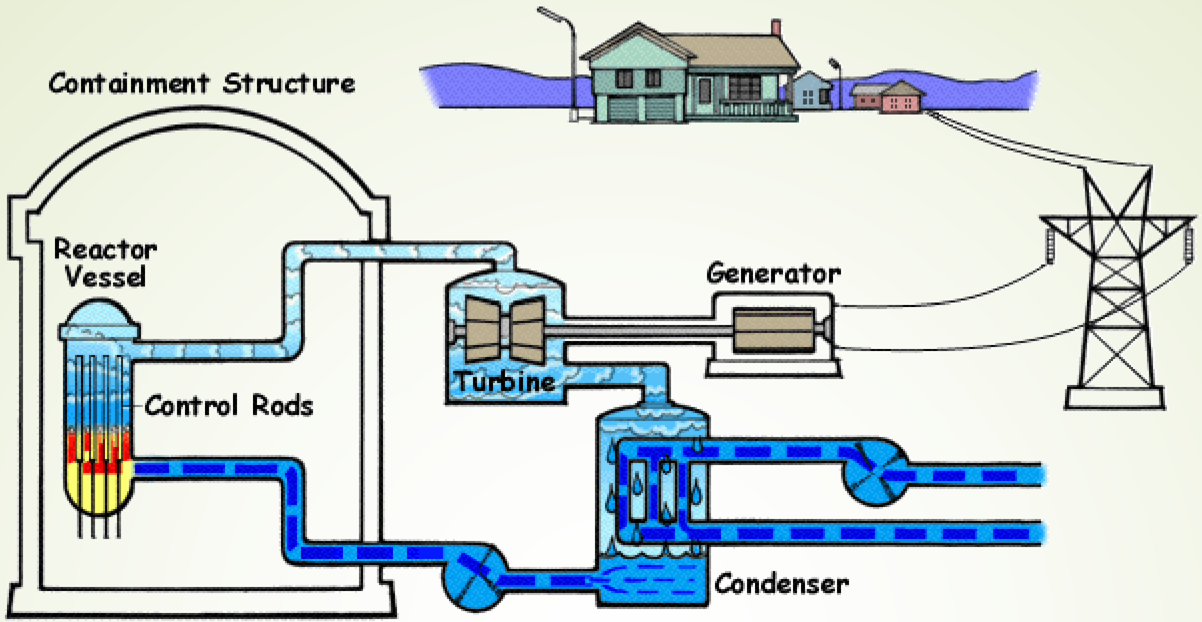


RANKINE CYCLE & NUCLEAR POWER

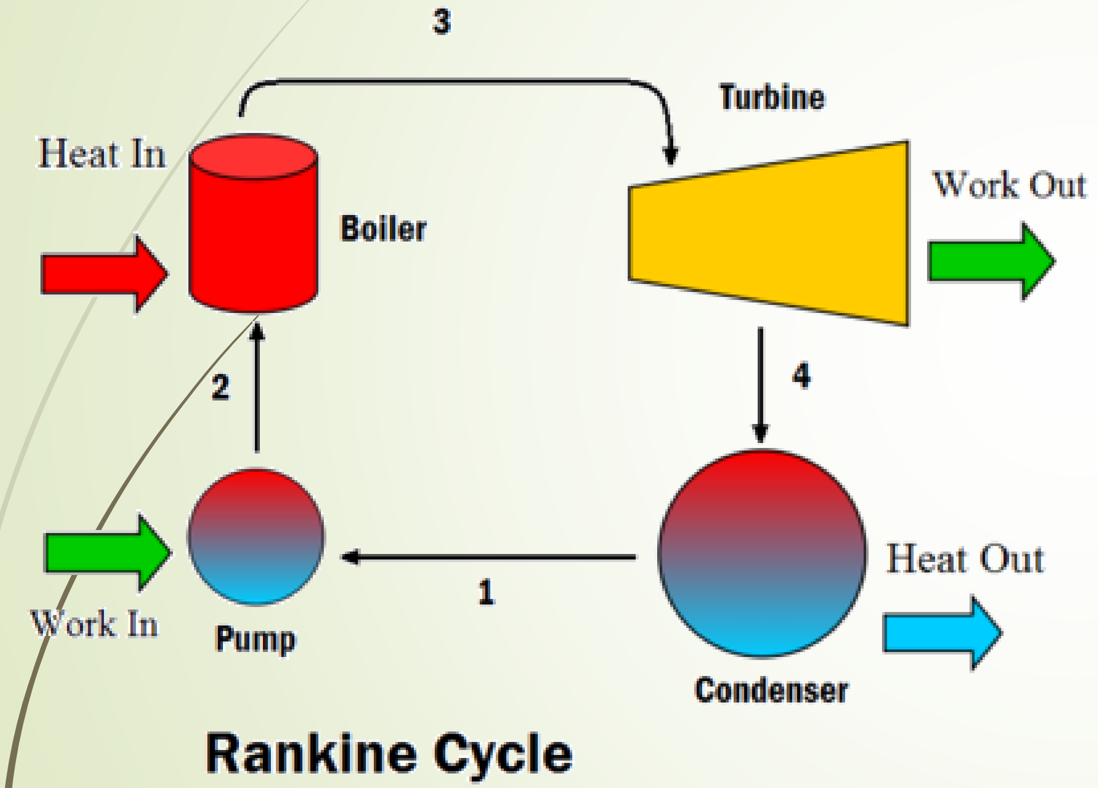
MECH-420 HEAT TRANSFER STUDY AID

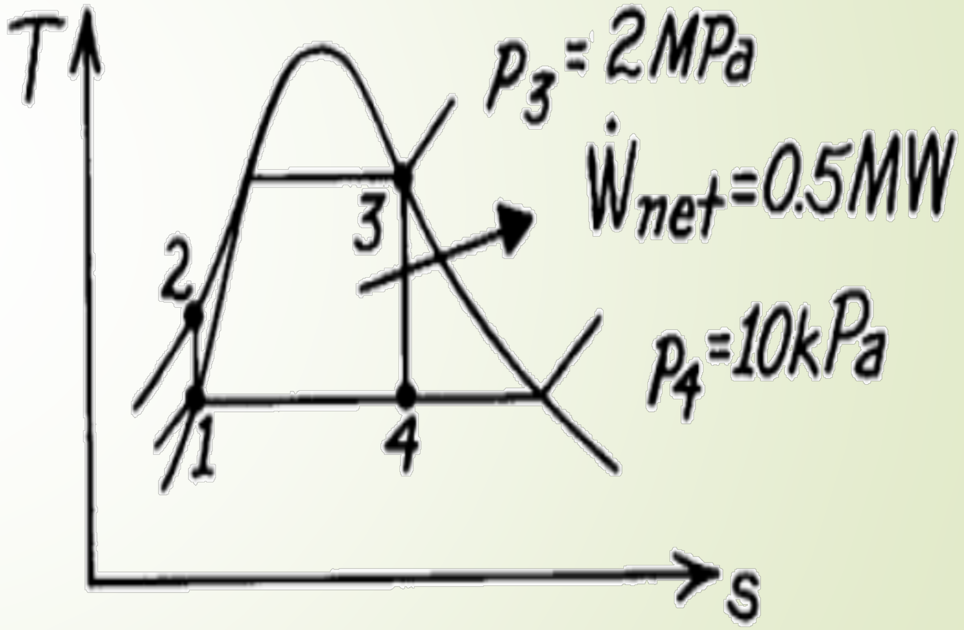
Dr. K. J. Berry

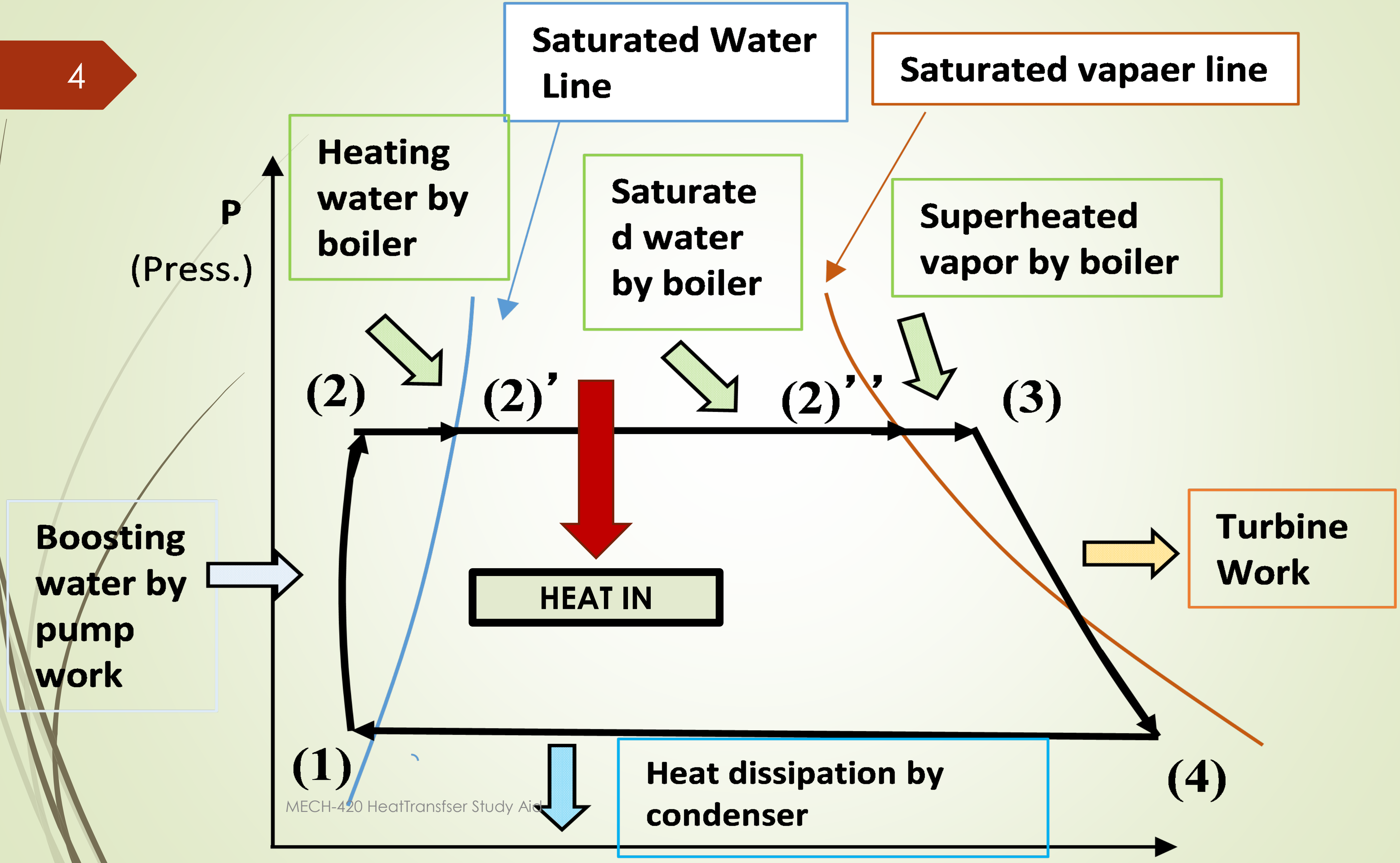
PROBLEM

- KNOWN
  - Rankine cycle with saturated steam leaving the boiler at 2 MPA and a condenser pressure of 10 kPa. Net reversible work of 0.5 MW. Tube Diameter = 0.015m, Thermal Efficiency = 40.2%, Tubes: N=80. Steam side outer heat transfer coefficient = 9000W/m2-K.
- FIND
  - Required cooling water flow rate to condenser at 15C with temperature rise of 10C
  - Shell-n-Tube exchanger (one shell/n-tube passes) to satisfy condenser flow rate and temperature rise.

