Heat Exchanger Analysis

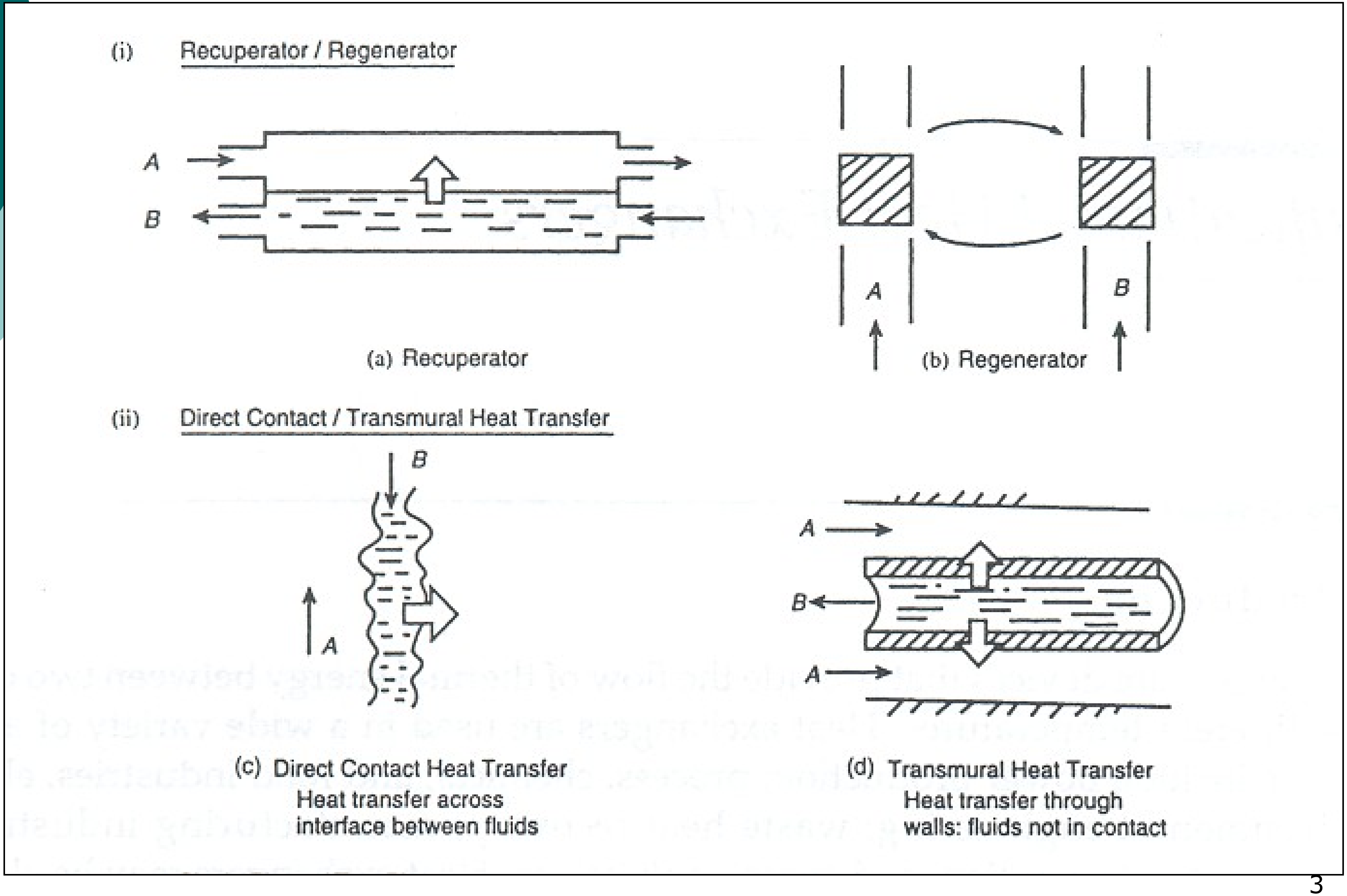
Outline

(1) Heat Exchanger Types

(2) Heat Exchanger Analysis Methods

- Overall Heat Transfer Coefficient
  - fouling, enhanced surfaces
- LMTD Method
- Effectiveness-NTU Method

HX Classifications



(i) Recuperator / Regenerator

(a) Recuperator

(b) Regenerator

(ii) Direct Contact / Transmural Heat Transfer

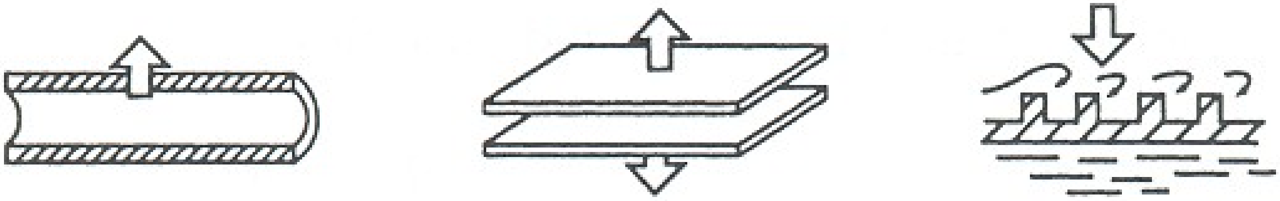
(c) Direct Contact Heat Transfer
Heat transfer across
interface between fluids

(d) Transmural Heat Transfer
Heat transfer through
walls: fluids not in contact

(iii) Single Phase / Two Phase

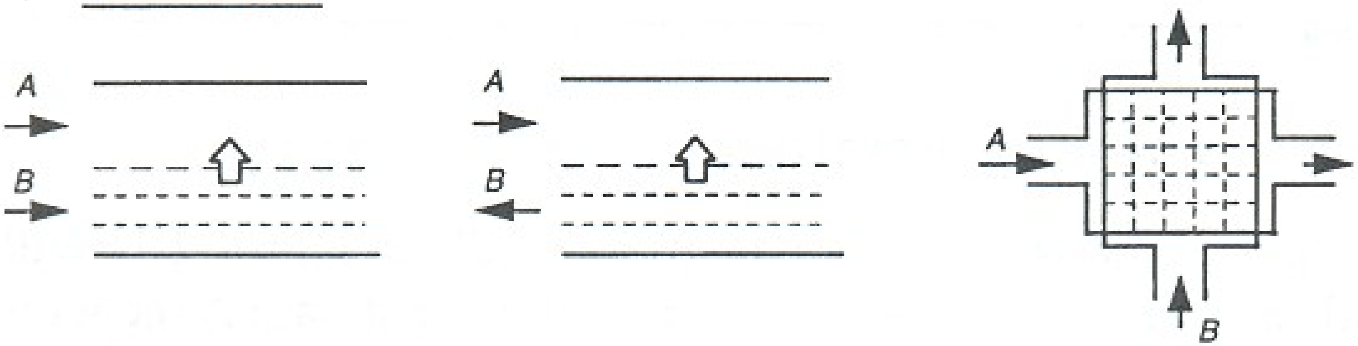
(e) Single Phase (f) Evaporation (g) Condensation

