INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Department of Chemical Engineering

Mid-semester (Spring) Examination 2022-23

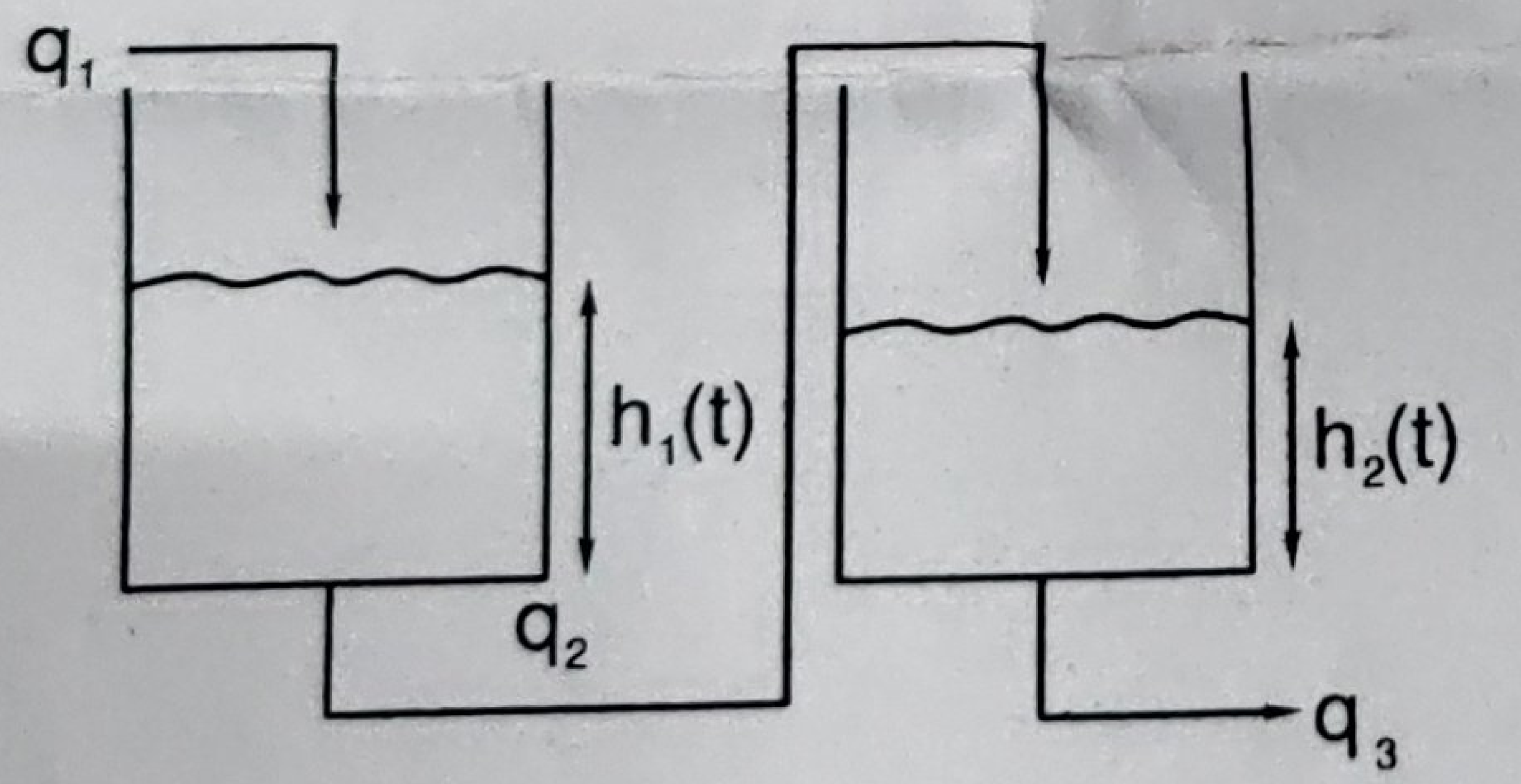
Subject: Process Dynamics and Control (CH61016)

Remarks:

1. This question paper contains two parts: **Part A** and **Part B**. Attempt both parts.
2. Write all the answers of a part together.
3. You may make suitable assumptions but clearly specify and justify them. **No queries will be entertained during exam hours.**
4. Unless otherwise stated, usual notations apply.
5. Time = 2 h; maximum marks = 30; total number of printed pages = 2.

