

1. (5 points) Consider two separate, open systems. In the first system, pure liquid octane is flowing through a pipe. In the second system, pure saturated octane vapor is flowing through a pipe. If they are at the same temperature and pressure, specific enthalpy of the superheated octane is \_\_\_\_\_ the specific enthalpy of liquid octane. Justify your answer.

- a. Greater than
- b. Less than
- c. Equal to

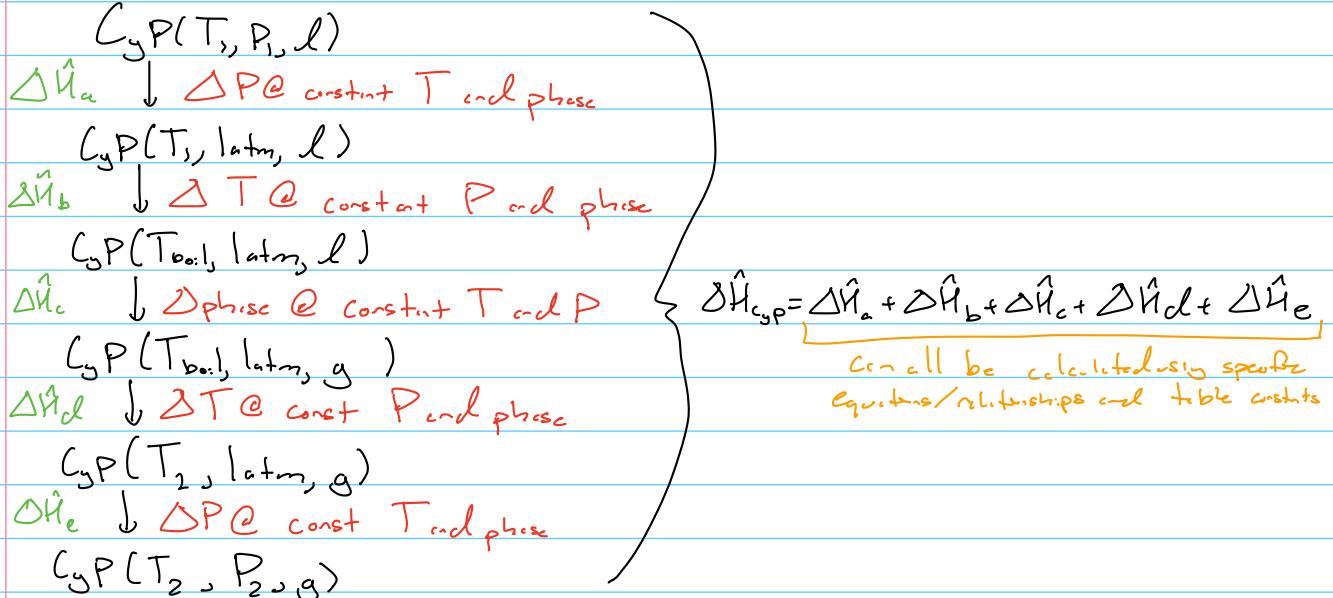
$$\begin{array}{ll}
 \text{Ref State} & \text{Octane } (25^\circ\text{C}, 1 \text{ atm}, \text{ liquid}) \\
 \Delta T, \text{const P} & \downarrow \quad \Delta \hat{H}_a = \int_{25^\circ\text{C}}^{T_1} C_p dT \\
 \text{and phase} & \\
 \text{Octane } (T_1, 1 \text{ atm}, l) & \\
 \Delta P, \text{const T} & \downarrow \quad \Delta \hat{H}_b = V \Delta P \\
 \text{and phase} & \\
 \text{Octane } (T_1, P_1, l) \text{ (1)} & \\
 \\ 
 & \text{Octane } (25^\circ\text{C}, 1 \text{ atm}, l) \\
 \Delta T, \text{const P} & \downarrow \quad \Delta \hat{H}_c = \int_{25^\circ\text{C}}^{T_{\text{boil}}} C_p dT \\
 \text{and phase} & \\
 \text{Octane } (T_{\text{boil}}, 1 \text{ atm}, l) & \\
 \Delta P, \text{const T} & \downarrow \quad \Delta \hat{H}_d = \Delta \hat{H}_{\text{vap}}^0 \\
 \text{and phase} & \\
 \text{Octane } (T_{\text{boil}}, 1 \text{ atm}, g) & \\
 \Delta T, \text{const P} & \downarrow \quad \Delta \hat{H}_e = \int_{T_{\text{boil}}}^{T_2} C_p dT \\
 \text{and phase} & \\
 \text{Octane } (T_2, 1 \text{ atm}, g) \text{ (2)} & \\
 \Delta P, \text{const T} & \uparrow \quad \Delta \hat{H}_f = \Delta \hat{H}_{\text{vap}}^0 \\
 \text{and phase} & \\
 \text{Octane } (T_2, P_2, g) & \\
 \end{array}$$

