National Exams May 2010

04-Chem-A6, Process Dynamics and 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. Any non-communicating calculator is permitted. This is an Open Book exam. You must indicate the type of calculator being used, ie, write the name and model designation of the calculator on the first inside left hand sheet of the exam work book.

3. Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.

4. All questions are of equal value.

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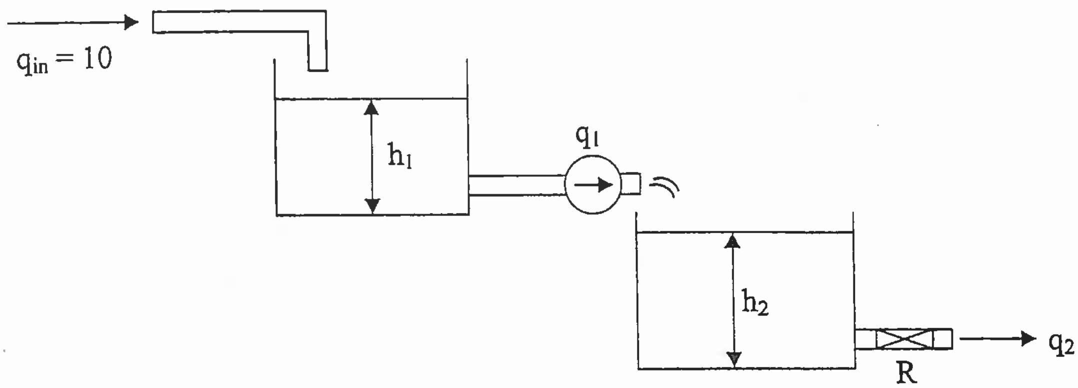
Problem #1 (20% total)



Two tanks are connected in series in a noninteracting fashion as shown in the figure.

Assume: $\rho = 1$ $A = 1$ (A-cross-section of each tank)

$$q_2 = \frac{1}{R}\sqrt{\frac{\Delta P}{\rho g}}$$ and q_1 is determined by a pump.

The initial value of the inlet flowrate is $q_{in} = 10$. The initial level in tank 1 is $h_1(t=0) = 10$. q_1 is the manipulated variable. All q's are volumetric flow rates. $R = 2$.

(10%) (a) Show the differential equations that describe the behaviour of $h_1(t)$ and $h_2(t)$.

(10%) (b) Compute transfer functions between h_1 to q_{in} and h_2 to q_{in}.

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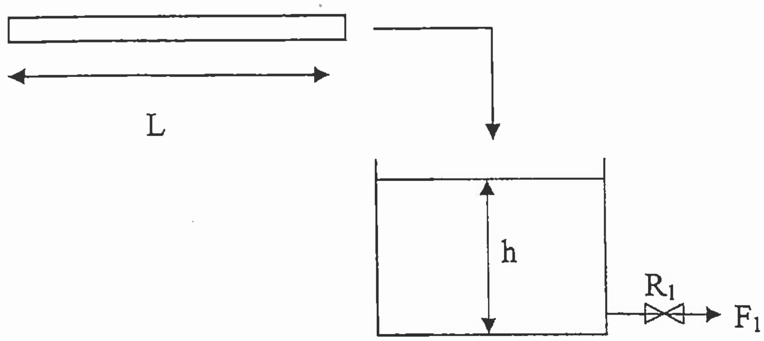
Problem #2 (20% total)

For the draining tank fed through a pipe of length L 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 (Dirac function) in inlet flow F_0

The cross-section area of the tank is 1 m^2. The length of the inlet pipe is 1.0m and the cross sectional area of the pipe is 0.01m^2. Initial level = 1 m

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

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Problem #3 (20% total)

A process is described by the following transfer function:

$$G_p = \frac{10(0.5 - s)e^{-10s}}{100s + 1}$$

(10%) (a) Design an IMC (Internal Model Controller). for this process. Show your design with a block diagram.

(10%) (b) Assuming a perfect model of the process, compute the closed loop response for a unit step in set point if the desired closed loop time constant is equal to 5.

Problem 4 (20% total)

A process given by:

$$G_p = \frac{100}{s - 10}$$

is controlled by a proportional controller with gain k_c.

(10%) (a) Using the Nyquist theorem test the closed loop stability for $k_c = 1$ and $k_c = 0.01$.

(10%) (b) Using the Nyquist criterion, compute the limiting value of k_c for which the system is stable.

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Problem #5 (20% total)

A first order process is given by:

$$G_p(s) = \frac{1}{s+5}$$

This process is controlled by a Proportional Integral (PI) controller given by:

$$G_c(s) = k_c\left(1 + \frac{1}{s}\right)$$

(10%) (a) Compute ranges of k_c values for which the closed loop is stable using the Routh test.

(10%) (b) For a controller with gain $k_c = 1$, compute the closed loop time response for a unit step change in set point.

Problem #6 (20% total)

A process given by

$$G_p = \frac{e^{-0.1s}}{0.5s+1}$$

is controlled by a proportional controller with gain k_c.

(10%) (a) Plot qualitatively the Bode Plot for this system (show slope values, corner frequencies and extreme amplitude and phase values).

(10%) (b) Compute k_c to obtain a gain margin of 1.7.

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Problem #7 (20% total)

Consider the following state space model:

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

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

$$y = x_2$$

Where u, x_1 and x_2 are in deviation variables so the initial conditions are $x_1 = x_2 = 0$.

(10%) (a) Calculate the transfer function Y(s)/U(s).

(10%) (b) Solve for the output response (y(t)) for a unit step change in the input u.

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Problem #8 (20% total)

The dynamic response of the reactant concentration in a CSTR reactor, C_A, to a change in inlet concentration, C_{A_0}, has to be evaluated.

The reactor is operated with constant volume V and isothermal conditions.
The density ρ is constant

The reaction rate is:

$$r_A = \frac{k_1 C_A}{1 + k_2 C_A}$$

The mass flow is F.

(5%) (a) Derive a mathematical model to describe $C_A(t)$.

(5%) (b) Compute steady state conditions for concentration.

(10%) (c) Compute a transfer function $\delta C_A / \delta C_{A_0}$ (where δ indicates deviation variables), i.e. changes in exit concentration to inlet concentration, when the system is operated close to the steady state found in (b).