

104 ☺

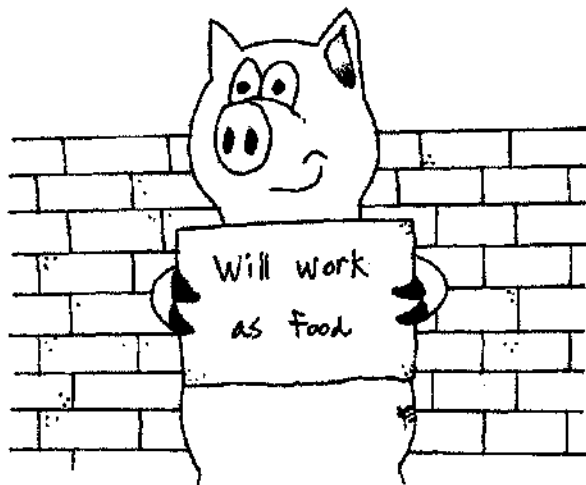
Exam 3
C&PE 211
Monday December 3, 2012
Closed Book - Closed Notes

Name: _____

1. Please do not turn the page until you are instructed to do so.
2. Please write your name in the space provided and if you separate the pages, put your initials on all of the pages.
3. Please read each question carefully and work those that you know first. Do not spend too much time on one problem. If you get stuck move on to the next question. Partial credit is given so working through a problem as much as you can is to your benefit.
4. Do all of the work on the sheets provided. Write clearly and organized. If I cannot read your writing or follow the solution, no credit will be given.
5. Only a small amount of credit is given for the answer to the problem. The majority of the credit is given for the formulas and the work you use to solve the problem. If you do not show all of your work you will not receive full credit for the problem.
6. Cheating on this exam will result in a no credit for the exam. Two instances of cheating will result in failure of the course.
7. If a box is provided please put your answers in the box. If a box is not provided, please box your final answers. All work will be checked, but the answer in the box will be considered to be the final answer.

Please remember:

Don't panic! Panicking can cause silly errors.
Good Luck!



Due to his grammar mistake, Wilbur found a position. It just wasn't the one he wanted.

1. (2 points each - no partial credit for each part)
Define sensible heat and latent heat.

4

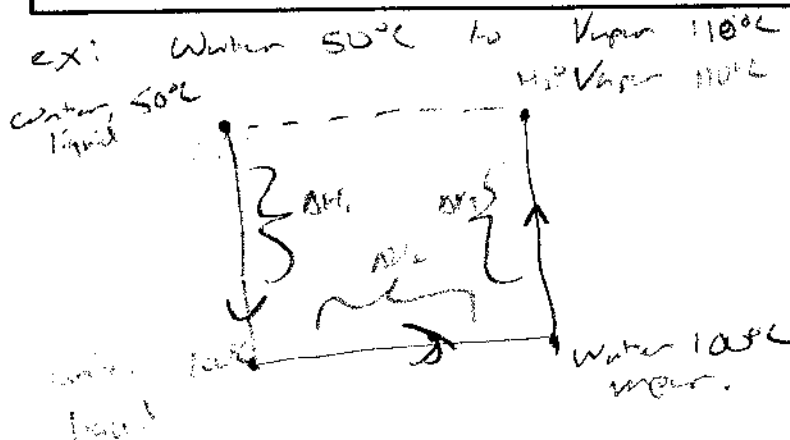
sensible heat: - Heat that cause the raising/lowering the temperature of a substance
ie. from 25°C to 75°C ✓

latent heat - Heat that causes a change in phase of a substance
ie. from a liquid to a vapor

2. (3 points - no partial credit)
Discuss why reference states are so important and how they are used.

7

Since ΔH or ΔU are not a definitive value, one must know a reference state in order to calculate ΔH or ΔU . Both of these are state properties which means it depends on the state of the system and not on how the system reached that state. Reference states are used to calculate process paths in order to determine $\Delta H/\Delta U$



Reference states are also useful to know how data values were determined.
 $H = U + PV$

3. (2 points each – no partial credit for each part.) Define what reference state you would use in the following cases.

4

- a. Solving a problem using the steam tables in the back of the book?

Saturated Steam is referenced at the triple point of water. ✓

- b. Using the heat of reaction method?

Reference is usually at a stream's T temperature, pressure, and phase of a non-reactive species in order to simplify calculations.

- c. Using the heat of formation method?

