## 23CGB014
Instrumentation & Control

Semester 1 2023/24                                    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.

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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.

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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 THREE** questions. Each question carries 25 marks.

Candidates should show full working for calculations and derivations.

An A3 size P&ID is provided as a separate sheet but is also shown as Fig Q1A in this exam paper.

1.  (a) Industrial processes employ both mechanical sensors, which display a direct analogue output in response to process changes, and digital sensors, which generate and transmit an electrical or electromagnetic signal, which needs to be translated into a process reading. Provide two distinct advantages or disadvantages for each type of sensor.

[4 marks]

(b) Consider the P&ID for a triethylene glycol (TEG) system, used for the removal of water from process gases, shown in Figure Q1A and on the separate A3 sheet provided. The system consists of an absorber, D-101, where process gases are contacted with dry ('lean') TEG, before the wet ('rich') TEG stream from the absorber bottom is passed through a flash drum (D-201) and reboiler (R-205) to safely vent dissolved process gases and drive off the absorbed water. Regenerated TEG is stored in drum D-206 from where it can be recirculated to the absorber.

Referring to this P&ID, provide one example for each of the seven control objectives.

[7 marks]

(c) Explain why safety systems should be independent from the control system and describe how this can be achieved. [4 marks]

(d) Thermal decomposition of TEG in the reboiler causes the formation of corrosive breakdown products, which must be purged from the system by replacing at least 1% of TEG with fresh material during each cycle. You have received quotes for two different control systems, together with test data on their expected performance (Figure Q1B). The costs for systems A and B are £54,900 and £44,750, respectively. Given a daily TEG flowrate of 5,000 L, average TEG price of £1,500 $m^{-3}$ and annual plant operation of 330 days, calculate the annual operating cost for each system and select which system you would like to purchase. Clearly state any assumptions you make. [10 marks]

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# Figure Q1A
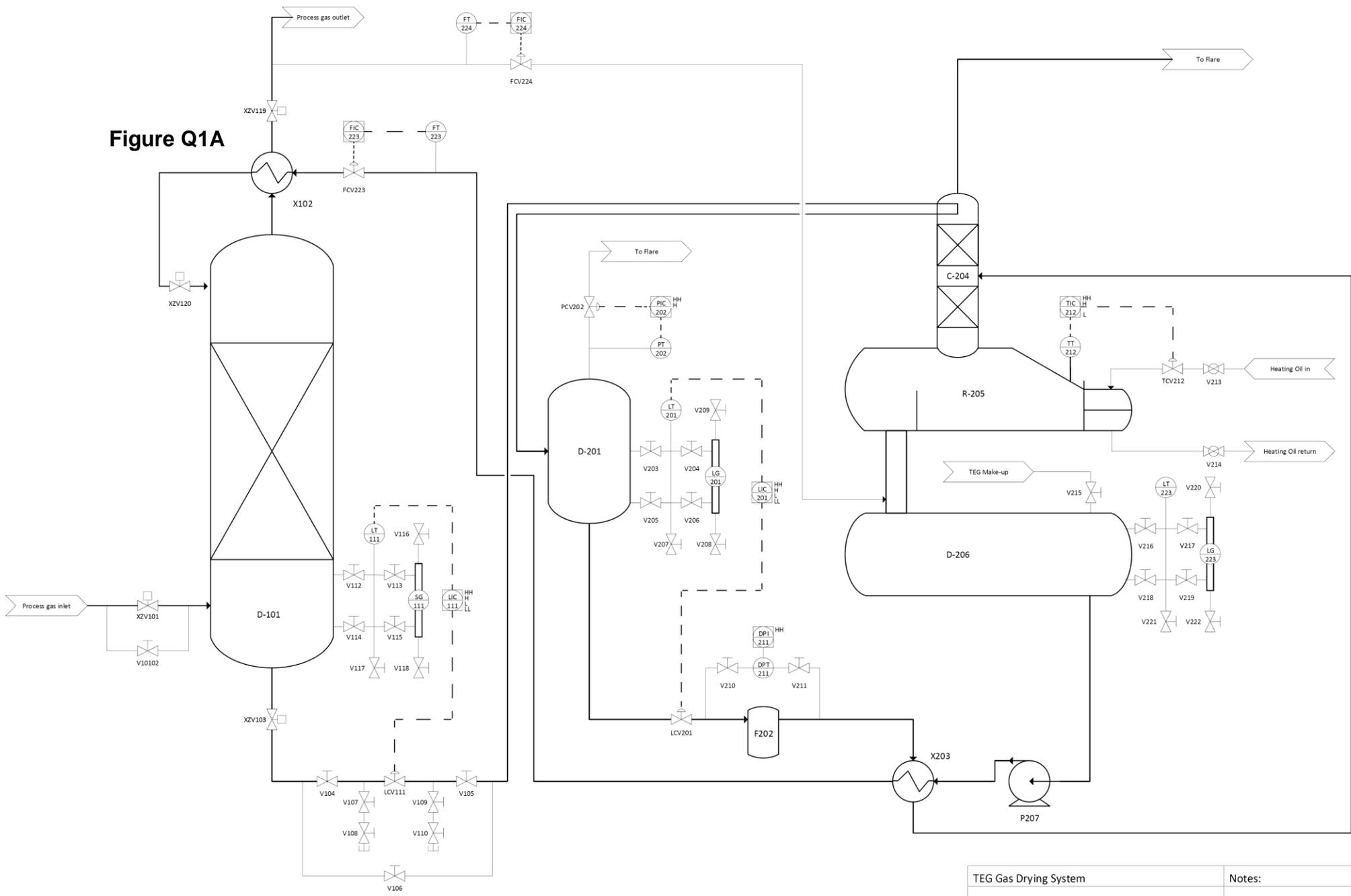


