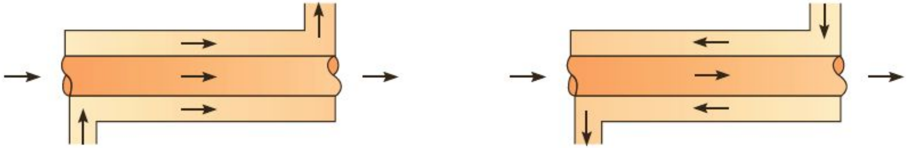
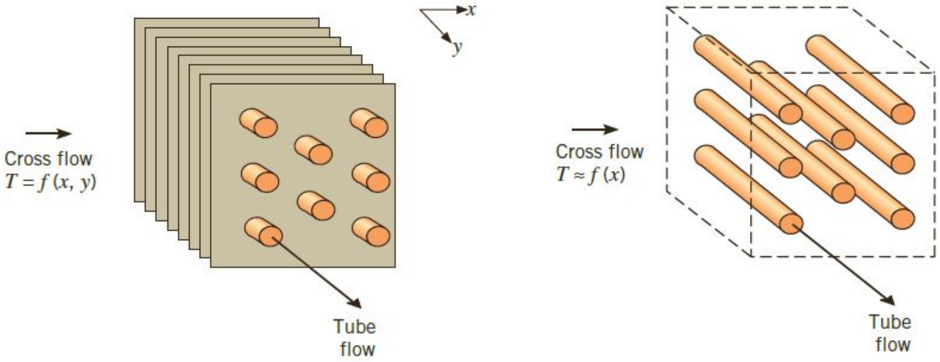
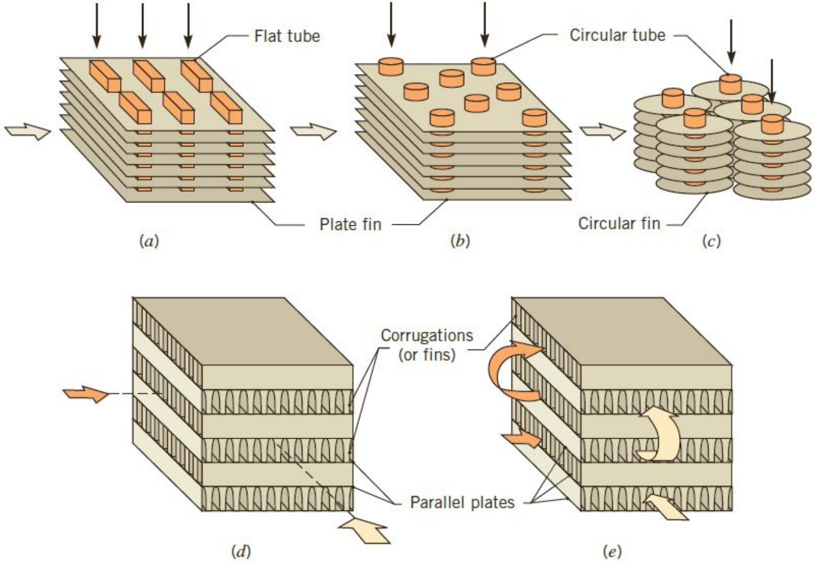


(a) (b)

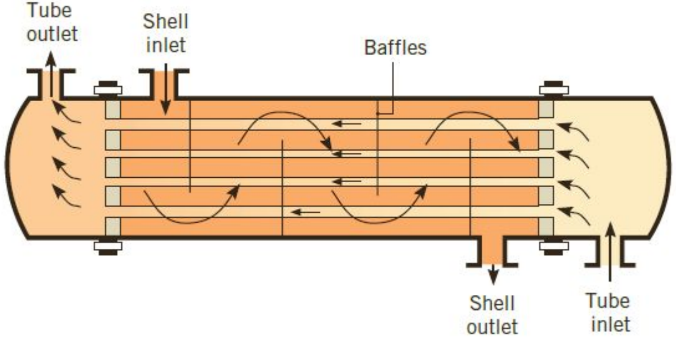


x
y
Cross flow
T = f (x, y)
Tube flow
Cross flow
T ≈ f (x)
Tube flow

(a) (b)