The vapor (2) should have a higher specific enthalpy than the liquid as its enthalpy is lost in part by the heat of vaporization, which is not present in steam (1)

2. (10 points) Write a hypothetical process path for the real process path shown below. Write each hypothetical step, describe each transition (e.g. constant T, constant phase, change in P). You do not need to include any equations or calculations; however, your path should be written such that you can use data from Table B.1 or Table B.2 to calculate the change in specific enthalpy of the process.

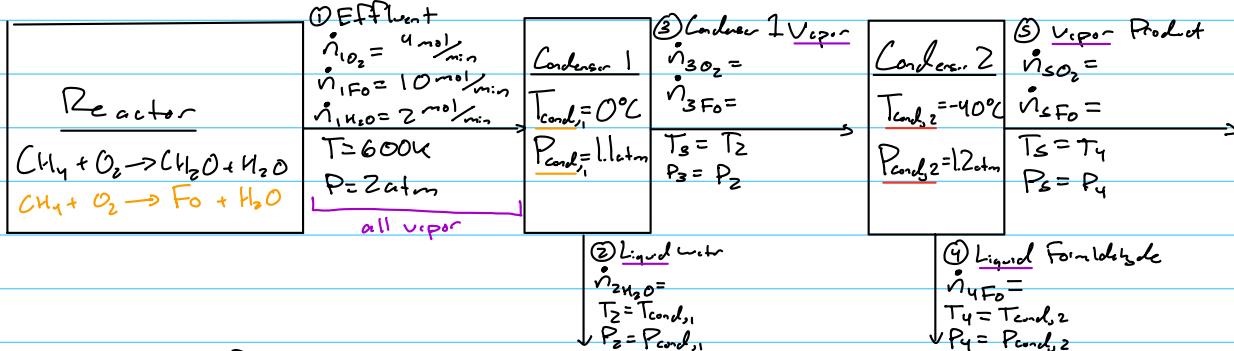
"CycP"

Cyclopentane ( $T_1, P_1$ , liquid)  $\rightarrow$  Cyclopentane ( $T_2, P_2$ , gas)



Formaldehyde Production

A) PFD

Note  $\dot{n}_{\text{CH}_4} = 0$  as problem statement does not state it as effluent, so its left out on PFD belowAdd'l Info / Eqs

~~(1)~~  $\dot{n}_s F_o = \dot{n}_4 F_o P_{F_o}^{\text{sat}} ; \log_{10} P_{F_o}^{\text{sat}} = A - \frac{B}{T_s + C}$

↳ FO post-condenser 2 is any species in VLE

$C_{P,F_o,l} = 105 \frac{\text{KJ}}{\text{mol}\text{K}}$

•  $\text{CH}_4$  is not present in reactor effluent

↳ do not need to worry about reactor inlet

Table ValuesAntoine Constants: ~~Table B.4~~  $P = \text{mmHg}, T = {}^\circ\text{C}$ 

$$\begin{cases} A = 7.19578 \\ B = 970.595 \\ C = 244.124 \end{cases}$$

Want to know:  $\dot{Q} \left( \frac{\text{W}}{\text{min}} \right)$ B) Dof not requiredCondenser 1 Material Balances in/out

