Excellent!

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

Chemical Process Integration

Exam on Heat and Mass Integration

March 6, 2019 (5:30-6:45 pm)

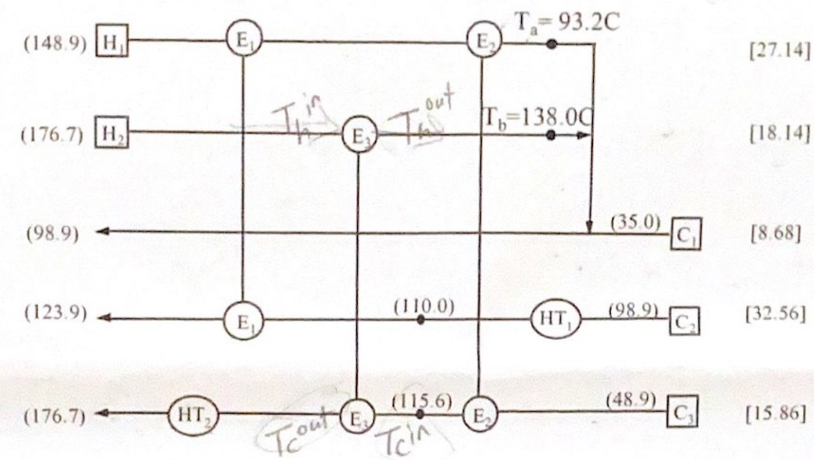
Student Name: ______________ Score: 70+2/70

Detailed steps and/or explanations need be provided to avoid point reduction.

35

Problem 1 (35 points)

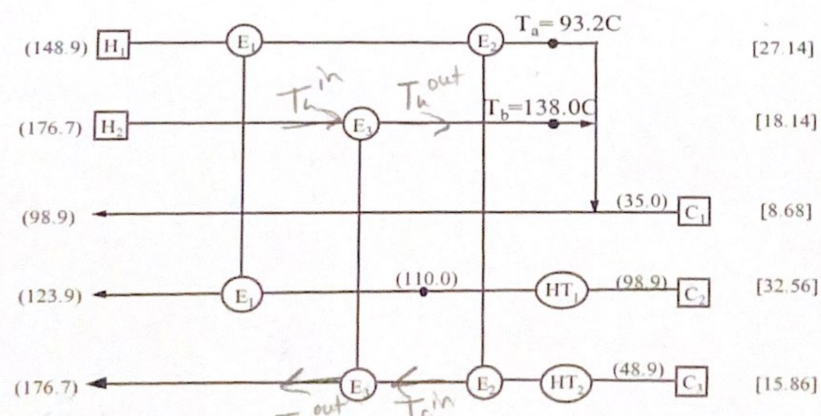
In class, we studied a HEN design showed in Fig. (a), where stream temperatures and heat capacity flowrates are listed, and ΔT_{min} is given (10°C). The flowsheet contains two heaters (HT_1 and HT_2).



Legend: ( ): Temperature (°C); [ ]: Heat capacity flow rate (kW/°C)

(a)

(a) Figure (b) below shows a slightly different design, i.e., heater HT2 is moved to the right side of exchanger E2 on stream C3. Please judge if this design change causes any design feasibility problem, i.e., the feasibility of relevant exchanger(s). You need to show all necessary calculations. **(18 points)** 18

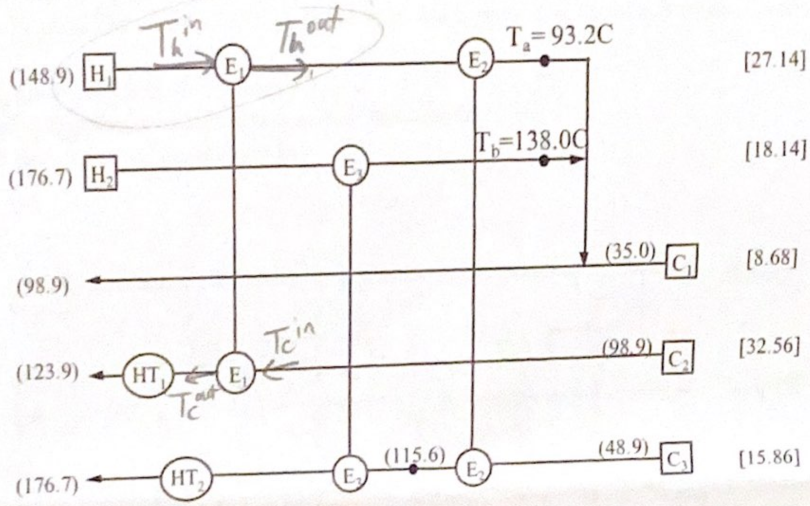


Legend: ( ): Temperature (°C); [ ]: Heat capacity flow rate (kW/°C)

