National Exams May 2017

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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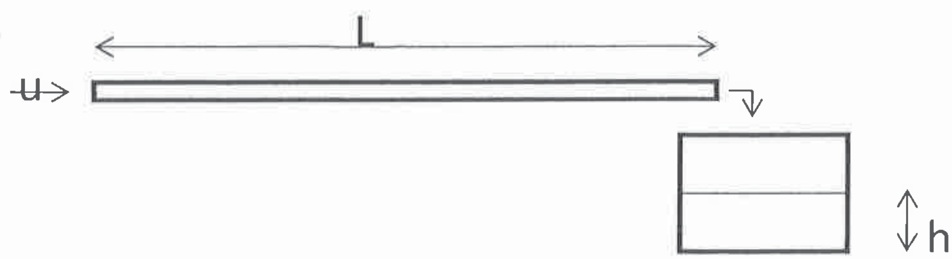
PROBLEM 1 (20%)



A pipe of length L=10 m is feeding liquid into a tank. The speed of the liquid in the pipe is u=1 m/s. The level of liquid in the tank is h. The cross section area of the tank is A=1 m^2.

(5%) a) Calculate the time delay in the pipe between inlet to outlet for the given velocity. Assume that this delay remains constant for the rest of this problem despite changes in flowrate.

(5%) b) Model the system, i.e. formulate differential equations to calculate h(t) with respect to inlet velocity u and find the open loop transfer function between h to u.

(10%) c) If the height h is controlled by manipulating the velocity u with a proportional controller with gain Kc, find the closed loop transfer function between the set point changes in h to changes in h.

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PROBLEM #2 (20% total)

A process is described by the following transfer function:

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

The process is controlled by a proportional controller with gain k_c.

(10%) (a) Plot qualitatively the gain and phase diagrams for $k_c G_p(s)$. Indicate "corner" frequencies, asymptotic values of gain and phase angles and slope values.

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

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PROBLEM #3 (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. Use the Routh Test.

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

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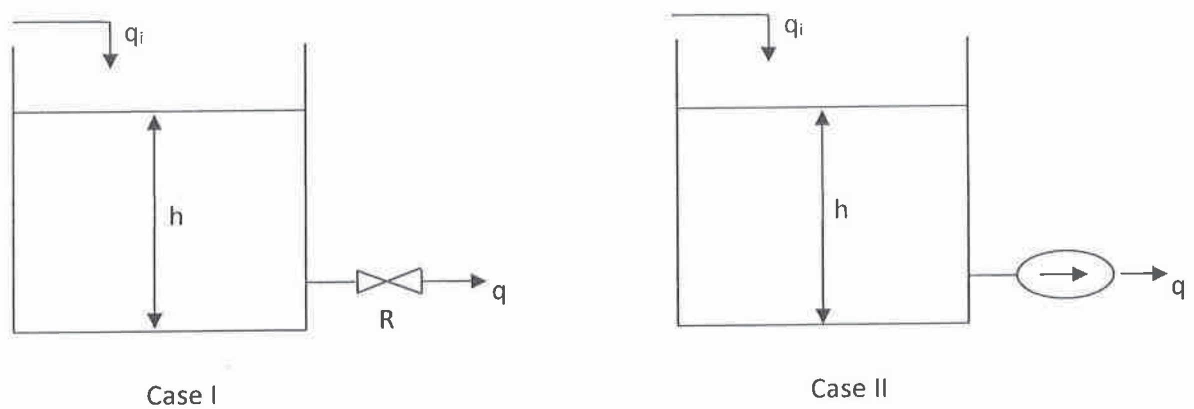
PROBLEM #4 (20% total)

Two liquid storage tanks are shown in the drawing:



Each tank is $1 m^2$ in cross sectional area.

For case I, the valve acts as a resistance to flow and $q = R\sqrt{\frac{\Delta P}{\rho g}}$ where ΔP is the pressure difference across the valve (ρ is the density). For case II, the exit flow q is determined by the exit pump. Suppose that each system is initially at steady state with $h(t=0) = 1 m$ and $q = 1\frac{m^3}{s}$, $R = 1$. At t=0 the inlet flow is suddenly changed from its initial value to $2\frac{m^3}{s}$.

(10%) (a) Compute the transfer function $\delta h/\delta q_i$ (δ indicates deviation variable) for Case I and Case II around the initial steady state.

(10%) (b) Using the transfer functions, compute the transient response $\delta h(t)$ for each case.

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PROBLEM 5 (20%)

A process described by the following transfer function:

$$G(s) = \frac{10e^{-5s}}{100s + 1}$$

Is to be controlled by an IMC (Internal Model Controller) controller. Time is in seconds.

(10%) a) Show the block diagram of the closed loop. Calculate the IMC controller Gc^* and the classical feedback controller equivalent Gc (**without assuming Pade approximation at this point**).Assume that the IMC filter parameter is τ_C=10 sec.
Is the resulting Gc o PID form?

(10%) b) Calculate the closed loop response for the controlled variable $\delta C(t)$ for a unit step change in set point for the controller in item a)
do not use Pade and assume that the model is perfect.

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PROBLEM #6 (20% total)

For the equation

$$\frac{d^2y}{dt^2} + k\frac{dy}{dt} + 10y = 2x$$

(10%) (a) Find the transfer function between the input x to the output y and put it in the standard gain-time constant form.

(5%) (b) Discuss for which values of k is the open loop response for a unit step in x (i) stable, (ii) underdamped, and (iii) overdamped.

(5%) (c) If the response is underdamped, compute expressions as a function of k for the time constant and the damping coefficient according to the standard form definitions.

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PROBLEM #7 (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:

$$F_A = k_1 C_A^2$$

The mass flowrate is F.

(10%) (a) Derive a mathematical model to describe $C_A(t)$ and compute steady state conditions for concentration.

(10%) (b) Compute a transfer function

$\delta C_A / \delta C_{A_0}$ (where δ indicates deviation variables) when the system is operated around the steady state computed in (a).

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PROBLEM 8 (20%)

A process given by:

$$G_p = \frac{20}{s-3}$$

Is to be controlled by a proportional controller with gain k_c.

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

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