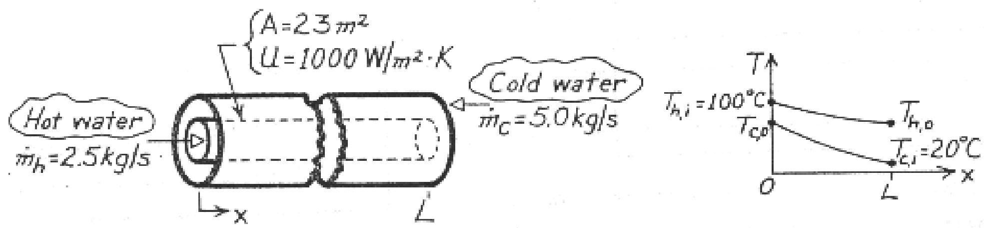
Part A

PROBLEM 11.53

KNOWN: Concentric tube, counter-flow heat exchanger.

FIND: Total heat transfer rate and outlet temperatures of both fluids.

SCHEMATIC:



ASSUMPTIONS: (1) Negligible heat loss to surroundings, (2) Negligible kinetic and potential energy changes, (3) Constant properties.

PROPERTIES: *Table A-6*, Water ($\overline{T}_h \approx 68°C = 340K$): $c_h = 4188$ J/kg·K; *Table A-6*, Water ($\overline{T}_C \approx 37°C = 310K$): $c_c = 4178$ J/kg·K.

ANALYSIS: Using the ε-NTU method, begin by evaluating the capacity rates.

$$\left.\begin{array}{l} c_h = \dot{m}_h\, C_h = 2.5\,\text{kg/s} \times 4188\,\text{J/kg·K} = 10,470\,\text{W/K} \\ c_c = \dot{m}_c\, C_c = 5.0\,\text{kg/s} \times 4178\,\text{J/kg·K} = 20,890\,\text{W/K} \end{array}\right\} \begin{array}{l} C_{min} = C_h \\ C_{min}/C_{max} = 0.50 \end{array}$$

From the definition, Eq. 11.25,

$$NTU = UA/C_{min} = 1000 W/m^2·K \times 23\,m^2/(10,470\,W/K) = 2.20.$$

Using values of NTU and C_{min}/C_{max}, find from Fig. 11.15, that

$$\varepsilon = 0.80\,.$$

From the definition of ε, Eq. 11.20, it follows that

$$q = \varepsilon\, q_{max} = \varepsilon\, C_{min}\,(T_{h,i} - T_{c,i}) = 0.80 \times 10,470 W/K (100-20) K = 670\,kW\,. \quad \triangleleft$$

Performing energy balances on both fluids, find

$$T_{c,o} = T_{c,i} + q/C_c = 20°C + 670\,kW/20,890\,W/K = 52.1°C \quad \triangleleft$$

$$T_{h,o} = T_{h,i} - q/C_h = 100°C - 670\,kW/10,470\,W/K = 36.0°C\,. \quad \triangleleft$$

COMMENTS: (1) Note that $\overline{T}_c = (20+52.1)°C/2 = 310K$ and $\overline{T}_h = (100+36)°\ C/2 = 341K$ and that these values agree well with those used to evaluate the properties.

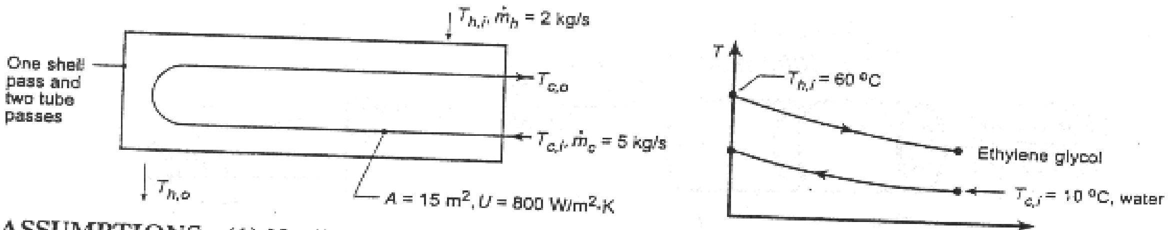
(2) Eq. 11.30 could be used to evaluate ε; the result gives $\varepsilon = 0.800$.

