BENCH-TOP HEAT EXCHANGERS

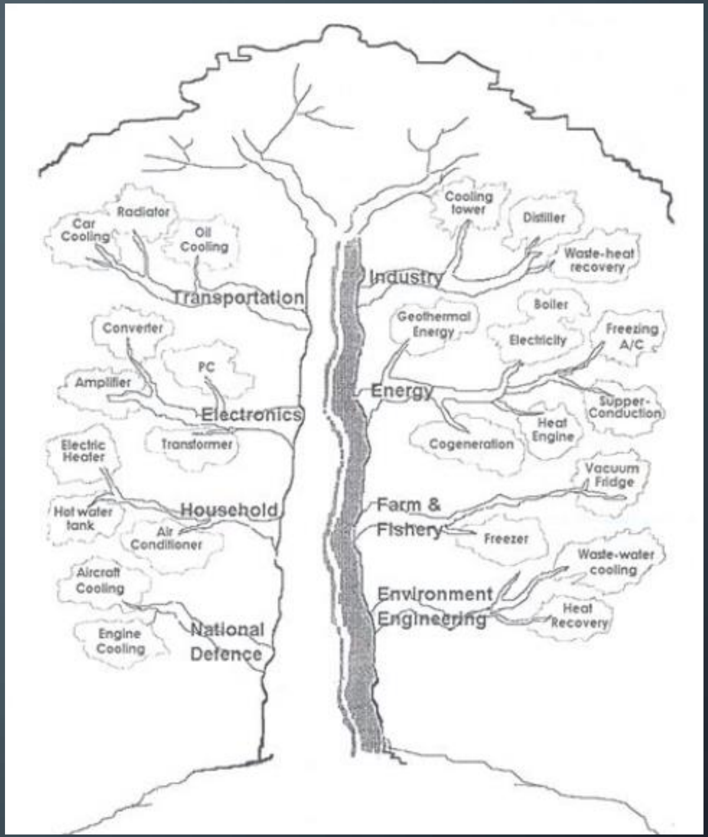
LAB 9

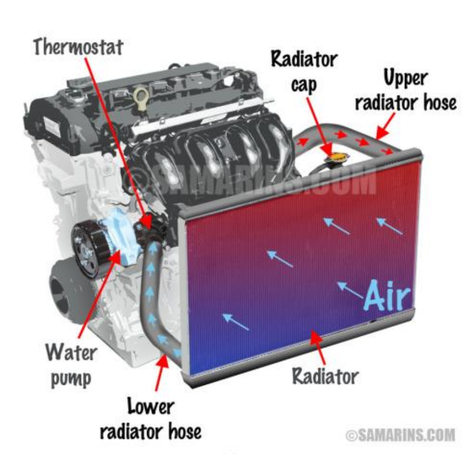
BENCH-TOP HEAT EXCHANGERS

- Heat Exchangers
  - Introduction
  - Types of heat exchangers
  - Theory
- Lab 9
  - Goal: To explore the heat-transfer characteristics of: 1) Concentric tube heat exchangers and 2) shell-and-tube heat exchangers

HEAT EXCHANGERS

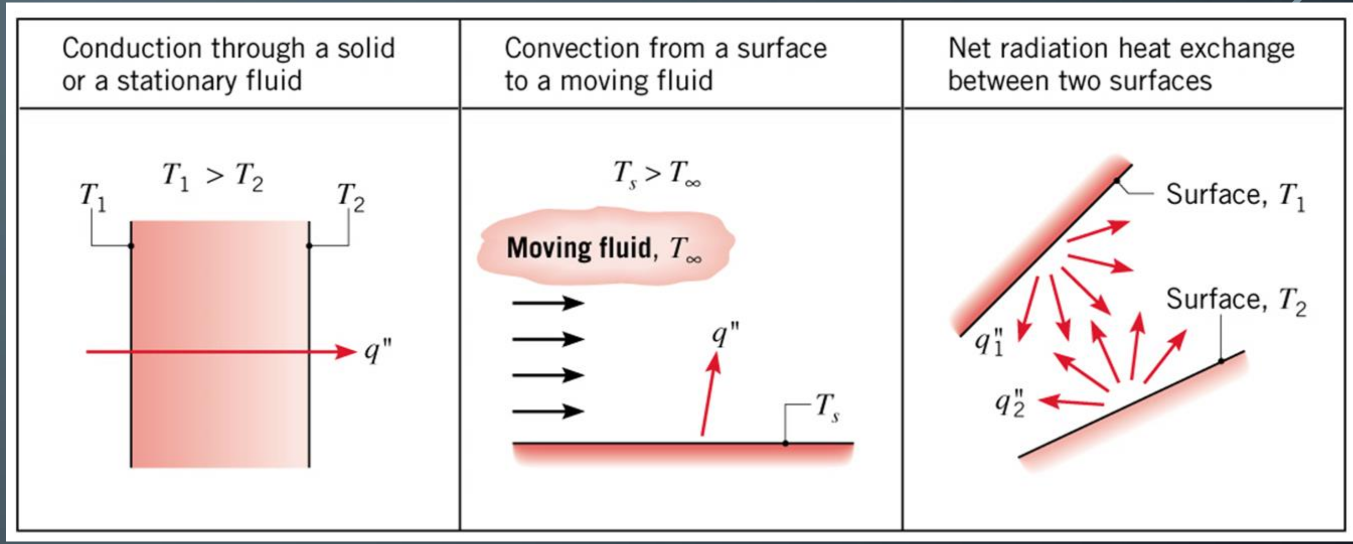
- Heat exchangers are devices that provide the flow of thermal energy between two or more fluids at different temperatures while keeping them from mixing with each other.