Reference states are the elements that make up the products and reactants at 25°C and 1 atm. ✓

4. (4 points - no partial credit)

The heat of reaction for the following reaction at 25°C and 1 atm is:

4



- a) -1084.76 kJ/mol b) -904.74 kJ/mol c) -820.7 kJ/mol d) -1165.68 kJ/mol

$$\Delta H_R = \sum \text{Products} - \sum \text{Reactants}$$

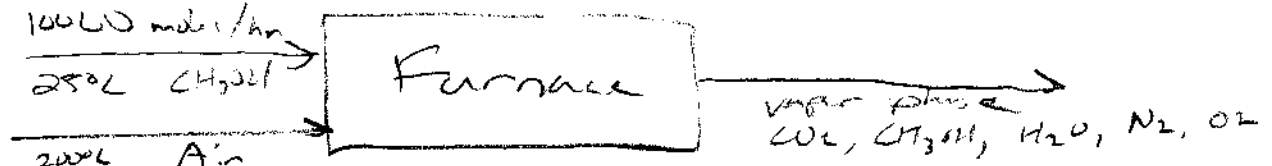
$$= \left[4 \left(91.37 \frac{\text{kJ}}{\text{mol}} \right) + 6 \left(-241.83 \frac{\text{kJ}}{\text{mol}} \right) \right] - \left[4 \left(-46.19 \frac{\text{kJ}}{\text{mol}} \right) + 5 \left(0 \frac{\text{kJ}}{\text{mol}} \right) \right]$$

$$= -904.74 \frac{\text{kJ}}{\text{mol}}$$

5. (43 points)

43

10,000 moles/hr of liquid methanol (CH_3OH) enters a furnace at 25°C where it is burned with 100% excess air. The air enters the furnace as a separate stream at 200°C . Only complete combustion products are formed and all species exiting the furnace are in the vapor phase.



	1	2	3
CH_3OH	10,000	0	n_{13}
N_2	0	$0.79 S_2$	n_{23}
O_2	0	$0.21 S_2$	n_{33}
CO_2	0	0	n_{43}
H_2O	0	0	n_{53}
Total	10,000	S_2	S_3

Possible unknowns: (5 comp. H) \cdot 3 stream + (1 rxn) (1 cv)

= 14 unknowns
Knowns = 12

8 unknowns
MS 5
PS 1 (excess)
Sum (SS) 1

NOT solvable

a. Write the balanced reaction for the complete combustion of liquid methanol. You must show the phase of each species to receive full credit.



b. The furnace is being cooled by a cooling jacket with flowing water to help remove the some of the heat generated. Assuming that the only heat removed from the reactor is through the cooling jacket, find the heat removed from the reactor (kJ/hr) if the inlet to the cooling jacket is 1250 kg/hr of water at 75°C and 1 bar and the outlet of the cooling jacket is steam at 1 bar and 350°C .

$$\text{Heat removed from reactor (kJ/hr)} = 3,577,500 \frac{\text{kJ}}{\text{hr}}$$

works on back

Equations:

Assuming steady state: $I_n - O_n + G_n - C_n = 0$
 $\therefore O_n = I_n + G_n - C_n$

WB

$$n_{13} = 10,000 = 2 \epsilon_1$$

$$n_{23} = 0.79 S_2$$

$$n_{33} = 0.21 S_2 = 3 \epsilon_1$$

$$n_{43} = 2 \epsilon_1$$

$$n_{53} = 4 \epsilon_1$$

Sum:

$$S_3 = n_{13} + n_{23} + n_{33} + n_{43} + n_{53}$$

PS:

Percent Excess = $\frac{\text{moles fed} - \text{moles required}}{\text{moles required}}$

$$\frac{0.21 S_2 - 2 \text{ mol } \text{O}_2 (10,000 \text{ mol/hr})}{2 \text{ mol } \text{O}_2 (10,000)} = 1$$

$$\frac{0.21 S_2 - \frac{3}{2}(10,000 \text{ miles})}{\frac{3}{2}(10,000 \text{ miles})} = 1 \Rightarrow S_2 = 142,857.1 \text{ miles}$$

