UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:-

M.Sc.

D7: Process Dynamics and Control

COURSE CODE : **CENG00D7**

DATE : **23-MAY-05**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

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*Answer **FOUR** questions,* TWO *from **Part A** and **TWO** from **Part B.*** **Only the first TWO answers from each part will be marked.** *ALL questions carry a total of 25 MARKS each, distributed as shown* [ ]

PART A

1.

i) What are the physical characteristics of a first order process? [3]

ii) Write the transfer functions for a first order lag process and a purely capacitive first order process and compare, with the aid of a sketch, their responses to a unit step change in the input function. Where are purely capacitive processes most commonly encountered? [6]

A storage tank is illustrated in figure 1:

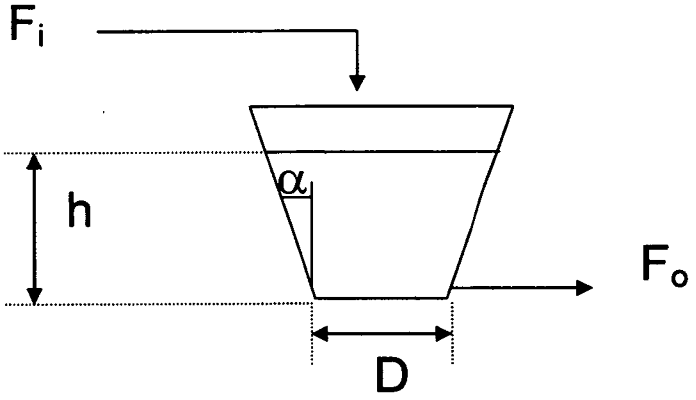

Figure 1.

The sides of the tank are inclined at an angle α to the vertical and the outlet flowrate is proportional to the liquid head, h, in the tank:

$$F_o = ch$$

where c is the proportionality constant.

The diameter of the tank base is D.

iii) By integrating the general expression for the cross-sectional area, at any height from 0 to h, find the general expression for the tank volume, V. [3]

iv) Listing your assumptions, set-up the total mass balance for the system. Substitute the expression for V found in (iii) in the total mass balance and linearise around the normal operating level, h_s. If $\alpha = 15^\circ$, $c = 8$, $h_s = 2$m and $D = 3$m, find the values of the static gain and process time constant. Hence, find the equation for the dynamic response of the tank to a unit step change in the inlet flowrate. [13]

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2.

i) What is the stability criterion for a chemical process? [2]

Consider the complex plane shown in figure 2.

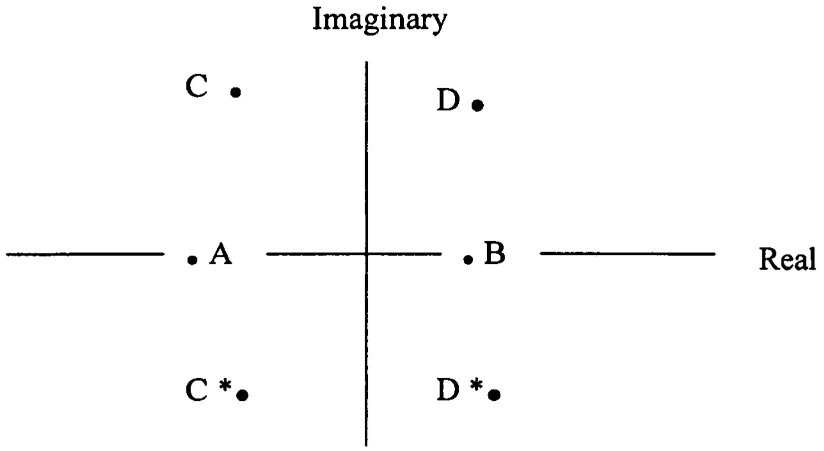

Figure 2

The points labelled A-D signify different types of poles. * signifies a complex conjugate.

ii) In general, what are the poles in relation to process control and how can they assist in the qualitative analysis of the stability of system responses? [3]

iii) Sketch the expected type of responses that can arise from each of the poles A to D in figure 2, indicating the range of values the poles must possess for a process to be stable. [10]

iv) The stability of a three-tank mixing process is to be evaluated under feedback control with a proportional-only controller. Assuming that the sensor and final control element dynamics are fast (*i.e.* $G_m = G_f = 1$), use the Routh-Hurwitz criteria to determine the stability limit for the system if the process transfer function is

$$G_p(s) = \frac{0.039}{(5s+1)^3}$$

General formula for the Routh array:

Row	1	a_0	a_2	a_4	a_6
	2	a_1	a_3	a_5	a_7
	3	A_1	A_2	A_3	...
	4	B_1	B_2	B_3	...

