CHBE 241 Material and Energy Balances
Department of Chemical and Biological Engineering
The University of British Columbia

Final Examination (3 hours) **Monday, 10 December 2007**

Answer all 6 questions. Present all your calculations!

1. (5%) A suspension of calcium carbonate particles in water flows through a pipe. Your assignment is to determine both the flow rate and the composition of this suspension. You proceed to collect the stream in a graduated cylinder for 1 min; you then weigh the cylinder, evaporate the collected water, and reweigh the cylinder. The following results are obtained:

   Mass of empty cylinder: 65 g
   Mass of cylinder + collected suspension: 565 g
   Volume collected: 455 mL
   Mass of cylinder after evaporation: 215 g.

   Calculate:

   (a) The volumetric flow rate and mass flow rate of the suspension.

   (b) The density of the suspension.

   (c) The mass fraction of calcium carbonate in the suspension.

2. (20%) According to http://www.mayoclinic.com/health/caffeine/AN01211, a 12 oz cup of Starbucks Tazo Chai Tea Latte contains 75 mg caffeine. If caffeine is eliminated from the body at a rate of $dm_{c,sys}/dt = -0.15 m_{c,sys}$, how long it will take for the caffeine in your body to drop to 25 mg after you consumed one cup of Tazo Chai Tea Latte? ($m_{c,sys}$ (mg) is the mass of caffeine in the body, and t is time in hours.) You drink one cup at 8am and another one at 4pm. Plot the caffeine content of your body as a function of time for a period 8am–10pm (step 2 hours).

3. (20%) Hydrogen is produced in the reaction of methane and steam:

   $$CH_4 + H_2O = CO + 3H_2$$

   The fresh feed to the process contains methane, steam, and 0.25 mol% inerts (I). The reactor effluent passes to a separator that removes essentially all of the CO and H_2 and none of the reactants or inerts. The latter substances (reactants and inerts) are recycled to the reactor. To avoid buildup of the inerts in the system, a purge stream is withdrawn from the recycle.

   The feed to the *reactor* (not the fresh feed to the process) contains 30 mol% CH_4, 69 mol% H_2O and 1 mol% inerts. The single-pass conversion of methane is 75%.

   (a) Sketch a flow diagram of the process and label all streams, compositions, and flow rates.

(b) Do a DOF analysis.

(c) Calculate the molar flow rates and molar compositions of the fresh feed, the total feed to the reactor, the recycle stream, and the purge stream for a hydrogen production rate of 300 kmol H_2/h.

4. (20%) A soap manufacturer is considering converting its excess glycerol byproduct to hydrogen for use in fuel cells, using a new catalytic process. The process operates the following reaction:

$$C_3H_8O_3 + 3H_2O \leftrightarrows 3CO_2 + 7H_2.$$

The reactor operates in the gas phase, at 1.2 atm and 200°C, with a feed ratio of water:glycerol of 5:1 (mol/mol). The glycerol feed rate in the pilot plant reactor is 1.6 mol/hr, and an exit stream hydrogen mole fraction of 0.54 is measured.

(a) What is the fractional conversion of the limiting reactant under these conditions?

(b) If the equilibrium constant for this reaction at 200°C is $K_a = 55\,\text{atm}^6$, is the reaction achieving equilibrium?

(c) Will an increase in pressure to 3 atm increase or decrease equilibrium conversion?

5. (15%) A 25 wt% solution of acetic acid in methylisobutylketone (MIBK), flow rate 100 kg/h, and a second stream of pure water, are fed to a mixer. After complete mixing, the mixture is fed to a separator where two phases form and are withdrawn separately at 25°C. How much water must be fed to the process to reduce the acetic acid concentration in the MIBK-rich phase to 5 wt%, assuming that the fluids remain in the separator long enough for equilibrium to be achieved? What are the flow rates of the MIBK-rich and water-reach streams leaving the separator? MIBK-acetic acid-water liquid-liquid phase diagram is given in Figure 1.