TEG Gas Drying System

Notes:

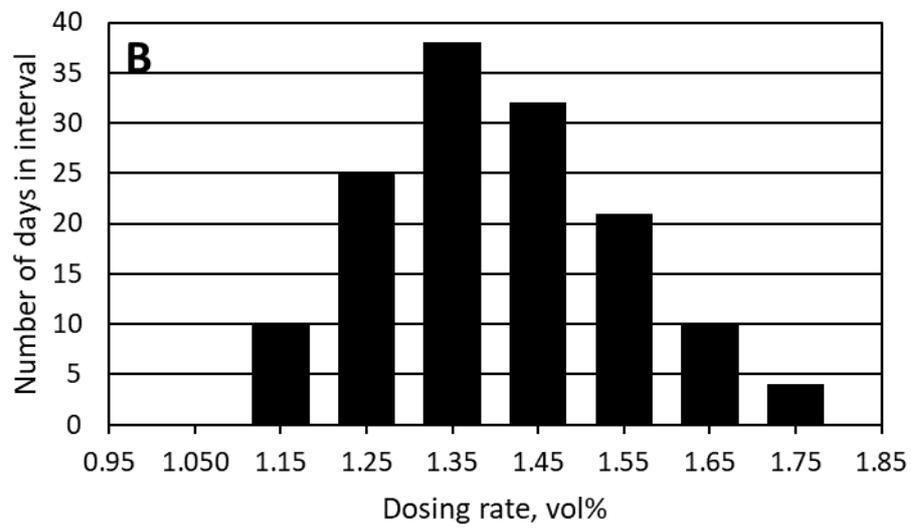12/08/2019 – JW (LU) – Rev. A
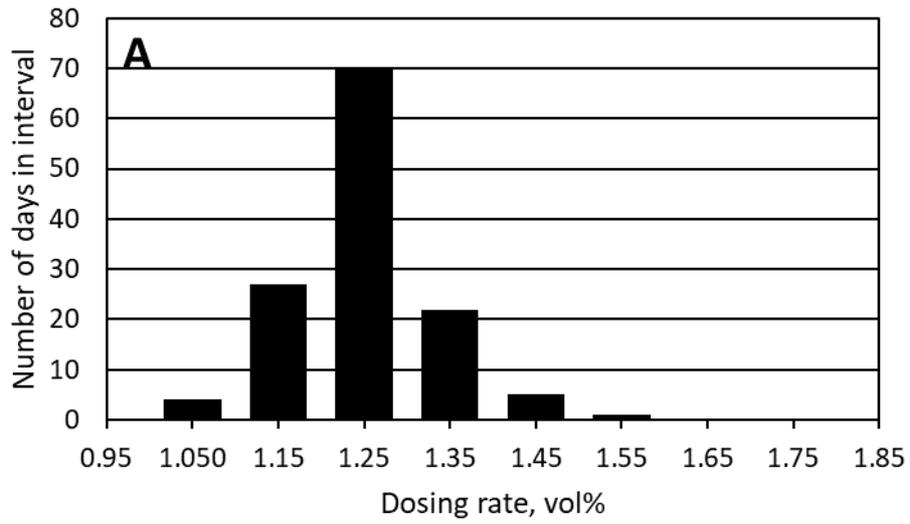
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Q1 Continued/…