MOE
 $0.79 S_2 = n_{N_2} = 112,857.1 \text{ miles } N_2$

$0.21 S_2 = 30,000 \text{ miles } O_2$

bad assumption

$n_{N_2} = 15,000$

$15,000 = 30,000 - 3(\epsilon_1) \Rightarrow \epsilon_1 = 5,000$

$n_{H_2} = 10,000 - 2(5,000) \Rightarrow n_{H_2} = 0$

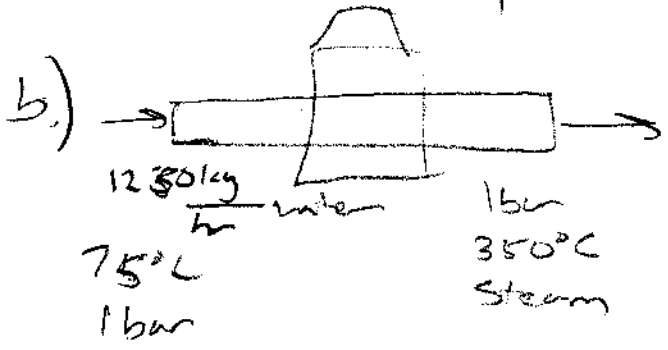
$n_{H_2O} = 2(5,000) = 10,000 \text{ miles}$

$n_{CO_2} = 4(5,000) = 20,000 \text{ miles}$

$S_3 = \frac{15,000}{\epsilon_1} n_{N_2}$

miles / hr Steam Comps	1	2	3
CO_2	10,000	0	0
N_2	0	112,857.1	112,857.1
O_2	0	30,000	10,000
CO_2	0	0	10,000
H_2O	0	0	20,000
Total	10,000	142,857.1	157,857.1

disregard
 see part C
 but equations still
 usable



$$\Delta H + \Delta KE + \Delta PE = Q$$

no velocity *no height change* *no shaft work*

$$\therefore \Delta H = Q$$

$$Q = \dot{m} (H_{out} - H_{in}) = 1250 \frac{kg}{hr} \left(3176 \frac{kJ}{kg} - 314 \frac{kJ}{kg} \right)$$

$\hat{H}_{in} =$
 Table B.7
 75°C
 1 bar

$314.0 \frac{kJ}{kg}$

Table B.7
 350°C
 1 bar
 steam

$3176 \frac{kJ}{kg}$

$$Q = 3,577,500 \frac{kJ}{hr}$$

- c. If the outlet temperature of the reactor is 400°C, using the heat removed from the reactor that you calculated in part b, solve for the fractional conversion of methanol. You must clearly show all reference states and any assumptions you make for simplifying the general energy balance. **You can assume that you only need to use the first term in the heat capacities.** If you could not solve for the heat on part b, you can assume that the heat removed from the reactor is 4×10^6 kJ/hr. **If you assume this you will automatically lose at least 5 points.**

Fractional Conversion =

73.8% ✓

$$\Delta H = \cancel{\Delta KE} + \cancel{\Delta PE} = Q \quad \Rightarrow \quad \Delta H = Q$$

no relation pipe diameter no height no shaft work

$$\Delta H_{out} - \Delta H_{in} = Q$$

Reference: 25°C, later of the elements that make reactants/products
 Method: Heat of formation.

Component	1	2	3
CH ₃ OH	4	0	A ₄
N ₂	0	H ₂	A ₅
O ₂	0	A ₃	A ₆
CO ₂	0	0	A ₇
H ₂ O	0	0	A ₈
Phase	Liquid	Vapor	Vapor
Temperature	25°C	200°C	400°C

$$A_1 = -238.6 \frac{\text{kJ}}{\text{mol}} \quad (\text{no need to raise temperature})$$

$$A_2 = 0 \frac{\text{kJ}}{\text{mol}} = \int_{200^\circ\text{C}}^{25^\circ\text{C}} 29.1 \times 10^{-3} dT = 5.08 \frac{\text{kJ}}{\text{mol}}$$

$$A_3 = 0 \frac{\text{kJ}}{\text{mol}} + \int_{200^\circ\text{C}}^{25^\circ\text{C}} 29.1 \times 10^{-3} dT = 5.09 \frac{\text{kJ}}{\text{mol}}$$

$$\hat{H}_4 = -201.22 + \int_{25}^{400} 2.93 \times 10^{-3} dT$$

$$= -185.10 \frac{\text{kJ}}{\text{mol}}$$

$$\hat{H}_5 = 0 \frac{\text{kJ}}{\text{mol}} + \int_{25}^{400} 2.9 \times 10^{-3} dT$$