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Where:

$$A = \frac{a_1a_2 - a_0a_3}{a_1}, A_2 = \frac{a_1a_4 - a_0a_5}{a_1}, A_3 = \frac{a_1a_6 - a_0a_7}{a_1}$$

$$B_1 = \frac{A_1a_3 - a_1A_2}{A_1}, B_2 = \frac{A_1a_5 - a_1A_3}{A_1}$$

[10]

3.

Consider two non-interacting isothermal CSTRs in series. Each tank is of equal volume, $V_1 = V_2 = 1.05\ m^3$. The inlet flowrate, F_{in}, is constant and $F_{in} = F_1 = F_2 = 0.085\ m^3/min$. There is a single component, A, in the inlet stream.

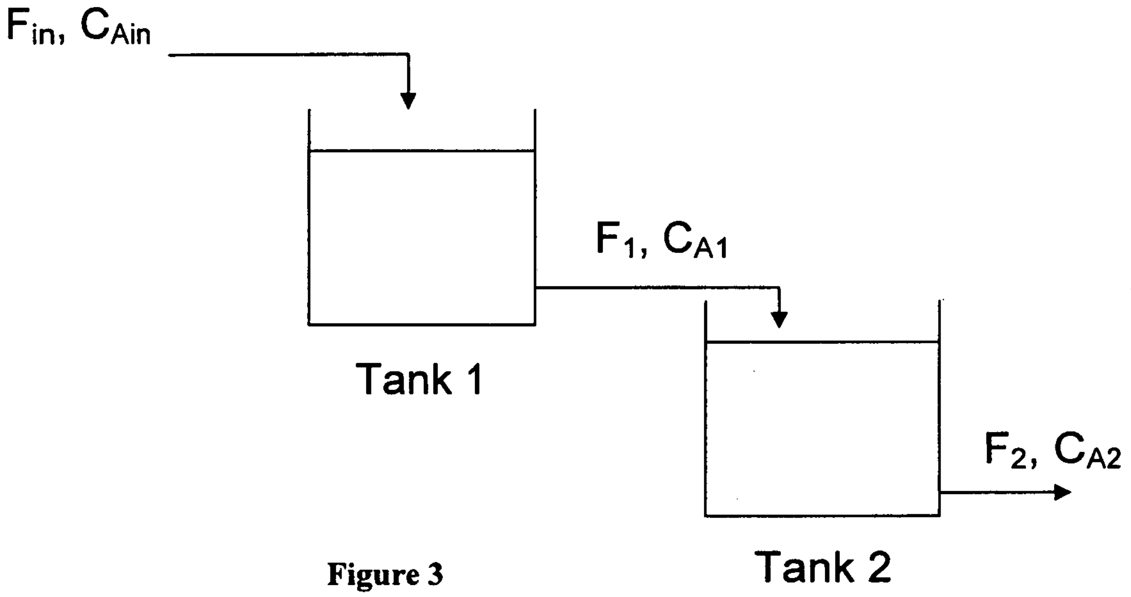

Figure 3

The rate of reaction in tank 1 is $r_{A1} = kC_{A1}$ and in tank 2 is $r_{A2} = kC_{A2}$, where $k = 0.040\ min^{-1}$.

i) Making the appropriate assumptions, derive the transfer functions relating C_{A1} to C_{Ain} and C_{A2} to C_{A1}, respectively. [8]

ii) If there is a step change in the inlet concentration to tank1 of $\Delta\ C_{Ain} = 0.925\ mol/m^3$, find the steady-state (before the step change) and final concentration values (after the step change) of A in tanks 1 and 2. The value of C_{Ain} after the step change is $1.85\ mol/m^3$. [11]

iii) From the overall transfer function, what is the value of the damping factor, ζ? Sketch the form of response of C_{A2} you would expect to the step change in C_{Ain} and describe its characteristics compared to that of the response of the concentration in tank 1, C_{A1}, to the same step change. [6]

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PART B

4.