(iv) Geometry



(h) Tubes (i) Plates (j) Enhanced Surfaces

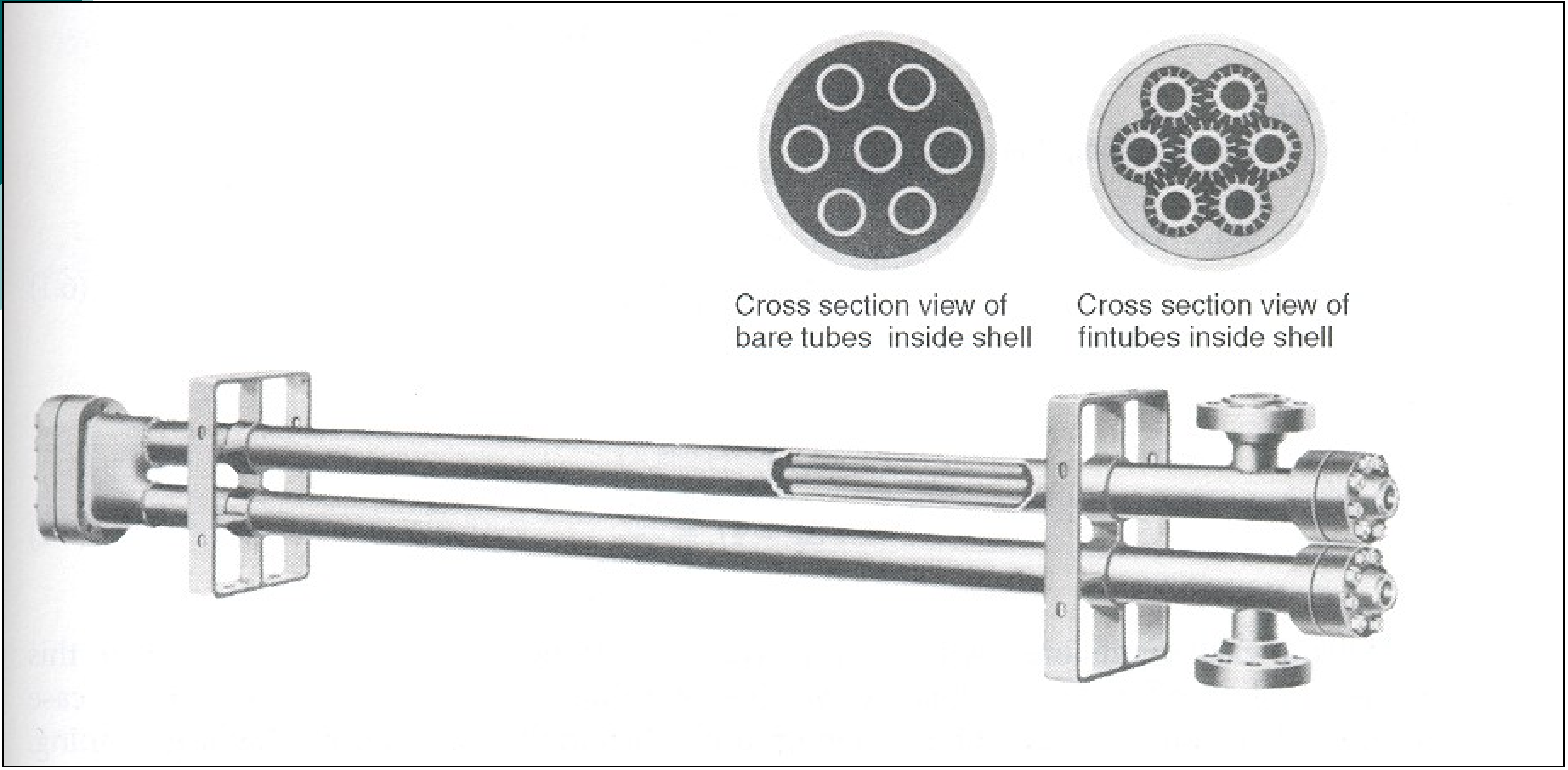
(v) Flow Arrangements



(k) Parallell Flow (l) Counter Flow (m) Cross Flow

Heat Exchanger Types

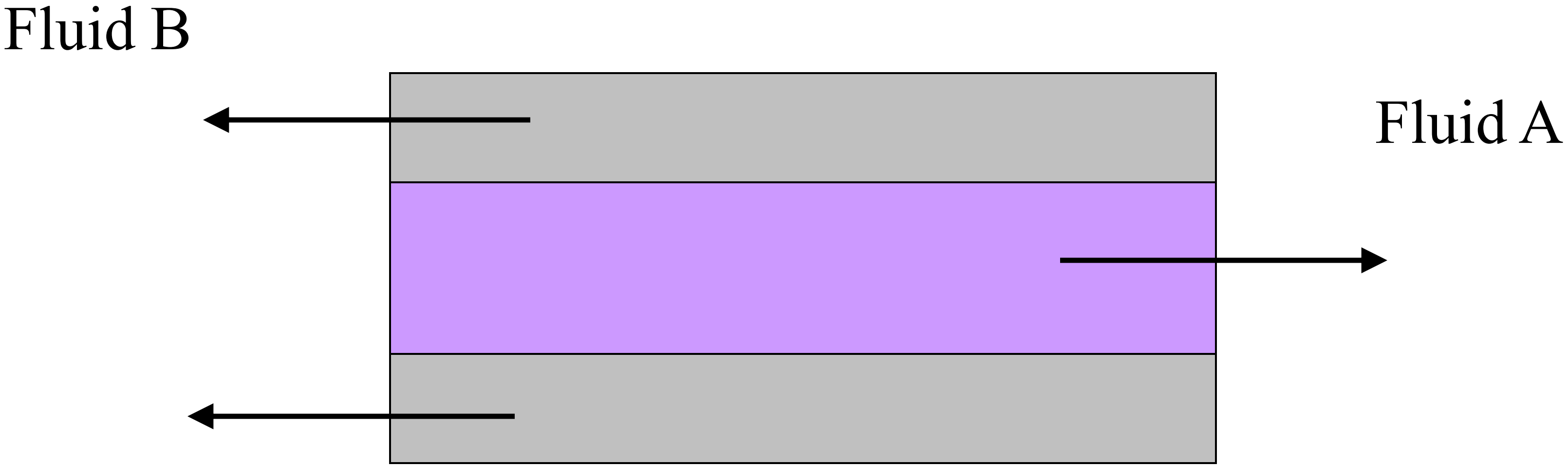
Concentric tube (double piped)