$O_2: \dot{n}_{1O_2} = \dot{n}_{3O_2}$

$F_O: \dot{n}_{1FO} = \dot{n}_{3FO}$

$H_2O: \dot{n}_{1H_2O} = \dot{n}_{2H_2O}$

How to Solve: Solve  $O_2, F_O, H_2O$ balances for  $\dot{n}_{1O_2}$  &  $\dot{n}_{3FO}$ 

↳ Just 3 equivalences of flow rates

Condenser 2 Material Balances in/out

$O_2: \dot{n}_{3O_2} = \dot{n}_{5O_2}$

$F_O: \dot{n}_{3FO} = \dot{n}_{4FO} + \dot{n}_{5FO}$

$\text{Total: } \dot{n}_{3O_2} + \dot{n}_{3FO} = \dot{n}_{5O_2} + \dot{n}_{4FO} + \dot{n}_{5FO}$

How to Solve(i) Solve  $O_2$  balance for  $\dot{n}_{5O_2}$ (ii) Use ~~(1)~~ and Antoine constants from ~~(2)~~ to solve  $P_{F_o}^{\text{sat}} = 10^A \left[ 7.19578 - \frac{970.595}{-40^\circ\text{C} + 244.124} \right]$ (iii) Convert  $P_{F_o}^{\text{sat}}$  from mmHg to atm by dividing by 760Note: 'Equation' ~~(1)~~ is considered

to be a two-part equation

with both results &amp; Antoine

Law

(iv) Rearrange ~~(2)~~ results to get  $\dot{n}_{5FO} = \frac{\dot{n}_{4FO} P_{F_o}^{\text{sat}}}{P_s}$ Plug this expression into FO balance, solve for  $\dot{n}_{4FO}$ (v) Solve FO balance for  $\dot{n}_{5FO}$ 

⇒ All molar flow rates have been calculated!

Formaldehyde Production (Continued)

$$C) \Delta \dot{E}_P + \Delta \dot{E}_K + \Delta \dot{H} = \dot{Q} - \dot{W}_S \quad \text{no moving parts, pumps, or turbines} \Rightarrow \dot{Q} = \Delta \dot{H}$$

no volume or height changes

$$\dot{Q} = \sum_{\text{out}, 2} n_i \dot{H}_i - \sum_{\text{out}, 2} n_i \dot{H}_i = \sum_{\text{out}, 2} n_i \dot{H}_i - (\sum_{\text{out}, 1} n_i \dot{H}_i - \sum_{\text{in}, 1} n_i \dot{H}_i)$$

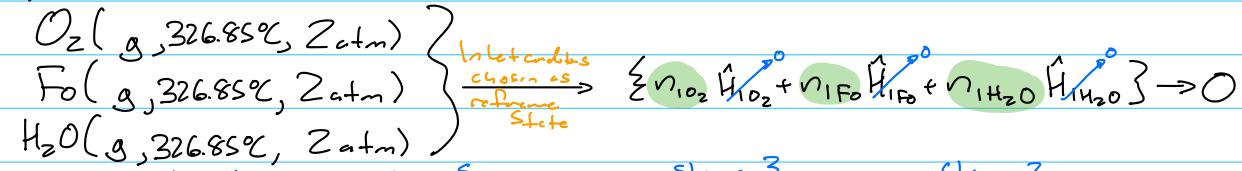
out of cond. into cond. out of cond. out of condenser into condenser

