

24CGB014
Instrumentation & Control

Semester 1 2024/25

In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer **ALL** questions. Each question carries 25 marks.

Candidates should show full working for calculations and derivations.

1. (a) Explain the different regions of the operating envelope and how they relate to the control and safety systems of a chemical plant. Draw a clear diagram to demonstrate your points. [10 marks]
- (b) Explain the purpose and the key design features of a cascade controller. Use a suitable example of a potential application to illustrate your points. [5 marks]
- (c) You have been asked to select a new control system for an ethanol purification column to produce fuel grade ethanol product. The minimum required ethanol purity is 99 vol% and the plant is expected to operate for 330 days per year. The ethanol concentration is maintained by controlling the reflux ratio in the system: increasing the reflux ratio will increase ethanol purity but also increase the heating duty of the reboiler. The relationship between ethanol outlet purity and reboiler duty is given in Table Q1.1.

Table Q1.1: Reboiler duty as a function of ethanol product purity

Ethanol outlet volume fraction	Reboiler duty, kW
0.9900	32
0.9905	35
0.9910	38
0.9915	41
0.9920	46
0.9925	51
0.9930	59
0.9935	70
0.9940	87
0.9945	115
0.9950	178

You have been provided with operating data for two alternative control system configurations, system A and system B (Table Q1.2). System A costs £10,000 to implement, while system B costs £20,000. Assuming an energy cost of £0.10 kWh⁻¹, calculate the annual cost for operating each of the two systems and select the most suitable option for your plant. Fully discuss and justify your decision. [10 marks]

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Table Q1.2: Test data for two alternative control system configurations

Ethanol volume fraction interval	Number of days in interval	
	System A	System B
0.9900 - 0.9905	0	1
0.9905 - 0.9910	7	5
0.9910 - 0.9915	10	20
0.9915 - 0.9920	16	27
0.9920 - 0.9925	13	5
0.9925 - 0.9930	12	2
0.9930 - 0.9935	4	0
0.9935 - 0.9940	2	0
0.9940 - 0.9945	0	0
0.9945 - 0.9950	0	0

2. (a) The maximum designed flow rate for a process is 150 gpm, the operating flow rate is 100 gpm, the minimum flow rate is 75 gpm, and the pipe diameter is 4 inches. Assume the pressure drop across the valve is 10 psig. For the equal percentage control valve DN65 (Table Q2.) evaluate the C_v values as well as the valve stem position for the maximum and minimum flow rates. Comment on the significance of these openings.

Table Q2. Valve coefficient values C_v , for an equal percentage valve at different valve openings

Valve size		Valve opening, percentage of total travel			
DIN	Inches	Valve Coefficient, C_v			
		10%	30%	70%	100%
DN25	1-1/4	0.8	2.2	7.8	17.2
DN40	1-1/2	1.5	3.9	17.4	35.8
DN50	2	1.7	4.7	25.4	59.7
DN65	2-1/2	3.4	10.8	49.2	99.4
DN80	3	4.3	10.9	66.0	136.0

[15 marks]

- (b) A proportional controller is used to control temperature within the temperature range 40-100 C and the controller output signal pressure goes from 3 psi (valve fully open) to 15 psi (valve fully closed).

(i) Calculate the value of the controller gain. [3 marks]

(ii) The sensitivity of the controller is adjusted such that the output pressure goes from 3 psi to 15 psi as the measured temperature goes from 60 to 80 C.

(a) Re-calculate the value of the controller gain. [1 mark]

(b) Calculate the value of the proportional band. [2 marks]

(c) Comment on the qualitative effect of the change in the gain value on the steady state offset and any other process stability related issues that one might expect to arise from this change in the controller gain setting. [4 marks]

3. (a) Consider the process shown in Fig. Q3(a) where liquid in the tank is draining through a valve at the exit of the tank. At steady state, the feed flow rate entering the tank is 150 L/min and the liquid height in the tank is 10 m. Assume the flow rate through the valve is directly proportional to the liquid height in the tank (i.e. $q = \beta \cdot h$). The tank has a constant cross-sectional area of 1 m².

(i) At steady state conditions (mentioned above), work out the valve coefficient value, β .
[4 marks]

(ii) If the inlet flow increases to 180 L/min, show that the new steady state height is 12 m.
[3 marks]