Heat Exchanger Types

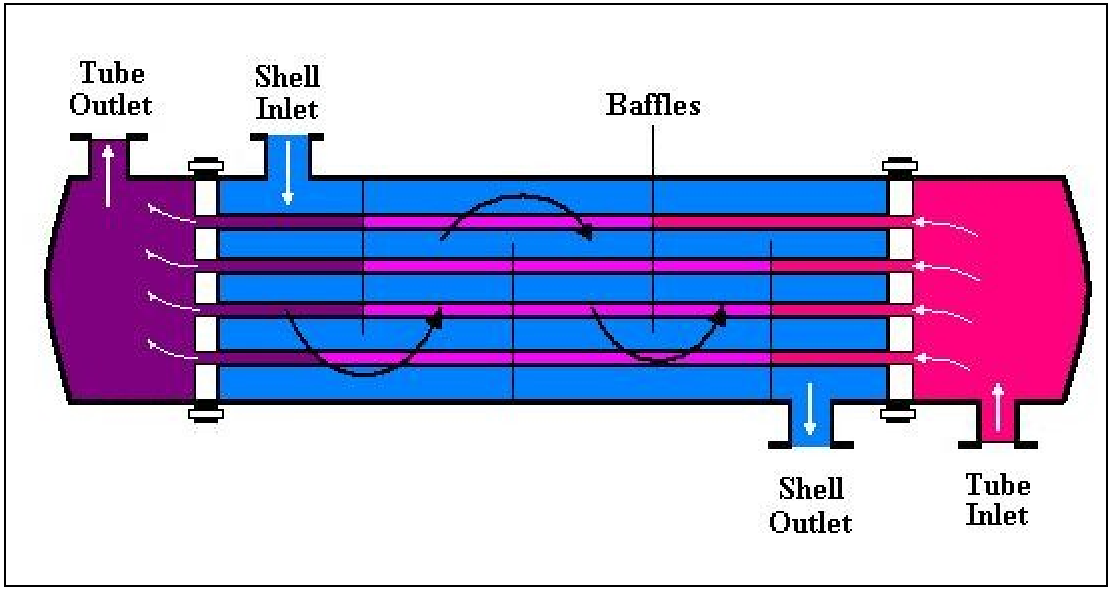
Concentric tube (double piped)

- One pipe is placed concentrically within the diameter of a larger pipe
- Parallel flow versus counter flow