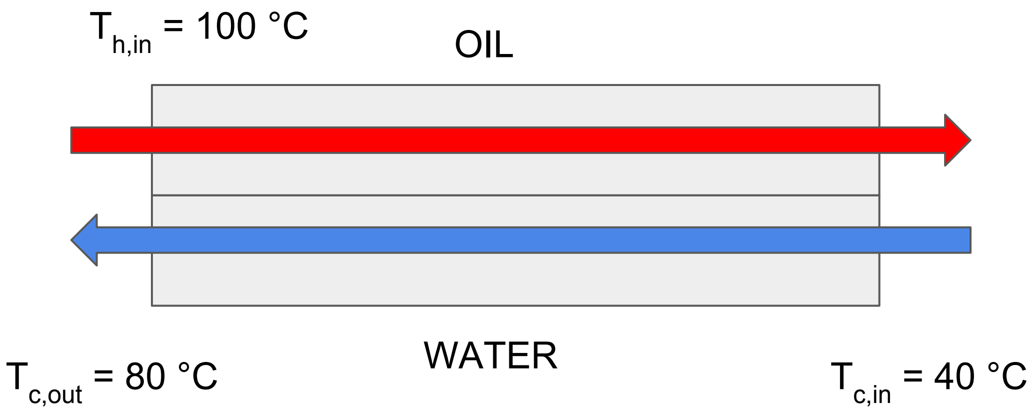
Flat tube
Circular tube
Plate fin
Circular fin
(a)
(b)
(c)
Corrugations (or fins)
Parallel plates
(d)
(e)



Tube outlet
Shell inlet
Baffles
Shell outlet
Tube inlet

3.5

A cross-flow heat exchanger with both fluids unmixed is used to heat water (c_p = 4.18 kJ/kg·K) from 40°C to 80°C, flowing at the rate of 1.0 kg/s. What is the overall heat transfer coefficient if hot engine oil (c_p = 1.9 kJ/kg·K), flowing at the rate of 2.6 kg/s, enters at 100°C? The heat transfer area is 20 m^2. (Note that you can use either an effectiveness or an LMTD method. It would be wise to use both as a check.)



Oil
$T_{h,in}$ = 100 °C
$c_{p,h}$ = 1.9 kJ/kgK
m_h = 2.6 kg/s

Water
$T_{c,in}$ = 40 °C; $T_{c,\ out}$ = 80 °C
$c_{p,h}$ = 4.18 kJ/kgK
m_h = 1.0 kg/s