RANKINE CYCLE OVERVIEW






Saturated Water Line
Saturated vapaer line
Heating water by boiler
P
(Press.)
Saturate d water by boiler
Superheated vapor by boiler
(2)
(2)'
(2)''
(3)
HEAT IN
Boosting water by pump work
Turbine Work
(1)
Heat dissipation by condenser
(4)

REQUIRED STEAM FLOW RATE

REVERSIBLE POWER

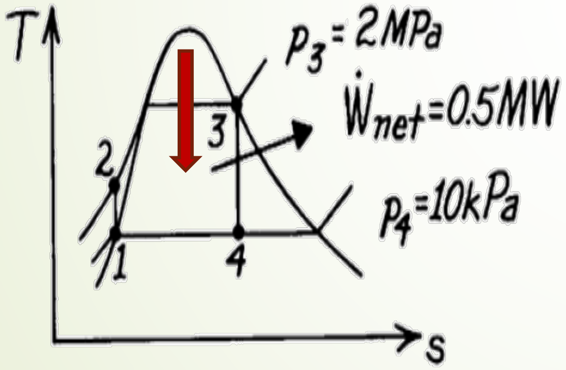
$$\dot{W}_{net} = 0.5x10^6 W$$

Thermal Efficiency

$$\eta_{th} = \frac{\dot{W}_{net}}{Q_{high}}$$

$$Q_{high} = \frac{\dot{W}_{net}}{\eta_{th}}$$

$$= \frac{0.5x10^6 W}{0.402} = 1.244x10^6 W$$



STEAM FLOW RATE

$$Q_{high} = \dot{m}_h h_{fg} \rightarrow \text{Phase Change}$$

$$\dot{m}_h = \frac{Q_{high}}{h_{fg}} = \frac{2.01x10^5 W}{h_4(P_4, s_3 = s_4) - h_f(P_4)}$$

$$h_4(P_4, s_3 = s_4) = 2007.5\frac{kJ}{kg} \rightarrow x = 0.759(\text{quality})$$

$$\rightarrow \text{Saturated Mixture (Isentropic Work 3-4)}$$

$$h_f(P_4) = 191.83\frac{kJ}{kg} \rightarrow \text{Saturated Liquid}$$

$$\dot{m}_h = \frac{2.01x10^5 W}{2007.5\frac{kJ}{kg} - 191.83\frac{kJ}{kg}} = 0.6850 kg/s$$