**Figure Q1B:** Expected performance data for control systems A and B.

2.  (a) Should the setting of the level controller in Figure Q2. be direct-acting or reverse-acting? Justify your choice with a brief explanation.                                    [3 marks]

   (b) Water (density 1000 kg m$^{-3}$) is supplied at a constant flow rate of $q = 5$ m$^3$ min$^{-1}$ into a cylindrical storage tank which has a cross-sectional area of 5 m$^2$ (Figure Q2.). The liquid level in the tank at steady state is 5 m. A control valve is installed on the outlet pipe. The storage tank and the outlet pipe are at atmospheric pressure and the flow rate across the valve is proportional to the square root of the level in the tank.

   (i)  If the input flow suddenly stops (i.e. q(t) is zero), how much time is required until the tank level falls to 1 m?                                                    [7 marks]

   (ii) What will be the level in the tank 5 min after the input flow is stopped?        [5 marks]

   (c) For a process like the one shown in Figure Q2, the designed steady-state operating conditions are q = q$_{(t)}$ = 200 L min$^{-1}$ and h(t) =h = 6 m. The level transmitter has a range of 0-20 metres (output 4-20 mA over this range). A proportional only controller, Kc = 1, is used in this process.

   (i)  What is the level transmitter output at the designed steady-state conditions?

                                                                                        [4 marks]

   (ii) The controller output is 3 psi when the transmitter input is 4 mA. For the designed steady state, the Air-to-Open (AO) valve requires a 9 psig signal. Calculate the offset, if the inlet flow increases to 225 L min$^{-1}$ and the valve requires 12 psi to pass this flow. Report the offset in metres.                                             [6 marks]
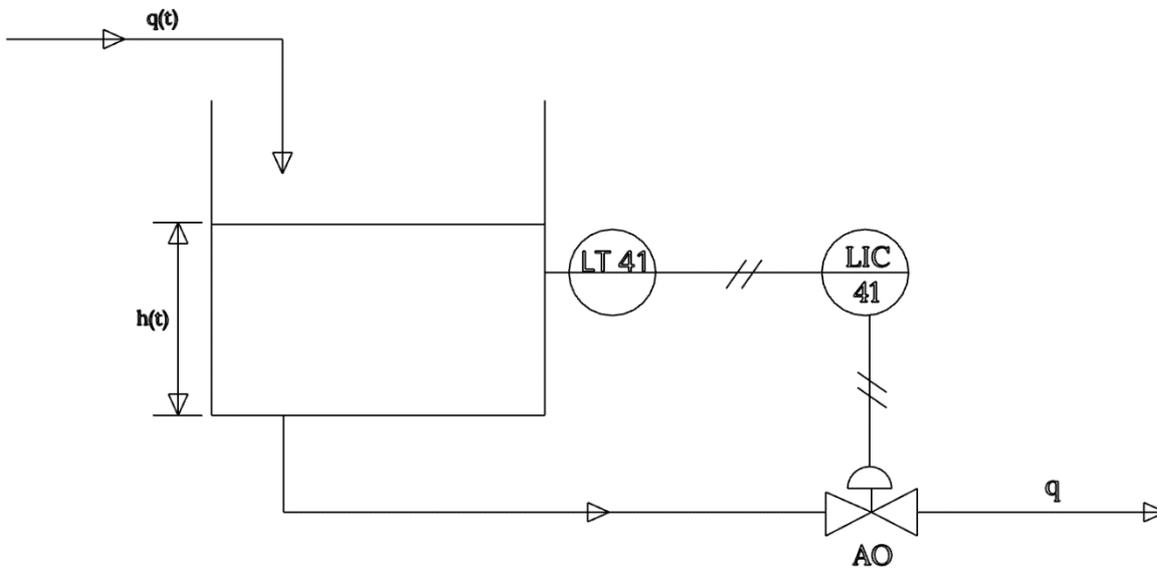
**Figure Q2.** Liquid level control loop.