1. Energy Balance

$Q_{cold} = m_c \cdot c_{p,c} \cdot \Delta T_c = 167200$ W

$Q_{hot} = Q_{cold}$

$Q_{hot} = m_h \cdot c_{p,h} \cdot \Delta T_h$

$T_{h,out} = T_{h,in} - Q_{hot}/m_h \cdot c_{p,h} = 66.15$ °C

2. Effectiveness method

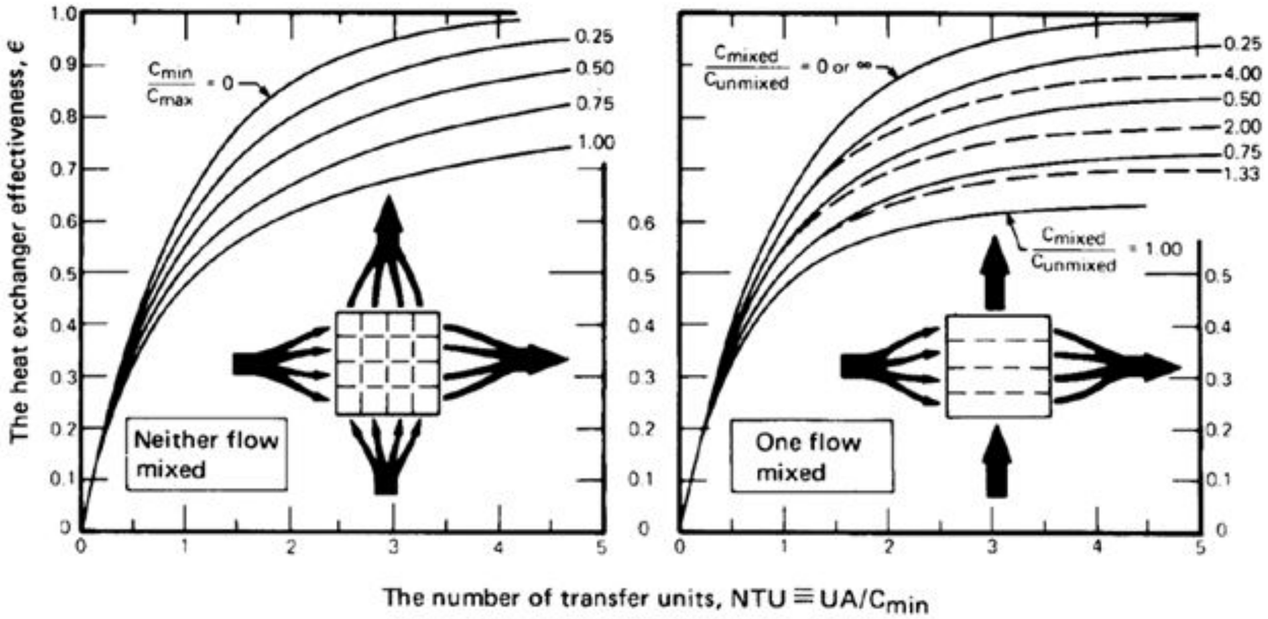
$$\varepsilon \equiv \frac{C_h(T_{h_{in}} - T_{h_{out}})}{C_{min}(T_{h_{in}} - T_{c_{in}})} = \frac{C_c(T_{c_{out}} - T_{c_{in}})}{C_{min}(T_{h_{in}} - T_{c_{in}})}$$

$\varepsilon = f(C_{min}/C_{max}, NTU) = 0.67$

$C_c = m_c \cdot c_{p,c} = 4180$ W/K $= C_{min}$

$C_h = m_h \cdot c_{p,h} = 4940$ W/K $= C_{max}$

$C_{min}/C_{max} = 0.85$



a.) Cross-flow exchanger, neither fluid mixed

b.) Cross-flow exchanger, one fluid mixed

$NTU = UA/C_{min} = 2.2$

$U = C_{min} \cdot NTU/A = 460\ W/m^2K$

3. LMTD method

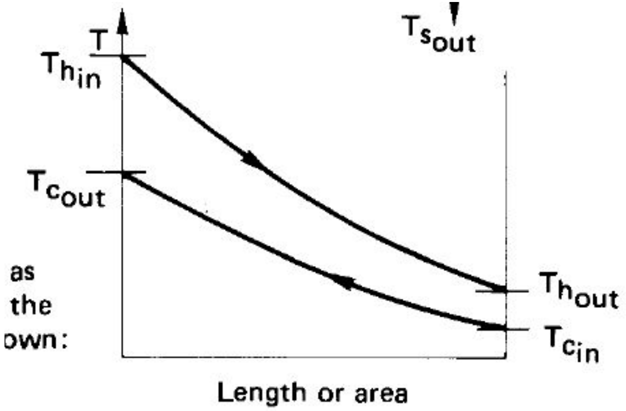
$$Q = UA(\text{LMTD}) \cdot F\left(\underbrace{\frac{T_{t_{\text{out}}} - T_{t_{\text{in}}}}{T_{s_{\text{in}}} - T_{t_{\text{in}}}}}_{P}, \underbrace{\frac{T_{s_{\text{in}}} - T_{s_{\text{out}}}}{T_{t_{\text{out}}} - T_{t_{\text{in}}}}}_{R}\right) \quad (3.14)$$