PROBLEM 11.56

KNOWN: Inlet temperatures and flow rates of water (c) and ethylene glycol (h) in a shell-and-tube heat exchanger (one shell pass and two tube passes) of prescribed area and overall heat transfer coefficient.

FIND: (a) Heat transfer rate and fluid outlet temperatures and (b) Compute and plot the effectiveness, ε, and fluid outlet temperatures, $T_{c,o}$ and $T_{h,o}$ as a function of the flow rate of ethylene glycol, $\dot{m}_h$, for the range $0.5 \le \dot{m}_h \le 5$ kg/s.

SCHEMATIC:



ASSUMPTIONS: (1) Negligible heat loss to surroundings, (2) Negligible kinetic and potential energy changes, (3) Constant properties, and (4) Overall coefficient remains unchanged.

PROPERTIES: *Table A-5*, Ethylene glycol ($\overline{T}_m = 40°C$): $c_p = 2474$ J/kg-K; *Table A-6*, Water ($\overline{T}_m$ = 15°C): $c_p = 4186$ J/kg-K.

ANALYSIS: (a) Using the ε-NTU method we first obtain

$$C_h = \left(\dot{m}_h c_{p,h}\right) = (2\,\text{kg/s} \times 2474\,\text{J/kg}\cdot\text{K}) = 4948\,\text{W/K}$$

$$C_c = \left(\dot{m}_c c_{p,c}\right) = (5\,\text{kg/s} \times 4186\,\text{J/kg}\cdot\text{K}) = 20{,}930\,\text{W/K}.$$

Hence with $C_{min} = C_h = 4948$ W/K and $C_r = C_{min}/C_{max} = 0.236$,

$$NTU = \frac{UA}{C_{min}} = \frac{\left(800\,\text{W/m}^2\cdot\text{K}\right)15\text{m}^2}{4948\,\text{W/K}} = 2.43.$$

From Fig. 11.16, $\varepsilon = 0.81$ and from Eq. 11.23

$$q = \varepsilon C_{min}\left(T_{h,i} - T_{c,i}\right) = 0.81(4948\,\text{W/K})(60-10)\text{K} = 2\times10^5\,\text{W}. \quad <$$

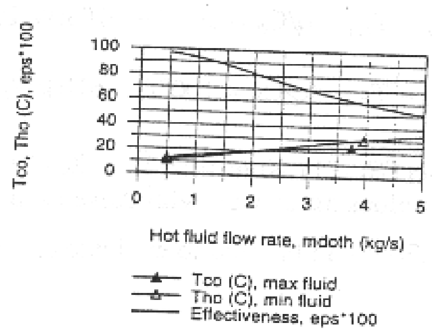
From Eqs. 11.6 and 11.7, energy balances on the fluids,

$$T_{h,o} = T_{h,i} - \frac{q}{C_h} = 60°C - \frac{2\times10^5\,\text{W}}{4948\,\text{W/K}} = 19.6°C \quad <$$

$$T_{c,o} = T_{c,i} - \frac{q}{C_c} = 10°C - \frac{2\times10^5\,\text{W}}{20{,}930\,\text{W/K}} = 19.6°C. \quad <$$

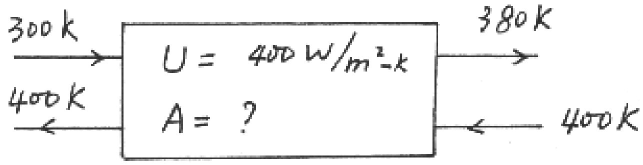
(b) Using the *IHT Heat Exchanger Tool, Shell and Tube*, and the *Properties Tool* for *Water* and *Ethylene Glycol*, $T_{c,o}$, $T_{h,o}$, and ε as a function of $\dot{m}_h$ were computed and plotted.