REQUIRED CONDENSER FLOW RATE

Condenser Flow Rate

1st Law--CYCLE

$$\delta Q = \dot{W}_{net}$$

$$\dot{Q}_H - \dot{Q}_C = \dot{W}_{net}$$

$$\dot{Q}_C = \dot{Q}_H - \dot{W}_{net}$$

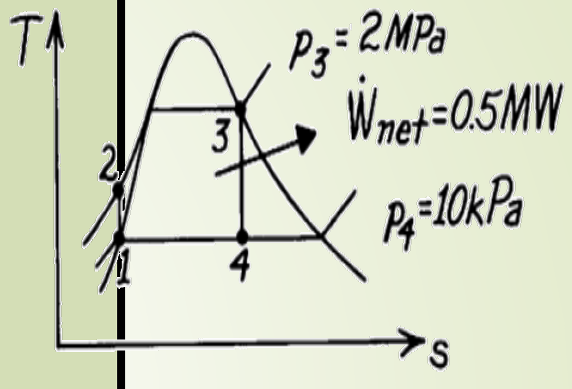
$$= 1.244x10^6 W - 0.5x10^6 W$$

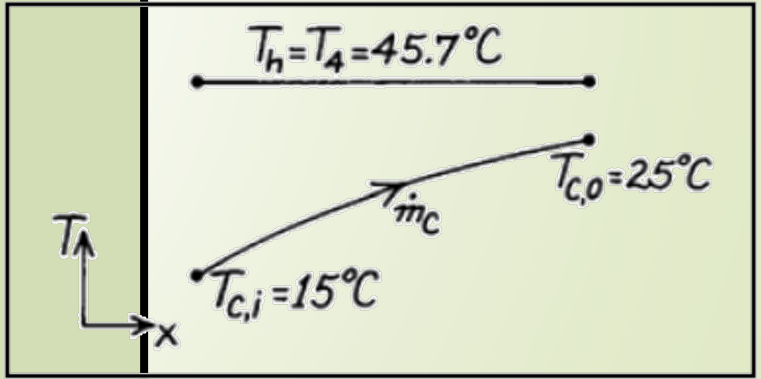
$$= 0.744x10^6 W$$

$$\dot{Q}_C = \dot{m}_c c_{p_c} (T_{c,out} - T_{c,in})$$

$$\dot{m}_c = \frac{\dot{Q}_C}{c_{p_f}(25C)(T_{c,out} - T_{c,in})}$$

$$= \frac{0.744x10^6 W}{4182 \frac{J}{kg-K}(25-15)K} = 17.8 kg/s \text{ (TOTAL FLOW)}$$





HEAT EXCHANGER DESIGN

To design the heat exchanger we need to evaluet UA.

Considering the shell-tube phase change CONDENSER configuration:

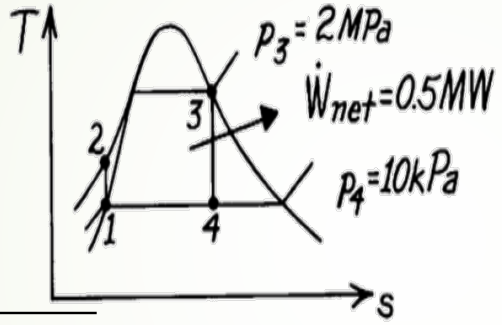
$$C_r = \frac{C_{\min}}{C_{\max}} = 0$$

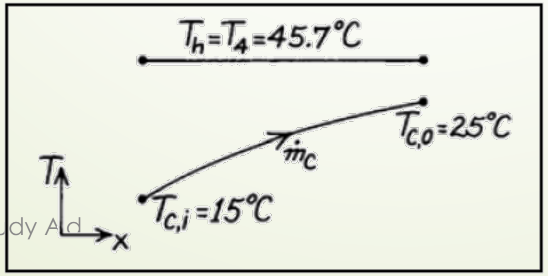
$$\varepsilon = 1 - \exp\left[-(\frac{UA}{C_{\min}}) \right]$$

$$\varepsilon = \frac{q}{q_{\max}} = \frac{q_c}{\dot{m}_c c_{p,c}(T_{h_i} - T_{ci})} = \frac{q_c}{\dot{m}_c c_{p,c}(T_4 - T_{ci})}$$

$$T_4 = T_{sat}(P_4 = 10kPa)$$

$$= \frac{0.744x10^6 W}{17.8\frac{kg}{s} \bullet 4182 \frac{J}{kg-K} \bullet (45.7-15)K} = 0.326$$





$$\varepsilon = 1 - \exp\left[-(\frac{UA_s}{C_{\min}}) \right]$$

$$-\ln[1-\varepsilon] = \left[-(\frac{UA_s}{C_{\min}}) \right]$$

$$C_{\min} \ln[1-\varepsilon] = UA_s$$

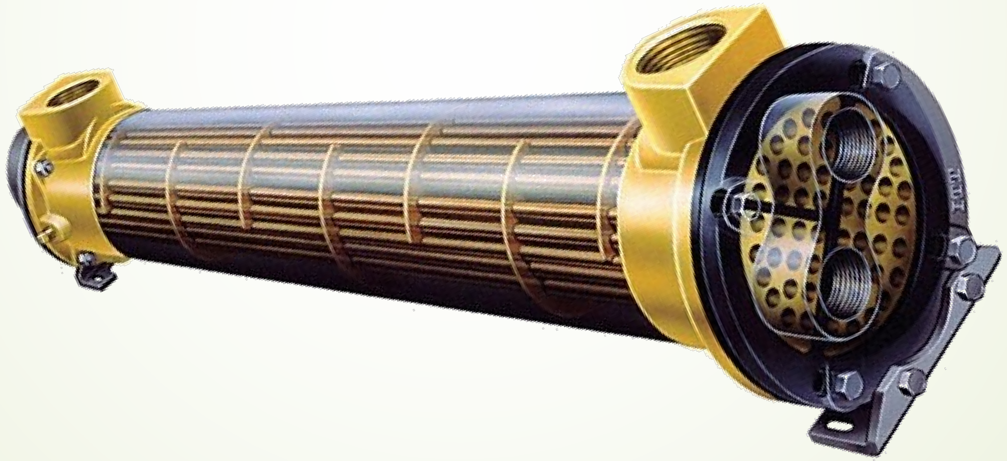
$$C_{\min} = \dot{m}_c c_{pc} = 17.8\frac{kg}{s} 4182 \frac{J}{kg-K}$$