All molar flow rates are known from B<sub>j</sub>, need to find  $\dot{H}_i$ 's

$$\Rightarrow \dot{Q} = [n_{4FO} \dot{H}_{4FO} + n_{SO_2} \dot{H}_{SO_2} + n_{SF_6} \dot{H}_{SF_6}] - [\{ [n_{3O_2} \dot{H}_{3O_2} + n_{3FO} \dot{H}_{3FO}] + n_{2H_2O} \dot{H}_{2H_2O} \} - \{ n_{1O_2} \dot{H}_{1O_2} + n_{1FO} \dot{H}_{1FO} + n_{1H_2O} \dot{H}_{1H_2O} \}]$$

Equation for reference later

D) Choose Reference States  $\text{Const } 600\text{K to } 0^\circ\text{C} \Rightarrow T_{ref} = 326.85^\circ\text{C}$



$$\therefore \dot{Q} = [n_{4FO} \dot{H}_{4FO} + n_{SO_2} \dot{H}_{SO_2} + n_{SF_6} \dot{H}_{SF_6}] - [n_{3O_2} \dot{H}_{3O_2} + n_{3FO} \dot{H}_{3FO} + n_{2H_2O} \dot{H}_{2H_2O}]$$

Table B4	a	b	c	d	Form	Phase	Units	$\Delta H_{\text{fus}}$	$T_{bo,1}$
All values used or from tables unless otherwise noted	$34.28 \times 10^{-3}$	$4.268 \times 10^{-5}$	$0 \times 10^{-8}$	$-8.644 \times 10^{-12}$	1	g	$\frac{\text{kJ}}{\text{mol}\cdot\text{K}}$	$24.48 \frac{\text{kJ}}{\text{mol}}$	$-19.3^\circ\text{C}$
$O_2$	$24.10 \times 10^{-3}$	$1.158 \times 10^{-5}$	$-0.6076 \times 10^{-8}$	$1.311 \times 10^{-12}$	1	g	$\frac{\text{kJ}}{\text{mol}\cdot\text{K}}$	$6.82 \frac{\text{kJ}}{\text{mol}}$	$-182.97^\circ\text{C}$
$H_2O$	$33.46 \times 10^{-3}$	$0.6880 \times 10^{-5}$	$0.7604 \times 10^{-8}$	$-3.593 \times 10^{-12}$	1	g	$\frac{\text{kJ}}{\text{mol}\cdot\text{K}}$	$40.656 \frac{\text{kJ}}{\text{mol}}$	$100.0^\circ\text{C}$
	$75.4 \times 10^{-3}$	—	—	—	1	l	$\frac{\text{kJ}}{\text{mol}\cdot\text{K}}$	/ / / / /	/ / / / /

$$\text{Given: } C_p, F_0, l = 105 \frac{\text{kJ}}{\text{mol}\cdot\text{K}} ; \text{ Form 1: } C_p = a + bT + cT^2 + dT^3$$

(i) Calculate  $\dot{H}_{4FO}$  stream 4 ( $l, -40^\circ\text{C}, 1.2 \text{ atm}$ )

$$\text{Note: } V = \frac{MW}{P}$$

$$P = SG * 1000 \text{ %}$$

Ref state  $\Delta \dot{H}_{1FO} = 0$

$$\dot{H}_a = F_0(g, T_{bo,1} = -19.3^\circ\text{C}, 2\text{ atm})$$

$$\downarrow \Delta P, \text{const } T_{\text{phase}}$$

$$a) \dot{H}_a = \int_{326.85^\circ\text{C}}^{-40^\circ\text{C}} C_{p, F_0, g} dT$$

$$\text{where: } C_{p, F_0, g} = 34.28 \times 10^{-3} + 4.268 \times 10^{-5}T - 8.644 \times 10^{-12}T^3$$

$$b) \dot{H}_b = 0 \rightarrow \text{assume ideal gas}$$

$$c) \dot{H}_c = \Delta \dot{H}_{\text{condens. kin}} = -\Delta \dot{H}_{\text{fus}} = 24.48 \frac{\text{kJ}}{\text{mol}}$$