At very low C_{min}, (low $\dot{m}_h$) note that $\varepsilon \to 1$ while $T_{h,o} \to T_{c,i}$. As $\dot{m}_h$ increases, both fluid outlet temperatures increase and the effectiveness decreases.



Part B of Pset 10

A.



LMTD Method

$F = 1$ for condenser.

$$\Delta T_{lm} = \frac{(400-300)-(400-380)}{\ln \frac{400-300}{400-380}}$$

$$= 49.7 \text{ K}$$

$$q_T = \dot{m}_c C_{p,c} (T_{c,o} - T_{c,i})$$

$$= (5)(2000)(380-300)$$

$$= 8 \times 10^5 \text{ J/s}$$

$$A = \frac{q_T}{U \Delta T_{lm}}$$

$$= \frac{8 \times 10^5}{(400)(49.7)}$$

$$= \boxed{40.2 \text{ m}^2}$$

ε- NTU Method

for condenser,

$C_{min} = C_c \quad C_{min}/C_{max} = 0$

$$\varepsilon = \frac{q}{q_{max}} = \frac{\cancel{C_c}(T_{c,o} - T_{c,i})}{\cancel{C_c}(T_h - T_{c,i})} = \frac{380-300}{400-300} = 0.8$$

from Equ. 11-36 b

$$NTU = -\ln(1-\varepsilon) = -\ln(1-0.8) = 1.61$$

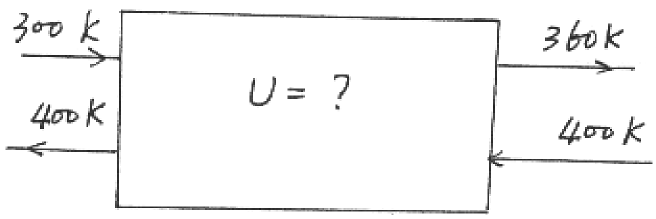
Therefore

$$A = \frac{NTU \cdot C_{min}}{U}$$

$$= \frac{(1.61)(2000 \cdot 5)}{400}$$

$$= \boxed{40.2\ m^2}$$

B.



Determin U_{new}

LMTD Method

$F = 1$ for condenser

$$\Delta T_{lm} = \frac{(400-300)-(400-360)}{\ln \frac{400-300}{400-360}}$$

$$= 65.5\ K$$

$$q_T = \dot{m}_c C_{p,c} (T_{c,o} - T_{c,i})$$

$$= (5)(2000)(360-300)$$

$$= 6 \times 10^5\ J/s$$

$$U = \frac{q_T}{A\, \Delta T_{lm}}$$

$$= \frac{6 \times 10^5}{(40.2)(65.5)} = \boxed{227.9\ W/m^2 \cdot K}$$

ε – NTU Method

for condenser

$C_{min} = C_c \qquad C_{min}/C_{max} = 0$

$$\varepsilon = \frac{q}{q_{max}} = \frac{\cancel{C_c}\,(T_{c,o} - T_{c,i})}{\cancel{C_c}\,(T_h - T_{c,i})} = \frac{360-300}{400-300} = 0.6$$

from Equ. 11-36 b

$$NTU = -\ln(1-\varepsilon) = -\ln(1-0.6) = 0.92$$

$$U = \frac{NTU \cdot C_{min}}{A}$$

$$= \frac{0.92 \cdot (5 \cdot 2000)}{40.2}$$

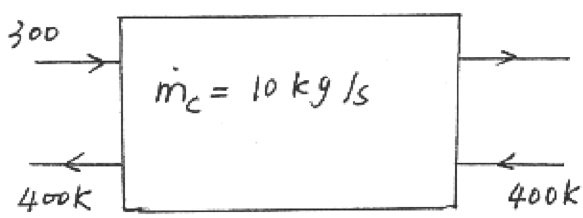
$$= \boxed{227.9\ W/m^2 \cdot K}$$

Based on

$$\frac{1}{U_{New}} = \frac{1}{U_{old}} + R_f$$

$$R_f = \frac{1}{U_{New}} - \frac{1}{U_{old}} = \frac{1}{227.9} - \frac{1}{400} = \boxed{1.89 \times 10^{-3}\ \frac{m^2 \cdot K}{W}}$$

C.