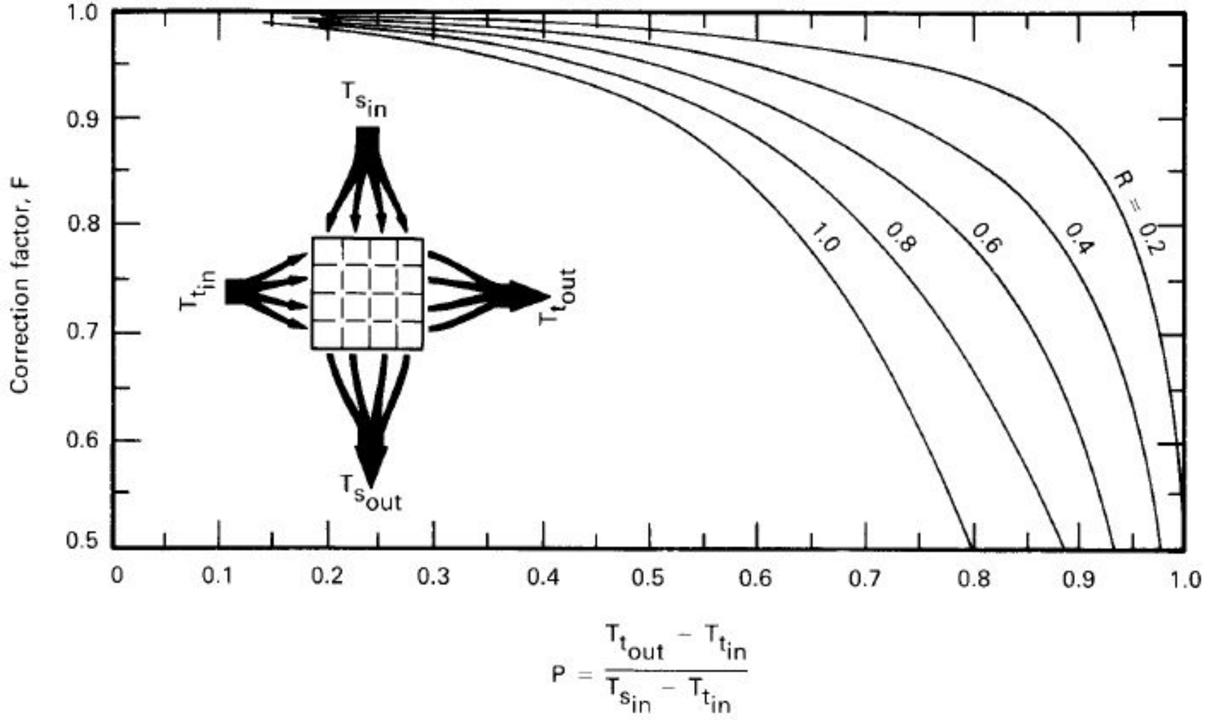
$$\text{LMTC} = \frac{(T_{h_{in}} - T_{c_{out}}) - (T_{h_{out}} - T_{c_{in}})}{\ln \dfrac{T_{h_{in}} - T_{c_{out}}}{T_{h_{out}} - T_{c_{in}}}}$$

The factor F is defined in such a way that *the LMTD should always be calculated for the equivalent counterflow single-pass exchanger with the same hot and cold temperatures.* This is explained in Fig. 3.13.

$$F(P, R) = F(PR, 1/R) \quad (3.15)$$

Thus, if R is greater than one, we need only evaluate F using PR in place of P and $1/R$ in place of R.





P = 0.67

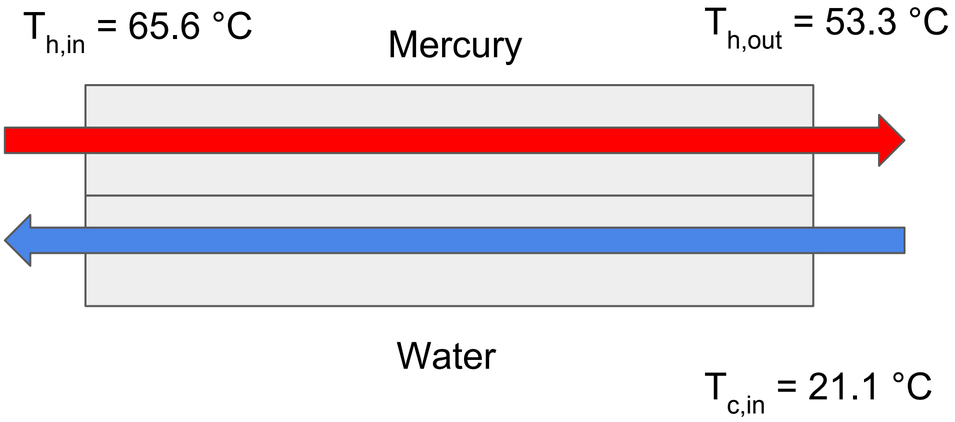
R = 0.85

F = 0.80

U = 455 W/m^{2}K

3.7

Consider a counterflow heat exchanger that must cool 3000 kg/h of mercury from 150°F to 128°F. The coolant is 100 kg/h of water, supplied at 70°F. If U is 300 W/m^{2}K, complete the design by determining reasonable value for the area and the exit-water temperature.
[A = 0.147 m^2.]