(b)

(b) Figure (c) below shows another slightly different design, i.e., heater HT1 has been moved to the left side of exchanger E1 on stream C2. Please judge if this design change causes any design feasibility problem, i.e., the feasibility of relevant exchanger(s). **(17 points)** 17

[Bonus] If the new location of HT1 does not cause any design feasibility problem, then calculate the capital cost ratio of exchanger E1 in Fig. (a) to exchanger E1 in Fig. (c). Please use the 0.6 power rule in calculation. However, if the new location of exchanger HT1 causes some design feasibility problem, then discuss if there is any advantage of keeping exchanger HT1 is the original place shown in Fig. (a) **(5 points)** 2



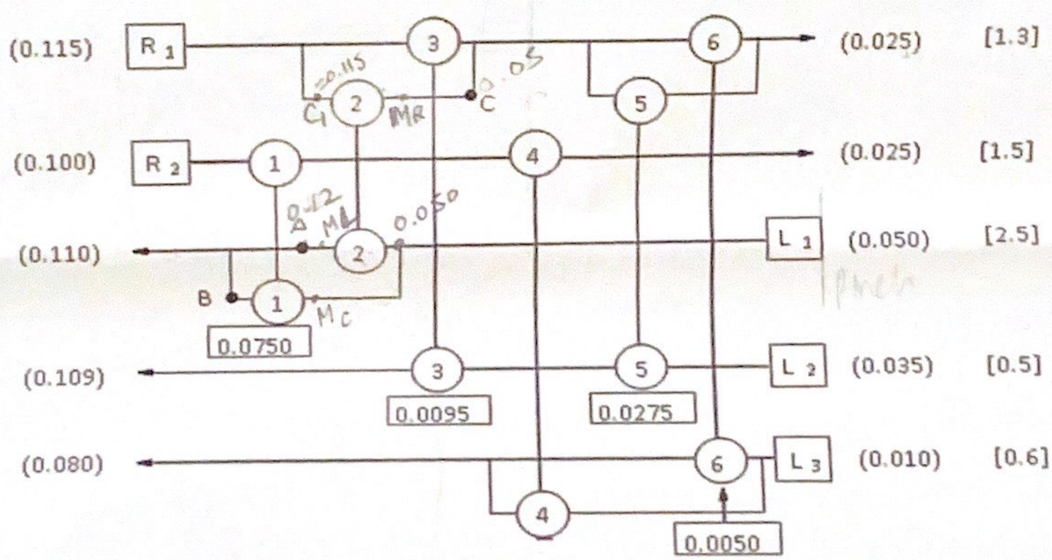
Legend: ( ): Temperature (°C); [ ]: Heat capacity flow rate (kW/°C)

(c)

Problem 2 (35 points).

For the following design, the equilibrium relations between the rich streams and the lean streams are: $C_R = 0.8C_{L1} + 0.002$, $C_R = 0.5C_{L2}$, and $C_R = 0.2C_{L3}$. The minimum allowable composition difference between a rich stream and a lean stream, ΔC_{min} , is fixed at 0.01 in any mass transfer unit (MTU). The pinch point is located at the composition of 0.05 for rich streams R_1 and R_2 , and 0.05, 0.09, and 0.24 for lean streams L_1 , L_2 , and L_3 , respectively. The mass loads of a few mass exchanger (kg/s) are given in the figure as well. It is known that the composition of the key component at point A in the figure is 0.12, and the composition at point C in the figure is at the pinch point. Now you are asked to:

(a) Calculate the mass load of exchanger No. 2, (10 points)
(b) Evaluate the feasibility of the placement of exchanger No. 2, (10 points)
(c) Calculate the composition at point B, (15 points)



Legend: ( ) Composition; [ ] Mass flowrate; ☐ Mass load of exchanger

I have neither given nor received unauthorized assistance on this work.