The liquid level in a tank is to be controlled with a P-controller. The tank is shown in Figure 4 a).

The outlet flow rate from the tank F_o can be assumed to be linearly related to the hydrostatic pressure of the liquid level h of the tank through the resistance R, i.e. $F_o = h/R$, where R is equal to $2\ s\ m^{-2}$. The cross-sectional area of the tank A is $1.5\ m^2$.

i) Set up the total mass balance for the tank shown in Figure 4 a) and list your assumptions.

The measurement of the liquid level is not instantaneous but is delayed by $5\ s$.

Find the transfer function $G(s) = h_m(s)/F_i(s)$ where h_m is the measured tank level and F_i is the inlet flow rate. [7]

ii) Sketch the open loop step response in the measured liquid level $h_m(t)$ to a step change of magnitude 2 in F_i.

Is the process (tank with measurement) open-loop stable?

Can the process (tank with measurement) become unstable in a closed loop-system, and if so, why? [6]

iii) The crossover frequency for the process (tank with measurement) ϖ_{CO} is $0.44\ rad/s$. A P-controller with proportionality gain $K_p = 0.5$ is suggested to control the process.

Will the closed-loop system (tank, measurement and controller) be stable with this controller?

What is the Gain Margin with this controller?

Do you consider this Gain Margin satisfactory?

How often should a measurement be made, i.e. what should the sampling interval be? [7]

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iv) It is suggested to install a positive displacement pump on the outlet flow rate instead of having a controller. The new tank is shown in Figure 4 b).

Find the transfer function $G(s) = h_m(s)/F_i(s)$ where h_m is the measured tank level and F_i is the inlet flow rate.

Is the new process (tank with measurement and pump) open-loop stable? [5]

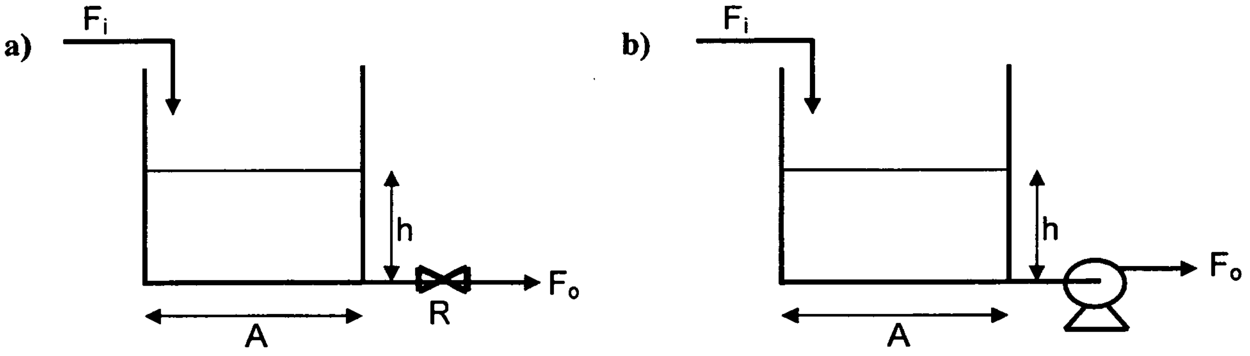

Figure 4. a) Tank with outlet flow rate proportional to the tank liquid level, b) Tank with positive-displacement pump on outlet flow.

5.

i) Vapour feed to an adiabatic tubular reactor is heated to about 370°C in a furnace, as illustrated in Figure 5. The reaction in the reactor is endothermic. The exit temperature of gas leaving the reactor is to be controlled at 310°C. Draw an instrumentation and control diagram that accomplishes the following objectives:

1) Feed is flow controlled.
2) Fuel gas is flow controlled and ratioed to the feed rate.
3) The fuel to feed ratio is cascaded with a furnace exit temperature controller.
4) The set point of the furnace exit temperature controller is adjusted by a reactor exit temperature controller.
5) Furnace exit temperature is not to exceed 400 °C.
6) High furnace stack-gas temperature should override the fuel gas control valve.