Determine Unew

$$U_{new} = U_{old}\left(\frac{\dot{m}_{c,new}}{\dot{m}_{c,old}}\right)^{0.8}$$

$$= 400\left(\frac{10}{5}\right)^{0.8}$$

$$= 696.4\ \frac{W}{m^2 \cdot K}$$

for condenser

$C_{min} = C_c \qquad C_{min}/C_{max} = 0$

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

$$= \frac{(696.4)(40.2)}{(2000.10)}$$

$$= 1.40$$

from Equ. 11.36 a

$$\varepsilon = 1 - \exp(-NTU)$$

$$= 0.753$$

Therefore

$$q = \varepsilon\, q_{max} \Rightarrow \dot{m}_c\, C_{p,c}\,(T_{c,o} - T_{c,i}) = \varepsilon\, \dot{m}_c\, C_{p,c}\,(T_h - T_{c,i})$$

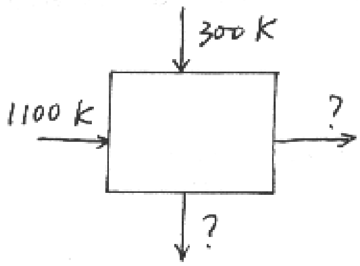
$$T_{c,o} = \varepsilon\,(T_h - T_{c,i}) + T_{c,i}$$

$$= 0.753\,(400 - 300) + 300$$

$$= \boxed{375.3\ K}$$

Part C of Pset 10

A.



$$C_h = C_c = 15 \cdot 1075 = 16125 \ J/k\text{-}s$$

$$C_{min} = 1.6125 \times 10^4 \ J/k.s$$

$$C_{min}/C_{max} = 1$$

$$NTU = \frac{UA}{C_{min}} = \frac{(100)(500)}{1.6125 \times 10^4} = 3.1$$

From Equ. 11.33

$$\varepsilon = 1 - \exp\left[(NTU)^{0.22}\{\exp[-NTU^{0.78}] - 1\}\right] \quad (C_r = 1)$$

$$= 1 - \exp[3.1^{0.22}\{\exp[-3.1^{0.78}] - 1\}]$$

$$= 0.69$$

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

$$T_{c,o} = \varepsilon(T_{H,i} - T_{c,i}) + T_{c,i}$$

$$= 0.69(1100 - 300) + 300$$

$$= \boxed{851.3 \ K}$$

B.

$$C_h = C_c$$

Therefore, both air and gas can attain the maximum temperature difference.

$$T_{c,o} = T_{H,i} = \boxed{1100 \ K}$$

C. In this case, $T_{c,o} = 1000\ K > T_{c,o} = 851.3\ (K)$ from part A, therefore, a higher flow rate of combustion gas is needed. So, C_h will be higher.