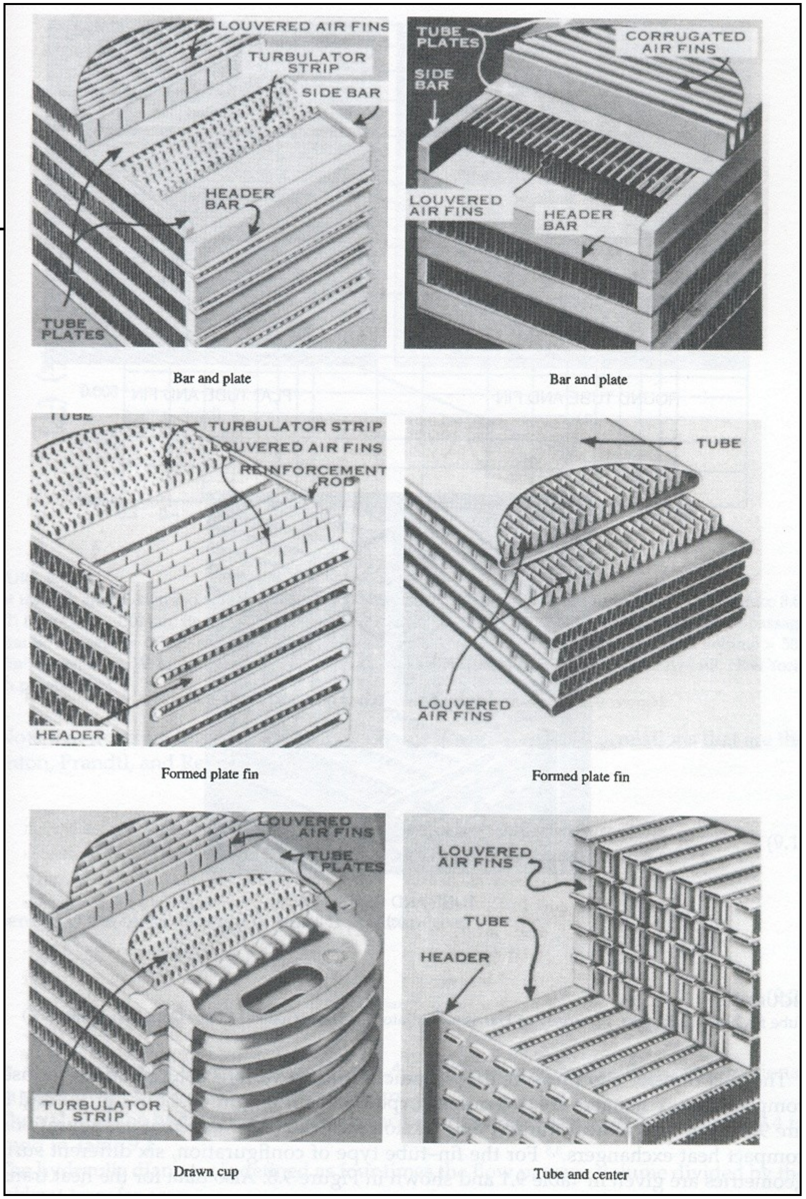
Heat Exchanger Types

Shell and Tube



Heat Exchanger Types

Compact Heat Exchangers



Bar and plate

Bar and plate

Formed plate fin

Formed plate fin

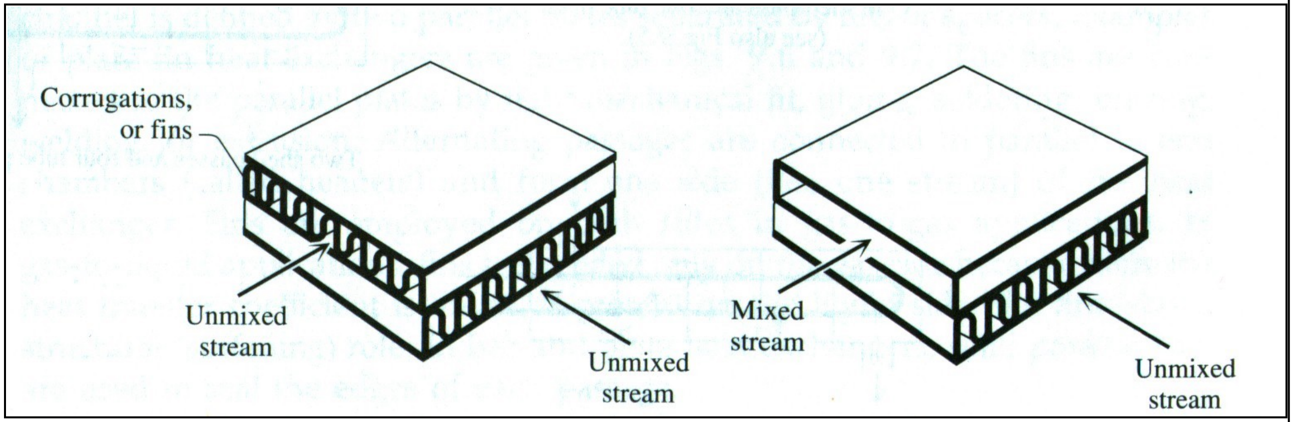
Drawn cup

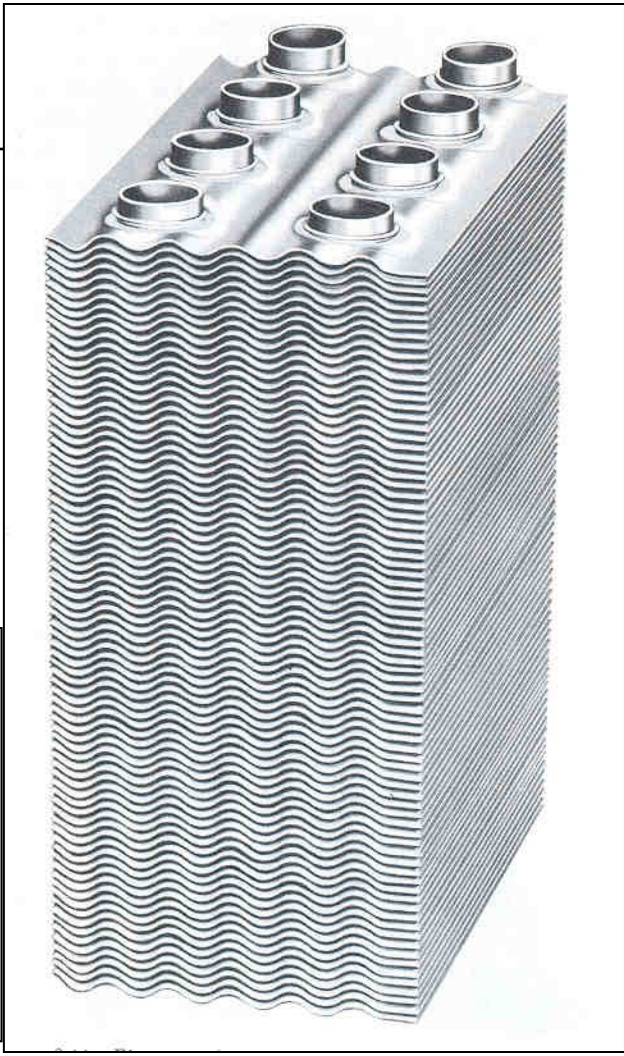
Tube and center

Heat Exchanger Types

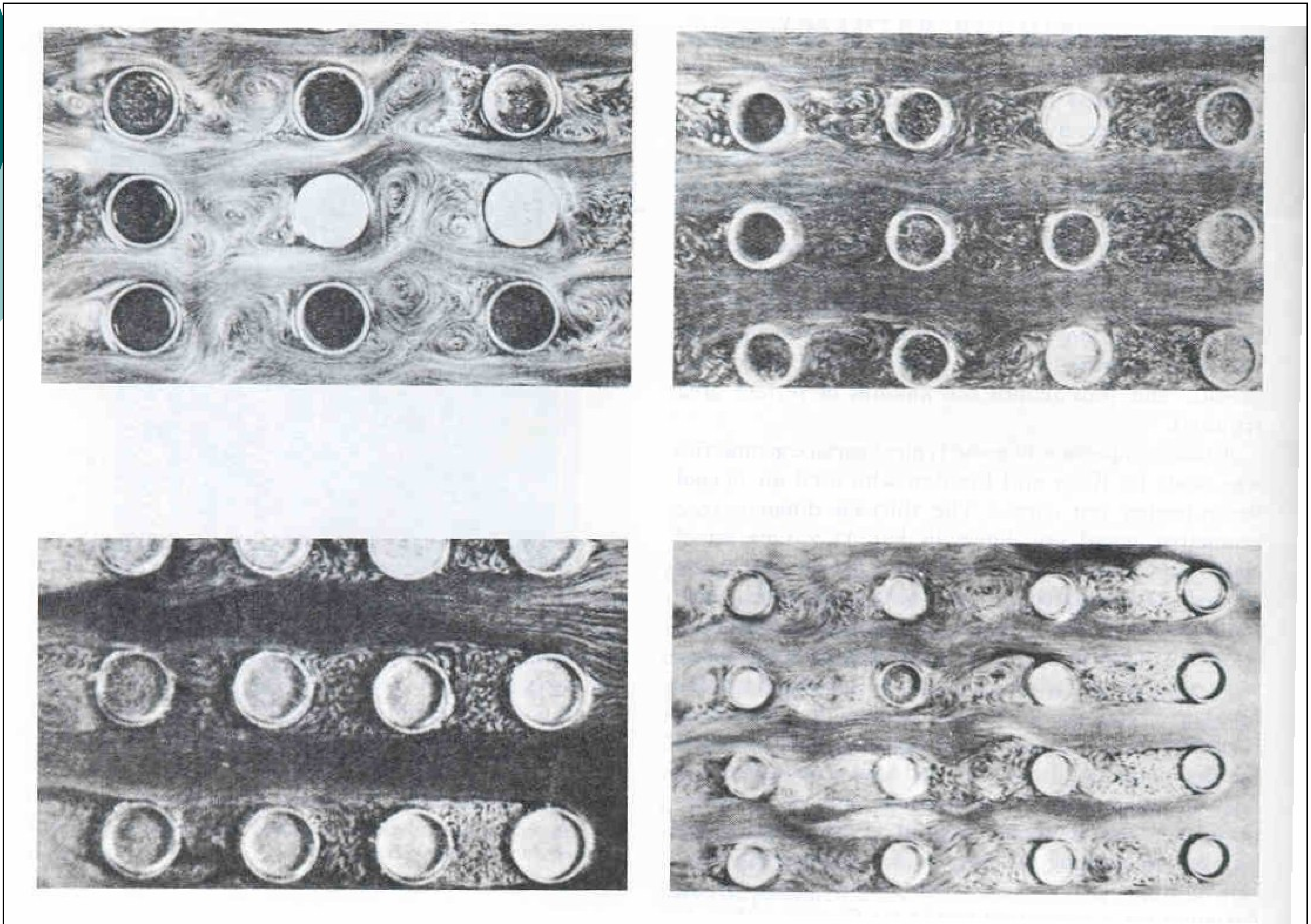
Cross Flow

- finned versus unfinned
- mixed versus unmixed

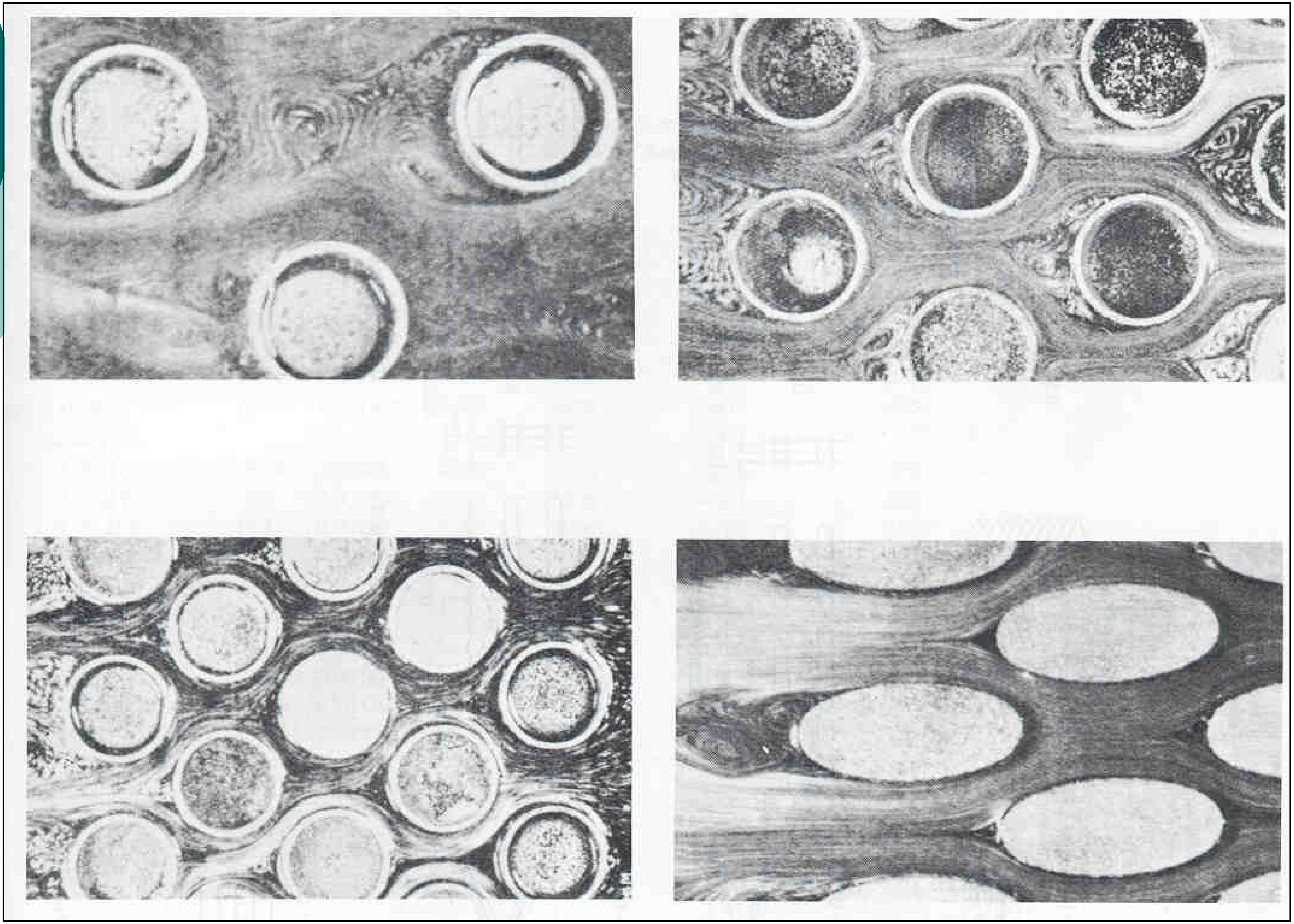




Heat Exchanger Types



Heat Exchanger Types