$$= 74,439.6 \frac{J/S}{K}$$

$$UA_s = 50,172\frac{W}{K}(\rightarrow \text{UA/Cmin=0.6740})$$

LENGTH/TUBE PER PASS

$$NTU = \frac{U_{total} A_{total}}{C_{min\,total}} = 0.6740 = \frac{U_{tube} \bullet \#tubes \bullet \pi DL / pass \bullet pass / shell \bullet \#shells}{C_{min_{total}}}$$



OVERALL THERMAL RESISTANCE

$$UA = \frac{1}{\sum R_{th}} = \frac{1}{\dfrac{1}{h_c A_c} + \dfrac{R_c'' \frac{m^2 - K}{W}}{A_c} + R_{t_{CONDUCTION}} + \dfrac{1}{h_h A_h} + \dfrac{R_h'' \frac{m^2 - K}{W}}{A_h}}$$

THIN TUBE/NO FOULING FACTORS

$$UA = \frac{1}{\sum R_{th}} = \frac{1}{\dfrac{1}{h_c A_c} + \cancel{\dfrac{R_c'' \frac{m^2 - K}{W}}{A_c}} + \cancel{R_{t_{CONDUCTION}}} + \dfrac{1}{h_h A_h} + \cancel{\dfrac{R_h'' \frac{m^2 - K}{W}}{A_h}}}$$

$$UA = U_c A_c = U_h A_h$$

THIN WALL

$$A_c = A_h$$

$$U_c = \frac{1}{A_c \sum R_{th}} = \frac{1}{\dfrac{A_c}{h_c A_c} + \dfrac{A_c}{h_h A_h}} = \frac{1}{\dfrac{1}{h_c} + \dfrac{1}{h_h}}$$

INTERNAL FLOW: HEAT TRANSFER COEFFICIENT

$$\mathrm{Re}_D = \frac{4\dfrac{\dot{m}_c}{tube}}{\pi D \mu} = \frac{4 \bullet \dfrac{17.8}{80} kg/s}{\pi 0.015m \bullet 1007x10^{-6} N-s/m^2} = 18,755 \text{ (TURBULENT)}$$

$$\mathrm{Nu} = \frac{h_c D}{k_{fluid}} = 0.023\,\mathrm{Re}_D^{0.8}\,\mathrm{Pr}^{0.4} = 131.3$$

$$k_{fluid} = 0.603 W/m-K$$

$$h_c = \frac{\mathrm{Nu} \bullet k_{fluid}}{D} = 5,278.2 W/m^2-K$$

$$U_c = \frac{1}{A_c \sum R_{th}} = \frac{1}{\dfrac{1}{h_c} + + \dfrac{1}{h_h}} = \frac{1}{\dfrac{1}{5,278.2} + \dfrac{1}{9000}} = 3,327 \frac{W}{m^2-K}$$

TUBE LENGTH/PASS

$$0.6740 = \frac{U_{tube} \bullet \#tubes \bullet \pi DL/pass \bullet pass/shell \bullet shells}{C_{\min}}$$

$$\frac{L}{pass} = \frac{0.6740 \bullet C_{\min}\left[\frac{\cancel{W}}{\cancel{K}}\right]}{U_c\left[\cancel{W}/m^2 - \cancel{K}\right] \bullet 80 \bullet \pi D[m] \bullet 2\,pass/shell \bullet 1} = 2.00m/pass$$

NTUBES = 80