$$d) \dot{H}_d = \int_{-19.3^\circ\text{C}}^{-40^\circ\text{C}} C_{p, F_0, l} dT$$

$$\text{where: } C_{p, F_0, l} = 105 \frac{\text{kJ}}{\text{mol}\cdot\text{K}}$$

$$e) \dot{H}_e = \dot{V}_{F_0, l} \Delta P = \frac{MW_{F_0}}{P_{F_0, l}} (1.2 \text{ atm} - 1 \text{ atm}) \cdot 0.103 \frac{\text{kJ}}{\text{L atm}}$$

$$\text{where: } MW_{F_0} = 30.039 \text{ mol} \& P_{F_0, l} = 0.815 \times 1000 \text{ %}$$

Table B1

$$\dot{H}_c = F_0(l, T_{bo,1}, 1 \text{ atm})$$

$$\downarrow \Delta T, \text{const } P_{\text{phase}}$$

$$\Rightarrow \dot{H}_{4FO} = \dot{H}_a + \dot{H}_b + \dot{H}_c + \dot{H}_d + \dot{H}_e$$

$$\dot{H}_d = F_0(l, -40^\circ\text{C}, 1 \text{ atm})$$

$$\downarrow \Delta P, \text{const } T_{\text{phase}}$$

$$\dot{H}_e = F_0(l, -40^\circ\text{C}, 1.2 \text{ atm})$$

Formaldehyde Production (Continued)

(i) Calculate  $\hat{H}_{SO_2}$  stream S ( $g, -40^\circ C, 1.2 \text{ atm}$ )  
 Ref state \*  $\Delta \hat{H}_{SO_2} = 0$   
 $O_2(g, 326.88^\circ C, 2 \text{ atm})$

$$\downarrow \Delta T, \text{const } P, \text{phase} \quad f) \hat{H}_f = \int_{326.88^\circ C}^{-40^\circ C} C_{PO_2,g} dT$$

$\hat{H}_f$   $O_2(g, -40^\circ C, 2 \text{ atm})$

$$\downarrow \Delta P, \text{const } T, \text{phase}$$

$$g) \hat{H}_g = 0 \rightarrow \text{assume ideal g.s}$$

$\hat{H}_g$   $O_2(g, -40^\circ C, 1.2 \text{ atm})$

$$\hat{H}_{SO_2} = \hat{H}_f + 0$$

Ref state \* (ii) Calculate  $\hat{H}_{SO_2}$  stream S ( $g, -40^\circ C, 1.2 \text{ atm}$ )  
 $\Delta \hat{H}_{FO_2} = 0$   
 $Fo(g, 326.88^\circ C, 2 \text{ atm})$

$$\downarrow \Delta T, \text{const } P, \text{phase}$$

$$h) \hat{H}_h = \int_{326.88^\circ C}^{-40^\circ C} C_{PF_{O_2},g} dT \quad C_{PF_{O_2},g} \text{ defined (i.a)}$$

$\hat{H}_h$   $Fo(g, -40^\circ C, 2 \text{ atm})$

$$\downarrow \Delta P, \text{const } T, \text{phase}$$

$$i) \hat{H}_i = 0 \rightarrow \text{assume ideal g.s}$$

$\hat{H}_i$   $Fo(g, -40^\circ C, 1.2 \text{ atm})$

$$\Rightarrow \hat{H}_{SO_2} = \hat{H}_h + 0$$

Ref state \* (iii) Calculate  $\hat{H}_{SO_2}$  stream 3 ( $g, 0^\circ C, 1.1 \text{ atm}$ )  
 $\Delta \hat{H}_{SO_2} = 0$   
 $O_2(g, 326.88^\circ C, 2 \text{ atm})$

$$\downarrow \Delta T, \text{const } P, \text{phase}$$

$$j) \hat{H}_j = \int_{326.88^\circ C}^{0^\circ C} C_{PO_2,g} dT \quad C_{PO_2,g} \text{ defined (i.f)}$$