Signed ____________________

$\Delta T_{min} = 10°C$

[Ch]eck the feasibility of (E3) in figure a)

If T_h^{out} and T_c^{in} for (E3) are at pinch temperatures, it's a pinch match (not a pinch match for (E3))

- feasibility

$\Delta T_h^{in} - T_c^{out} \geq \Delta T_{min}$

$\Delta T_h^{out} - T_c^{in} \geq \Delta T_{min}$

→ $176.7 - T_c^{out} \geq \Delta T_{min}$ (10) ← temperature between HT2 and E3

$138.0 - 115.6 \geq \Delta T_{min}$ (10)

$22.4 \geq 10$ ✓ (feasible)

Calculate T_c^{out} to check feasibility →

Now with figure b)

New feasibility of E3 (Not pinch match)

$\Delta T_h^{in} - T_c^{out} \geq \Delta T_{min}$ → $0 \geq 10$ X (Not feasible)
(176.7, 176.7, 10)

$\Delta T_h^{out} - T_c^{in} \geq \Delta T_{min}$
(138.0, unknown temp. after E2 and before E3, 10)

} do not even need to calculate this because the cold stream leaving (E3) and the hot stream entering (E3) do not have the min. T difference of 10°C. The hot stream entering cannot heat up the cold stream entering (E3) to a temp. that is greater than 166.7°C, or else the min. T difference, ΔT_{min}, is not satisfied, and if this requirement is not met, the whole HEN system is not feasible

a)

∴, figure b) not feasible

b) Calculate feasibility of E1

Not pinch match

$\Delta T_h^{in} - T_c^{out} \geq \Delta T_{min}$ (148.9; unknown; 10)

$\Delta T_h^{out} - T_c^{in} \geq \Delta T_{min}$ (unknown; 98.9; 10)

Calculate ΔT_h^{out} → between E1/E2

Balance on H1: $(148.9 - 93.2)(27.14) = Q_{E1} + Q_{E2}$

Q_{E2}: $(115.6 - 48.9)(15.86) = 1057.862$

~~$(T_h^{out} - 2922)(27.14)$~~

Q_{E1}: $(T_h^{out} - 148.9)(27.14)$

$1511.698 = (148.9 - T_h^{out})(27.14) + 1057.862$

$Q_{E1} = 453.836$ from $Q_{H1} - Q_{E2}$ (1511.698 − 1057.862)

$T_h^{out} = 132.177$

$132.177 - 98.9 \geq 10 \rightarrow 33.27 \geq 10$ ✓ feasible

Calculate T_c^{out}: balance on E1 → $Q_{E1} = 453.836 = (T_c^{out} - 98.9)(32.56)$

$T_c^{out} = 112.83°C$

$\Delta T_h^{in} - T_c^{out} \geq \Delta T_{min} \rightarrow 36.06 \geq 10$ ✓ feasible

(148.9; 112.83; 10)

∴ E1 is feasible → the temperature entering HT1 should be 112.83 °C and can be heated to 123.9°C over HT1

$C_R = 0.8\, C_{L1} + 0.002$

$C_R = 0.5\, C_{L2}$

$C_R = 0.2\, C_{L3}$

$\Delta C_{min} = 0.01$

Pinch, rich → 0.05

Pinch, lean → L1 = 0.05
L2 = 0.09
L3 = 0.24

- Point A composition = 0.12
- Point C composition = pinch point so 0.05 for R1

(a) $M_{P,E2} = ?$ $\quad M_{PE2} = (\Delta C)(M_2)$

$M_{P,L1} \rightarrow (0.110 - 0.050)(2.5) = 0.15 = M_{PE2} + M_{PE1}$

$M_{P,R1} = (0.115 - 0.025)(1.3) = 0.117 = M_{PE2} + M_{PE3} + M_{PE5} + M_{PE6}$

$M_{PE1} = 0.0750$

so $0.15 = 0.0750 + M_{PE2}$

(a) $M_{PE2} = 0.075\ \frac{kg}{s}$

(b) feasibility: (E2) is a pinch match (see back page for method ② to confirm feasibility)