Mercury
$T_{h,in}$ = 65.6 °C; $T_{h,out}$ = 53.3 °C
$c_{p,h}$ = 139,4 J/kgK
m_h = 0.83 kg/s

Water
$T_{c,in}$ = 21.1 °C
$c_{p,h}$ = 4.18 kJ/kgK
m_h = 0.028 kg/s

1. Energy Balance

$Q_{hot} = m_h \cdot c_{p,h} \cdot \Delta T_h = 1415$ W

$Q_{hot} = Q_{cold}$

$Q_{cold} = m_c \cdot c_{p,c} \cdot \Delta T_c$

$T_{c,in} = T_{c,out} + Q_{cold}/m_c \cdot c_{p,c} = 33.2$ °C

2. LMTD method

$$Q = UA(\mathrm{LMTD}) \cdot F$$

F = 1
(it is a perfectly countercurrent arrangement)

LMTD = 32.6 K

$A = 0.145\ m^2$

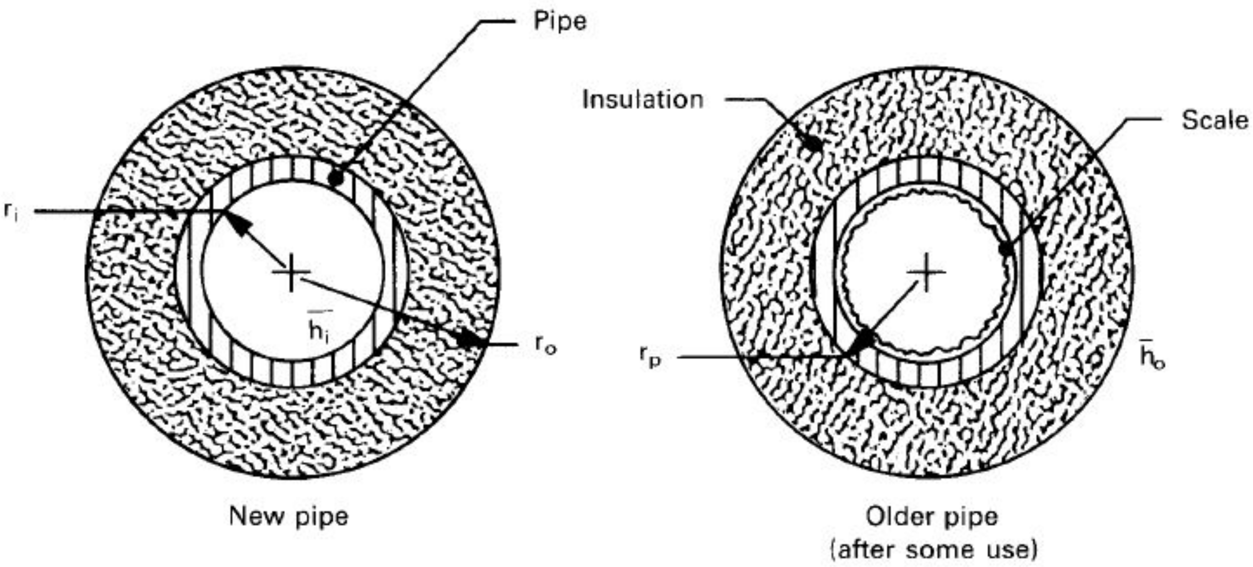


Figure 2.21 The fouling of a pipe.

