CHEM: BE/VII/CBGS/ PP&C

Process Dynamics & Control QP Code: 5957

(REVISED COURSE)

(3 Hours) [Total Marks: 80

N.B. :

1) Question – 1 is compulsory. Answer any three questions from the remaining.
2) Assume data if necessary and specify the assumptions clearly.
3) Draw neat sketches wherever required.
4) Answer to the sub-questions of an individual question should be grouped and written together i.e. one below the other.

1. (a) Consider the heating of a liquid in a continuous stirred tank. Assume that the density and heat capacity of the liquid remain constant. The liquid hold-up may vary. Derive a dynamic model for the process, assuming the usual notation. Carry out the degrees of freedom analysis, and classify the variables. [05]

(b) The following reaction takes place in a CSTR at a constant temperature: [05]

$$2A \xrightarrow{k_1} B \qquad -r_A = k_1 C_A^2$$

where C_A is the concentration of A in the reactor. Derive the transfer function relating the outlet concentration C_A to the inlet concentration C_{Ai}. Assume that volume is constant.

(c) A liquid surge tank has the following transfer function: [05]

$$\frac{H(s)}{Q_i(s)} = \frac{10}{(50s+1)}$$

The system is operating at steady-state with $q_{is} = 0.4\ m^3/s$ and $h_s = 4m$, when the inlet flow rate fluctuates as a sine wave with an amplitude of 0.1 m^3/s and a period of 500 *sec*. What are the maximum and minimum values of the level after 10 *min*?

(d) Consider the Nyquist plot of the following system: [05]

$$G_{OL} = \frac{2.5K_c}{s^2+s-2}$$

For what value of K_c will the point −1 be encircled? Will it be in a clock-wise direction? Will the closed loop system be stable? How about the open-loop system?

2. (a) Two streams, w_1 and w_2, each at a constant density of 900 kg/m^3, and carrying a solute of mass fractions x_1 and x_2 respectively, enter a continuous stirred tank of 2 m^3 capacity. At steady-state, $w_{1s} = 500\ kg/min$, $w_{2s} = 200\ kg/min$, $x_{1s} = 0.4$, and $x_{2s} = 0.75$. Suddenly the inlet flow rate w_2 decreases to 100 kg/min and remains there. Determine an expression for the mass-fraction of the solute in the outlet $x(t)$. Assume that liquid hold up is constant. [10]

(b) Consider a liquid phase, irreversible, first order reaction taking place in a CSTR, where reactant A gets converted to product B. The reaction is cooled by coolant passing through a coil at a temperature T_c. Develop a State Space model, assuming volume is constant, if both, the concentration of A and the reaction temperature T, are required to be monitored: [10]

[TURN OVER

MD-Con. 9984-15.

volumetric flow rate of liquid: $q\ m^3/hr$
density of liquid: $\rho\ kg/m^3$
volume of reactor: $V\ m^3$
concentration of reactant in feed: $C_{Ai}\ mol/m^3$
concentration of reactant in reactor: $C_A\ mol/m^3$
heat capacity of liquid: $C\ J/kg.K$
heat transfer coeff. of the coil: $U\ J/m^2.hr.K$
surface area of cooling coil: $A\ m^2$

3. (a) A composition sensor is used to continually monitor the contaminant level in a liquid stream. The transfer function of the sensor is given by: [10]

$$\frac{C_m(s)}{C(s)} = \frac{1}{(10s+1)}$$

where C is the deviation in the actual contamination, and C_m is the deviation in the measured value. The process is at steady state initially, with the contamination at 5 ppm, when the input starts increasing as $c(t) = 5 + 0.2t$, where t is in sec. An alarm sounds if the measured value exceeds the environmental limit of 7 ppm. After the actual contamination exceeds the limit, how long will it take for the alarm to sound?

(b) The variation of liquid level in a spherical tank, with inlet flow rate q_i, and the outlet dicharging through a valve, can be described as: [10]

$$\frac{dh}{dt} = \frac{1}{\pi(D-h)h}q_i - C_v\sqrt{h}$$

Derive a transfer function relating the changes in liquid level h to changes in the inlet flow rate q_i. The diameter of the tank is D, and C_v is the constant of the valve in the cutlet line.

4. (a) An electronic PI temperature controller has an output of 4 *to* $20\ mA$ when the temperature input changes from 60 *to* 120 $°C$. The controller is at steady state, with an output of 8 mA for an input temperature of 75 $°C$, when a pulse input of magnitude 5 $°C$ occurs for 10 *sec*. Calculate the output of the controller during and after the disturbance. The integral time is 20 *sec*. What is the proportional band of the controller? [10]

(b) Consider the following transfer function of a first order process with dead time: [10]

$$G_p(s) = \frac{2e^{-0.5s}}{(\tau s+1)}$$

A proportional controller is used to complete a negative feedback loop with the process. When the controller gain is set equal to 2.5, the phase margin is found to be 30°. What is the value of the process time constant? What is the corresponding gain margin?

5. Consider the following negative feedback control system: [20]

$$Process: \; G_p(s) = \frac{2}{(4s+1)}$$

$$Controller: \; G_c(s) = K_c(\tau_D s + 1)$$

$$Control\ Valve: \; G_v(s) = \frac{2.5}{(0.1s+1)}$$

$$Transmitter: \; H_m(s) = \frac{0.6}{(0.5s+1)}$$

A load variable enters the process through the following transfer function:

$$Disturbance: \; G_d(s) = \frac{0.5}{(2s+1)}$$

(a) Derive the closed loop transfer functions for both the Servo and Regulatory operations.

(b) Obtain the ultimate gain for the controller, for a derivative time of 1, in the same units as other time constants.

(c) Using half of the ultimate gain calculated above, determine the offset for a unit step change in the load variable.

(d) What are the Gain and Phase margins for the above settings?

6. (a) The following response was obtained from a dynamic system when a step of magnitude 0.2 was introduced: [10]

time, min	*response*
0	0.000000
5	0.001757
10	0.025273
15	0.088674
20	0.178158
25	0.268563
30	0.343173
35	0.396964
40	0.432176
45	0.453617

Finally, the response approaches a constant value of 0.4798 after a long time. Use the data to fit a First Order plus dead time model to the system.

(b) Consider the following transfer function of a process: [10]

$$G_p(s) = \frac{5e^{-0.2s}}{(2s^2+s+1)}$$

Design a PI controller, for a negative feddback loop of the process, based on the Zeigler and Nichols tuning rules.

****