National Exams December 2011

04-Chem-A6, Process Dynamics & Control

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
   Any non-communicating calculator is permitted.

3. FIVE (5) questions constitute a complete exam paper.
   The first five questions as they appear in the answer book will be marked.

4. Each question is of equal value.

5. Most questions require an answer in essay format. Clarity and organization of the answer are important.

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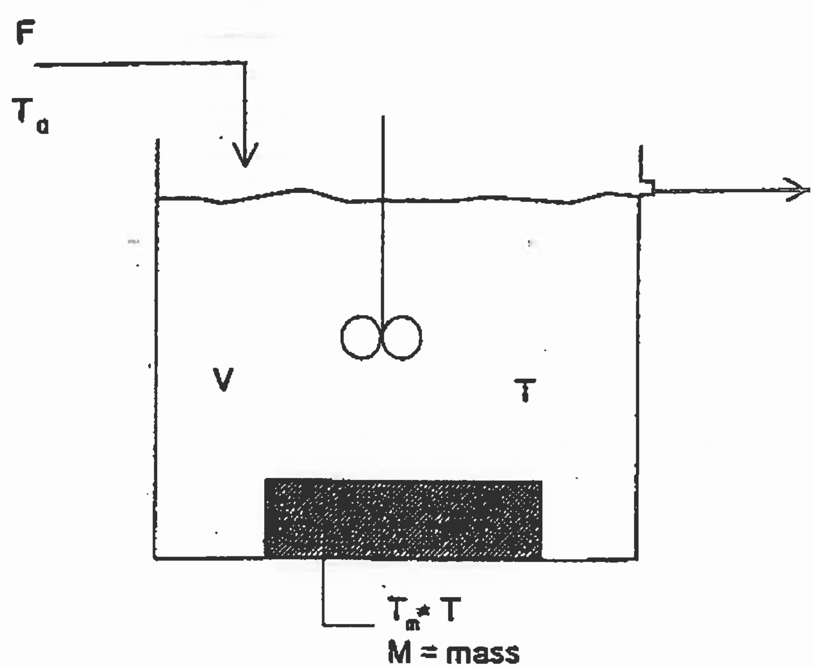
PROBLEM # 1 (20%)

The process in the figure involves a continuous flow stirred tank with a mass of solid material. The assumptions for the system are:

1) well mixed tank
2) specific heat of liquid Cp, density of liquid ρ, and specific heat of solid Cps are constant.
3) V = constant , F = constant [vol/time],
4) the solid material contributes a significant portion of the energy storage, and the temperature is uniform throughout the solid.
5) the heat transfer from the liquid to the metal, is UA ($T-T_m$),
6) heat losses are negligible, and
7) all variables are initially at steady state
8) Mass of solid M

5% a) Determine the fundamental model equations that relate the behaviours of T(t) as $T_0(t)$, the temperature at the inlet stream, changes.
10% b) Derive the transfer function $T(s)/T_0(s)$.
5% c) Describe briefly how the results in steps a-b would change as UA → ∞.



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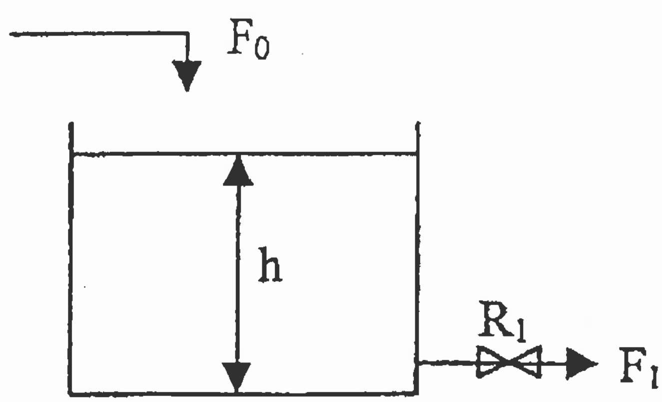
PROBLEM #2 (20%)

For the draining tank shown in the figure



Compute the change in level $\delta h(t)$ as a function of time for the following two cases:

10% a) a step of one unit in inlet flow F_0

10% b) a unit impulse in inlet flow F_0

The cross-section area of the tank is 1 m^2. Initial level – 1m. Density is constant.

The flow out is given by $F_1 = R_1 \cdot h$, where the hydraulic resistance R1 $= 1 \frac{m^2}{min}$

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PROBLEM # 3 (20%)

Consider the following system of equations:

$$\frac{dx_1}{dt} = -2.4048x_1 + 7u$$

$$\frac{dx_2}{dt} = 0.8333x_1 - 2.2381x_2 - 1.117u$$

$$y = x_2$$

10% a) Find the transfer function Y/U

10% b) Solve for y in response to a unit step change in u.