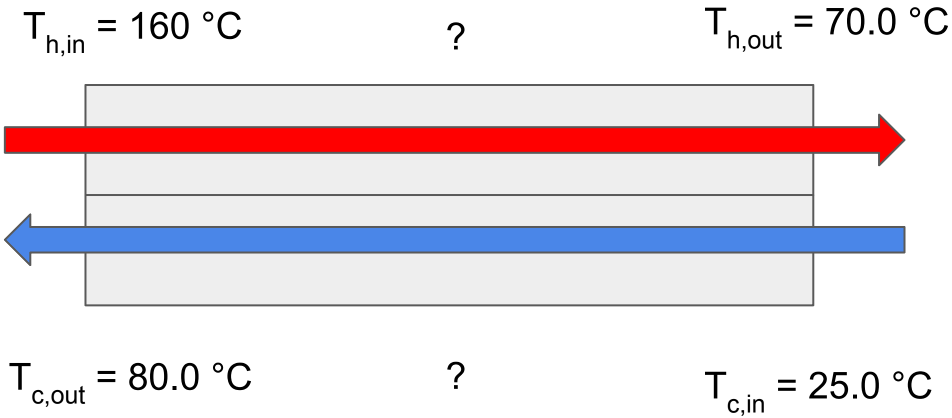
$$U^{-1}_{design} = \sum R_i$$

$$U^{-1}_{fouling} = \sum R_i + R_{fouling}$$

$$R_{fouling} = U^{-1}_{fouling} - U^{-1}_{design}$$

3.16

A particular cross-flow process heat exchanger operates with the fluid mixed on one side only. When it is new, $U = 2000\ \mathrm{W/m^2K}$, $T_{Cin} = 25^\circ\mathrm{C}$, $T_{Cout} = 80^\circ\mathrm{C}$, $T_{hin} = 160^\circ\mathrm{C}$, and $T_{hout} = 70^\circ\mathrm{C}$. After 6 months of operation, the plant manager reports that the hot fluid is only being cooled to 90°C and that he is suffering a 30% reduction in total heat transfer. What is the fouling resistance after 6 months of use? (Assume no reduction of cold-side flow rate by fouling.)



