MIDTERM EXAMINATION
Chemical Engineering 140
Fall 2002
Professors Jay D. Keasling and Jeffrey A. Reimer

Your SID #:___________________________________

DO NOT PRINT YOUR NAME ANYWHERE ON THIS EXAM!!

INSTRUCTIONS

Read over the whole exam before beginning to write anything.

Choose the problem or question that seems easiest to you and do it first. Continue to do the problems in order of increasing difficulty.

Stay in motion.

Show your work. Use reverse sides for scratch paper.

Watch out for significant figures.

Keep your work legible.

If you don't understand a question, ask the instructor/proctor for help.

Don't panic.

If you have time at the end, check your solutions.

Hand in your paper when time is called.

1. (3 points) List three types of energy.

2. (2 points) Fill in the blank:

A change in temperature results in a change in **__________________** energy.

3. (2 points) Write an equation to describe the heat capacity at constant temperature.

4. (4 points) List 4 steps of the “Keasling 8-fold path” that was discusses as a blueprint for solving problems.

5. (4 points) List 2 reasons why you would add a recycle stream to a process.

6. (5 points) A 3.2 kg weight is dropped from a height of 3.0 m.
Set up an energy balance, state any assumptions, and calculate its velocity just before it hits the ground. Calculate the velocity of the weight if it weighs 5.6 kg.

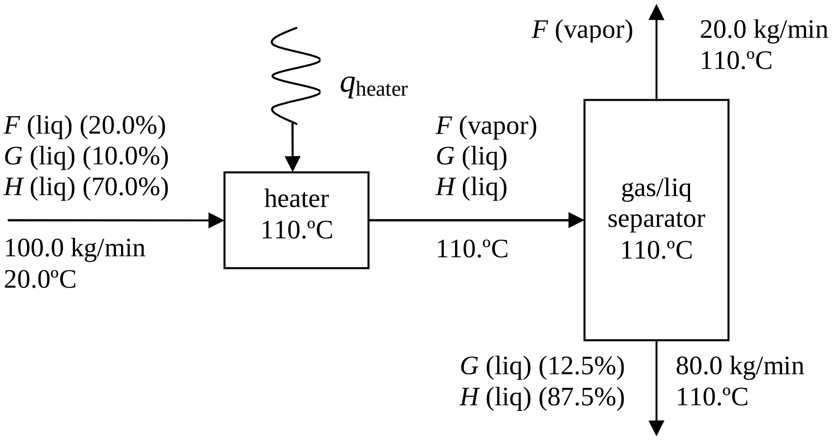
7. (10 points) A general equation is shown below that relates the concentration (C) of a component within a hydraulic stirred tank to the component's initial concentration (C_o) and the residence time of the tank (θ).

$$C = C_o \exp(-t / \theta)$$

a) What is the required ratio of t/θ for the concentration of the component within the tank to decay to 5% of the initial concentration? Please show your work.

b) What effect does residence time have on the actual time required to reach this concentration?

8. (20 points) In the scheme shown below, calculate q_{heater} in kJ/min.