$$C_{min} = C_c = 15 \cdot 1075 = 1.6125 \times 10^4 \ \frac{W}{K}$$

$$NTU = \frac{UA}{C_{min}} = \frac{(100)(500)}{1.6125 \times 10^4} = 3.1$$

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

$$= \frac{(1000-300)}{(1100-300)}$$

$$= 0.875$$

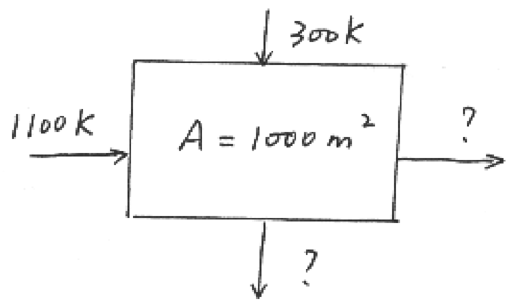
Using Figure 11.18

$$\frac{C_{min}}{C_{max}} = 0.36$$

$$\frac{\dot{m}_c\, \cancel{C_p}_{,c}}{\dot{m}_h\, \cancel{C_p}_{,h}} = 0.36$$

$$\dot{m}_h = \frac{\dot{m}_c}{0.36} = \frac{15}{0.36} = \boxed{41.7\ kg/s}$$

D. (1)



$$C_{min} = C_c = C_h = 1.6125 \times 10^4 \ \frac{W}{K}$$

$$C_{min} / C_{max} = 1$$

$$NTU = \frac{UA}{C_{min}} = \frac{(100)(1000)}{1.6125 \times 10^4} = 6.20$$

From Equ. 11.33

$C_{min}/C_{max} = 1$

$$\varepsilon = 1 - \exp\left[(NTU)^{0.22}\left\{\exp\left[-NTU^{0.78}\right]-1\right\}\right]$$

$$= 1 - \exp\left[6.2^{0.22}\left\{\exp\left[-6.2^{0.78}\right]-1\right\}\right]$$

$$= 0.77$$

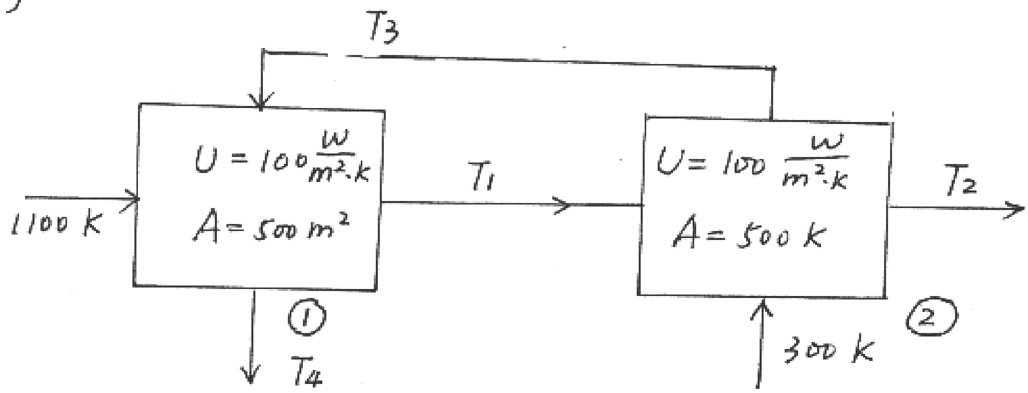
$$\varepsilon = \frac{q}{q_{max}} = \frac{\cancel{C_c}\,(T_{c,o}-T_{c,i})}{\cancel{C_c}\,(T_{h,i}-T_{c,i})}$$

$$T_{c,o} = T_{c,i} + \varepsilon\,(T_{h,i}-T_{c,i})$$

$$= 300 + 0.77\,(1100-300)$$

$$= \boxed{916.1\ K}$$

(ii)



Based on the calculation procedure of Part A

$$\varepsilon_1 = 0.69$$

$$\varepsilon_2 = 0.69$$

Therefore

$$\varepsilon_1 = \frac{T_4 - T_3}{1100 - T_3} = 0.69 \quad \text{for heat exchanger (1)} \qquad (1)$$

$$\varepsilon_2 = \frac{T_3 - 300}{T_1 - 300} = 0.69 \quad \text{for heat exchanger (2)} \qquad (2)$$

Energy balance for the whole system ①

$$\dot{m}_c \cancel{c_{p,c}} \, (T_{c,o} - T_{c,i}) = \dot{m}_h \cancel{c_{p,h}} \, (T_{h,i} - T_{h,o})$$

$$T_4 - T_3 = 1100 - T_1 \qquad (3)$$

Combine Equ. (1), (2), and (3), and get

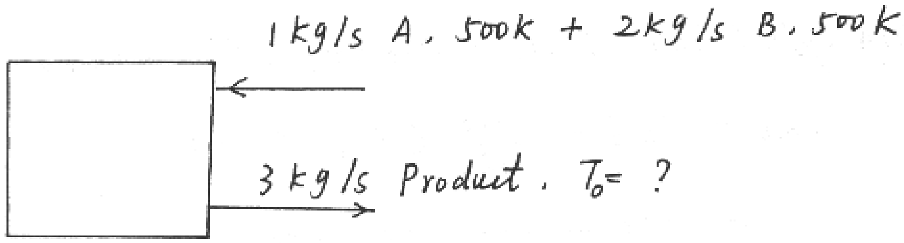
$$T_1 = 773 \text{ K}$$

$$T_3 = 626 \text{ K}$$

$$\boxed{T_4 = 953 \text{ K}}$$

Therefore, scheme (ii) gives the higher air exit temperature, 953 K than that of scheme (i), 916.1 K.