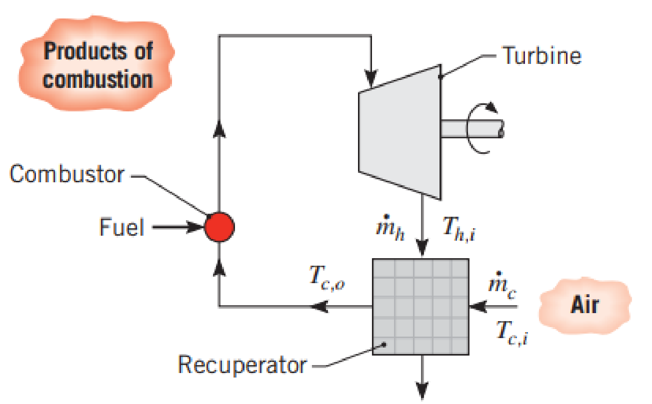


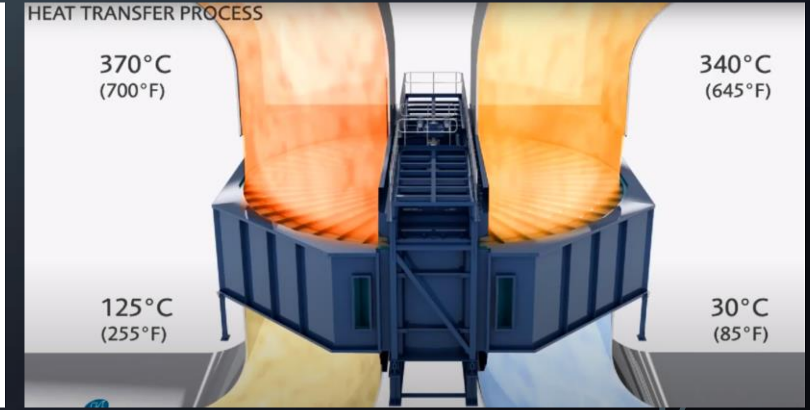


HEAT EXCHANGERS

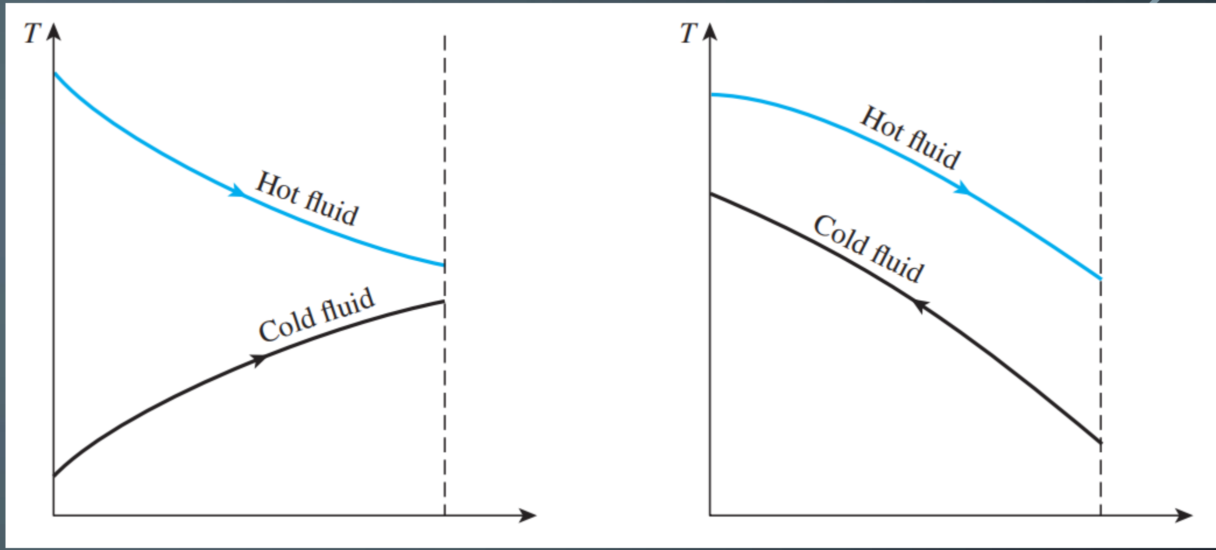
- Heat transfer in a heat exchanger usually involves
    - Convection
    - Conduction
    - Overall heat transfer coefficient U
- Classified according to:
    - Recuperating or Regenerating
    - Tubes, plates or extended surfaces
    - Parallel flow, counter flow or cross flow



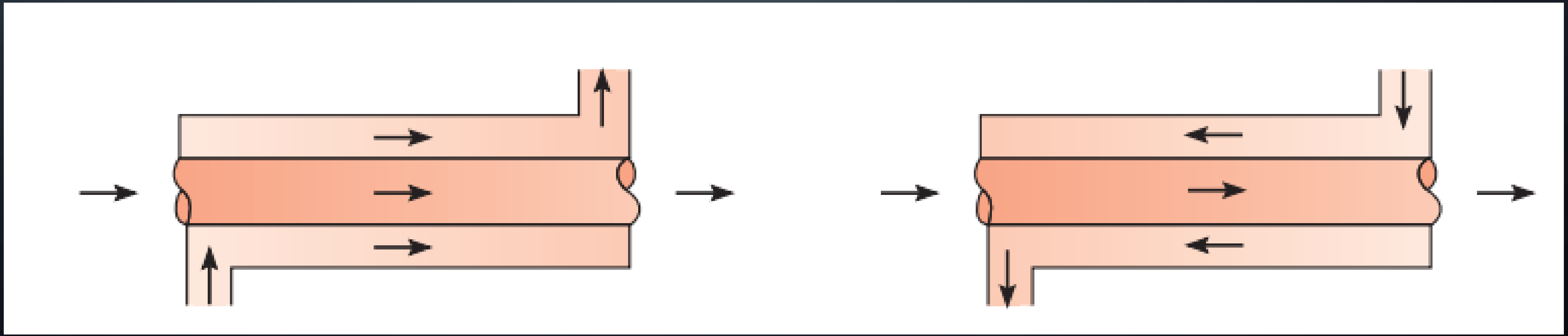




HEAT EXCHANGER TYPES

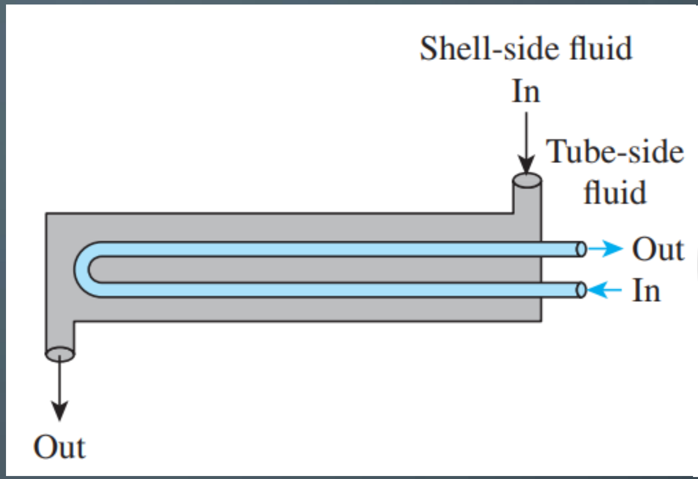


- Concentric Tube Heat Exchangers
- Double Piped Heat Exchangers
  - A pipe is placed concentrically within a larger pipe.
  - Commonly used for small heat transfer areas.
  - Simple construction, flexible.
  - Bulky and Expensive