Heat Exchanger Analysis

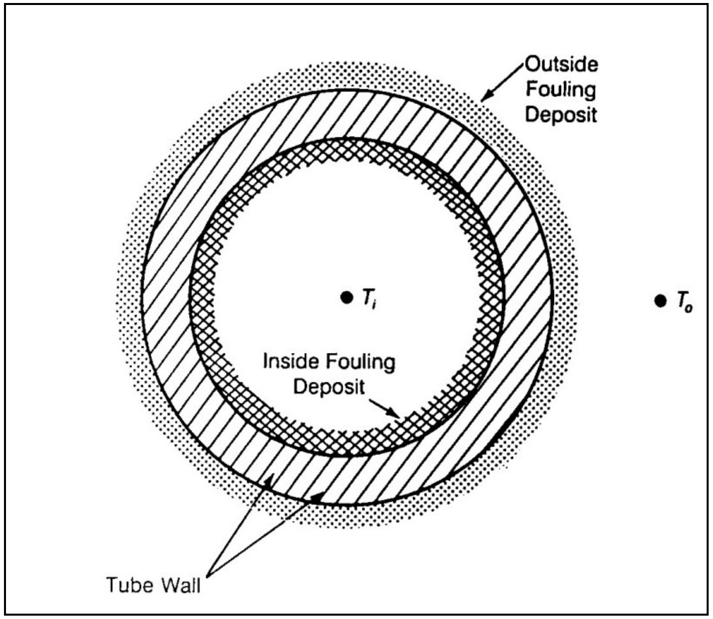
- Overall Heat Transfer Coefficient
- LMTD
- Effectiveness-NTU

Overall Heat Transfer Coefficient

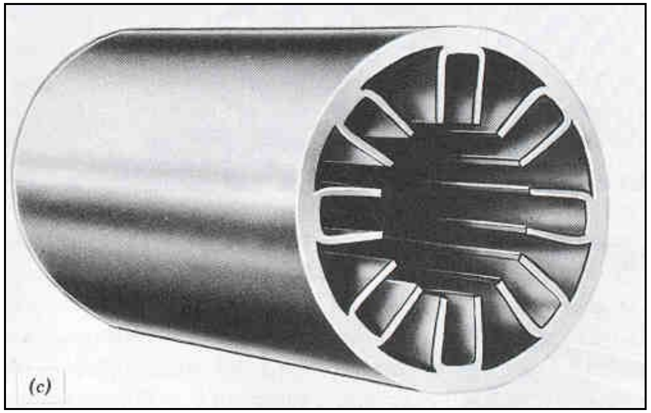
The overall coefficient is used to analyze heat exchangers. It contains the effect of hot and cold side convection, conduction as well as fouling and fins.

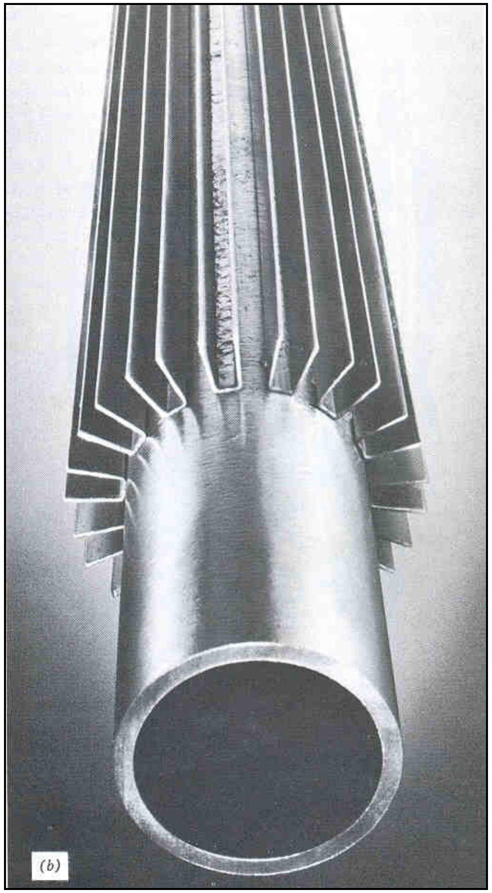
$$\frac{1}{UA} = \frac{1}{(\eta_o hA)_c} + \frac{R''_{f,c}}{(\eta_o A)_c} + R_w + \frac{R''_{f,h}}{(\eta_o A)_h} + \frac{1}{(\eta_o hA)_h}$$