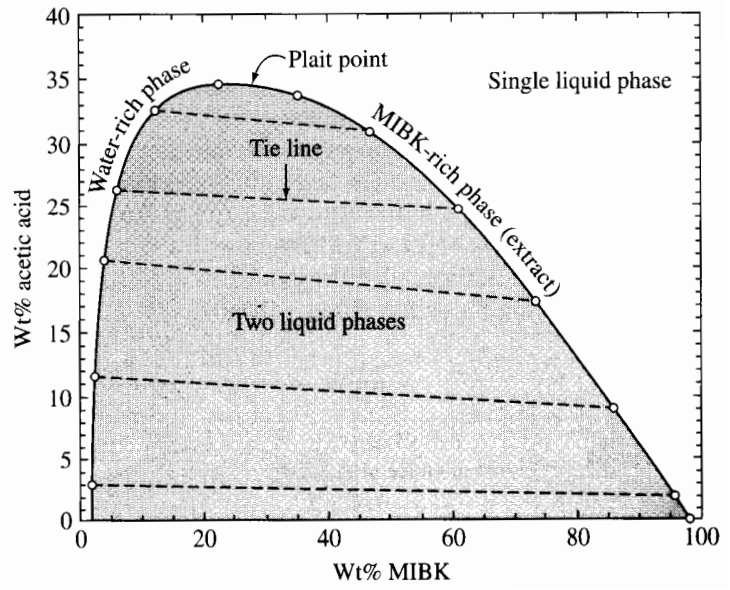

Figure 1: MIBK-acetic acid-water liquid-liquid phase diagram at 25°C

6. (20%) Steam produced in a boiler is frequently "wet"—a mist composed of saturated water vapour and entrained liquid droplets. (Note: Droplets are at the same temperature as saturated steam.) The quality of a wet steam is defined as the fraction of the mixture by mass that is vapour.

   A wet steam at a pressure of 7.5 bar with a quality of 0.90 is isothermally "dried" by evaporating the entrained liquid. The flow rate of the dried steam is 50 m^3/h.

   (a) Use the steam tables to determine the temperature at which this operation occurs, the specific enthalpies of the wet and dry steam, and the total mass flow rate of the process stream.

   (b) Calculate the heat input (kW) required for the evaporation process.

   (Use Steam tables at the last page of the exam sheet.)

Table 6.1 Specific Enthalpy $\hat{H}$ (kJ/kg), Specific Energy $\hat{U}$ (kJ/kg), and Specific Volume $\hat{V}$ (m^3/kg) of water and steam. Reference state is liquid water at its triple point, $T = 0.01°C$, $P = 0.006116$ bar

P, bar (T^{sat}, °C)		Sat'd liquid	Sat'd vapor	Temperature (°C)						
				50	100	150	200	250	300	350
0.006116	$\hat{H}$	0.00	2500.9	2594.5	2688.6	2783.7	2880.0	2977.8	3077.0	3177.7
(0.01)	$\hat{U}$	0.00	2374.9	2445.4	2516.4	2588.4	2661.7	2736.3	2812.5	2890.1
	$\hat{V}$	0.00100	206.55	244.45	282.30	320.14	357.98	395.81	433.64	470.69
0.1	$\hat{H}$	191.81	2583.9	2592.0	2687.5	2783.1	2879.6	2977.5	3076.8	3177.6
(45.806)	$\hat{U}$	191.80	2437.2	2443.3	2515.5	2587.9	2661.4	2736.1	2812.3	2890.0
	$\hat{V}$	0.00101	14.670	14.867	17.197	19.514	21.826	24.137	26.446	28.755
1.0	$\hat{H}$	417.50	2674.9	209.46	2675.8	2776.6	2875.5	2974.5	3074.6	3175.8
(99.606)	$\hat{U}$	417.40	2505.6	209.36	2506.2	2583.0	2658.2	2733.9	2810.7	2888.7
	$\hat{V}$	0.00104	1.6939	0.00101	1.6959	1.9367	2.1725	2.4062	2.6389	2.8710
5.0	$\hat{H}$	640.09	2748.1	209.80	419.51	632.24	2855.9	2961.1	3064.6	3168.1
(151.83)	$\hat{U}$	639.54	2560.7	209.30	418.99	631.69	2643.3	2723.8	2803.3	2883.0
	$\hat{V}$	0.00109	0.37481	0.00101	0.00104	0.00109	0.4250	0.4744	0.5226	0.57016
10.0	$\hat{H}$	762.52	2777.1	210.19	419.84	632.5	2828.3	2943.1	3051.6	3158.2
(179.88)	$\hat{U}$	761.39	2582.7	209.18	418.80	631.41	2622.2	2710.4	2793.6	2875.7
	$\hat{V}$	0.00113	0.1944	0.00101	0.00104	0.00109	0.2060	0.2328	0.2580	0.2825
20.0	$\hat{H}$	908.5	2798.3	211.06	420.59	633.12	852.45	2903.2	3024.2	3137.7
(212.38)	$\hat{U}$	906.14	2599.1	209.03	418.51	630.94	850.14	2680.2	2773.2	2860.5
	$\hat{V}$	0.00118	0.0996	0.00101	0.00104	0.00109	0.00116	0.1115	0.1255	0.1386