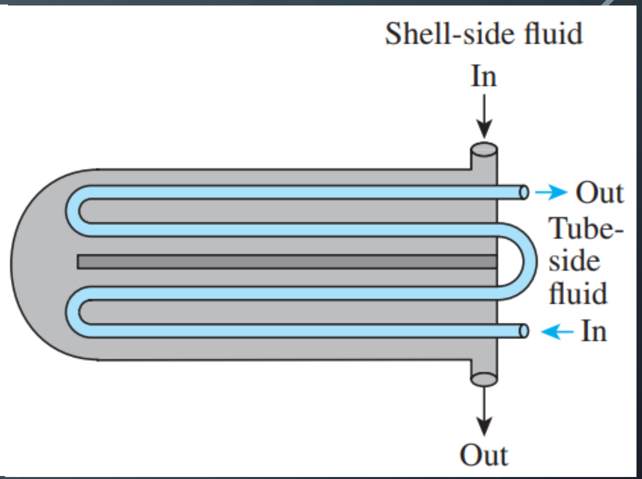


HEAT EXCHANGER TYPES

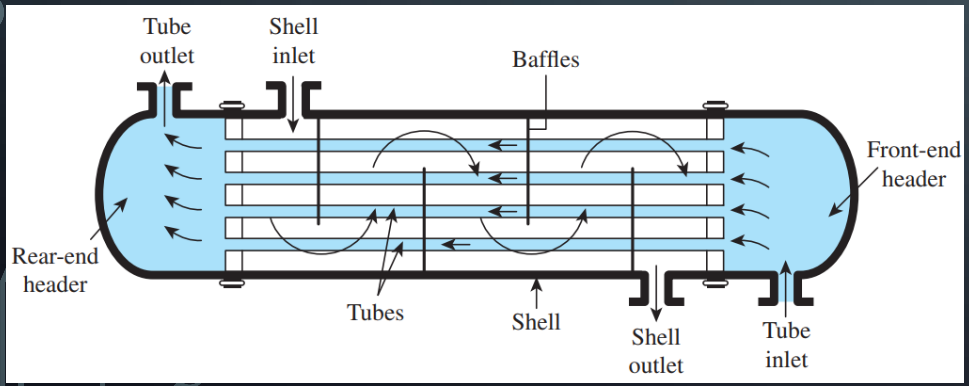
- Shell-and-Tube Heat Exchangers
  - Most versatile heat exchanger type
  - Large heat transfer area per volume.