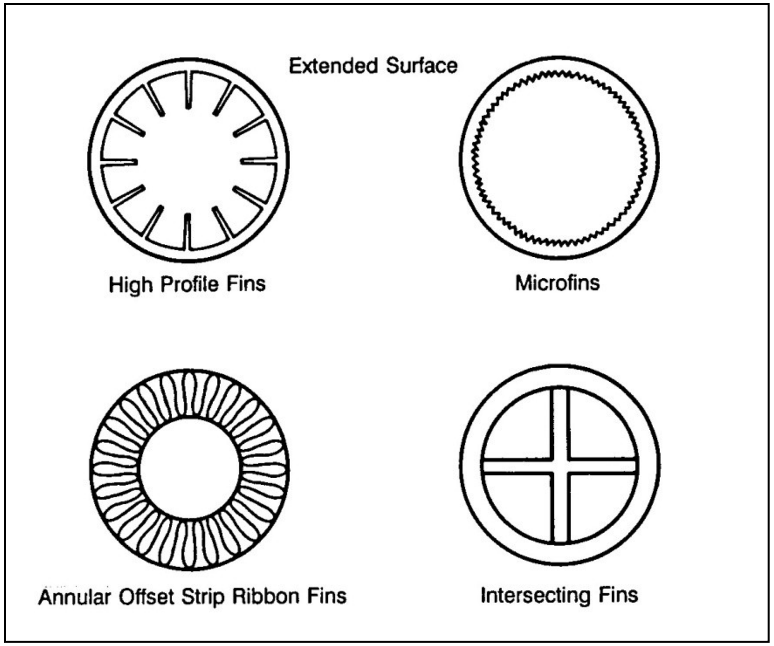
$R''_f =$ fouling factor



Enhanced Surfaces

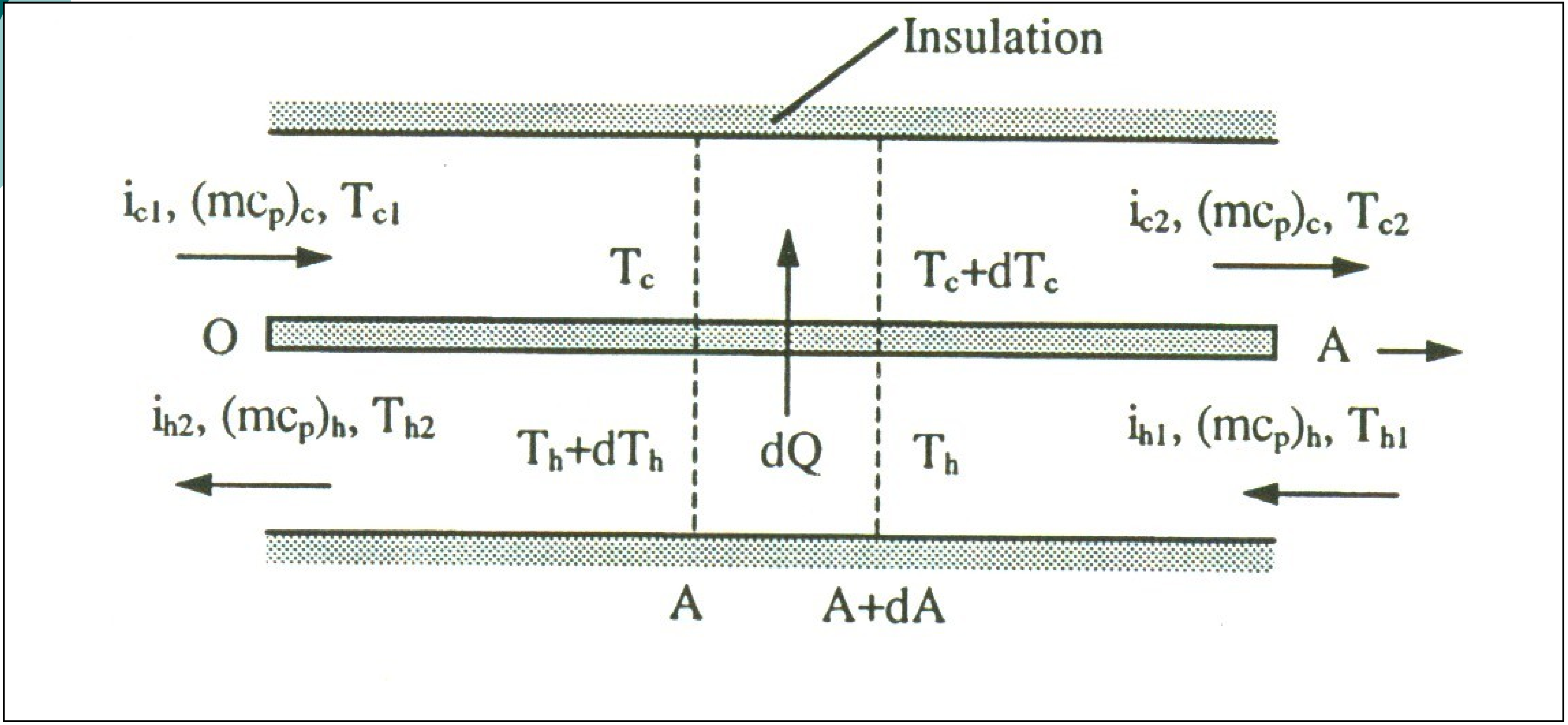






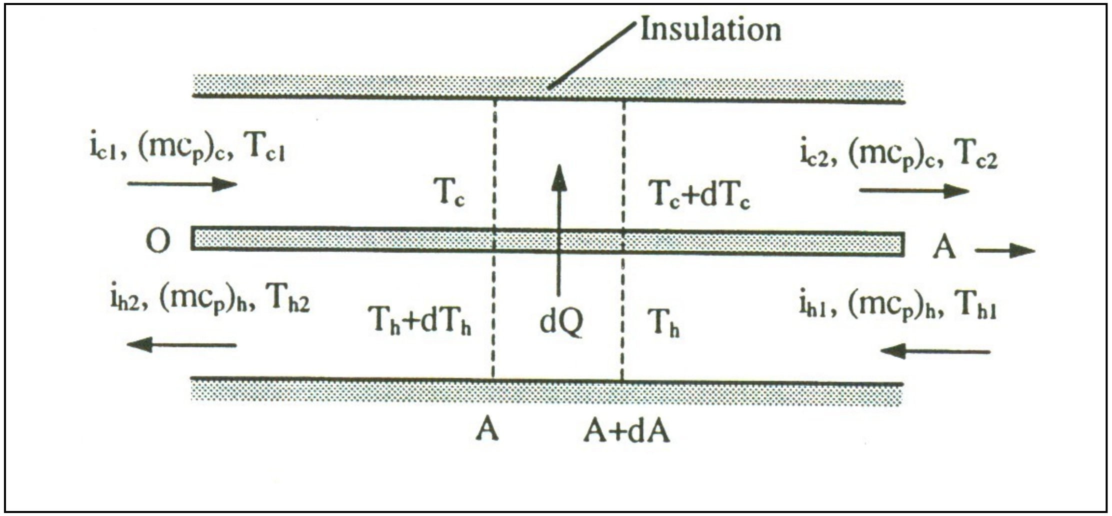
Log-Mean Temperature Difference

To relate the total heat transfer rate to inlet and outlet fluid temperatures. Apply energy balance:



Log-Mean Temperature Difference

We can also relate the total heat transfer rate to the temperature difference between the hot and cold fluids.

