Georgia Tech
School of Chemical Engineering
ChE 4400 Spring, 2003
Extra Credit Opportunity for Exam I

Here is an opportunity to add up to 10 points for Exam I.

1. Solve the 10 quantitative problems.
2. Take the **oral exam**.
3. The bonus points you earn will depend on the quality of both the written and oral solutions.
4. Turn in the written solution by the 14th of March. The oral exams should be during the last two weeks of March.
5. There is no "cap" on the number of points you can earn for Exam I. This means a person who got 42 on the exam can still benefit from doing the extra credit work. This may prove to be unnecessary, however.
6. The University's policy regarding academic dishonesty is in effect. Any kind of "cutting and pasting" or similar copying of someone else's solutions will be subject to this policy.

Even though you are encouraged to discuss the problems with one another, the TA, and myself, you should ultimately be able to solve the problems on your own. This will be tested during the oral exam. You will earn little credit if you fail to demonstrate this ability.

You may ask questions regarding these problems during the problem sessions.

Extra Problems
HW#4

2.3. A jacketed vessel is used to cool a process stream as shown in the figure. The following information is available:

i. The volume of liquid in the tank V and the volume of coolant in the jacket V_J remain constant. Volumetric flow rate q_F is constant but q_J varies with time.
ii. Heat losses from the jacketed vessel are negligible.
iii. Both the tank contents and the jacket contents are well-mixed and have significant thermal capacitances.
iv. The thermal capacitances of the tank wall and the jacket wall are negligible.
v. The overall heat transfer coefficient for transfer between the tank liquid and the coolant varies with coolant flow rate:

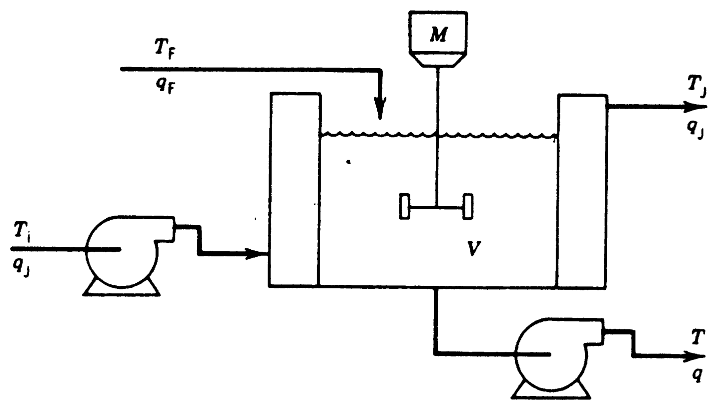
$$U = Kq_J^{0.8}$$

where U [=] Btu/h ft^2 °F

q_J [=] ft^3/h

K = constant

Derive a dynamic model for this system. (State any additional assumptions that you make.)



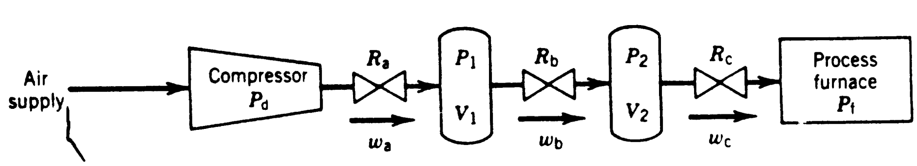
2.4. A jacketed vessel similar to the one in Exercise 2.3 is used to *heat* a liquid by means of condensing steam. The following information is available:

i. The volume of liquid within the tank may vary.
ii. Heat losses are negligible.
iii. The tank contents are well mixed. Steam condensate is removed from the jacket by a steam trap as soon as it has formed.
iv. Thermal capacitances of the tank and jacket walls are negligible.
v. The steam condensation pressure P_s is set by a control valve and is not necessarily constant.
vi. The overall heat transfer coefficient U for this system is constant.
vii. Flow rates q_F and q are independently set by external valves and may vary.

Derive a dynamic model for this process. The model should be simplified as much as possible. State any additional assumptions that you make.