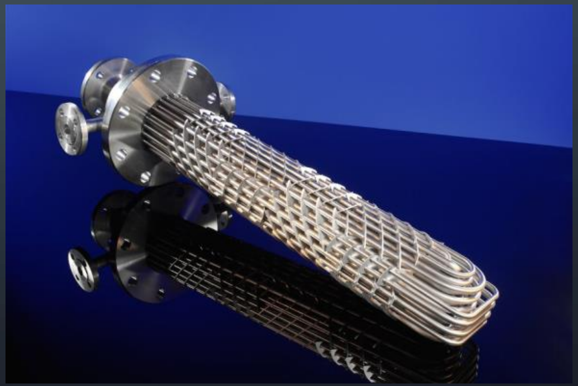


One-shell pass and two-tube passes



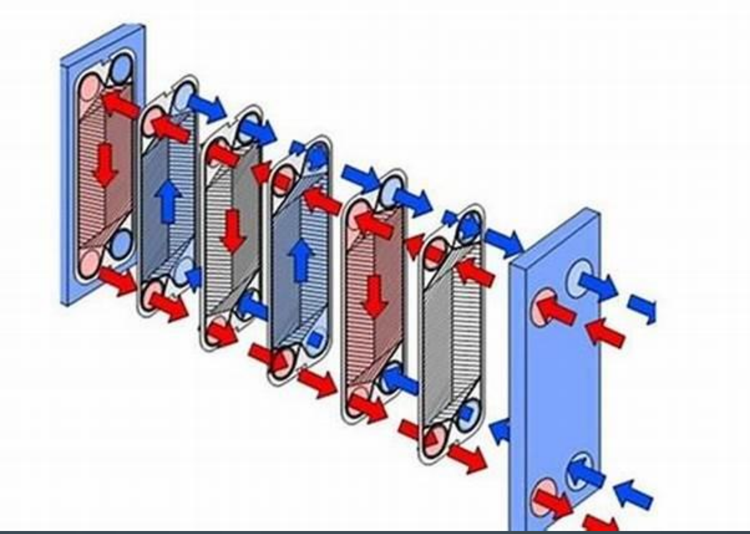
Two-shell passes and four-tube passes

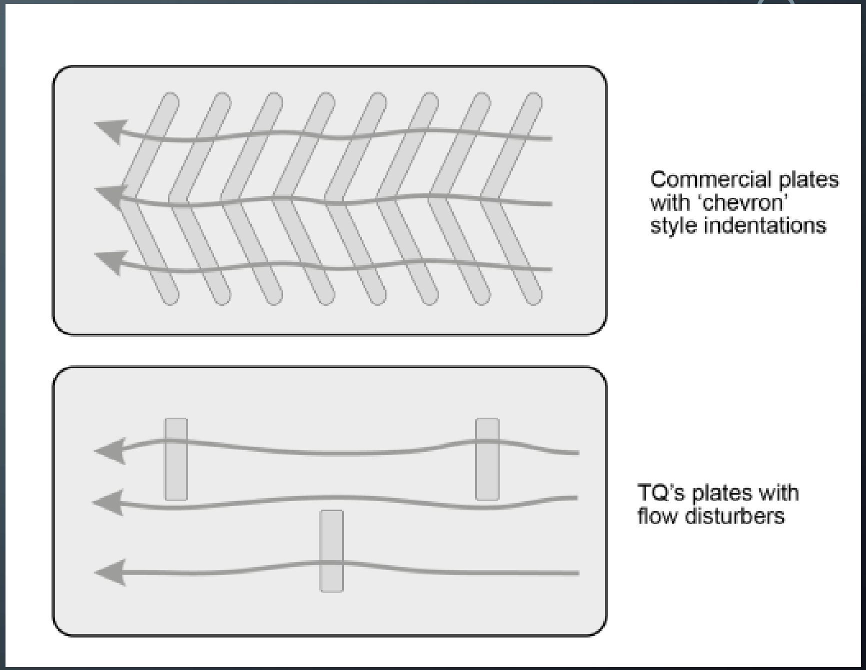


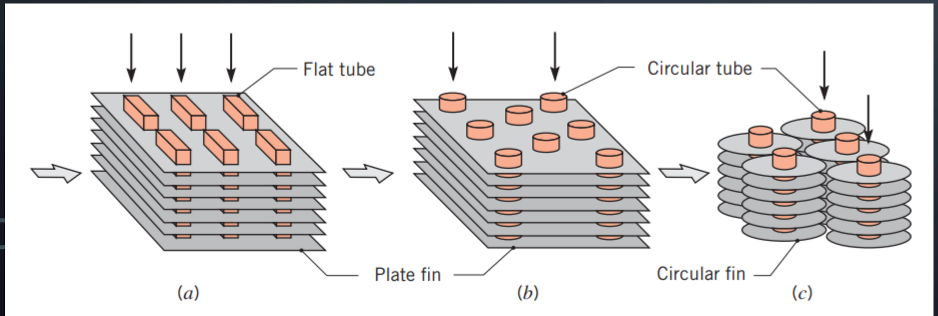


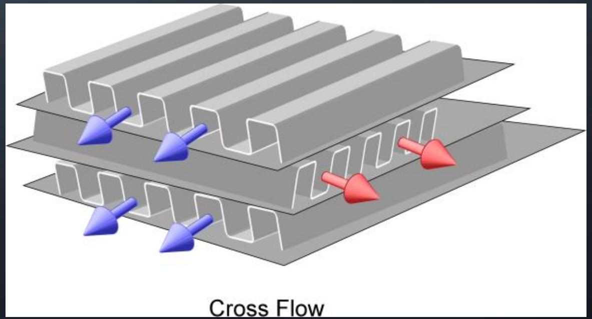
HEAT EXCHANGER TYPES

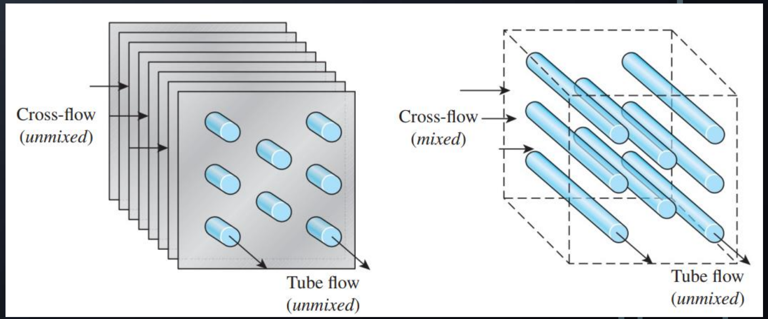
- Compact Heat Exchangers
  - Commonly used in gas flow applications
  - Plate fin or tube fin geometries
  - Fins increase heat transfer rate by increasing contact area
  - Cross flow conditions



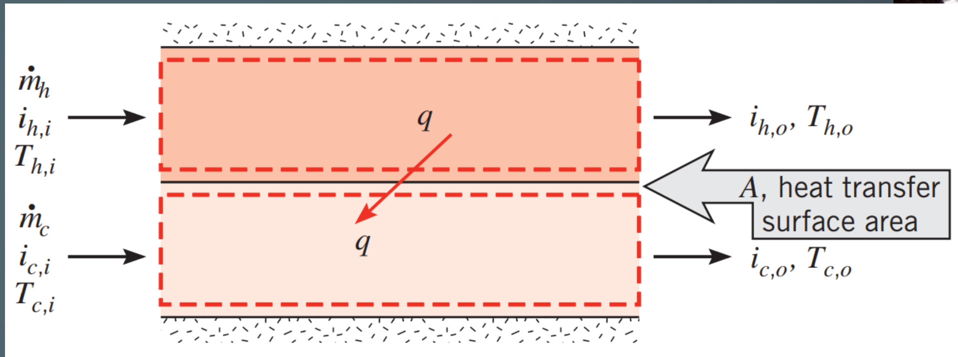


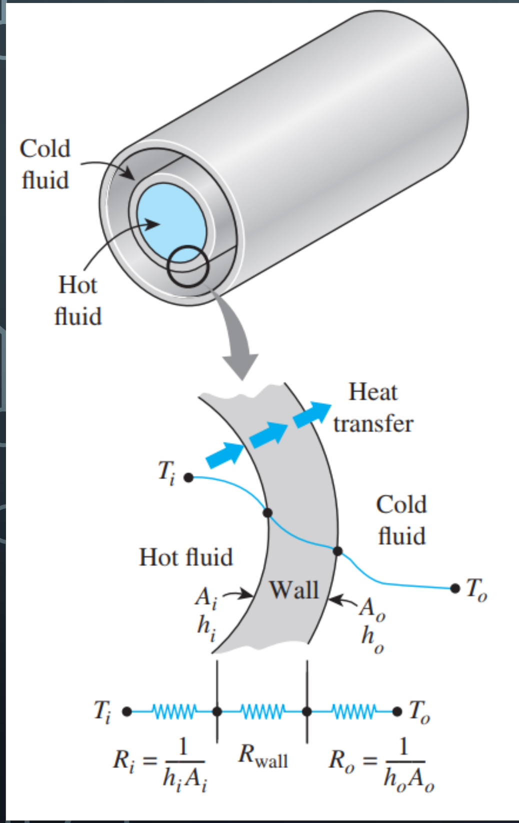






HEAT EXCHANGER THEORY





$$Q = \dot{m}_h(i_{h,i} - i_{h,o}) = \dot{m}_h c_{p,h}(T_{h,i} - T_{h,o})$$

$$Q = \dot{m}_c(i_{c,i} - i_{c,o}) = \dot{m}_c c_{p,c}(T_{c,i} - T_{c,o})$$

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

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

$$R''_f = \text{fouling factor}$$

HEAT EXCHANGER THEORY

- Tube Flow:

$$\frac{1}{UA} = \frac{1}{U_oA_o} = \frac{1}{U_iA_i}$$

$$= \frac{1}{h_iAi} + \frac{R"_{f,i}}{A_i} + \frac{\ln\left(\frac{D_o}{D_i}\right)}{2\pi kL} + \frac{R"_{f,o}}{A_o} + \frac{1}{h_oA_o}$$