(above pinch) $\frac{M_L}{m_L} \geq M_R$

(E2) goes from R1 to L1 so use $C_R = 0.8\, C_{L1} + 0.002$

$m_L = 0.8$

$M_L =$ } calculate
$M_R =$

$M_R \rightarrow M_{PE2} = M_R(0.115 - 0.05) \rightarrow M_R = 1.1538\ \frac{kg}{s}$
0.075

$M_L \rightarrow (0.12 - 0.050)(M_L) = M_{PE2} = 0.075 \rightarrow M_L = 1.07142$ kg/s

now check equation:

$\frac{M_L}{m_L} \geq M_R$

$\frac{1.07142}{0.8} \geq 1.1538$

$1.339 \geq 1.1538$

✓ feasible

(c) Composition at point B?

Balance over E1:

$M_{P,E1} = \Delta C \cdot M_C$

$M_{P,E1}$: 0.0750 kg/s

ΔC → $(C_B - 0.050)$

M_C → $2.5 = M_L + M_C$ (labelled on exam page diagram)

M_L → calculated in (b) $= 1.07142$

$M_C = 2.5 - 1.07142 = 1.42858$ kg/s

$0.0750 = (C_B - 0.050)(1.42858)$

$\boxed{C_B = 0.10249}$ ✓

(b) checking feasibility of E2 in another way

left: $C_{L}^{*} \le \frac{C_R^{*} - b_{Li}}{m_{Li}} - \Delta C_{min}$ → $0.12 \le 0.13125$ ✓ feasible

($C_L^* = 0.12$, $C_R^* = 0.115$, $b_{Li} = 0.002$, $m_{Li} = 0.8$, $\Delta C_{min} = 0.01$)

right: $C_{Li}^{*} \le \frac{C_R^{*} - b_{Li}}{m_{Li}} - \Delta C_{min}$ → $0.05 \le 0.05$ ✓ feasible

($C_{Li}^* = 0.05$, $C_R^* = 0.05$, $b_{Li} = 0.002$, $m_{Li} = 0.8$, $\Delta C_{min} = 0.01$)

∴, E2 is feasible

Neha, tv6870
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$$\Delta T_{ln} = \frac{(T_h^{in} - T_c^{out}) - (T_h^{out} - T_c^{in})}{\ln\left(\frac{T_h^{in} - T_c^{out}}{T_h^{out} - T_c^{in}}\right)}$$

-3

The new location of HTI did not cause any problems because it was feasible

should be $\left(\frac{\Delta T_{lm,c}}{\Delta T_{lm,a}}\right)^{0.6}$

0.6 power rule →

Capital cost ratio $\left(\frac{C_a}{C_c}\right)^{0.6} \Rightarrow \left(\frac{\Delta T_{lm,a}}{\Delta T_{ln,c}}\right)^{0.6}$ X

you used E2 data, which is wrong

$\Delta T_{ln}(a) \rightarrow T_h^{in} \rightarrow 176.7$

$T_h^{out} \rightarrow 138.0$

$T_c^{in} \rightarrow 115.6$

$T_c^{out} \rightarrow [(176.7-138)(18.14)] = (T_c^{out} - 115.6)(15.86)$

$T_c^{out} \Rightarrow \frac{702.018}{15.86} + 115.6 = 159.86\,^\circ C$

$$\Delta T_{ln} = \frac{(176.7 - 159.86) - (138 - 115.6)}{\ln\left(\frac{176.7 - 159.86}{138 - 115.6}\right)}$$

$\Delta T_{ln} = 19.48$

$\Delta T_{ln}(c) \rightarrow T_h^{in} \rightarrow 148.9$

$T_h^{out} \rightarrow 132.177$

$T_c^{in} \rightarrow 98.9$

$T_c^{out} \rightarrow 112.83$

$$\Delta T_{ln} = \frac{(148.9 - 112.83) - (132.177 - 98.9)}{\ln\left(\frac{148.9 - 112.83}{132.177 - 98.9}\right)}$$

0.080

$\Delta T_{ln} = 34.91$ ✓

Cost estimation: $\left(\frac{19.48}{34.91}\right)^{0.6} = (0.558)^{0.6} \rightarrow$ **0.7046**