$$= 10.9 \frac{\text{kJ}}{\text{mol}}$$

$$\hat{H}_6 = 0 \frac{\text{kJ}}{\text{mol}} + \int_{25}^{400} 24.1 \times 10^{-3} dT$$

$$= 10.9 \frac{\text{kJ}}{\text{mol}}$$

$$\hat{H}_7 = -393.5 \frac{\text{kJ}}{\text{mol}} + \int_{25}^{400} 36.11 \times 10^{-3} dT$$

$$= -380.0 \frac{\text{kJ}}{\text{mol}}$$

$$\hat{H}_8 = -241.83 \frac{\text{kJ}}{\text{mol}} + \int_{25}^{400} 33.416 \times 10^{-3} dT$$

$$= -229.3 \frac{\text{kJ}}{\text{mol}}$$

Energy

Species	1	2	3	$\frac{\text{kJ}}{\text{mol}}$
H_2O	-238.6	—	-185.10	
N_2	—	5.08	10.9	
O_2	—	5.09	10.9	
CO_2	—	—	-380.0	
H_2O	—	—	-229.3	
Phase	Liquid	Vapor	Vapor	
Energy	25°C	200°C	400°C	

Problem 3

Use PS

$$\frac{0.21 S_2 - \frac{3}{2}(10,000)}{\frac{3}{2}(10,000)} = 1 \Rightarrow S_2 = 142857.1 \text{ moles}$$

$$0.79 S_2 (N_2) = 112857.1 \text{ moles}$$

$$0.21 S_2 (O_2) = 30,000 \text{ moles}$$

Since heat removed (from Part B) = $3,577,500 \frac{kJ}{hr}$
 and $\Delta H = Q \Rightarrow \Delta H_{out} = \Delta H_{in} = Q$

Use MB equations and S_1 and S_2 for moles

values (Question 5 page)

Combine these two equations to get ϵ_1 (ϵ_1 in $\frac{mole}{hr}$)

$$\begin{aligned} & -185.10 \frac{kJ}{mol} (10000 - 2\epsilon_1) + 10.4 \frac{kJ}{mol} \left(112857.1 \frac{mole}{hr} \right) + \\ & 10.4 \frac{kJ}{mol} (30000 - 3\epsilon_1) + -380.0 \frac{kJ}{mol} (2\epsilon_1) + -229.3 (4\epsilon_1) \\ & = \left[-1238.6 \frac{kJ}{mol} \left(10000 \frac{mole}{hr} \right) + 5.08 \frac{kJ}{mol} \left(112857.1 \text{ moles} \right) \right. \\ & \left. + 5.04 \frac{kJ}{mol} \left(30,000 \frac{mole}{hr} \right) \right] = -3,577,500 \frac{kJ}{hr} \end{aligned}$$

That simplifies to: $-1339.7 \epsilon_1 - 293857.61 \frac{kJ}{hr}$

H_{in} simplifies to: -1659985.932

$Q = 3,577,500 \frac{kJ}{hr}$

$$-1339.7 \epsilon_1 - 293857.61 \frac{kJ}{hr} - (-1659985.932) = -3577,500 \frac{kJ}{hr}$$

Since Q is leaving the reaction, calculated value for B is $-Q$ to be known

$$-1339.7 \xi_1 = -4943628.322$$

$$\xi_1 = 3640.1$$

$$n_{13} = 10,000 - 2(3640.1) \\ = 2619.8 \text{ moles}$$

$$\text{Conversion} = \frac{\text{amount reacted}}{\text{amount fed}}$$

$$= \frac{2\xi_1}{10,000} = \frac{2(3640.1)}{10,000} \\ = 0.738$$

or 73.8% conversion

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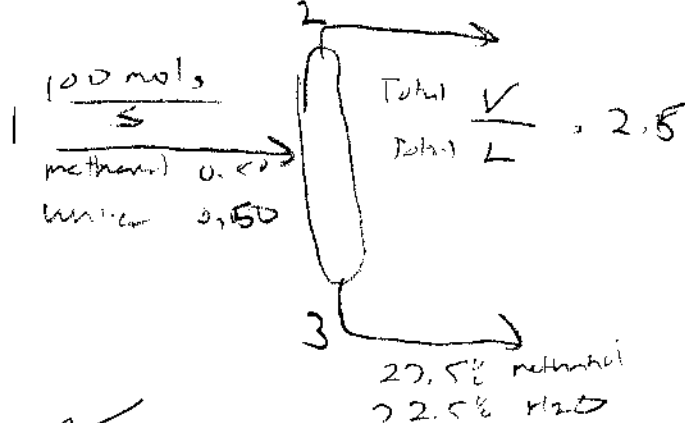
Question