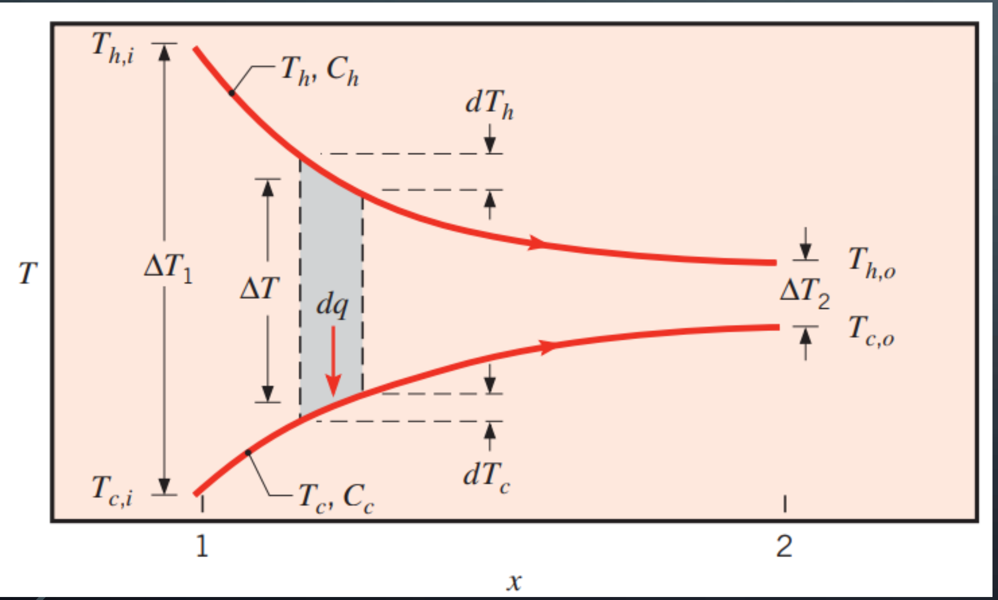
Overall Heat Transfer Coefficients for Common Arrangements	
Fluid Combination	U $(\frac{W}{m^2K})$
Water to water	850-1700
Water to oil	110-350
Steam Condenser	1000-6000
Ammonia Condenser	800-1400
Alcohol Condenser	250-700
Fined-Tube Heat Exchanger	25-50

HEAT EXCHANGER THEORY

Parallel Flow

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

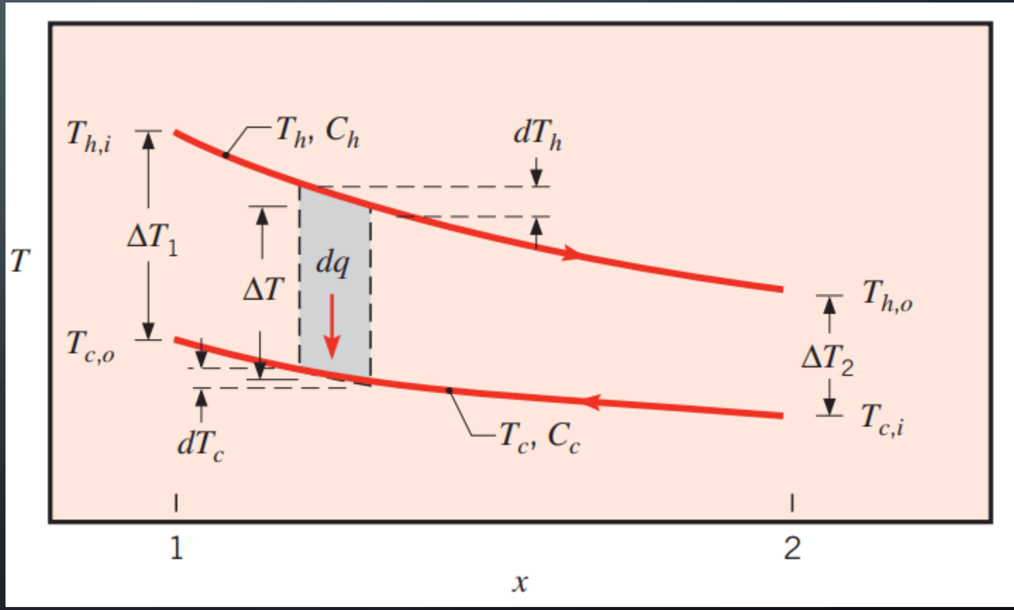
$$\Delta T_2 = T_{h,2} - T_{c,2} = T_{h,o} - T_{c,o}$$



Counter Flow

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

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



HEAT EXCHANGER THEORY

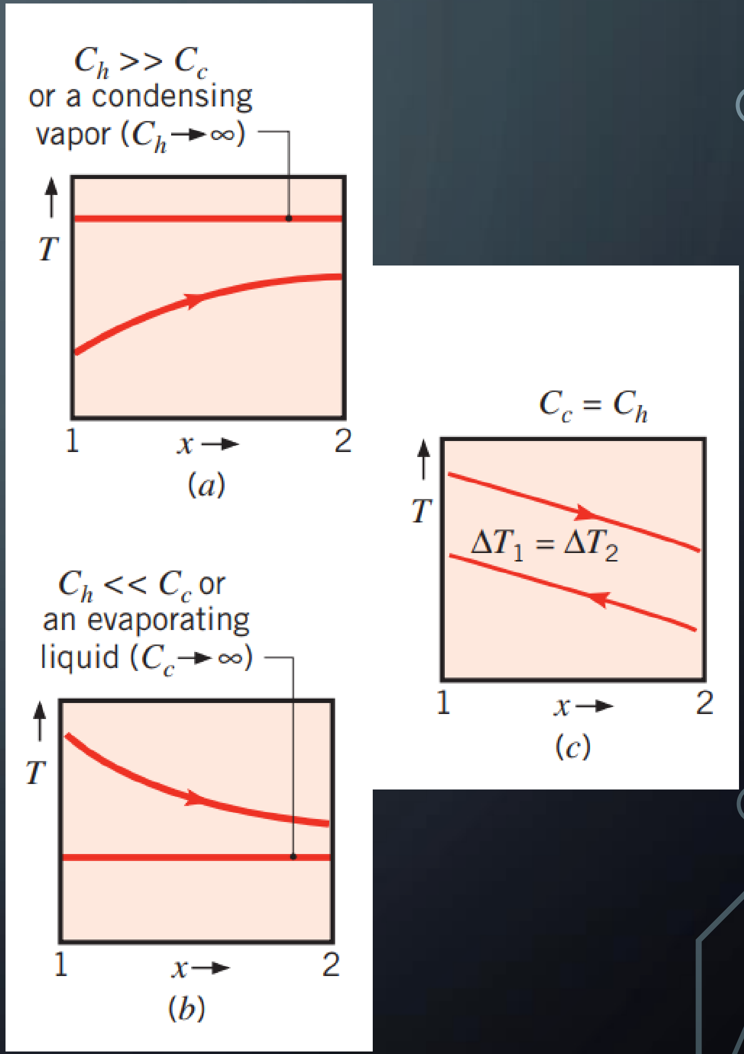
$$\dot{Q} = \dot{Q}_e = \dot{Q}_a = \dot{m}_H c_{p_H} \Delta T_H = \dot{m}_C c_{p_C} \Delta T_C$$

