

Name _____

Student ID _____

CHEE 2331 Exam 2 – April 6, 2015

State all assumptions, show all work. Credit will not be given for unsupported answers. Please note the UH Academic Honesty Policies are in effect.

There are 3 problem statements/questions.

When done with your exam, do not leave your seat. When time is called, turn your exam over and remain seated until the exam is collected.

1. (30 points total) You run a reactor to form CH_3OH from a 2:1 molar feed ratio of $\text{H}_2:\text{CO}$. The feed gas to the reactor is compressed to 50 MPa (abs). A single pass conversion of 25.0% is attained with the reactor running at 700K. Your boss tells you to produce 54.5 kmol/h of methanol. Estimate the volumetric flow rate that the compressor must deliver to the reactor.

2. (40 points total) Air at atmospheric pressure, 38°C and 97% relative humidity is to be cooled to 18°C. The gas stream is then fed to a plant at a rate of 510 m³/min. The gas stream to the plant can be considered ideal. In the cooling unit, how much water condenses? What is the cooling rate in the unit?

Note: the specific enthalpy of air at 18°C is -0.204 kJ/mol and at 38°C is 0.378 kJ/mol.

3. (30 points) A liquid stream composed of 12.5 mol% n-butane with a balance of a heavy nonvolatile hydrocarbon is fed to the top of a separation column, where it is brought into contact with an upward flowing stream of nitrogen, which entered the column pure. The residual liquid leaving the bottom of the bottom still contains 5.00% of the butane that entered, all of the entering heavy hydrocarbon and no nitrogen. The column is isothermal at 30°C and isobaric at 1 atm. Find the minimum flow rate of nitrogen, in mol/s, required to accomplish this separation.

Molecule	Critical Constants		Antoine's Equation Constants		
	T _c (K)	P _c (atm)	A	B	C
H ₂	33.3	12.8	Not provided	Not provided	Not provided
CO	133.0	34.5	Not provided	Not provided	Not provided
CH ₃ OH	513.2	78.5	7.87863	1473.11	230.0
Nitrogen	126.2	33.5	Not provided	Not provided	Not provided
Oxygen	154.4	49.7	Not provided	Not provided	Not provided
Water	647.4	218.3	7.96681	1668.210	228.000
n-Butane	425.17	37.47	6.82485	943.453	239.711

Newton's correction for critical T and P, $P_c^a = P_c + 8$, $T_c^a = T_c + 8$

Antoine's Equation $\rightarrow \log_{10} p^* = A - \frac{B}{T+C}$ for pressure in mm Hg

Clapeyron equation $\rightarrow \frac{dp^*}{dT} = \frac{\Delta \bar{H}_V}{T(\bar{V}_g - \bar{V}_l)}$