Fouling condition

$Q_{fouling} = 0.7\ Q_{design}$

$T_{h,out,fouling} = 90\ ^\circ\mathrm{C}$

1. Energy Balance

$Q_{fouling} = 0.7\ Q_{design}$

$mc_p(T_{c,out,fouling} - T_{c,in}) = 0.7mc_p(T_{c,out} - T_{c,in})$

$T_{c,out,fouling} = 0.7T_{c,out} + 0.3T_{c,in} = 63.5\ °C$

2. LMTD

$LMTD_{design} = 60.8\ K$

$LMTD_{fouling} = 79.7\ K$

3. Correction factors

$P_{design} = 0.67$

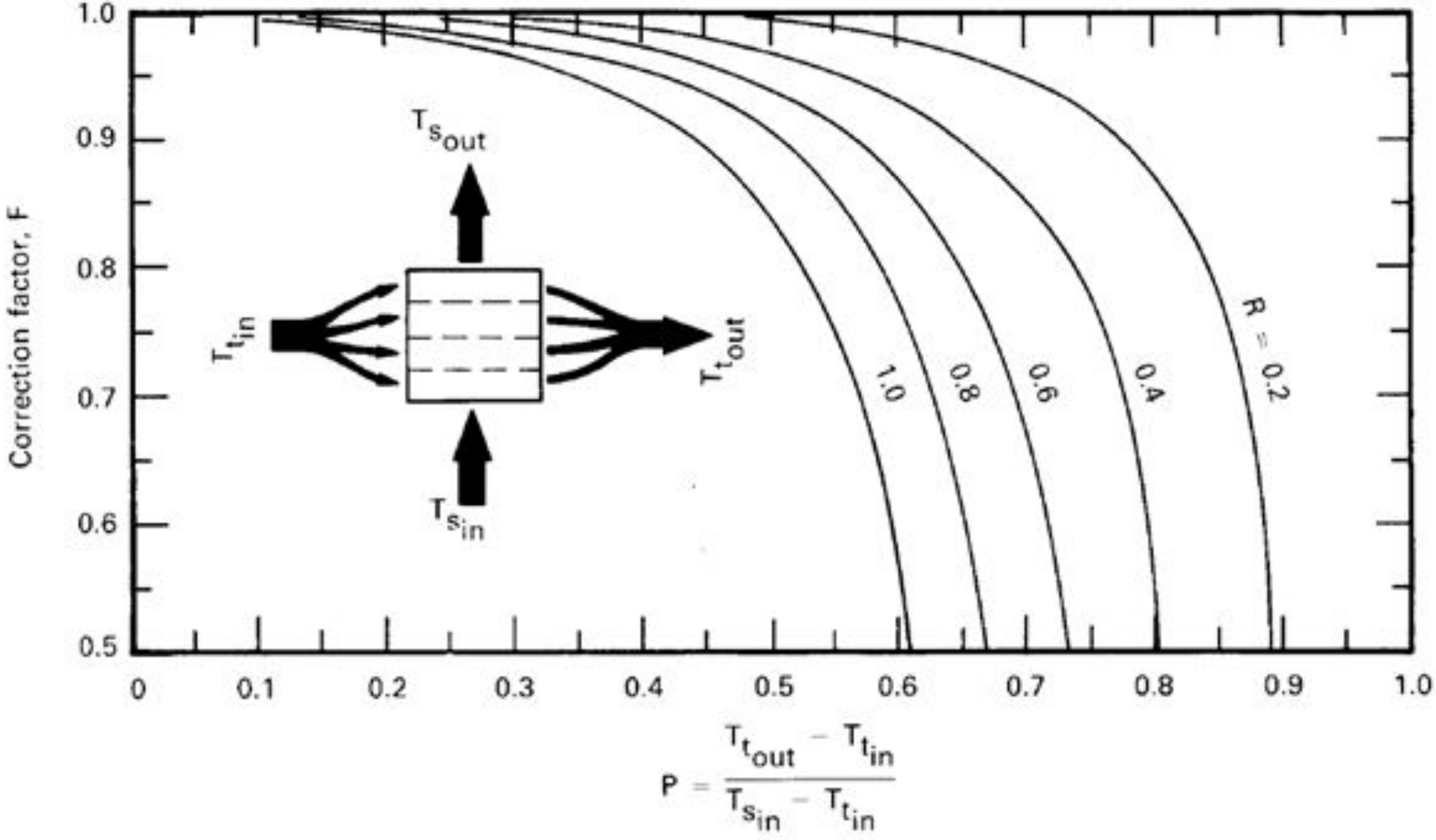
$R_{design} = 0.61$

$F_{design} = 0.80$

$P_{fouling} = 0.52$

$R_{fouling} = 0.55$

$F_{fouling} = 0.95$



1.0
0.9
0.8
0.7
0.6
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Correction factor, F
$T_{s_{out}}$
$T_{t_{in}}$
$T_{t_{out}}$
$T_{s_{in}}$
1.0
0.8
0.6
0.4
R = 0.2
$P = \frac{T_{t_{out}} - T_{t_{in}}}{T_{s_{in}} - T_{t_{in}}}$

4. Energy Balance + LMTD

$$Q_{fouling} = 0.7\ Q_{design}$$

$$U_{fouling}\ A\ LMTD_{fouling}\ F_{fouling} = 0.7\ U_{design}\ A\ LMTD_{design}\ F_{design}$$

$$U_{fouling} = 0.7\ U_{design}\ \ LMTD_{design} / LMTD_{fouling}\ F_{design} / F_{fouling} = 899\ W/m^2K$$