Part A

1. Consider a two-tank system, each with unit cross-section, with other details as shown in the figure below. The model equations have been provided alongside.



$$\frac{dh_1}{dt} = q_1 - q_2 \tag{1}$$

$$\frac{dh_2}{dt} = q_2 - q_3 \tag{2}$$

$$q_2 = 0.94h_1 \tag{3}$$

$$q_3 = 0.53h_2 \tag{4}$$

(a) For zero inlet flowrate q_1, verify if the system is linear.

(b) Draw the phase portrait for the system.

(c) Solve for the time-evolution of h_1 and h_2 using similarity transformation technique.

...3+3+5 = 11 marks

2. The model for the evolution of dimensionless population of insects, $x(t)$, in a given region is given by the following equation.

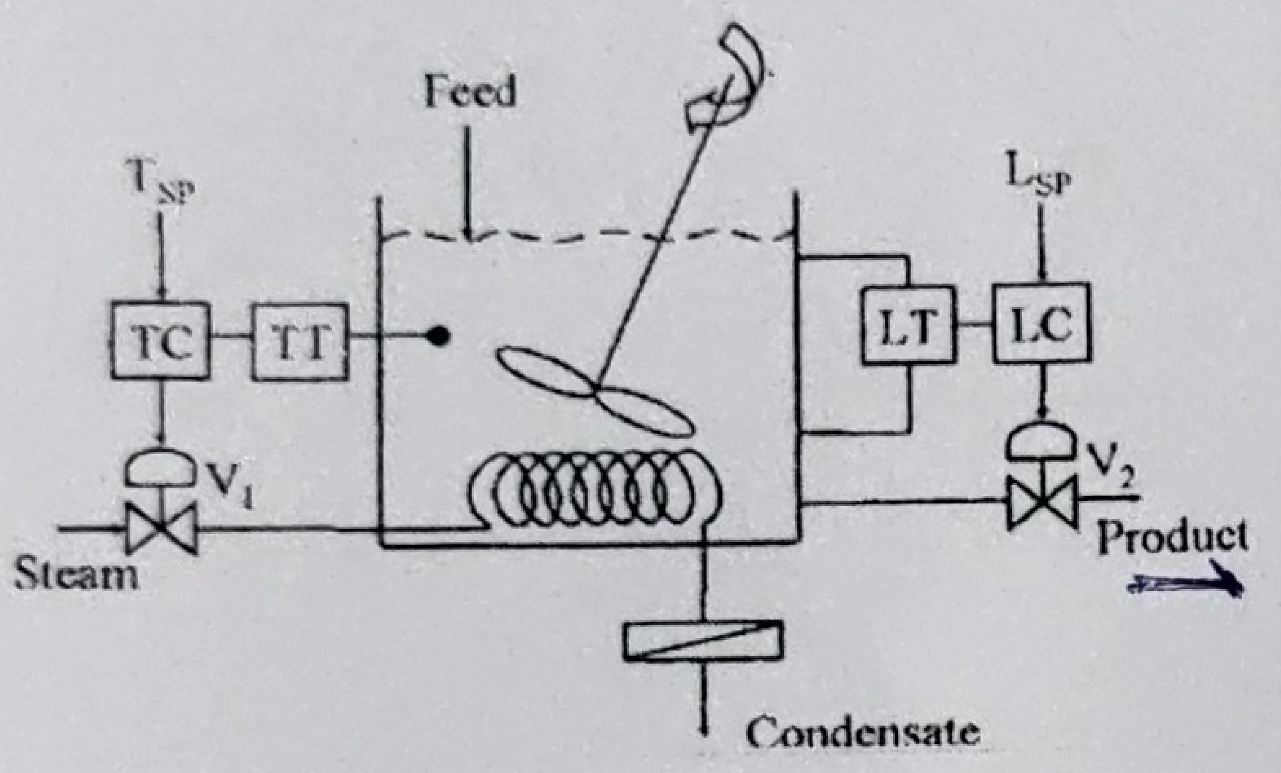
$$\frac{dx}{dt} = x(1-x) + \frac{x}{1+x} \tag{5}$$

Draw a well-labelled phase protrait for the system conforming to the physically realisable constraints. Show all the steps and calculations in detail.