$$\dot{Q}_e = UA\Delta T$$

- Log-Mean Temperature Difference

$$LMTD = \Delta T_{lm} = \frac{\left(\left(T_{H_2} - T_{C_2}\right) - \left(T_{H_1} - T_{C_1}\right)\right)}{\ln \frac{\left(T_{H_2} - T_{C_2}\right)}{\left(T_{H_1} - T_{C_1}\right)}}$$

$$\dot{Q}_e = UA\Delta T_{lm}$$



HEAT EXCHANGER DESIGN

- If only the inlet temperature are specified, effectiveness-NTU Method

$$q_{max} = C_{min}(T_{h,i} - T_{c,i})$$

$$\varepsilon = \frac{q}{q_{max}}, \text{effectiveness}$$

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

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

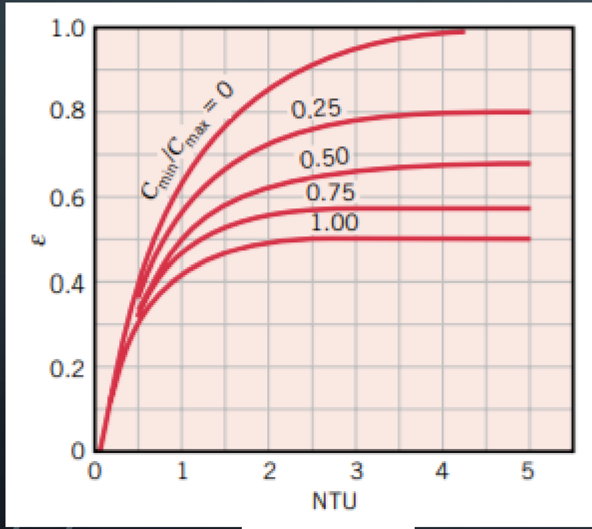
$$\varepsilon = f\left(NTU, \frac{C_{min}}{C_{max}}\right)$$

HEAT EXCHANGER DESIGN

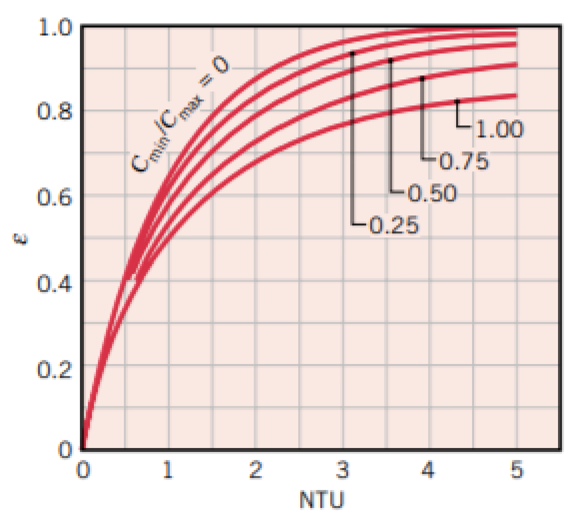
Flow Arrangement	Relation	
Concentric tube		
Parallel flow	$\varepsilon = \dfrac{1 - \exp[-\mathrm{NTU}(1 + C_r)]}{1 + C_r}$	
Counterflow	$\varepsilon = \dfrac{1 - \exp[-\mathrm{NTU}(1 - C_r)]}{1 - C_r \exp[-\mathrm{NTU}(1 - C_r)]}$	$(C_r < 1)$
	$\varepsilon = \dfrac{\mathrm{NTU}}{1 + \mathrm{NTU}}$	$(C_r = 1)$
Shell-and-tube		
One shell pass (2, 4, . . . tube passes)	$\varepsilon_1 = 2\left\{1 + C_r + (1 + C_r^2)^{1/2} \times \dfrac{1 + \exp[-(\mathrm{NTU})_1(1 + C_r^2)^{1/2}]}{1 - \exp[-(\mathrm{NTU})_1(1 + C_r^2)^{1/2}]}\right\}^{-1}$	
n Shell passes ($2n$, $4n$, . . . tube passes)	$\varepsilon = \left[\left(\dfrac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1}\right)^n - 1\right]\left[\left(\dfrac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1}\right)^n - C_r\right]^{-1}$	
Cross-flow (single pass)		
Both fluids unmixed	$\varepsilon = 1 - \exp\left[\left(\dfrac{1}{C_r}\right)(\mathrm{NTU})^{0.22}\{\exp[-C_r(\mathrm{NTU})^{0.78}] - 1\}\right]$	
$C_{\max}$ (mixed), $C_{\min}$ (unmixed)	$\varepsilon = \left(\dfrac{1}{C_r}\right)(1 - \exp\{-C_r[1 - \exp(-\mathrm{NTU})]\})$	
$C_{\min}$ (mixed), $C_{\max}$ (unmixed)	$\varepsilon = 1 - \exp(-C_r^{-1}\{1 - \exp[-C_r(\mathrm{NTU})]\})$	
All exchangers ($C_r = 0$)	$\varepsilon = 1 - \exp(-\mathrm{NTU})$	

Flow Arrangement	Relation	
Concentric tube		
Parallel flow	$\mathrm{NTU} = -\dfrac{\ln[1 - \varepsilon(1 + C_r)]}{1 + C_r}$	
Counterflow	$\mathrm{NTU} = \dfrac{1}{C_r - 1}\ln\left(\dfrac{\varepsilon - 1}{\varepsilon C_r - 1}\right)$	$(C_r < 1)$
	$\mathrm{NTU} = \dfrac{\varepsilon}{1 - \varepsilon}$	$(C_r = 1)$
Shell-and-tube		
One shell pass (2, 4, . . . tube passes)	$(\mathrm{NTU})_1 = -(1 + C_r^2)^{-1/2}\ln\left(\dfrac{E - 1}{E + 1}\right)$ $E = \dfrac{2/\varepsilon_1 - (1 + C_r)}{(1 + C_r^2)^{1/2}}$	
n Shell passes ($2n$, $4n$, . . . tube passes)	Use Equations 11.30b and 11.30c with $\varepsilon_1 = \dfrac{F - 1}{F - C_r}$ $\quad F = \left(\dfrac{\varepsilon C_r - 1}{\varepsilon - 1}\right)^{1/n}$ $\quad \mathrm{NTU} = n(\mathrm{NTU})_1$	
Cross-flow (single pass)		
$C_{\max}$ (mixed), $C_{\min}$ (unmixed)	$\mathrm{NTU} = -\ln\left[1 + \left(\dfrac{1}{C_r}\right)\ln(1 - \varepsilon C_r)\right]$	
$C_{\min}$ (mixed), $C_{\max}$ (unmixed)	$\mathrm{NTU} = -\left(\dfrac{1}{C_r}\right)\ln[C_r \ln(1 - \varepsilon) + 1]$	
All exchangers ($C_r = 0$)	$\mathrm{NTU} = -\ln(1 - \varepsilon)$	