[10]

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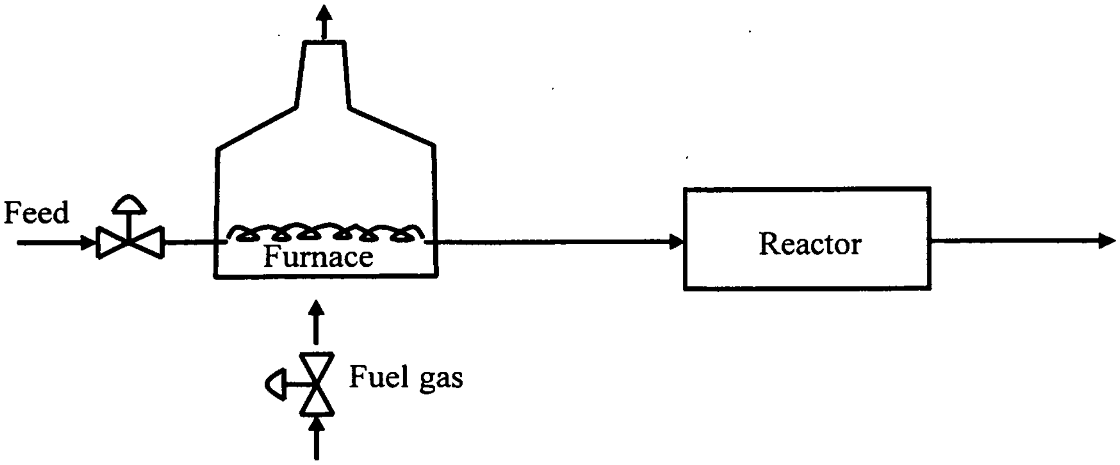

Figure 5. Furnace heating feed to adiabatic tubular reactor

ii) The stirred tank heater shown in Figure 6 is to be controlled using a feedforward-feedback control system. The control objective is to maintain a constant temperature in the exit stream. The input stream is coming from an upstream unit and may vary in temperature. The steam input can be manipulated.

Propose and illustrate a control strategy based on feedforward-feedback control for this system.

Draw the corresponding block diagram. [8]

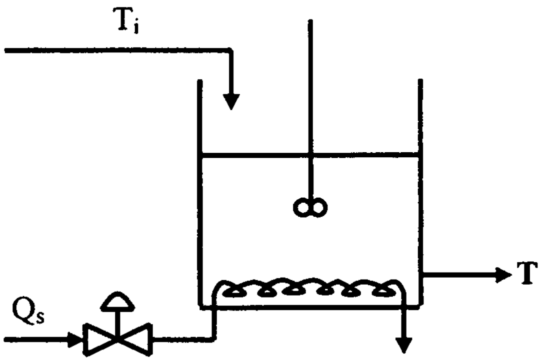

Figure 6. Stirred tank heater.

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iii) Consider the process given in Figure 7. The drum boiler is typically used for producing steam as a plant utility. The boiler contains boiling liquid, vapour bubbles and steam. The level of non-gaseous liquid material accumulated in the drum is the key variable of interest desired to be kept under control. The observed level of material in the drum is due to both the liquid and the entrainer vapour bubbles that, because of their higher specific volumes, rise through the boiling liquid and temporarily "settle" on the boiling liquid surface.

Explain how the level in the drum boiler will respond to a positive step change in the input, i.e. an increase in the cold feedwater flowrate.

Explain and illustrate, under which general conditions inverse response may be observed. [7]

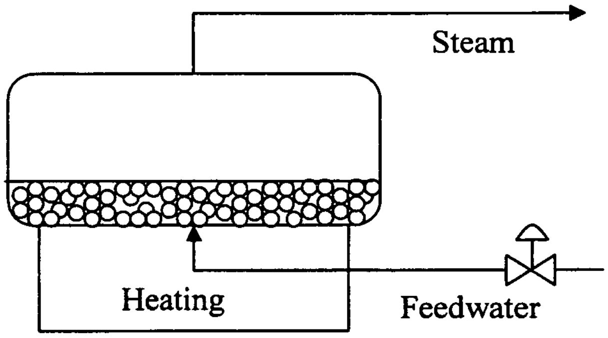

Figure 7. Schematic diagram of a drum boiler process

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6.

i) Consider the Continuous Stirred Tank Reactor (CSTR) given in Figure 8. The inlet flow rate F_i is used to control the product concentration C_A (loop1) and the coolant flow rate F_{CW} to control the tank temperature T (loop 2). The input stream is coming from an upstream unit and might vary both in concentration C_{Ai} and temperature T_i.