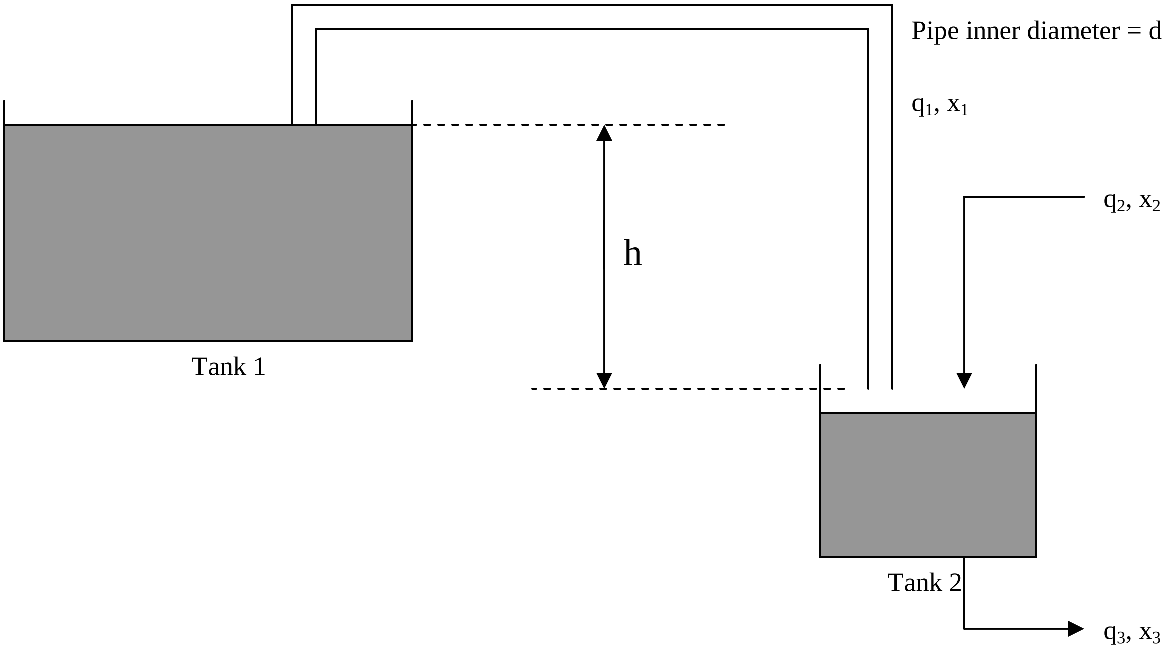


You may assume that heating a mixture of *F*, *G* and *H* is equal to heating *F*, *G* and *H* separately. Also, you may assume that the parameters in the table below are independent of temperature.

Some properties at 1 atm:

	boiling pt (°C)	C_P (kJ/kg·°C) liquid	C_P (kJ/kg·°C) vapor	ΔH_{vap} (kJ/kg)	ΔH_{fusion} (kJ/kg)
F	105.	1.60	1.20	380.	100.
G	176.	2.00	1.40	400.	120.
H	197.	2.40	1.60	420.	140.

9. (25 points) Wastewater from a sewage holding tank is siphoned into a smaller tank for dilution. The diluted wastewater is then sent on to the rest of the treatment process.



Stream 1 is the undiluted wastewater, stream 2 is the pure water used in the dilution, and stream 3 is the diluted wastewater that goes on for more processing.

q_i is the volumetric flow rate of each stream.

x_i represents the concentration of cells in each stream in dimensions of (cells/volume).

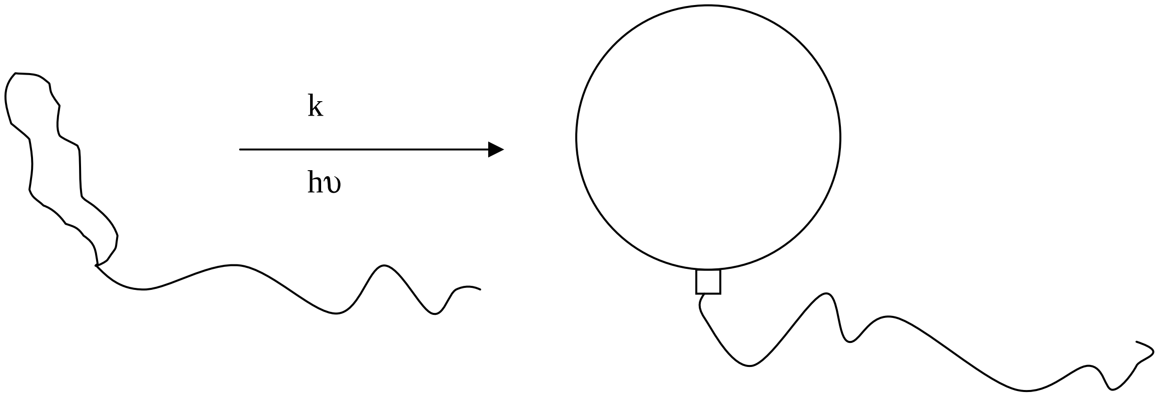
a) Neglecting friction and assuming that tank 1 is so large that the change in liquid level is negligible, find an equation for the volumetric flow rate of liquid from tank 1 to tank 2 in terms of d and h.

b) It is important in a process like this to control the concentration of bacteria in the outlet stream from tank 2. For that reason, we must be able to relate the flow rates and bacterial concentrations of all the process streams.