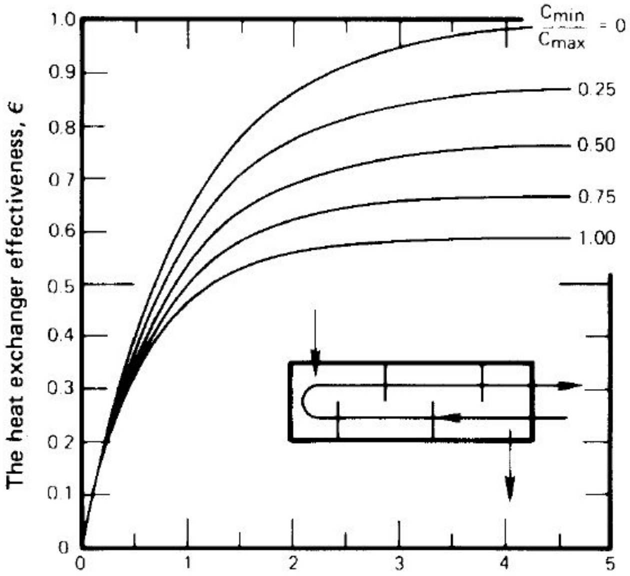
5. Fouling resistance

$$R_{fouling} = U^{-1}_{fouling} - U^{-1}_{design} = 6.1235e\text{-}04\ m^2K/W$$

3.39 Calculate the area required in a two-tube-pass, one-shell-pass condenser that is to condense 10^6 kg/h of steam at 40°C using water at 17°C. Assume that $U = 4700$ W/m^{2}K, the maximum allowable temperature rise of the water is 10°C, and $h_{fg} = 2406$ kJ/kg. [$A = 8,112$ m^2]

Water
$T_{c,in}$ = 17 °C
$T_{c,out}$ = 27 °C
$c_{p,h}$ = 4.18 kJ/kgK

Steam
$T_{h,in}$ = $T_{h,out}$ = 40°C
h_{lv} = 2406 kJ/kg



1. Energy Balance

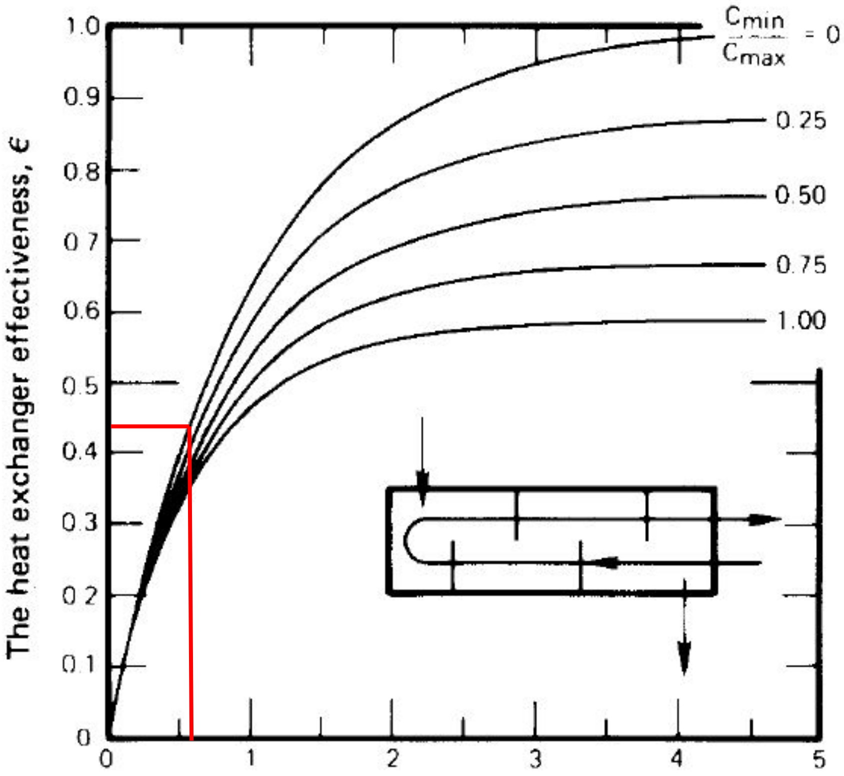
$Q = m_{steam} h_{lv} = 6.6833e{+}05$ kW

$m_{water} = Q/(c_p \Delta T)_{water} = 1.5989e{+}04$ kg/s

$$\varepsilon \equiv \frac{C_h(T_{h_{in}} - T_{h_{out}})}{C_{min}(T_{h_{in}} - T_{c_{in}})} = \frac{C_c(T_{c_{out}} - T_{c_{in}})}{C_{min}(T_{h_{in}} - T_{c_{in}})}$$

2. Effectiveness

$\varepsilon = \Delta T_{water} / \Delta T_{max} = 0.43478$



$NTU = UA/C_{min} = 0.57$

$A = C_{min} \cdot NTU/U = 8105.4\ m^2$