A.



Assume the reactor to be well insulated,

$$\dot{m}\, C_p \,(T_o - T_i) = \Delta H_{rxn}$$

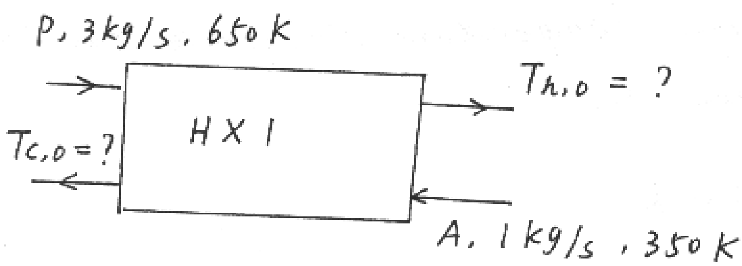
$$T_o = \frac{\Delta H_{rxn}}{\dot{m}\, C_p} + T_i$$

$$= \frac{(900,000)(1\,kg)}{(1+2)\cdot 2000} + T_i$$

$$= 150 + 500$$

$$= \boxed{650\,K}$$

B.



Assuming the reactor effluent temperature to be 650 K,

$$C_c = (1)(2000) = 2000\ \frac{W}{K}$$

$$C_h = (3)(2000) = 6000\ \frac{W}{K}$$

$$C_{min} = C_c$$

Therefore, the maximum temperature difference can be attained by the cold flow, A.

$$T_{c,o} = T_{h,i} = 650\,K$$

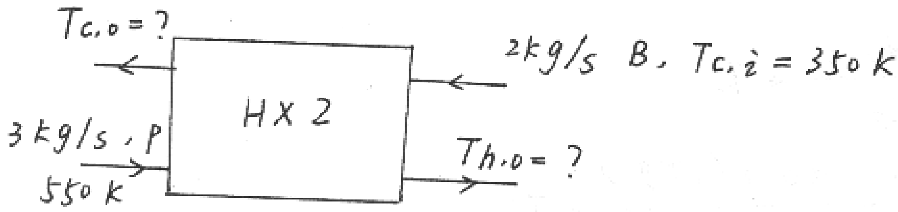
Energy Balance for both streams

$$\dot{m}_A \cancel{C_{p,A}} (T_{c,o} - T_{c,i}) = \dot{m}_p \cancel{C_{p,p}} (T_{h,i} - T_{h,o})$$

$$T_{h,o} = T_{h,i} - \frac{\dot{m}_A}{\dot{m}_p}(T_{c,o} - T_{c,i})$$

$$= 650 - \frac{1}{3}(650 - 350)$$

$$= 550\ K$$



$$C_c = (2000)(2) = 4000 \frac{W}{K}$$

$$C_h = (2000)(3) = 6000 \frac{W}{K}$$

$$C_{min} = C_c$$

Therefore, the maximum temperature difference can be attained by the cold flow, B.

$$T_{c,o} = T_{h,i} = 550\ K$$

The temperature of A+B stream

$$T_{feed} = (T_A \dot{m}_A + T_B \dot{m}_B) / (\dot{m}_A + \dot{m}_B)$$

$$= \frac{650 \cdot 1 + 550 \cdot 2}{3}$$

$$= \boxed{583.3\ K} > 500\ K$$

So it will be above 500 K.