5

6. (40 points)

39

An equimolar vapor stream containing methanol and water at 150°C is fed to a continuous condenser at a rate of 100 mol/s. Some of the vapor stream condenses and both the liquid and the vapor streams leaving the condenser contain methanol and water. The liquid contains 27.5 mole% methanol and 72.5 mole% water. The ratio of the total vapor to total liquid leaving the condenser is 2.5. Using the information given, solve the material balance to the nearest mole/s around the condenser and fill in the material and enthalpy table below.



Stream Components	1	2	3
CH ₃ OH	50	n ₁₂	0.275 S ₃
H ₂ O	50	n ₂₂	0.725 S ₃
Total	100	S ₂	S ₃

unknowns = (2 components) (3 streams) = 6 unknowns
 5 knowns

~~Material balance = In - out + generation - consumption~~
~~is done in this stream~~
~~stream~~
 ∴ In = Out

$S_{sum} = n_{12} + n_{22} = S_2$

4 unknowns
 MB 2
 PS 1 (1/2)
 Sum (5/2) = 0 ✓ solution

MB
 $50 = n_{12} + 0.275 S_3$
 $50 = n_{22} + 0.725 S_3$

$\frac{S_2}{S_3} = 2.5 \Rightarrow S_2 = 2.5 S_3$

Solved in book →

a) Material balance and enthalpy table for the system.

mols

	Stream 1		Stream 2		Stream 3	
	n	H	n	H	n	H
CH ₃ OH	50	A ₁	42	A ₃	8	A ₅
H ₂ O	50	A ₂	29	A ₄	21	A ₆
Total	100		71		29	
Phase	Vapor		Vapor		Liquid	
Temperature	150°C		?		?	

1
 To solve for

$$\frac{S_2}{S_3} = 2.5 \Rightarrow S_2 = 2.5 S_3$$

$$S_2 = n_{12} + n_{22}$$

NB

$$SD = n_{12} + 0.275 S_3$$

$$SD = n_{22} + 0.725 S_3$$

$$100 = \underbrace{n_{12} + n_{22}}_{S_2 = 2.5 S_3} + S_3$$

$$\Rightarrow 100 = 3.5 S_3$$

$$S_3 = 28.57$$

Solve to nearest mile

$$\text{so } S_3 = 29$$

$$0.275 S_3 = 8 \text{ miles}$$

$$0.725 S_3 = 21 \text{ miles}$$

$$SD = n_{12} + 8 \text{ miles} \Rightarrow$$

$$SD = n_{22} + 21 \text{ miles} \Rightarrow$$

$$n_{12} + n_{22} = 71 = S_2$$

$$n_{12} = 42 \text{ miles}$$

$$n_{22} = 29 \text{ miles}$$

b) If you know that 1335 KW of heat is removed from the process, calculate the temperature of the streams exiting the condenser. You must clearly show all reference states and any assumptions you make for simplifying the general energy balance. You can assume that you only need to use the first term in the heat capacities.

Temperature ($^{\circ}\text{C}$ of condenser) = 107.2°C

$$\Delta H + \cancel{\Delta PE} + \cancel{\Delta KE} = Q = \cancel{0} \Rightarrow \Delta H = Q$$

no velocity change no height change no shaft work

Reference state: 25°C , 1 atm of the elements

Method: Heat of Formation; Assume Vapor and Liquid are at the same temperature

Enthalpy Table on Question (6a)

$$\hat{H}_1 = -201.2 \frac{\text{kJ}}{\text{mol}} + \int_{25}^{T} 42.93 \times 10^{-3} dT$$

$$= \boxed{-195.8 \frac{\text{kJ}}{\text{mol}}}$$

$$\hat{H}_2 = -241.83 \frac{\text{kJ}}{\text{mol}} + \int_{25}^{T} 33.46 \times 10^{-3} dT$$

$$= \boxed{-237.6 \frac{\text{kJ}}{\text{mol}}}$$

$$\hat{H}_3 = -201.2 \frac{\text{kJ}}{\text{mol}} + \int_{25}^{T} 42.93 \times 10^{-3} dT$$