2.7. Two surge tanks are used to dampen pressure fluctuations caused by erratic operation of a large air compressor (see drawing).

(a) If the discharge pressure of the compressor is $P_d(t)$ and the operating pressure of the furnace is P_f (constant), develop a dynamic model for the pressures in the two surge tanks as well as for the air mass flows at points a, b, and c. You may assume that the valve resistances are constant, that the valve flow characteristics are linear, that the surge processes operate isothermally, and that the ideal gas law holds.

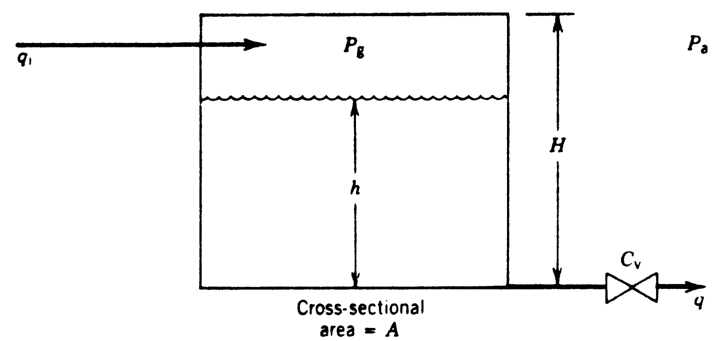


[redacted]

2.5. Consider a liquid flow system consisting of a sealed tank with noncondensible gas above the liquid as shown in the drawing. Derive an unsteady-state model relating the liquid level h to the input flow rate q_i. Is operation of this system independent of the ambient presure P_a? What about for a system open to the atmosphere?

You may make the following assumptions:

i. The gas obeys the ideal gas law. A constant amount of m_g/M moles of gas are present in the tank.
ii. The operation is isothermal.
iii. A square root relation holds for flow through the valve.



2.9. Water is blended with a slurry to give the slurry the proper consistency. They are mixed in a blending tank that has a constant volume V. The slurry solids mass fraction in the inlet is x_s with volumetric flow rate q_s. Since x_s and q_s vary somewhat, the water makeup mass flow rate w is changed to compensate for these variations. Write an unsteady-state model for this blender that can be used to predict the dynamic behavior of the mass fraction of solids in the exit stream x_e for changes in x_s, q_s, or w.

2.10. The chemical reaction sequence

$$A \longrightarrow B$$
$$A + B \longrightarrow C$$

takes place isothermally in a continuous, stirred-tank reactor. Batch kinetic studies have indicated that the first reaction is second order with respect to c_A while the reaction rate for the second reaction is first order with respect to both c_A and c_B:

$$\left.\begin{aligned} r_1 &= k_1 c_A^2 \\ r_2 &= k_2 c_A c_B \end{aligned}\right\} r_1, r_2 \,[=]\, \frac{\text{mol}}{(\text{ft}^3)(\text{h})}$$

It can be assumed that the reactor has a constant volume V and constant feed rate q, and that the feed contains traces of B but no C. Derive an unsteady-state model that will yield the concentrations of A, B, and C for variations in the concentration of B in the feed.

3.19. I. M. Appelpolscher has just returned home from a hard day at work and is looking forward to a cool, refreshing drink of his favorite beer, Old Froth and Slosh. Unfortunately, the only can available has been left sitting on the kitchen counter. Since sunlight from the kitchen window has been warming the beer all afternoon, it is hardly fit to drink. He is interested in cooling the beer to the desired temperature of 60 °F as quickly as possible.

(a) Appelpolscher immediately springs into action by placing the can in the freezer section of the refrigerator, which has a temperature of −6 °F. If the initial temperature of the beer is 85 °F, estimate how long it will take to cool it to 60 °F. (You may assume that a can of beer weighs 0.8 lb and that the heat capacity is ~1 Btu/lb °F). $2\frac{1}{2}$" OD 6" tall surface area = 0.327 ft²

(b) Is there a faster method of cooling the beer, using only the resources that normally would be found in Appelpolscher's house? Justify your answer.