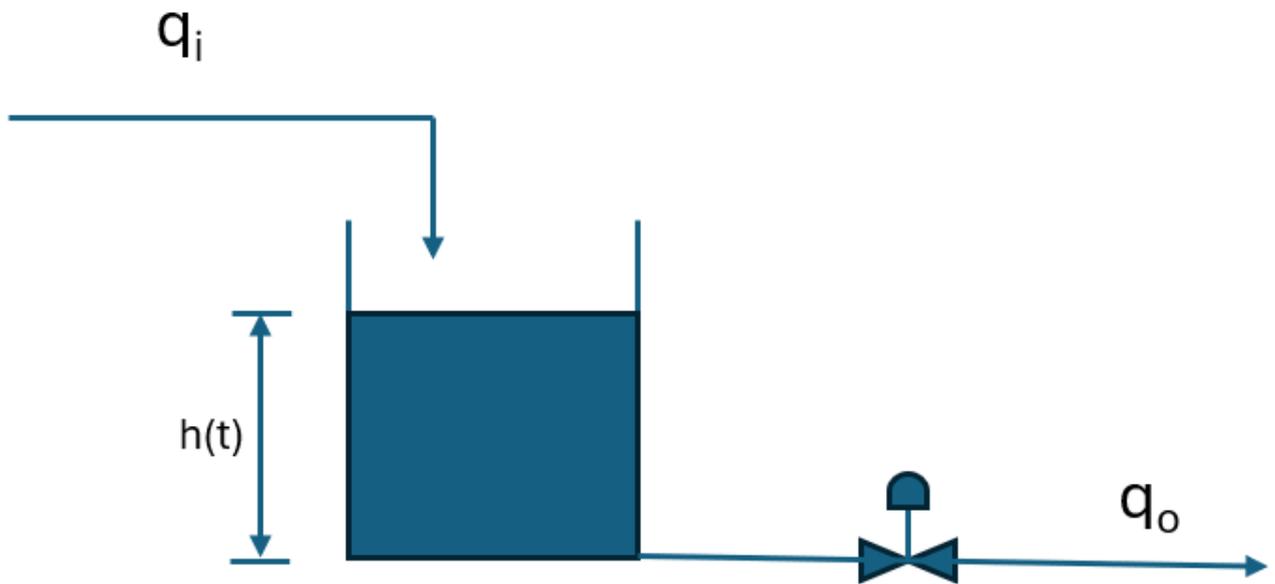


Fig. Q3(a). Tank drainage through a valve.

(b) Consider the process shown in Fig. Q3(b). Liquid is pumped through an air-to-open (AO) control valve installed on the outlet of the tank. A feedback level control strategy is implemented to control the level in the tank. The AO linear control valve receives an input signal from the controller between 3-15 psig resulting in a flowrate range 0-300 L/min. At 9 psi the linear valve is half open and at 15 psi the maximum flow rate through the valve is 300 L/min.

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- (i) A level transmitter is connected to the tank and has a measurement range of 0-20 m and is direct acting with an output signal range 3-15 psi (after I/P signal conversion). Derive a mathematical relationship between the transmitter output signal and the liquid height in the tank. Hence, show that the transmitter output for a liquid height of 12 m is 10.2 psi. [4 marks]
- (ii) Write down the equation relating the valve stem position (range 0-1) and the controller output signal (range 3-15 psi). [4 marks]
- (iii) Derive a relationship between the controller output signal (range 3-15 psi) and the flow rate (range 0-300 L/min) through the valve. [4 marks]
- (iv) If the inlet flow rate changes to 180 L/min, calculate the new valve stem position at steady state. If the controller gain K_c value for a P controller is -1, what is the error term $e(t)$ value at steady state? [6 marks]

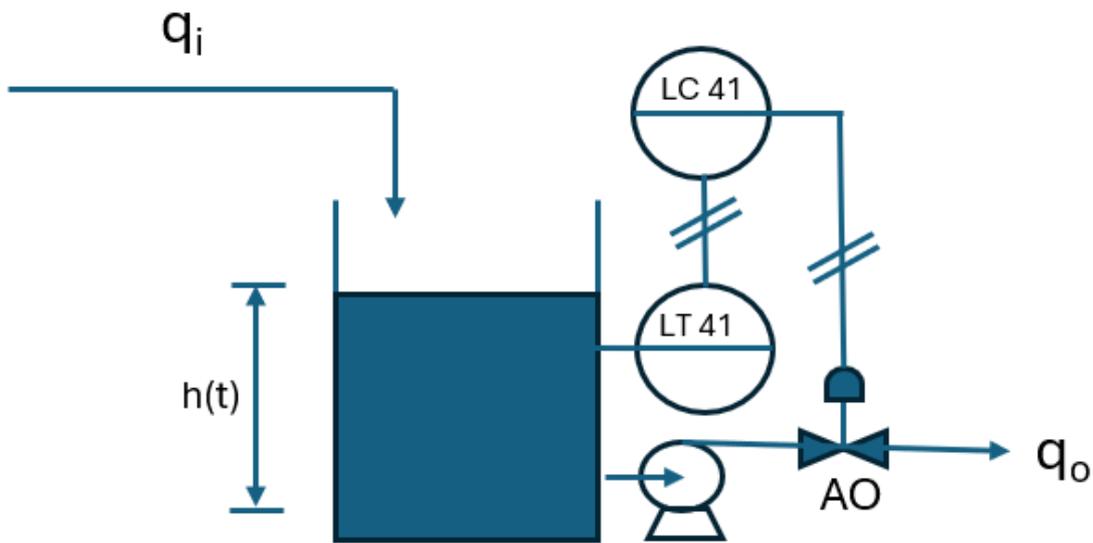


Fig. Q3(b). Liquid level control loop.

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