$$= \boxed{0.04293T - 202.27 \frac{\text{kJ}}{\text{mol}}}$$

$$\hat{H}_4 = -241.83 \frac{\text{kJ}}{\text{mol}} + \int_{25}^{T} 33.46 \times 10^{-3} dT$$

$$= \boxed{-0.03346T - 236.811 \frac{\text{kJ}}{\text{mol}}}$$

$$\hat{H}_5 + \hat{H}_6$$

$$\hat{H}_5 = -238.6 \frac{\text{kJ}}{\text{mol}} + \int_{25}^T 75.86 \times 10^{-3} dT$$

$$= \boxed{0.07586 T - 240.4965 \frac{\text{kJ}}{\text{mol}}}$$

$$\hat{H}_6 = -285.84 \frac{\text{kJ}}{\text{mol}} + \int_{25}^T 75.4 \times 10^{-3} dT$$

$$= \boxed{0.0754 T - 287.725 \frac{\text{kJ}}{\text{mol}}}$$

Give Energy Balance simplifies to $\Delta H = Q$ or $\Delta H_{out} - \Delta H_{in} = Q$

$\Delta H_{out} =$

$$\left[42 \frac{\text{mol}}{\text{s}} \left(0.04293 T - 202.27 \frac{\text{kJ}}{\text{mol}} \right) + 29 \frac{\text{mol}}{\text{s}} \left(-0.03346 T - 236.81 \frac{\text{kJ}}{\text{mol}} \right) \right]$$

$$+ 8 \frac{\text{mol}}{\text{s}} \left(0.07586 T - 240.4965 \frac{\text{kJ}}{\text{mol}} \right) + 21 \frac{\text{mol}}{\text{s}} \left(0.0754 T - 287.725 \frac{\text{kJ}}{\text{mol}} \right)$$

$$= 3.023 T - 23329.056 \text{ kW}$$

$\Delta H_{in} =$

$$50 \frac{\text{mol}}{\text{s}} \left(-195.8 \frac{\text{kJ}}{\text{mol}} \right) + 50 \frac{\text{mol}}{\text{s}} \left(-237.6 \frac{\text{kJ}}{\text{mol}} \right)$$

$$= -21670 \text{ kW}$$

$$Q = -1335 \text{ kW}$$

Put everything together
Q removed from system is negative

$$\left[3.023 T - 23329.056 \text{ kW} \right] - \left[-21670 \text{ kW} \right] = -1335 \text{ kW}$$

$$3.023 T = 324.056$$

$$\boxed{T(^\circ\text{C}) = 107.2^\circ\text{C}}$$

check math (-1)

Extra Credit:

(+5)

Knowing that condensation is a fast process and thus, the vapor and liquid streams exiting the condenser can be assumed to be in equilibrium with each other, show that if the condenser in problem 6 is operating at atmospheric pressure, show that the temperature you calculated in 6b is reasonable.

If the vapor and the liquid streams are in equilibrium, then we can assume that Raoult's law can be applied to the system.

Raoult's Law: $P_{\text{Total}} y_i = P^* x_i$

Using Antoine's Equation:

$$\log(P^*) = A - \frac{B}{T+C} \quad \text{where } T = ^\circ\text{C}$$

Using 107.2°C as temperature:

Water: $\log(P^*) = 8.10765 - \frac{1750.286}{(107.2^\circ\text{C}) + 235.600} = 483.66 \text{ mmHg}$

$P_{\text{H}_2\text{O}}^* = 10$

Methanol: $\log(P^*) = 8.08097 - \frac{1582.271}{(107.2) + 239.726} = 3379.62 \text{ mmHg}$

$P_{\text{Methanol}}^* = 10$

Given that the sum of all partial fractions of the vapor stream is equal to 1, that is, $\sum y_i = 1$

Raoult's law can be simplified down to

$$P_{\text{Total}} = P^* x_i \Rightarrow x_i = \frac{P_{\text{Total}}}{P^*}$$

If $P_{\text{Total}} = 1 \text{ atm}$ or 760 mmHg then:

$$X_{\text{water}} = \left(\frac{760 \text{ mmHg}}{983.66 \text{ mmHg}} \right) = 0.77 = 77\%$$

$$X_{\text{CH}_3\text{OH}} = \left(\frac{760 \text{ mmHg}}{3379.625 \text{ mmHg}} \right) = 0.23 = 23\%$$

These values are close to the original values of 72.5% mole of water and 27.5% mole of methanol.