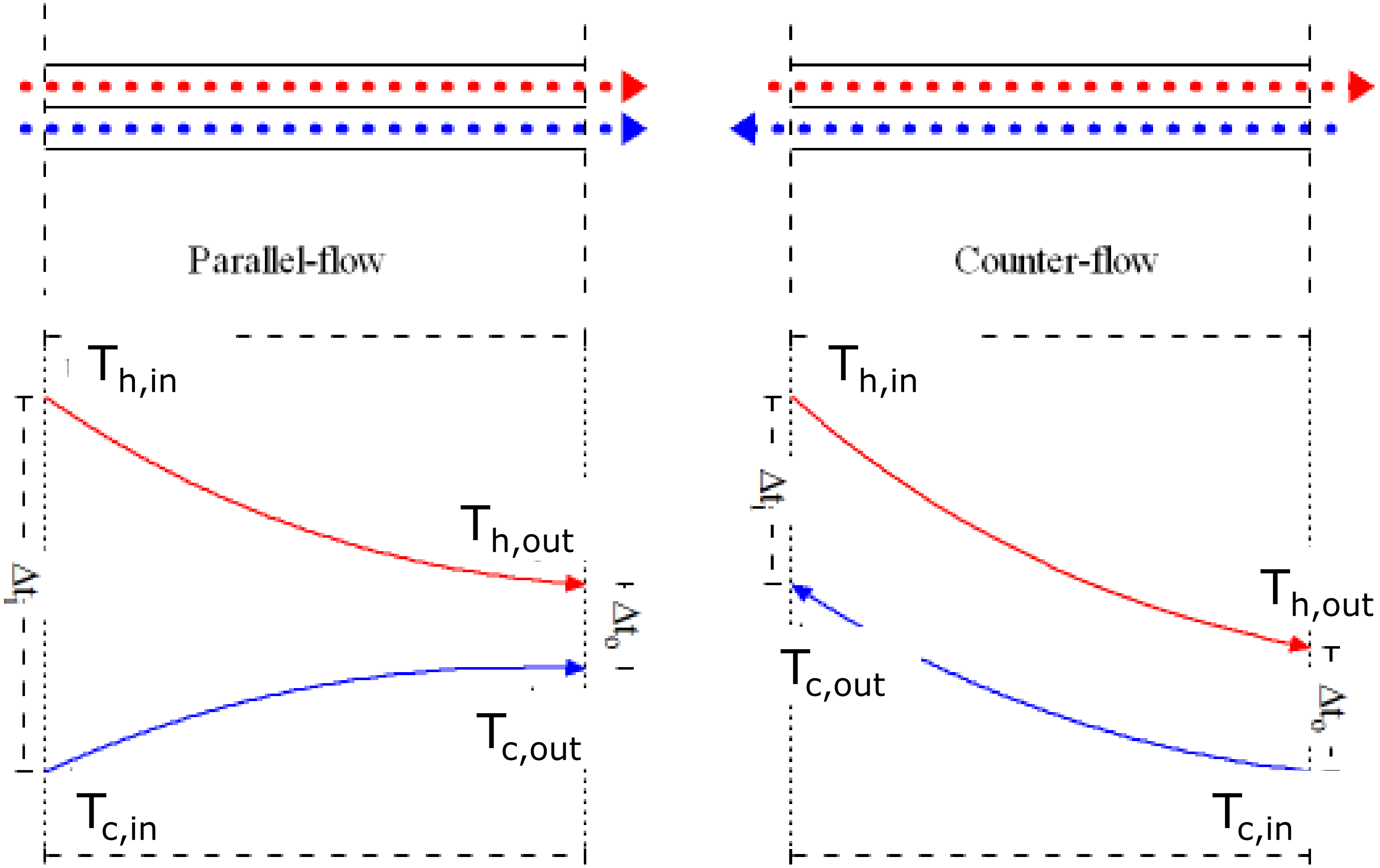


$$let \quad \Delta T = T_h - T_c$$

$$Q = UA\Delta T_{LM}$$

.

The log mean temperature difference depends on the heat exchanger configuration



LMTD Parallel-Flow HX

$$Q = UA\Delta T_{LM} \qquad \Delta T_{LM} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2 / \Delta T_{1)}}$$

$$\text{Where for Parallel Flow :}$$

$$\Delta T_1 = T_{h,1} - T_{c,1} = T_{h,i} - T_{c,i}$$

$$\Delta T_2 = T_{h,2} - T_{c,2} = T_{h,o} - T_{c,o}$$

LMTD Counter-Flow HX

$$Q = UA\Delta T_{LM} \qquad \Delta T_{LM} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2 / \Delta T_{1})}$$

Where for Counter Flow :

$$\Delta T_1 = T_{h,1} - T_{c,1} = T_{h,i} - T_{c,o}$$

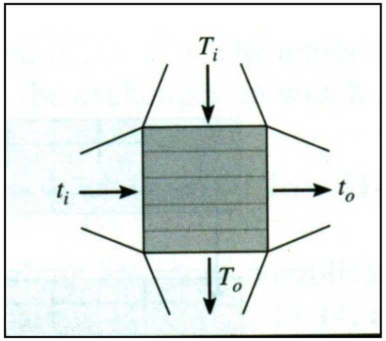
$$\Delta T_2 = T_{h,2} - T_{c,2} = T_{h,o} - T_{c,i}$$

$\Delta T_{lm,CF} > \Delta T_{lm,PF}$ FOR SAME U: $A_{CF} < A_{PF}$

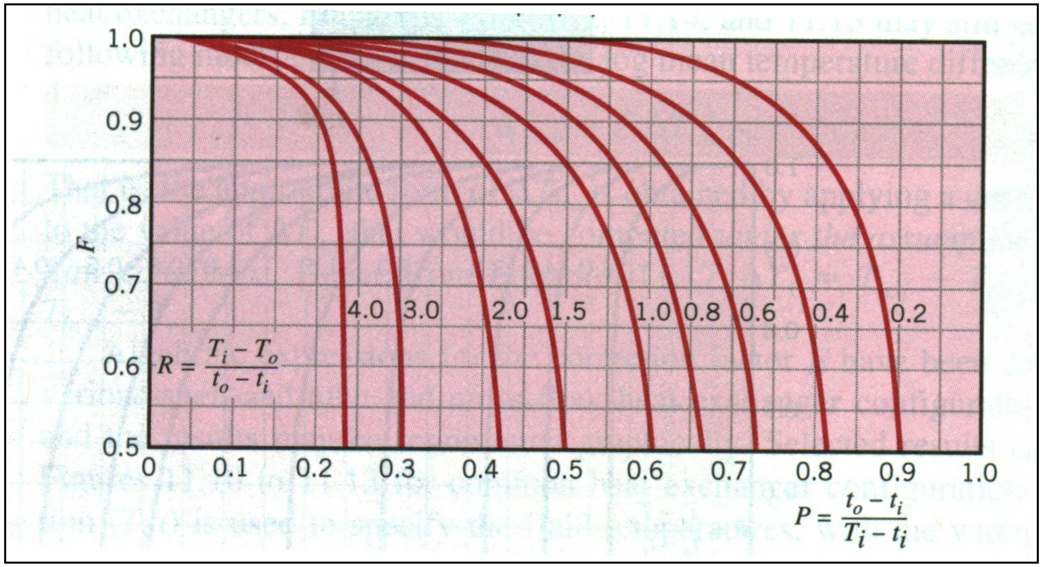
LMTD- Multi-Pass and Cross-Flow

Apply a correction factor to obtain LMTD

$$Q = UA\Delta T_{LM} \qquad \Delta T_{LM} = F\Delta T_{LM,CF}$$



t: Tube Side



LMTD Method

Sizing a Heat Exchanger:

- Calculate Q and the unknown outlet temperature.
- Calculate DT_{lm} and obtain the correction factor (F) if necessary
- Calculate the overall heat transfer coefficient.
- Determine A.