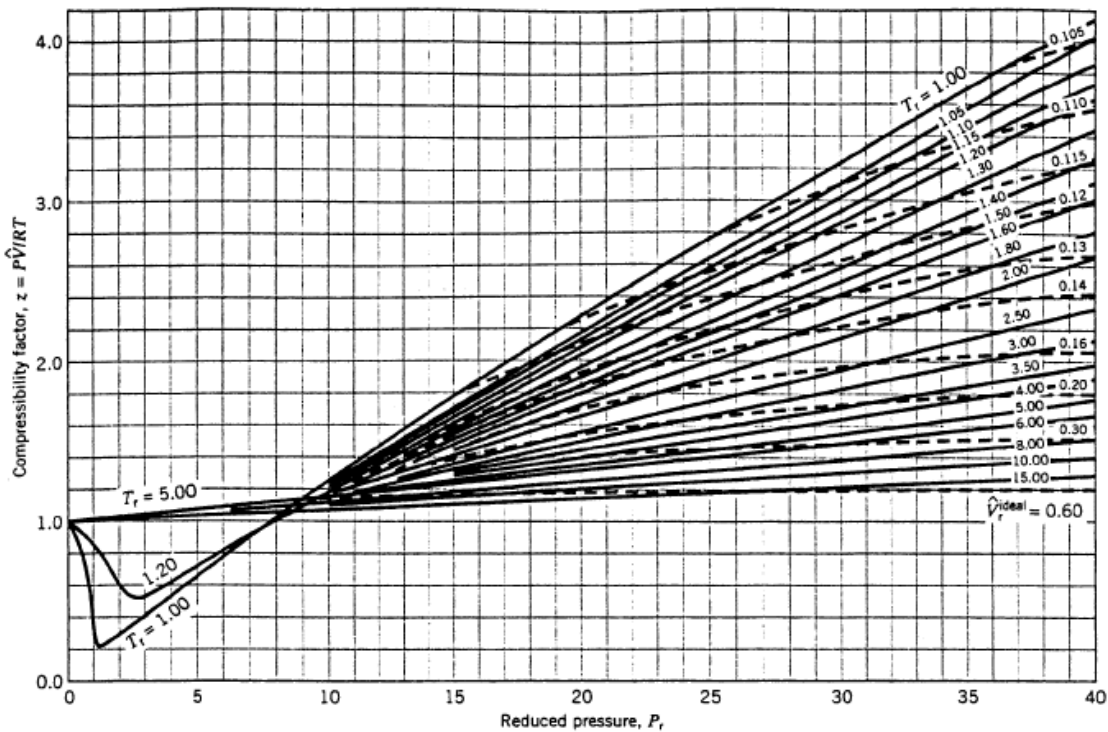


Table B.5 Properties of Saturated Steam: Temperature Table^a

$T(^{\circ}\text{C})$	$P(\text{bar})$	$\hat{V}(\text{m}^3/\text{kg})$		$\hat{U}(\text{kJ}/\text{kg})$		$\hat{H}(\text{kJ}/\text{kg})$		
		Water	Steam	Water	Steam	Water	Evaporation	Steam
0.01	0.00611	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
2	0.00705	0.001000	179.9	8.4	2378.3	8.4	2496.8	2505.2
4	0.00813	0.001000	157.3	16.8	2381.1	16.8	2492.1	2508.9
6	0.00935	0.001000	137.8	25.2	2383.8	25.2	2487.4	2512.6
8	0.01072	0.001000	121.0	33.6	2386.6	33.6	2482.6	2516.2
10	0.01227	0.001000	106.4	42.0	2389.3	42.0	2477.9	2519.9
12	0.01401	0.001000	93.8	50.4	2392.1	50.4	2473.2	2523.6
14	0.01597	0.001001	82.9	58.8	2394.8	58.8	2468.5	2527.2
16	0.01817	0.001001	73.4	67.1	2397.6	67.1	2463.8	2530.9
18	0.02062	0.001001	65.1	75.5	2400.3	75.5	2459.0	2534.5
20	0.0234	0.001002	57.8	83.9	2403.0	83.9	2454.3	2538.2
22	0.0264	0.001002	51.5	92.2	2405.8	92.2	2449.6	2541.8
24	0.0298	0.001003	45.9	100.6	2408.5	100.6	2444.9	2545.5
25	0.0317	0.001003	43.4	104.8	2409.9	104.8	2442.5	2547.3
26	0.0336	0.001003	41.0	108.9	2411.2	108.9	2440.2	2549.1
28	0.0378	0.001004	36.7	117.3	2414.0	117.3	2435.4	2552.7
30	0.0424	0.001004	32.9	125.7	2416.7	125.7	2430.7	2556.4
32	0.0475	0.001005	29.6	134.0	2419.4	134.0	2425.9	2560.0
34	0.0532	0.001006	26.6	142.4	2422.1	142.4	2421.2	2563.6
36	0.0594	0.001006	24.0	150.7	2424.8	150.7	2416.4	2567.2
38	0.0662	0.001007	21.6	159.1	2427.5	159.1	2411.7	2570.8
40	0.0738	0.001008	19.55	167.4	2430.2	167.5	2406.9	2574.4
42	0.0820	0.001009	17.69	175.8	2432.9	175.8	2402.1	2577.9
44	0.0910	0.001009	16.04	184.2	2435.6	184.2	2397.3	2581.5
46	0.1009	0.001010	14.56	192.5	2438.3	192.5	2392.5	2585.1
48	0.1116	0.001011	13.23	200.9	2440.9	200.9	2387.7	2588.6
50	0.1234	0.001012	12.05	209.2	2443.6	209.3	2382.9	2592.2
52	0.1361	0.001013	10.98	217.7	2446	217.7	2377	2595
54	0.1500	0.001014	10.02	226.0	2449	226.0	2373	2599
56	0.1651	0.001015	9.158	234.4	2451	234.4	2368	2602
58	0.1815	0.001016	8.380	242.8	2454	242.8	2363	2606
60	0.1992	0.001017	7.678	251.1	2456	251.1	2358	2609
62	0.2184	0.001018	7.043	259.5	2459	259.5	2353	2613
64	0.2391	0.001019	6.468	267.9	2461	267.9	2348	2616
66	0.2615	0.001020	5.947	276.2	2464	276.2	2343	2619
68	0.2856	0.001022	5.475	284.6	2467	284.6	2338	2623