3. (a) The maximum designed flow rate for a process is 140 gpm, the operating flow rate is 70 gpm, the minimum flow rate is 40 gpm, and the pipe diameter is 3 inches. Assume the pressure drop across the valve is 10 psig. For the equal percentage control valve DN50 (Table Q3a.) evaluate the $C_v$ values for all three flow rates and the valve stem position for the maximum flow rate of 140 gpm. [10 marks]

**Table Q3a.**

| Valve size | | Valve opening, percent of total travel | | | |
|---|---|---|---|---|---|
| | | 10 | 30 | 70 | 100 |
| DIN | Inches | $C_v$ | | | |
| DN 25 | 1-1/4 | 0.78 | 2.20 | 7.83 | 17.2 |
| DN 40 | 1-1/2 | 1.52 | 3.87 | 17.4 | 35.8 |
| DN 50 | 2 | 1.66 | 4.66 | 23.4 | 57.7 |
| DN 65 | 2-1/2 | 3.43 | 10.8 | 49.2 | 99.4 |
| DN 80 | 3 | 4.32 | 10.9 | 66.0 | 136 |

(b) Draw the open loop response expected of a P (proportional) controller for the situation shown in Figure Q3. Assume a reverse-acting controller. Consider the variation of process variable from t5 to t6 to be quadratic. A qualitative diagram will suffice, but indicate the magnitude of response and slopes where possible. [5 marks]
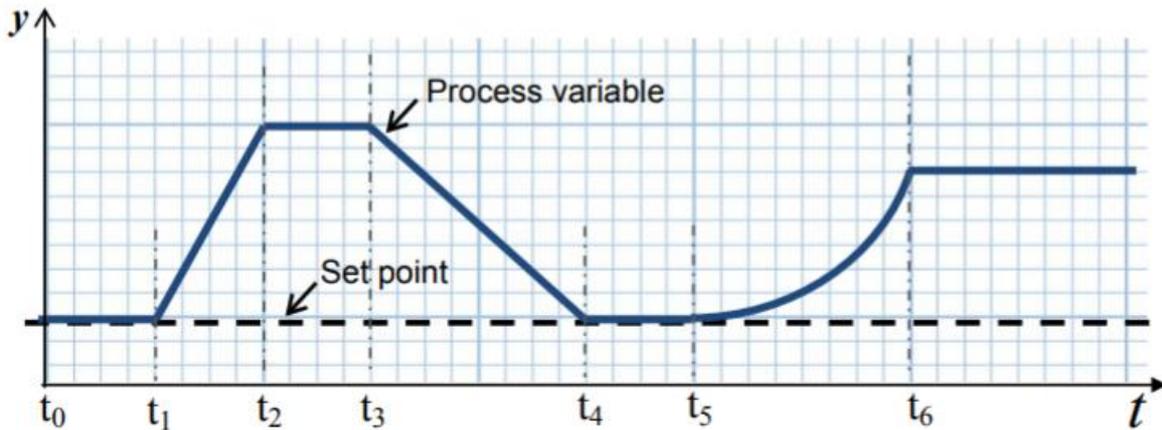


**Figure Q3.** Signal input to controller (open loop).

(c) A differential pressure sensor measures flow by measuring the differential pressure, h, across an orifice. The differential pressure is related to the square of the volumetric flow rate, q, i.e $q^2 \propto h$. Eq.1 (below) describes the output signal from an electronic differential pressure transmitter with a range of 0-$q_{max}$ gpm. Using Eq.1, find the equation of the transmitter gain, $K_T$. If the nominal gain is defined as $K_T' = \frac{16}{q_{max}}$, complete Table Q3c. below, (reproduce the completed table in your answer booklet), hence comment on whether the gain is constant or a function of flow rate.

$$M_F = 4 + \frac{16}{(q_{max})^2} q^2 \qquad \text{(Eq.1)}$$

Where: $M_F$ is the output signal in mA.

**Table Q3c.**

| $\dfrac{q}{q_{max}}$ | 0 | 0.1 | 0.5 | 0.75 | 1.0 |
|---|---|---|---|---|---|
| $\dfrac{K_T}{K_T'}$ | | | | | |

[10 marks]

END OF PAPER

**Prof DJ Malik, Dr JL Wagner**