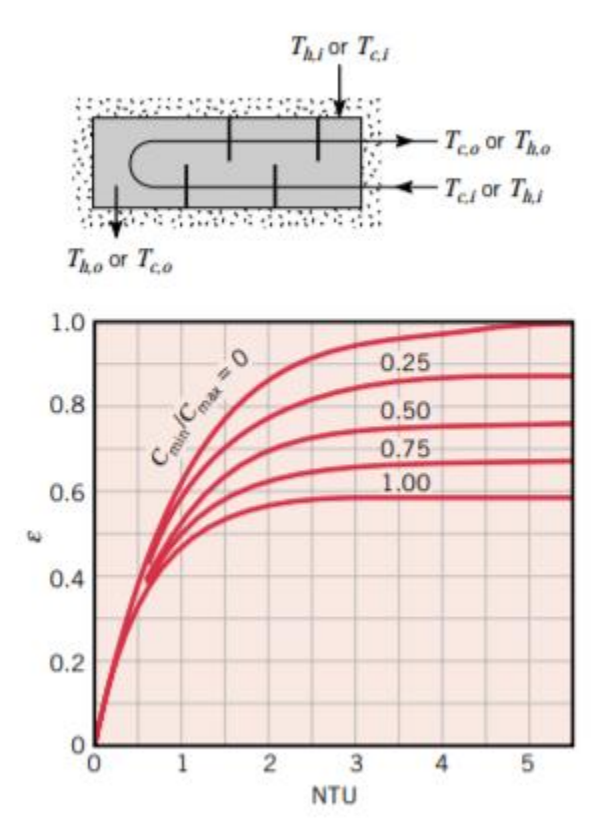
HEAT EXCHANGER DESIGN

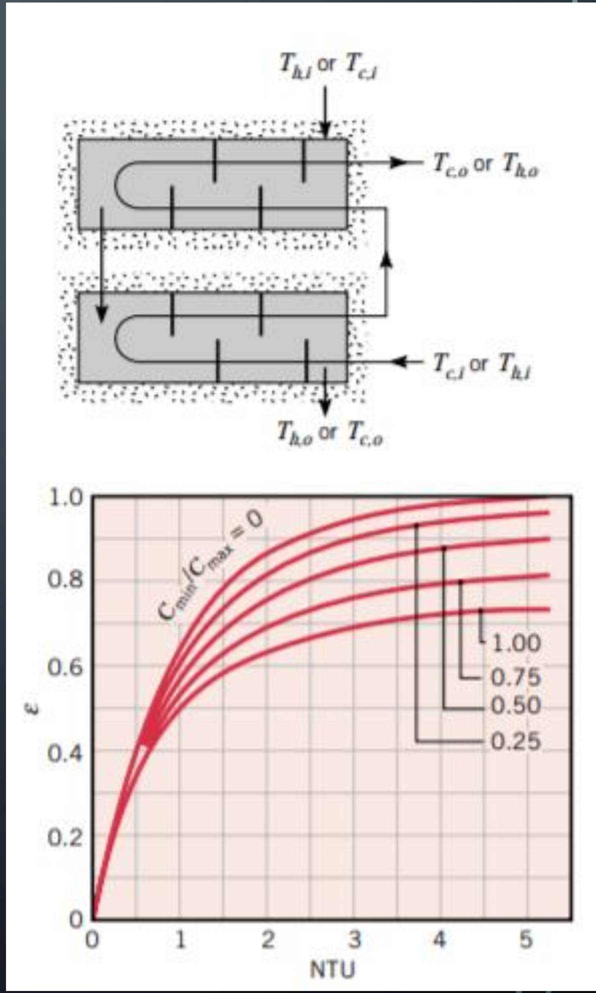


Parallel flow

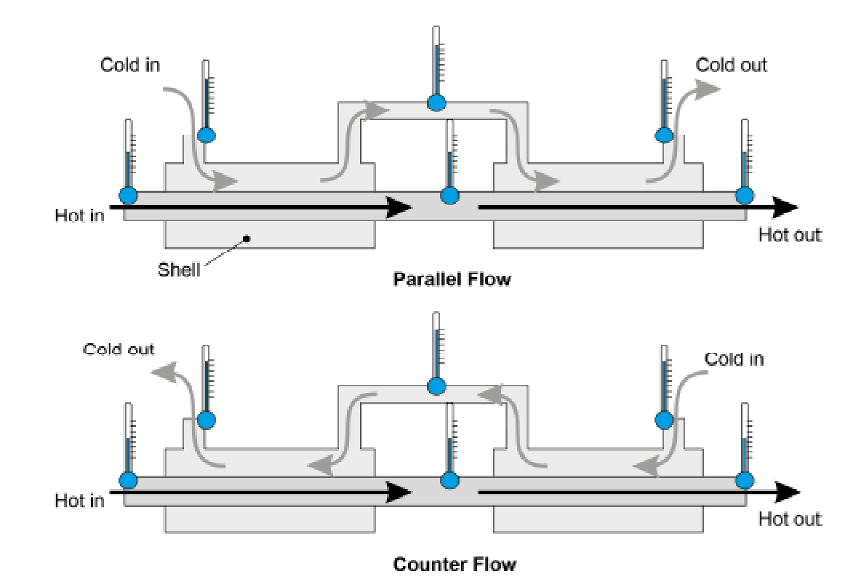


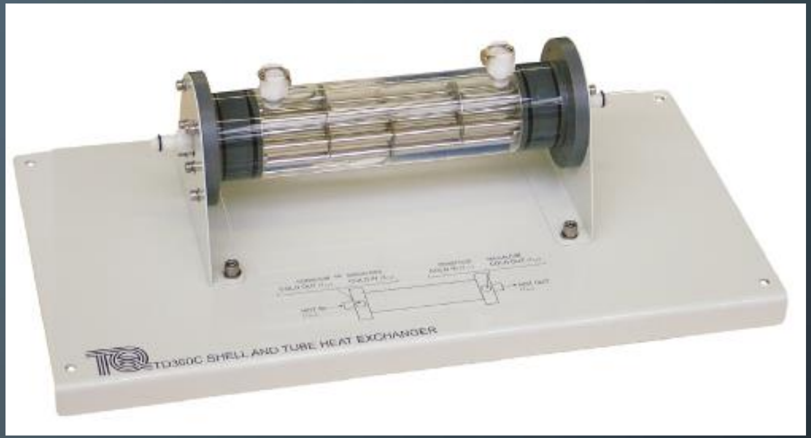
Counterflow

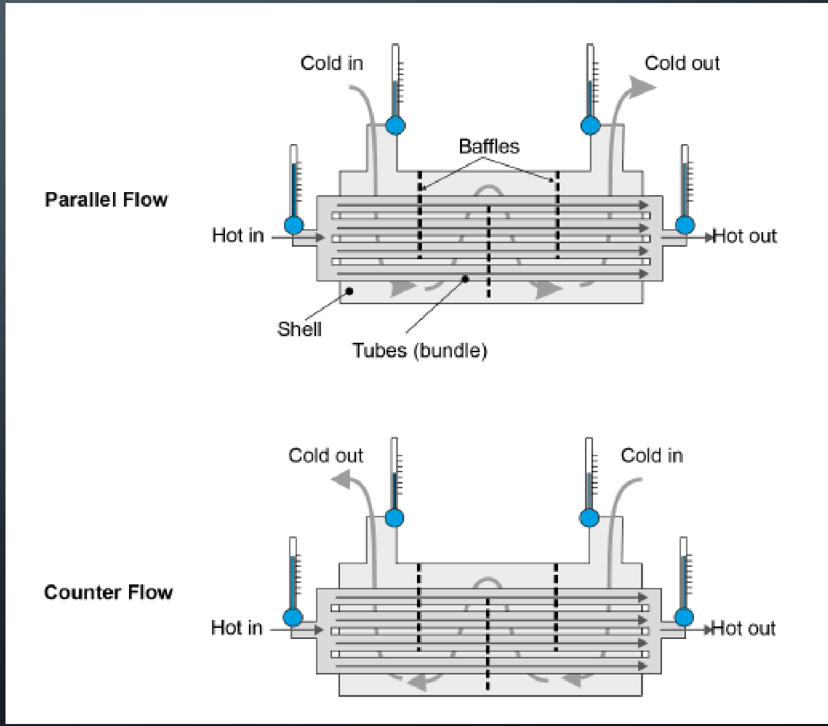




LAB 9 ASSIGNMENT







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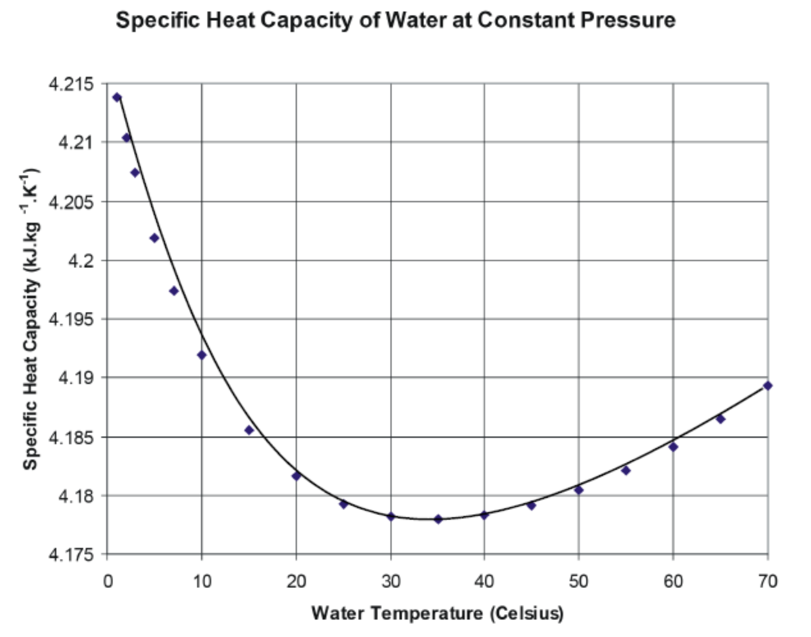

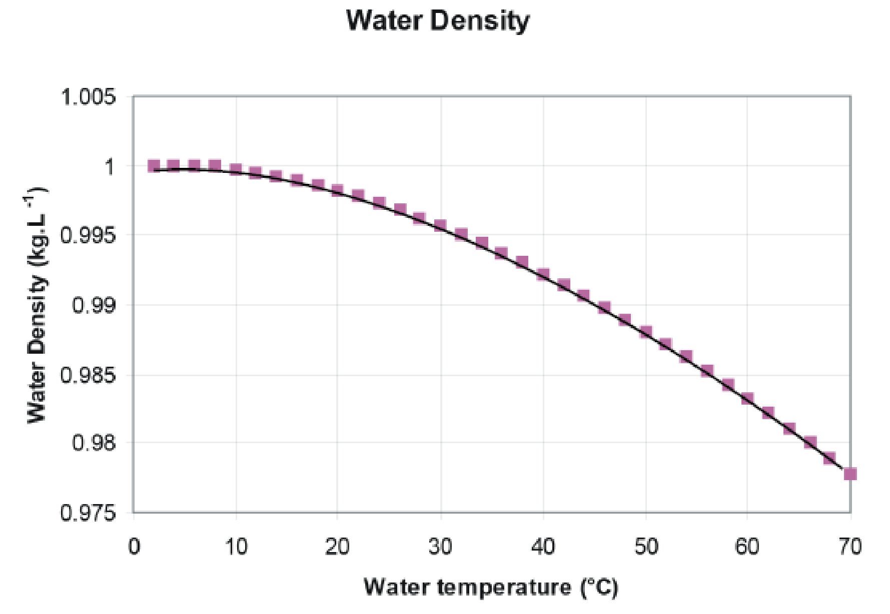

LAB 9 ASSIGNMENT

$$\dot{Q} = \dot{Q}_e = \dot{Q}_a = \dot{m}_H {c_p}_H \Delta T_H = \dot{m}_C {c_p}_C \Delta T_C$$

$$LMTD = \frac{\left(\left(T_{H_2} - T_{C_2}\right) - \left(T_{H_1} - T_{C_1}\right)\right)}{\ln \frac{\left(T_{H_2} - T_{C_2}\right)}{\left(T_{H_1} - T_{C_1}\right)}}$$

$$U = \frac{\dot{Q}_e}{A \times LMTD}$$

$$\eta_H = \frac{T_{H1} - T_{H2}}{T_{H1} - T_{C1}} \times 100\%, \qquad \eta_c = \frac{T_{C2} - T_{C1}}{T_{H1} - T_{C1}} \times 100\%$$

$$\bar{\eta} = \frac{\eta_H + \eta_C}{2}$$