The LMTD method is not as easy to use for performance analysis….

The Effectiveness-NTU Method

- Define Q_{max}

  for $C_c < C_h$ $\quad Q_{max} = C_c(T_{h,i} - T_{c,i})$

  for $C_h < C_c$ $\quad Q_{max} = C_h(T_{h,i} - T_{c,i})$

or $\quad Q_{max} = C_{min}(T_{h,i} - T_{c,i})$

$$\varepsilon = \frac{q}{q_{\max}} = \frac{C_h(T_{h,i} - T_{h,o})}{C_{\min}(T_{h,i} - T_{c,i})} = \frac{C_c(T_{c,o} - T_{c,i})}{C_{\min}(T_{h,i} - T_{c,i})}$$

$$Q = \varepsilon C_{min}(T_{h,i} - T_{c,i})$$

The Effectiveness-NTU Method

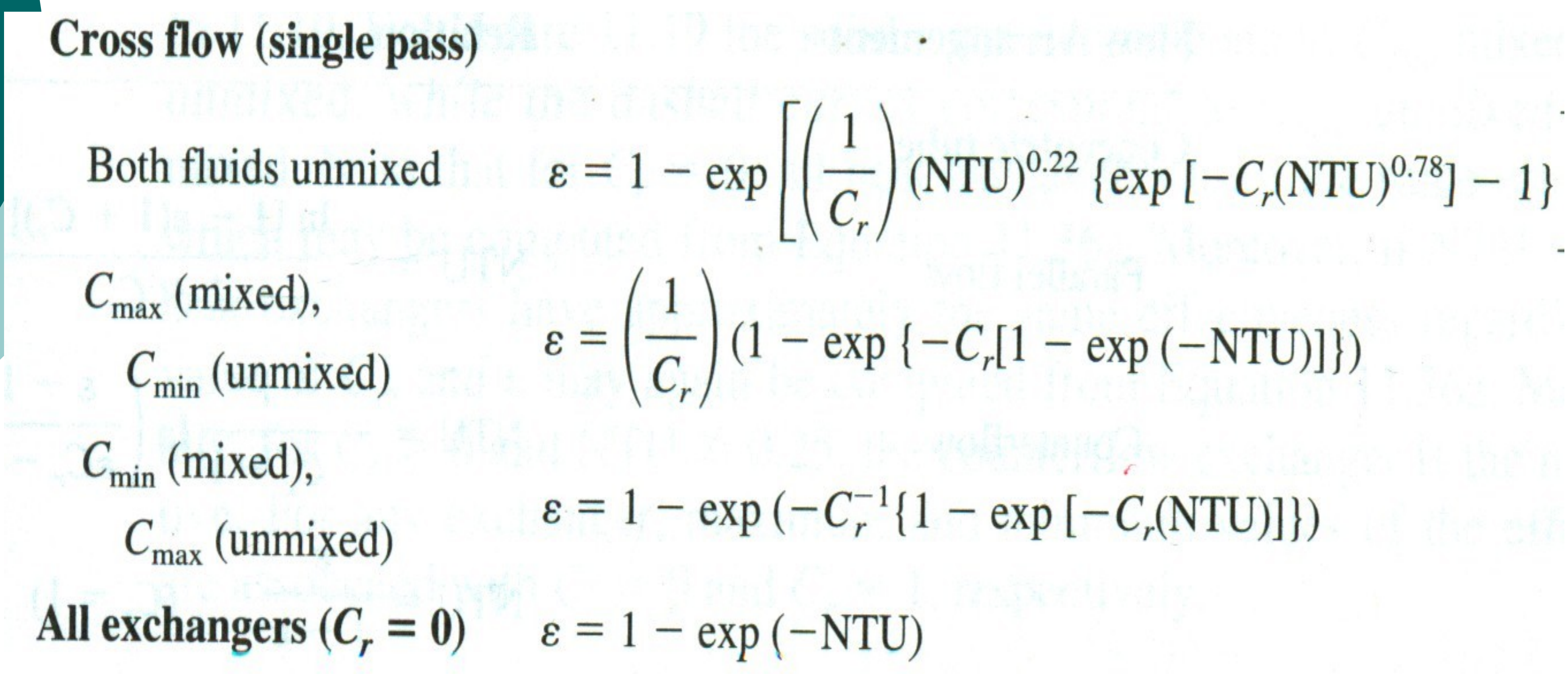
- For any heat exchanger:

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

- NTU (number of transfer units) designates the nondimensional heat transfer size of the heat exchanger:

$$NTU = \frac{UA}{C_{\min}}$$

The Effectiveness-NTU Method



Cross flow (single pass)

Both fluids unmixed
$$\varepsilon = 1 - \exp\left[\left(\frac{1}{C_r}\right)(\mathrm{NTU})^{0.22}\{\exp[-C_r(\mathrm{NTU})^{0.78}] - 1\}\right.$$

$C_{\max}$ (mixed), $C_{\min}$ (unmixed)
$$\varepsilon = \left(\frac{1}{C_r}\right)(1 - \exp\{-C_r[1 - \exp(-\mathrm{NTU})]\})$$

$C_{\min}$ (mixed), $C_{\max}$ (unmixed)
$$\varepsilon = 1 - \exp(-C_r^{-1}\{1 - \exp[-C_r(\mathrm{NTU})]\})$$

All exchangers ($C_r = 0$)
$$\varepsilon = 1 - \exp(-\mathrm{NTU})$$

The Effectiveness-NTU Method

PERFORMANCE ANALYSIS

- Calculate the capacity ratio $C_r = C_{min}/C_{max}$ and $NTU = UA/C_{min}$ from input data
- Determine the effectiveness from the appropriate charts or ε-NTU equations for the given heat exchanger and specified flow arrangement.
- When ε is known, calculate the total heat transfer rate
- Calculate the outlet temperature.

The Effectiveness-NTU Method

SIZING ANALYSIS

- When the outlet and inlet temperatures are known, calculate ε.
- Calculate the capacity ratio $C_r = C_{min}/C_{max}$
- Calculate the overall heat transfer coefficient, U
- When ε and C and the flow arrangement are known, determine NTU from the ε-NTU equations.
- When NTU is known, calculate the total heat transfer surface area.

The Homework