   Using the variables given in the diagram, set up BUT DO NOT SOLVE the differential equation(s) you would use to find the volumetric flow rate of pure water that is required to maintain the concentration of cells leaving tank 2 at a specified level.

   Assume the density of all streams is equal to the density of water. DO NOT assume steady state.

10. (25 points) Happy Clown Balloon Manufactures has decided to make an auto-inflating balloon product for its incapacitated customers. It is considering the following design, which will auto-inflate upon subjection to light,



by the reaction,

$\mathrm{A(gas)} \rightarrow 5\mathrm{B(gas)}$
where the disappearance (consumption) of A = k = 0.018 mol/s and both gases are ideal.

A. What is the final volume of the balloon if the elastic resistance for filling it is negligible and it starts at 0.5 L with only A inside (State any assumptions)?

B. Write a mass conservation statement for species A, which is consumed in the filling of the balloon. (Hint: you may use moles instead of mass since they differ only by a constant, the *molecular weight*).

C. Solve for the concentration of A as a function of time.

D. What is the range of applicability of this solution (is there a point where this equation no longer makes physical sense)?

MIDTERM EXAMINATION
Chemical Engineering 140
Fall 2002
Professors Jay D. Keasling and Jeffrey A. Reimer

SOLUTIONS

1. Kinetic, Potential, Internal

2. Internal

3. $C_P(T) = \left\{ \lim_{\Delta T \to 0} \frac{\Delta \underline{H}}{\Delta T} \right\} = \left(\frac{\partial \underline{H}}{\partial T} \right)_P$

4. - Visualize
   - Flowsheet
   - Fundamental Variables
   - Basis
   - Label Streams
   - Convert knowns to basis
   - Add known information
   - Work model equations and solve

5. - lower feed required (less raw materials)
   - to increase overall conversion (low single pass conversion)
   - as a cheap alternative to using multiple reactors

6.

$PE_i + KE_i = PE_f + KE_f$

which reduces to:

$$\boxed{PE_i = KE_f \quad \text{or} \quad mgh = \frac{mv^2}{2}}$$

Here we are assuming either:

$\boxed{\text{Wind resistance is negligible or the weight is dropped in a vacuum}}$

$v = \sqrt{2 * gh} = \sqrt{2 * 9.8\ (\text{m/s}^2) * 3.0\text{m}} = 7.668\ \text{m/s}$

$\boxed{v = 7.7\ \text{m/s}}$

The velocity holds regardless of the mass of the object

7. a) $0.05C_o = C_o \exp(-t/\theta)$

$t/\theta = \ln(1/0.05)$

$t/\theta = 3$

b) Longer residence times will result in more time required to reach the desired concentration ($0.05C_o$).

8. As suggested in the exercise statement, treat *F*, *G*, and *H* separately. *G* and *H* are both liquids heated to 110ºC from 20ºC. *F* is a liquid heated to 105ºC, then evaporated at 105ºC, then the vapor is heated to 110ºC.

$$q_{\text{heater}} = F_G C_{P,\text{liq } G}(110 - 20) + F_H C_{P,\text{liq } H}(110 - 20) + F_F(C_{P,\text{liq } F}(105 - 20) + \Delta H_{vap} + C_{P,\text{vap } F}(110 - 105))$$

$$= \left(\frac{10.\text{ kg } G}{\text{min}}\right)\left(\frac{2.0\text{ kJ}}{\text{kg·ºC}}\right)(110 - 20\text{ºC}) + \left(\frac{70.\text{ kg } H}{\text{min}}\right)\left(\frac{2.4\text{ kJ}}{\text{kg·ºC}}\right)(110 - 20\text{ºC})$$

$$+ \left(\frac{20.\text{ kg } H}{\text{min}}\right)\left(\frac{1.6\text{ kJ}}{\text{kg·ºC}}\right)(105 - 20\text{ºC}) + \left(\frac{20.\text{ kg } H}{\text{min}}\right)\left(\frac{1.2\text{ kJ}}{\text{kg·ºC}}\right)(110 - 105\text{ºC}) +$$

$$\left(\frac{20.\text{ kg } H}{\text{min}}\right)\left(\frac{380\text{ kJ}}{\text{kg}}\right) = 1800. + 15{,}120 + 10{,}440$$

$$q_{\text{heater}} = 27{,}360\text{ kJ/min}$$

Energy must be supplied to the heater at 2.74×10^4 kJ/min.