...4 marks

Part B

3. The following diagram shows a CSTR with two control loops. A liquid phase, endothermic reaction is taking place in the CSTR, and the system is initially at steady state. Assume that the changes in physical properties of the system are negligible.



TC: Temperature controller,

LC: Level controller,

TT: Temperature transmitter,

LT: Level transmitter,

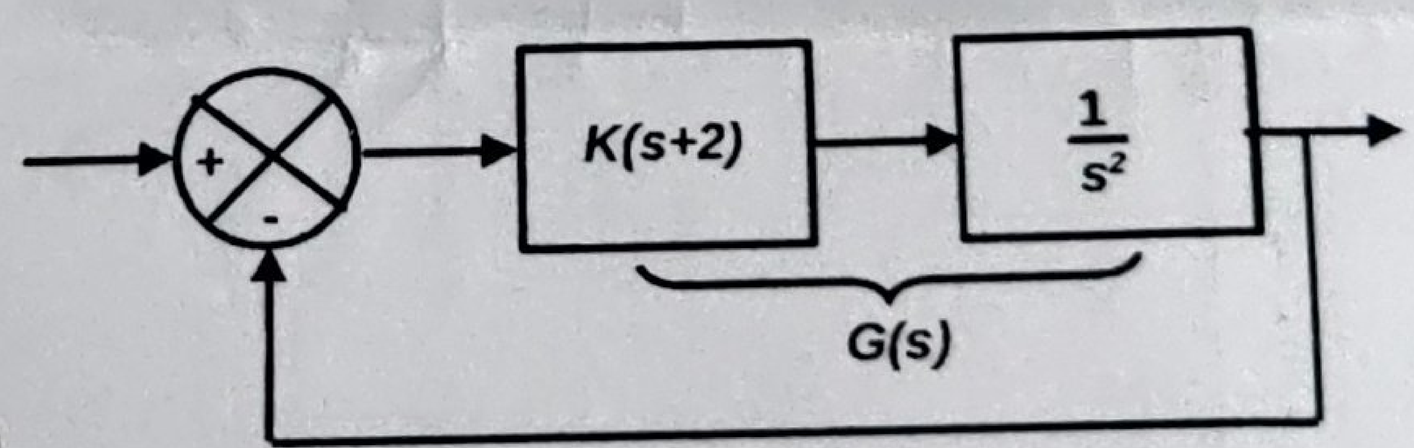
V_1 and V_2: Control valves

Processgain $\frac{\Delta \text{output}}{\Delta \text{input}}$ T

(a) What type (Air to Open or Air to Close) of control valves should be selected?
(b) What should be the action (Reverse or Direct) of the controllers?
(c) How the opening of control valves will change if the LC set point is increased?
(d) How the opening of control valves will change if the TC set point is increased?

...0.5×4 = 2 marks

4. Consider the adjacent block diagram. Determine the gain K such that the phase margin is 60°. What is the gain margin in this case?



$\pi + \phi|_{AR=1}$

...3 marks

5. In a non-isothermal jacketed CSTR process, the reactor temperature (y) is related to the coolant flow rate (u) by this relation: $y(s) = \dfrac{-2(6s+1)e^{-2s}}{(10s+1)(3s+1)}u(s)$. G_p
(a) Design an IMC controller for this process and draw the IMC block diagram accordingly.
(b) Convert the IMC controller to IMC-PID controller (with or without filter).

...2+3 = 5 marks

6. A chemical process with Process Transfer function $\dfrac{5e^{-2s}}{(s+1)(s+2)(s+3)(s+4)}$ is to be controlled using a Smith predictor control strategy.
(a) Convert the above transfer function to first order with dead time (FODT) transfer function using method of moments.
(b) Draw Smith predictor control strategy block diagram
(c) Design the controller using IMC-PID approach with filter time constant 20% of the process time constant.

...2+1+2 = 5 marks

***

$\frac{1}{(s+1)(s+2)} \cdot \frac{1}{(s+3)(s+4)}$ $\quad \frac{1}{(s+1)(s+3)} - \frac{1}{(s+4)(}$

$\left(\left(\frac{1}{s+1} - \frac{1}{s+2}\right)\frac{1}{s+3}\right)$ $\quad \frac{1}{2}\left(\frac{1}{s+1} - \frac{1}{s+3}\right) -$