The reason why these values are off could be the following reasons:

- Actual pressure of the system is not at 1 atm
- Rounding error due to rounding to the nearest whole mole.
- Rounding error in calculating enthalpies values.
- Rounding error in solving for T after multiplying enthalpy value with the moles calculated

∴ ~107.2°C was unreasonable temperature for the condenser.

Species	phase	MW	SG	Tb (C)	ΔH_{vap} (Tb) KJ/mol	ΔH_f^o KJ/mol	heat capacity constant (kJ/molC)	Antoine Coefficients		
								A	B	C
NH ₃	l	17.03		-33.43	23.351	-67.20				
	g					-46.19	35.15	7.55466	1002.711	247.885
NO	g	30.01		-151.8	15.73	50.37	25.5			
Oxygen	g	32	---	182.97	6.82	0	29.1			
Carbon Dioxide	l	44	---			-412.9				
	g					-393.5	36.11			
Nitrogen	g	28	---	-195.8	5.577	0	29			
Water	l	18	1	100	40.656	-285.84	75.4	8.10765	1750.286	235.000
	g					-241.83	33.46			
Methanol	l	32.04	0.792	64.7	35.27	-238.6	75.86	8.08097	1582.271	239.726
	g					-201.2	42.93			

1 kW = 1 kJ/s

Table B.7 Properties of Superheated Steam^a

P(bar) (T _{sat} , °C)	Sat'd		Temperature (°C) →								
	Water	Steam	50	75	100	150	200	250	300	350	
0.0 (-)	<i>h</i>	--	--	2595	2642	2689	2784	2880	2978	3077	3177
	<i>u</i>	--	--	2446	2481	2517	2589	2662	2736	2812	2890
	<i>v</i>	--	--	--	--	--	--	--	--	--	--
0.1 (45.8)	<i>h</i>	191.8	2584.8	2593	2640	2688	2783	2880	2977	3077	3177
	<i>u</i>	191.8	2438.0	2444	2480	2516	2588	2661	2736	2812	2890
	<i>v</i>	0.00101	14.7	14.8	16.0	17.2	19.5	21.8	24.2	26.5	28.7
0.5 (81.3)	<i>h</i>	340.6	2646.0	209.3	313.9	2683	2780	2878	2979	3076	3177
	<i>u</i>	340.6	2484.0	209.2	313.9	2512	2586	2660	2735	2811	2889
	<i>v</i>	0.00103	3.24	0.00101	0.00103	3.41	3.89	4.35	4.83	5.29	5.75
1.0 (99.6)	<i>h</i>	417.5	2675.4	209.3	314.0	2676	2776	2875	2975	3074	3176
	<i>u</i>	417.5	2506.1	209.2	313.9	2507	2583	2658	2734	2811	2889
	<i>v</i>	0.00104	1.69	0.00101	0.00103	1.69	1.94	2.17	2.40	2.64	2.87
5.0 (151.8)	<i>h</i>	640.1	2747.5	209.7	314.3	419.4	632.2	2855	2961	3065	3168
	<i>u</i>	639.6	2560.2	209.2	313.8	418.8	631.6	2643	2734	2803	2883
	<i>v</i>	0.00109	0.375	0.00101	0.00103	0.00104	0.00109	0.425	0.474	0.522	0.571
10 (179.9)	<i>h</i>	762.6	2776.2	210.1	314.7	419.7	632.5	2827	2943	3052	3159
	<i>u</i>	761.5	2582	209.1	313.7	418.7	631.4	2621	2710	2794	2876
	<i>v</i>	0.00113	0.194	0.00101	0.00103	0.00104	0.00109	0.206	0.233	0.258	0.282
20 (212.4)	<i>h</i>	908.6	2797.2	211.0	315.5	420.5	633.1	852.6	2902	3025	3139
	<i>u</i>	906.2	2598.2	209.0	313.5	418.4	603.9	850.2	2679	2774	2862
	<i>v</i>	0.00118	0.09950	0.00101	0.00102	0.00104	0.00109	0.00116	0.111	0.125	0.139
40 (250.3)	<i>h</i>	1087.4	2800.3	212.7	317.1	422.0	634.3	853.4	1085.8	2962	3095
	<i>u</i>	1082.4	2601.3	208.6	313.0	417.8	630.0	848.8	1080.8	2727	2829