C. the same procedure as A and B

$$T_o = \frac{\Delta H_{rxn}}{\dot{m}\,C_p} + T_i$$

$$= \frac{240{,}000}{(3)(2000)} + 500$$

$$= 540\ K$$

$$T_A = 540\ K$$

$$T_P = 540 - \frac{1}{3}(540 - 350)$$

$$= 476.7\ K$$

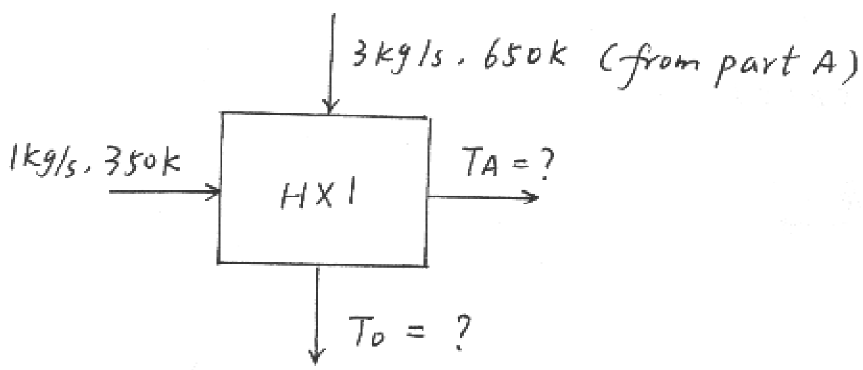
$$T_B = 476.7\ K$$

$$T_{feed} = \frac{1}{3} \cdot 540 + \frac{2}{3} \cdot 476.7$$

$$= \boxed{497.8\ K}$$

The feed temperature doesn't reach 500 K.

D.



$$C_c = (1)(2000) = 2000\ \frac{W}{K}$$

$$C_h = (3)(2000) = 6000\ \frac{W}{K}$$

$$C_{min} = 2000\ \frac{W}{K}$$

$$C_{min}/C_{max} = \frac{1}{3}$$

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

$$= \frac{(600)(10)}{2000}$$

$$= 3$$

for equ. 11.33

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

$$= 0.875$$

$$\varepsilon = \frac{q}{q_{max}} = \frac{\dot{m}_A C_{p,A}(T_A - 350)}{\dot{m}_A C_{p,A}(650-350)}$$

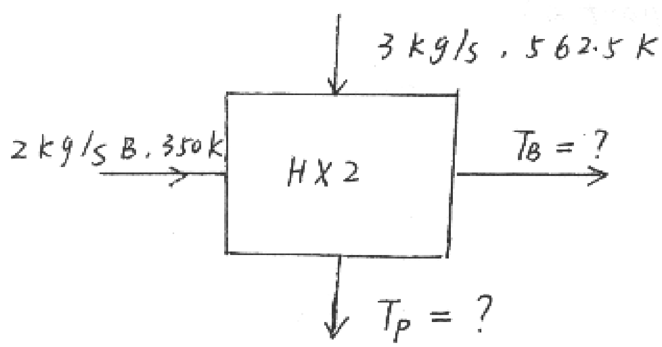
$$\boxed{T_A = 612.5\ K}$$

Energy Balance for A and p

$$\dot{m}_A \cancel{C_{p,A}}(T_A - 350) = \dot{m}_p \cancel{C_{p,p}}(650 - T_o)$$

$$T_o = 650 - \frac{612.5-350}{3}$$

$$= 562.5\ K$$



$$C_{min} = (2)(2000) = 4000\ \frac{W}{K}$$

$$\frac{C_{min}}{C_{max}} = \frac{2}{3}$$

$$NTU = \frac{UA}{C_{min}} = \frac{(600)(10)}{4000} = \frac{3}{2}$$

From Equ. 11.33

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

$$= 0.626$$

$$\varepsilon = \frac{q}{q_{max}} = \frac{T_B - 350}{562.5 - 350}$$

$$\boxed{T_B = 483.0\ K}$$

The feed temperature is

$$T_{feed} = \frac{1}{3}(612.5) + \frac{2}{3}(483.0)$$

$$= \boxed{526.2\ K}$$

It is above 500 K!