Explain how the two control loops may interact for this system.

Explain why interactions in multivariable processes are undesirable from a control point of view. [7]

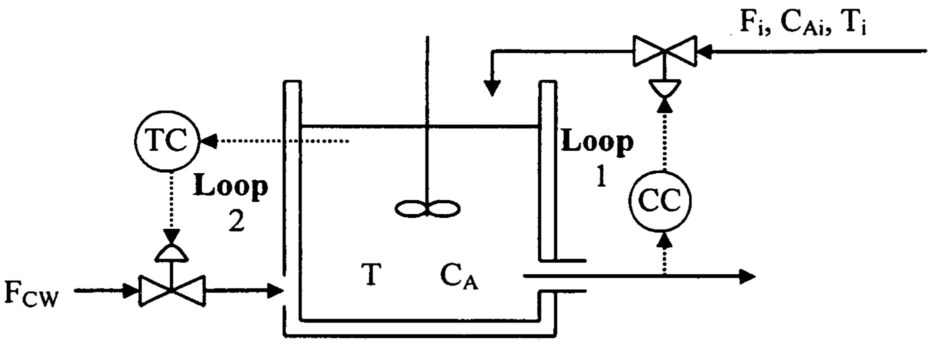

Figure 8. Control loops for CSTR.

ii) It is proposed to implement heat integration on the exothermic reactor process given in Figure 9. Propose a heat integration scheme for this process.

What is the main potential benefit from the heat integration scheme?

What are the potential control problems associated with the heat integration scheme? [6]

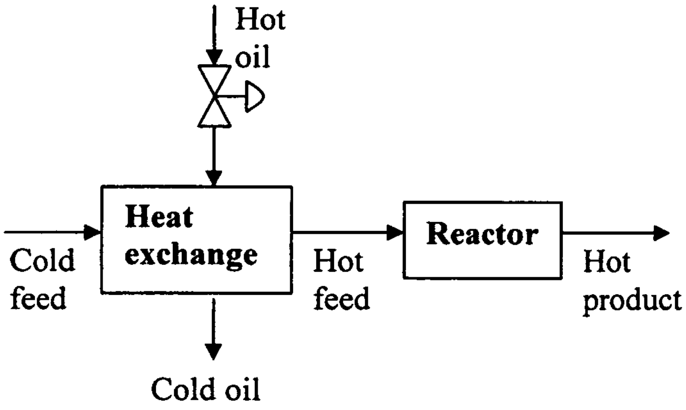

Figure 9. Exothermic reactor with feed pre-heater

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iii) Pneumatic control valves are to be specified for the applications listed below. State whether a Fail-Open or a Fail –Closed valve should be specified for the following manipulated variables and give reason(s).

1. Steam pressure in a reactor heating coil
2. Flow of effluent from a wastewater holding tank into a river
3. Flow of cooling water to a distillation condenser

What is the purpose of a Safety Interlock System (SIS)?

Why must the Safety Interlock System be independent of the regulatory control system? [6]

iv) A 2x2 process is given by:

$$y_1 = \frac{1}{s+1}m_1 + \frac{1}{0.1s+1}m_2$$
$$y_2 = \frac{-0.2}{0.5s+1}m_1 + \frac{0.8}{s+1}m_2$$

The Relative Gain Array (RGA) of the process is:

$$RGA = \begin{bmatrix} 0.8 & 0.2 \\ 0.2 & 0.8 \end{bmatrix}$$

The manipulated variable m_1 is used to control y_1 in control loop 1 and m_2 to control y_2 in loop 2.

Do dynamic considerations suggest the same pairing?

Assume loop 1 is open. Based on the values of the RGA, sketch the open loop time response in y_1 to a unit step in m_1 for the following situations:

1. The second loop is open and m_2 is constant
2. Both loops are closed and y_2 is constant

[6]

END OF PAPER