9. a)

$$\Delta P/\rho + \Delta(u^2)/2 + g\Delta z + \hat{F} = \frac{-W_s}{\dot{m}}$$

$$(u_2^2 - u_1^2)/2 + g(-h) = 0$$

$$u_2 = \sqrt{2gh}$$

$$q_1 = A \cdot u_2 = (\pi d^2)/4 \cdot \sqrt{2gh}$$

9. b) Overall Mass Balance:

$$d(V_{\tan k}\,\rho) / dt = \rho q_1 + \rho q_2 - \rho q_3$$

c) Component balance on cells:

$$d(V_{\tan k}\; x_3) / dt = q_1 x_1 + q_2 x_2 - q_3 x_3$$

10. a) The final volume can be calculated assuming that the gases are ideal.

$$\Delta V = \Delta n\; RT / P$$

$$V_f = V_i + (\Delta n\; RT/P) = 0.5\; L + RT/P\; (4\; moles \cdot (P \cdot 0.5L/RT)) = 2.5\; L$$

b) The mole balance for species A is below:

$$d(C_A V)/dt = V(dC_A/dt) + C_A(dV/dt) = -k$$

c) To solve this equation we must first consider an overall mole balance in order to solve for the volume as a function of time

$$dn/dt = 4k \rightarrow n = n_0 + 4kt$$

then we must consider the ideal gas law in normal and derivative form

$$V = (RT/P)n \;\text{ and }\; dV/dt = (RT/P) \cdot (dn/dt)$$

plugging into equation 1, we get

$$RT/P \cdot (n_0 + 4kt) \cdot dC_A/dt + C_A \cdot (RT/P) \cdot 4k = -k$$

We can notice that this is the same as

$$d[(n_0 + 4kt)C_A]/dt = -\,kP / RT$$

Please note, that this is the same result that you will get if you go through the rigorous integrating factor procedure. Upon integration we find,

$$[(n_0 + 4kt)C_A] = -\, kP / RT \cdot t + C$$

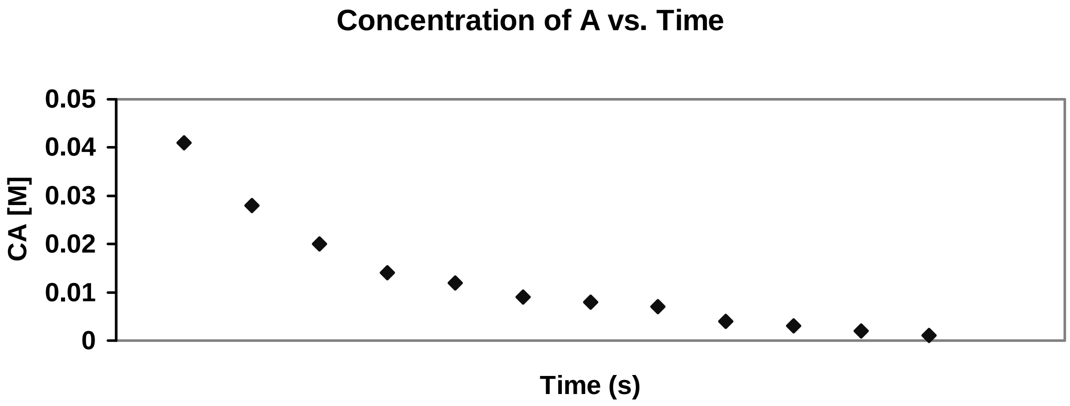
Applying the limits of integration, this reduces to:

$$C_A(t) = [\ C_{A,0}\, n_0 - (kP/RT)t\ ] \,/\, [\ n_0 + 4kt\ ]$$

$$= C_{A,0}\, n_0 \cdot [\ n_0 - kt\ ] \,/\, [\ n_0 + 4kt\ ]$$

A plot of the concentration vs. time is below.

The first point denotes time 0, and each subsequent point is + 0.1 s. Thus, the plot runs from 0.0 s to 1.1 s.



d) The concentration of A falls below zero at times greater than 1.1 seconds. This is because the rate equation is no longer valid when the concentration of A is this low. We should expect the disappearance of A only as long as A is present. Our solution is only physically relevant for times shorter than 1.1 seconds.