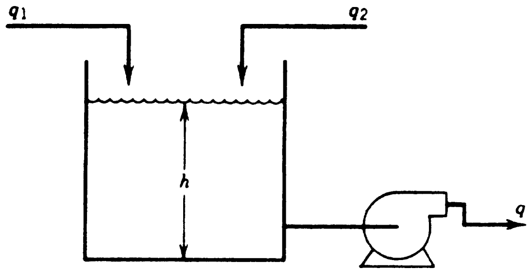
heat transfer coeff. = 2.2 Btu/hr°F ft²

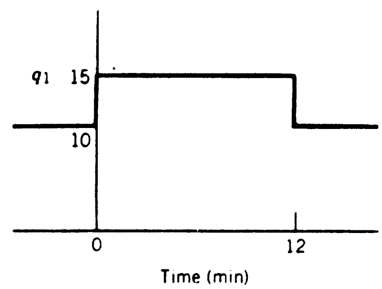
5.8. A liquid storage system is shown below. The normal operating conditions are

$\bar{q}_1 = 10$ ft^3/min, $\bar{q}_2 = 5$ ft^3/min, $\bar{h} = 4$ ft.

The tank is 6 ft in diameter and the density of each stream is 60 lb/ft^3. Suppose that a pulse change in q_1 occurs as shown in the drawing.

(a) What is the transfer function relating H' to Q_1'?
(b) Derive an expression for $h(t)$ for this input change.
(c) What is the new steady-state value of liquid level $\bar{h}_2$?
(d) Repeat (b) and (c) for the doublet pulse input of Exercise 5.1 where the changes in q_1 are from 10 to 15 to 5 to 10 ft^3/min and where $t_w = 12$ min.



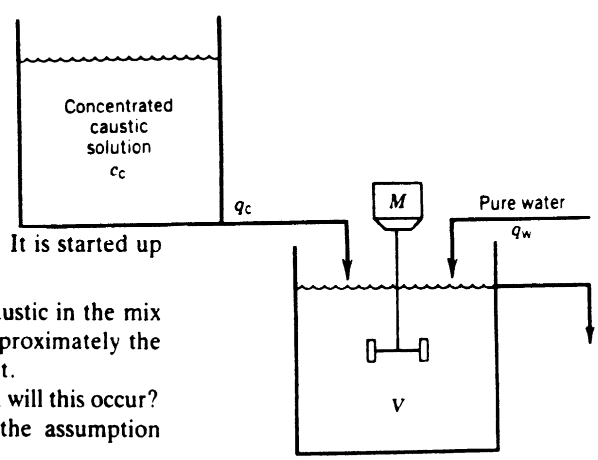


5.19. A surge tank system is to be installed as part of a pilot plant facility. The initial proposal calls for the configuration shown in Fig. 4.3. Each tank is 5 ft high and 3 ft in diameter. The design flow rate is $q_i = 100$ gal/min. It has been suggested that an improved design will occur if the two-tank system is replaced by a single tank that is 4 ft in diameter and has the same total volume (i.e., $V = V_1 + V_2$).

(a) Which surge system (original or modified) can handle larger step disturbances in q_i? (Justify your answer.)
(b) Which system provides the best damping of step disturbances in q_i? (Justify your answer).

In your analysis you may assume that:

i. The valves on the exit lines act as linear resistances.
ii. The valves are adjusted so that each tank is half full at the nominal design condition of $q_i = 100$ gal/min.



3.17. The system pictured is used to dilute a concentrated caustic solution. It is started up with pure water in the mix tank.

(a) Derive a mathematical model to describe the concentration of caustic in the mix tank effluent c. You may assume that the caustic solution has approximately the same density as the water and that volume in the tank is constant.
(b) Simplify the model for conditions which give rise to $c_c >> c$. When will this occur?
(c) Find the solution $c(t)$ for both $q_w(t)$ and $q_c(t)$ constant with the assumption $c_c >> c$.

Volumetric rate of caustic: $q_c(t)$
Volumetric rate of water: $q_w(t)$
Volume of stirred tank: V