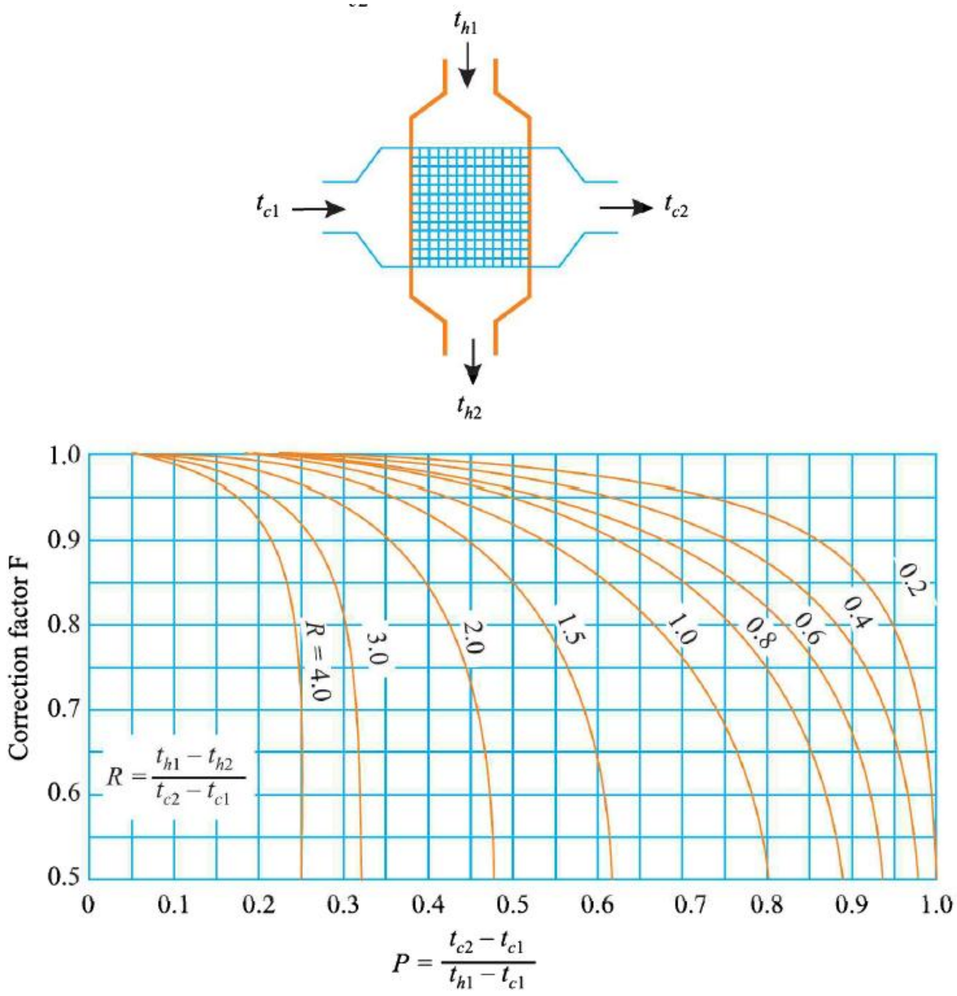

Figure 3: Correction factor plot for single cross-flow heat exchanger with both fluids unmixed.