	<i>v</i>	0.00125	0.04975	0.00101	0.00102	0.00104	0.00109	0.00115	0.00125	0.0588	0.0665
60 (275.6)	<i>h</i>	1213.7	2785.0	214.4	318.7	423.5	635.6	854.2	1085.8	2885	3046
	<i>u</i>	1205.8	2590.4	208.3	312.6	417.3	629.1	847.3	1078.3	2668	2792
	<i>v</i>	0.00132	0.0325	0.00101	0.00103	0.00104	0.00109	0.00115	0.00125	0.0361	0.0422
80 (295.0)	<i>h</i>	1317.1	2759.9	216.1	320.3	425.0	636.8	855.1	1085.8	2787	2991
	<i>u</i>	1306.0	2571.7	208.1	312.3	416.7	628.2	845.9	1075.8	2593	2750
	<i>v</i>	0.00139	0.0235	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.0243	0.0299
100 (311.0)	<i>h</i>	1408.0	2727.7	217.8	322.9	426.5	638.1	855.9	1085.8	1343.4	2926
	<i>u</i>	1393.5	2547.3	207.8	311.7	416.1	627.3	844.1	1073.4	1329.4	2702
	<i>v</i>	0.00145	0.0181	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.00140	0.0224
150 (342.1)	<i>h</i>	1611.0	2615.0	222.1	326.0	430.3	641.3	858.1	1086.2	1338.2	2695
	<i>u</i>	1586.1	2459.9	207.0	310.7	414.7	625.0	841.0	1067.7	1317.6	2523
	<i>v</i>	0.00166	0.0103	0.00101	0.00102	0.00104	0.00108	0.00114	0.00123	0.00138	0.0115
200 (365.7)	<i>h</i>	1826.5	2418.4	226.4	330.0	434.0	644.5	860.4	1086.7	1334.3	1647.1
	<i>u</i>	1785.7	2300.8	206.3	309.7	413.2	622.9	837.7	1062.2	1307.1	1613.7
	<i>v</i>	0.00204	0.005875	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00136	0.00167
221.2(P _s) (374.15)(T _s)	<i>h</i>	2108	2108	228.2	331.7	435.7	645.8	861.4	1087.0	1332.8	1635.5
	<i>u</i>	2037.8	2037.8	206.0	309.2	412.8	622.0	836.3	1060.0	1302.9	1600.3
	<i>v</i>	0.00317	0.00317	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00135	0.00163
250 (-)	<i>h</i>	--	--	230.7	334.0	437.8	647.7	862.8	1087.5	1331.1	1625.0
	<i>u</i>	--	--	205.7	308.7	412.1	620.8	834.4	1057.0	1297.5	1585.0
	<i>v</i>	--	--	0.00100	0.00101	0.00103	0.00108	0.00113	0.00122	0.00135	0.00160
300 (-)	<i>h</i>	--	--	235.0	338.1	441.6	650.9	865.2	1088.4	1328.7	1609.9
	<i>u</i>	--	--	205.0	307.7	410.8	618.7	831.3	1052.1	1288.7	1563.3
	<i>v</i>	--	--	0.0009990	0.00101	0.00103	0.00107	0.00113	0.00121	0.00133	0.00155
500 (-)	<i>h</i>	--	--	251.9	354.2	456.8	664.1	875.4	1093.6	1323.7	1576.3
	<i>u</i>	--	--	202.4	304.0	405.8	611.0	819.7	1034.3	1259.3	1504.1
	<i>v</i>	--	--	0.0009911	0.00100	0.00102	0.00106	0.00111	0.00119	0.00129	0.00144
1000 (-)	<i>h</i>	--	--	293.9	394.3	495.1	698.0	903.5	1113.0	1328.7	1550.5
	<i>u</i>	--	--	196.5	295.7	395.1	594.4	795.3	999.0	1207.1	1419.0
	<i>v</i>	--	--	0.0009737	0.0009852	0.001000	0.00104	0.00108	0.00114	0.00122	0.00131

^aAdapted from R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968. Water is a liquid in the enclosed region between 50°C and 350°C. *h* = specific enthalpy (kJ/kg), *u* = specific internal energy (kJ/kg), *v* = specific volume (m³/kg). Note: kJ/kg × 0.4303 = Btu/lb_m.

(continued)