$\hat{H}_j$   $O_2(g, 0^\circ C, 2 \text{ atm})$

$$\downarrow \Delta P, \text{const } T, \text{phase}$$

$$k) \hat{H}_k = 0 \rightarrow \text{assume ideal g.s}$$

$\hat{H}_k$   $O_2(g, 0^\circ C, 1.1 \text{ atm})$

$$\Rightarrow \hat{H}_{SO_2} = \hat{H}_j + 0$$

Ref state \* (iv) Calculate  $\hat{H}_{3FO_2}$  stream 3 ( $g, 0^\circ C, 1.1 \text{ atm}$ )  
 $\Delta \hat{H}_{FO_2} = 0$   
 $Fo(g, 326.88^\circ C, 2 \text{ atm})$

$$\downarrow \Delta T, \text{const } P, \text{phase}$$

$$l) \hat{H}_l = \int_{326.88^\circ C}^{0^\circ C} C_{PF_{O_2},g} dT \quad C_{PF_{O_2},g} \text{ defined (i.a)}$$

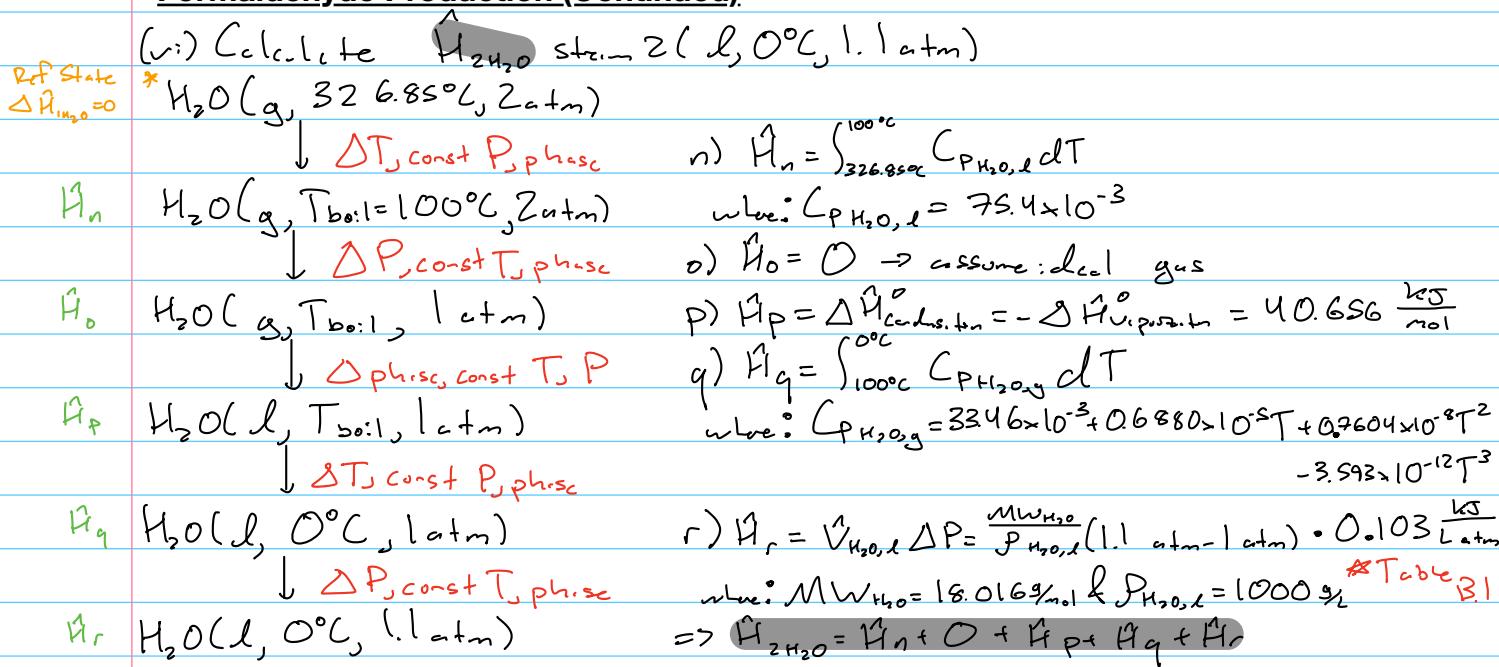
$\hat{H}_l$   $Fo(g, 0^\circ C, 2 \text{ atm})$