Table B.7 Properties of Superheated Steam^a

$P(\text{bar})$ ($T_{\text{sat}}(^{\circ}\text{C})$)	Sat'd Water	Sat'd Steam	Temperature ($^{\circ}\text{C}$) →								
			50	75	100	150	200	250	300	350	
0.0 (—)	\hat{H} — \hat{U} — \hat{V} —	— — —	2595 2446 —	2642 2481 —	2689 2517 —	2784 2589 —	2880 2662 —	2978 2736 —	3077 2812 —	3177 2890 —	
0.1 (45.8)	\hat{H} 191.8 \hat{U} 191.8 \hat{V} 0.00101	2584.8 2438.0 14.7	2593 2444 14.8	2640 2480 16.0	2688 2516 17.2	2783 2588 19.5	2880 2661 21.8	2977 2736 24.2	3077 2812 26.5	3177 2890 28.7	
0.5 (81.3)	\hat{H} 340.6 \hat{U} 340.6 \hat{V} 0.00103	2646.0 2484.0 3.24	209.3 209.2 0.00101	313.9 313.9 0.00103	2683 2512 3.41	2780 2586 3.89	2878 2660 4.35	2979 2735 4.83	3076 2811 5.29	3177 2889 5.75	
1.0 (99.6)	\hat{H} 417.5 \hat{U} 417.5 \hat{V} 0.00104	2675.4 2506.1 1.69	209.3 209.2 0.00101	314.0 313.9 0.00103	2676 2507 1.69	2776 2583 1.94	2875 2658 2.17	2975 2734 2.40	3074 2811 2.64	3176 2889 2.87	
5.0 (151.8)	\hat{H} 640.1 \hat{U} 639.6 \hat{V} 0.00109	2747.5 2560.2 0.375	209.7 209.2 0.00101	314.3 313.8 0.00103	419.4 418.8 0.00104	632.2 631.6 0.00109	2855 2643 0.425	2961 2724 0.474	3065 2803 0.522	3168 2883 0.571	
10 (179.9)	\hat{H} 762.6 \hat{U} 761.5 \hat{V} 0.00113	2776.2 2582 0.194	210.1 209.1 0.00101	314.7 313.7 0.00103	419.7 418.7 0.00104	632.5 631.4 0.00109	2827 2621 0.206	2943 2710 0.233	3052 2794 0.258	3159 2876 0.282	
20 (212.4)	\hat{H} 908.6 \hat{U} 906.2 \hat{V} 0.00118	2797.2 2598.2 0.09950	211.0 209.0 0.00101	315.5 313.5 0.00102	420.5 418.4 0.00104	633.1 603.9 0.00109	852.6 830.2 0.00116	2902 2679 0.111	3025 2774 0.125	3139 2862 0.139	
40 (250.3)	\hat{H} 1087.4 \hat{U} 1082.4 \hat{V} 0.00125	2800.3 2601.3 0.04975	212.7 208.6 0.00101	317.1 313.0 0.00102	422.0 417.8 0.00104	634.3 630.0 0.00109	853.4 848.8 0.00115	1085.8 1080.8 0.00125	2962 2727 0.0588	3095 2829 0.0665	
60 (275.6)	\hat{H} 1213.7 \hat{U} 1205.8 \hat{V} 0.00132	2785.0 2590.4 0.0325	214.4 208.3 0.00101	318.7 312.6 0.00103	423.5 417.3 0.00104	635.6 629.1 0.00109	854.2 847.3 0.00115	1085.8 1078.3 0.00125	2885 2668 0.0361	3046 2792 0.0422	