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PROBLEM # 4 (20%)

A thermocouple is immersed in a well stirred bath of liquid. The geometry and properties of the thermocouple's material are as follows:

mass = 0.25 g

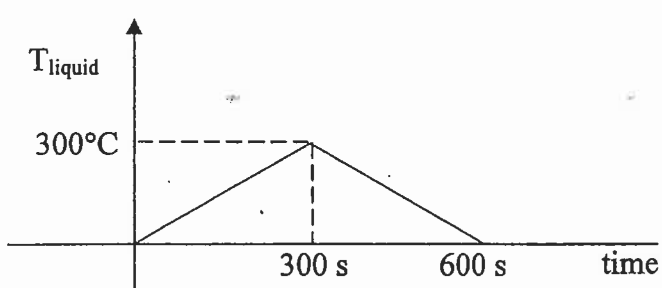
heat capacity = 1 cal/g °C

Heat transfer coefficient between the thermocouple and the liquid = 60 cal/cm^2 h °C

Surface area of the thermocouple = 1 cm^2.

(10%) 1. Find the transfer function that relates the temperature of the thermocouple to the temperature in the liquid. Assume that there are no gradients in the thermocouple bead, no conduction through the thermocouple wires and the conversion from millivolt to degrees occurs by a very fast reading device.

(10%) 2. If the temperature in the liquid changes according to the following diagram:



Calculate the temperature registered by the thermocouple as a function of time.

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PROBLEM # 5 (20%)

The dynamic behaviour of the levels in each leg of industrial manometer is given by the following differential equation:

$$\frac{d^2 h^1}{dt^2} + \frac{6\mu}{R^2 \rho} \frac{dh^1}{dt} + \frac{3}{2} \frac{g}{L} h^1 = \frac{3}{4 \rho L} p^1$$

where h^1 and p^1 are the level and measured pressure in deviation variables with respect to an initial steady state.

(10%) 1. Find the transfer function between the level and the measured pressure. Show a condition for the physical constants for which the response in level will be oscillatory.

(10%) 2. Does an increase in density ρ help to reduce oscillations? Does an increase in viscosity μ help to reduce oscillations? Justify your answers by using the condition developed in part 1.

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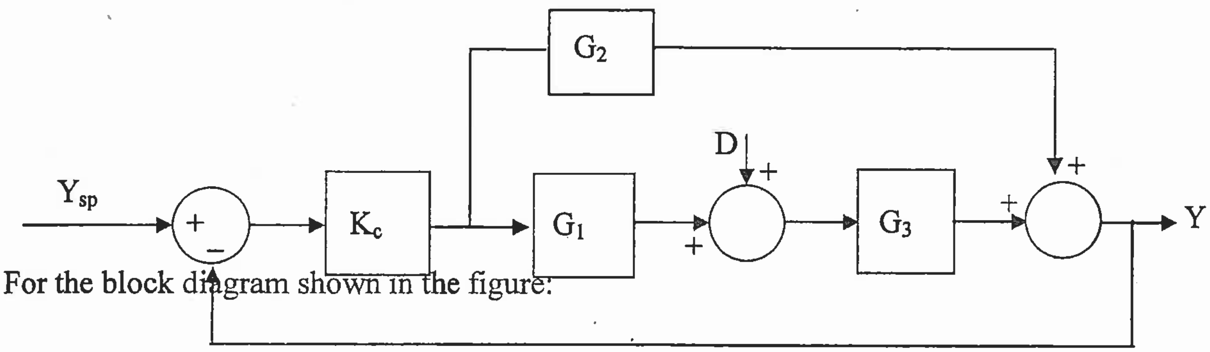
PROBLEM # 6 (20%)

For the block diagram shown in the figure:



$$G_1 = 10 \qquad G_2 = \frac{2}{3\,s+1} \quad G_3 = \frac{1}{s-1}$$

(10%) 1. Find the closed loop transfer function Y (s) / D (s).
What is the characteristic equation of the system?

(10%) 2. Find the values of K_c for which the closed loop system is stable.

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PROBLEM # 7 (20%)

A process given by:

$$G_p(s) = \frac{3}{s-1}$$

is to be controlled by a proportional controller with gain.

(10%) (a) show a qualitative Nyquist plot (show only 2-3 key points along the plot and the general shape of the plot for this problem) for $k_c = 1$.

Assess the closed loop stability based on Nyquist criterion.

(10%) (b) Based on the Nyquist criterion, compute a range of k_c values to obtain closed loop stability.

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PROBLEM # 8 (20%)

A process is described by the following transfer function

$$Gp = \frac{e^{-10s}}{(s+1)(5s+1)}$$

(10%) Compute the time response to a unit step change.

(10%) Compute expressions for the amplitude ratio and phase angle for a sinusoidal input as a function of frequency. Plot qualitatively the Bode plot for this process (indicate slopes and extreme values of amplitude and angle).