$$\downarrow \Delta P, \text{const } T, \text{phase}$$

$$m) \hat{H}_m = 0 \rightarrow \text{assume ideal g.s}$$

$\hat{H}_m$   $Fo(g, 0^\circ C, 1.1 \text{ atm})$

$$\Rightarrow \hat{H}_{3FO_2} = \hat{H}_l + 0$$

Formaldehyde Production (Continued)E) How to Solve for  $\dot{Q}$ 

$$\dot{Q} = [i_{\text{H}_4\text{FO}} \dot{H}_{\text{H}_4\text{FO}} + i_{\text{H}_2\text{SO}_4} \dot{H}_{\text{H}_2\text{SO}_4} + i_{\text{H}_2\text{FO}} \dot{H}_{\text{H}_2\text{FO}}] - [i_{\text{H}_3\text{O}_2} \dot{H}_{\text{H}_3\text{O}_2} + i_{\text{H}_3\text{FO}} \dot{H}_{\text{H}_3\text{FO}}] + i_{\text{H}_2\text{H}_2\text{O}} \dot{H}_{\text{H}_2\text{H}_2\text{O}}$$

- (i) Solve material balances as described Part B, now we have all  $i_i$
- (ii) Solve (D.i) to get  $\dot{H}_{\text{H}_4\text{FO}}$  using equations outlined for individual  $\dot{H}_i$
- (iii) Solve (D.ii) to get  $\dot{H}_{\text{H}_2\text{SO}_4}$  using equation outlined in  $\dot{H}_n$
- (iv) Solve (D.iii) to get  $\dot{H}_{\text{H}_2\text{FO}}$  using equation outlined in  $\dot{H}_n$
- (v) Solve (D.iv) to get  $\dot{H}_{\text{H}_3\text{O}_2}$  using equation outlined in  $\dot{H}_i$
- (vi) Solve (D.v) to get  $\dot{H}_{\text{H}_3\text{FO}}$  using equation outlined in  $\dot{H}_n$
- (vii) Solve (D.vi) to get  $\dot{H}_{\text{H}_2\text{H}_2\text{O}}$  using equation outlined in  $\dot{H}_n$
- (viii) Now Plug  $i_i$  and  $\dot{H}_i$  into  $\dot{Q}$  equation (energy balance) to find  $\dot{Q}$

**Reflection Questions**

4. Are there any concepts regarding energy balances (reactive and non-reactive) that you still find confusing?
5. Are there are concepts regarding material balances (reactive and non-reactive) that you still find confusing?

4. The content in the energy balances units do not seem to confuse me. The only issue I have with them is how long they take to fully write out, but I'm sure I will get more and more comfortable with the problem solving process as I do more practice. The only thing I find myself needing to reference my notes frequently for are the different ways to calculate the enthalpy based on the phase and what is being changed. That is also something I will be able to better understand as I do more practice, and can always make flashcards to help learn the patterns.

5. I do not find anything about the material balances confusing. I sometimes have trouble discerning what needs to be included in the DoF analysis, but it does not matter as much now that the DoF analysis is not explicitly required. I tend to include variables that aren't needed for the material balances, which makes my DoF more of a whole-process DoF instead of a Material Balance DoF. Again, this doesn't matter as much considering the end DoF result is the same and it is not part of any graded parts now.