80 (295.0)	\hat{H} 1317.1 \hat{U} 1306.0 \hat{V} 0.00139	2759.9 2571.7 0.0235	216.1 208.1 0.00101	320.3 312.3 0.00102	425.0 416.7 0.00104	636.8 628.2 0.00109	855.1 845.9 0.00115	1085.8 1075.8 0.00124	2787 2593 0.0243	2990 2750 0.0299	
100 (311.0)	\hat{H} 1408.0 \hat{U} 1393.5 \hat{V} 0.00145	2727.7 2547.3 0.0181	217.8 207.8 0.00101	322.9 311.7 0.00102	426.5 416.1 0.00104	638.1 627.3 0.00109	855.9 844.4 0.00115	1085.8 1073.4 0.00124	1343.4 1329.4 0.00140	2926 2702 0.0224	
150 (342.1)	\hat{H} 1611.0 \hat{U} 1586.1 \hat{V} 0.00166	2615.0 2459.9 0.0103	222.1 207.0 0.00101	326.0 310.7 0.00102	430.3 414.7 0.00104	641.3 625.0 0.00108	858.1 841.0 0.00114	1086.2 1067.7 0.00123	1338.2 1317.6 0.00138	2695 2523 0.0115	
200 (365.7)	\hat{H} 1826.5 \hat{U} 1785.7 \hat{V} 0.00204	2418.4 2300.8 0.005875	226.4 206.3 0.00100	330.0 309.7 0.00102	434.0 413.2 0.00103	644.5 622.9 0.00108	860.4 837.7 0.00114	1086.7 1062.2 0.00122	1334.3 1307.1 0.00136	1647.1 1613.7 0.00167	
221.2(P_c) (374.15)(T_c)	\hat{H} 2108 \hat{U} 2037.8 \hat{V} 0.00317	2108 2037.8 0.00317	228.2 206.0 0.00100	331.7 309.2 0.00102	435.7 412.8 0.00103	645.8 622.0 0.00108	861.4 836.3 0.00114	1087.0 1060.0 0.00122	1332.8 1302.9 0.00135	1635.5 1600.3 0.00163	
250 (—)	\hat{H} — \hat{U} — \hat{V} —	— — —	230.7 205.7 0.00100	334.0 308.7 0.00101	437.8 412.1 0.00103	647.7 620.8 0.00108	862.8 834.4 0.00113	1087.5 1057.0 0.00122	1331.1 1297.5 0.00135	1625.0 1585.0 0.00160	
300 (—)	\hat{H} — \hat{U} — \hat{V} —	— — —	235.0 205.0 0.0009990	338.1 307.7 0.00101	441.6 410.8 0.00103	650.9 618.7 0.00107	865.2 831.3 0.00113	1088.4 1052.1 0.00121	1328.7 1288.7 0.00133	1609.9 1563.3 0.00155	
500 (—)	\hat{H} — \hat{U} — \hat{V} —	— — —	251.9 202.4 0.0009911	354.2 304.0 0.00100	456.8 405.8 0.00102	664.1 611.0 0.00106	875.4 819.7 0.00111	1093.6 1034.3 0.00119	1323.7 1259.3 0.00129	1576.3 1504.1 0.00144	
1000 (—)	\hat{H} — \hat{U} — \hat{V} —	— — —	293.9 196.5 0.0009737	394.3 295.7 0.0009852	495.1 395.1 0.00100	698.0 594.4 0.00104	903.5 795.3 0.00108	1113.0 999.0 0.00114	1328.7 1207.1 0.00122	1550.5 1419.0 0.00131	

^aAdapted from R. W. Haywood, *Thermodynamic Tables for SI Units*, John Wiley, New York, 1982, p. 10.

FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	$1 \text{ kg} = 1000 \text{ g} = 0.001 \text{ metric ton} = 2.20462 \text{ lb}_m = 35.27392 \text{ oz}$ $1 \text{ lb}_m = 16 \text{ oz} = 5 \times 10^{-4} \text{ ton} = 453.593 \text{ g} = 0.453593 \text{ kg}$
Length	$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 10^6 \text{ microns } (\mu\text{m}) = 10^{10} \text{ angstroms } (\text{Å})$ $= 39.37 \text{ in.} = 3.2808 \text{ ft} = 1.0936 \text{ yd} = 0.0006214 \text{ mile}$ $1 \text{ ft} = 12 \text{ in.} = 1/3 \text{ yd} = 0.3048 \text{ m} = 30.48 \text{ cm}$
Volume	$1 \text{ m}^3 = 1000 \text{ L} = 10^6 \text{ cm}^3 = 10^6 \text{ mL}$ $= 35.3145 \text{ ft}^3 = 219.97 \text{ imperial gallons} = 264.17 \text{ gal}$ $= 1056.68 \text{ qt}$ $1 \text{ ft}^3 = 1728 \text{ in.}^3 = 7.4805 \text{ gal} = 0.028317 \text{ m}^3 = 28.317 \text{ L}$ $= 28,317 \text{ cm}^3$
Force	$1 \text{ N} = 1 \text{ kg}\cdot\text{m}/\text{s}^2 = 10^5 \text{ dynes} = 10^5 \text{ g}\cdot\text{cm}/\text{s}^2 = 0.22481 \text{ lb}_f$ $1 \text{ lb}_f = 32.174 \text{ lb}_m\cdot\text{ft}/\text{s}^2 = 4.4482 \text{ N} = 4.4482 \times 10^5 \text{ dynes}$
Pressure	$1 \text{ atm} = 1.01325 \times 10^5 \text{ N}/\text{m}^2 \text{ (Pa)} = 101.325 \text{ kPa} = 1.01325 \text{ bar}$ $= 1.01325 \times 10^6 \text{ dynes}/\text{cm}^2$ $= 760 \text{ mm Hg at } 0^\circ\text{C (torr)} = 10.333 \text{ m H}_2\text{O at } 4^\circ\text{C}$ $= 14.696 \text{ lb}_f/\text{in.}^2 \text{ (psi)} = 33.9 \text{ ft H}_2\text{O at } 4^\circ\text{C}$ $= 29.921 \text{ in. Hg at } 0^\circ\text{C}$
Energy	$1 \text{ J} = 1 \text{ N}\cdot\text{m} = 10^7 \text{ ergs} = 10^7 \text{ dyne}\cdot\text{cm}$ $= 2.778 \times 10^{-7} \text{ kW}\cdot\text{h} = 0.23901 \text{ cal}$ $= 0.7376 \text{ ft}\cdot\text{lb}_f = 9.486 \times 10^{-4} \text{ Btu}$
Power	$1 \text{ W} = 1 \text{ J}/\text{s} = 0.23901 \text{ cal}/\text{s} = 0.7376 \text{ ft}\cdot\text{lb}_f/\text{s} = 9.486 \times 10^{-4} \text{ Btu}/\text{s}$ $= 1.341 \times 10^{-3} \text{ hp}$

Example: The factor to convert grams to lb_m is $\left(\frac{2.20462 \text{ lb}_m}{1000 \text{ g}}\right)$.