INDIAN INSTITUTE OF TECHNOLOGY–KHARAGPUR

Mid-Autumn Semester 2016-17 (closed book)

Course No.: CH 31011 **Max. Time**: 2 hrs

Course Title: Instrumentation and Process Control **Total Marks**: 30

Answer all questions

Q1. Consider an isothermal stirred-tank blending system shown in Fig. 1. Here, V denotes the liquid volume. The mass fraction of component A in the two inlet streams are x_1 and x_2, and in the exit stream is x. The respective mass flow rates are F_1, F_2 and F.

(a) Stating suitable assumptions, develop the dynamic model.

(b) Supposing constant V, F_1, F_2 and F, develop the transfer function model in terms of gain K_p and time constant τ_p:

- When x_1 varies and x_2 remains constant,
- When both x_1 and x_2 vary. **[2.5+(2+2)+(2+2)=10.5]**

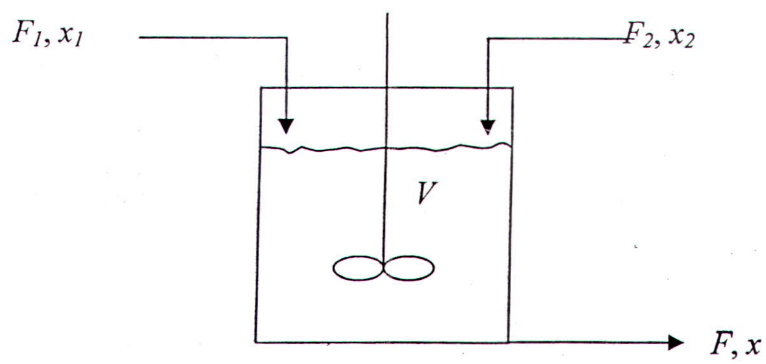

Fig. 1: A stirred-tank blending system.

(c) Consider a constant liquid holdup of 2 m^3 maintained to blend the said two streams whose densities are both approximately 900 kg/m^3. The density does not change during mixing.

- Assume that the process has been operating for a long period of time with flow rates of $F_1 = 500$ kg/min and $F_2 = 200$ kg/min, and the feed compositions (mass fractions) of $x_1 = 0.4$ and $x_2 = 0.75$. What is the steady state value of x?
- Suppose that F_1 changes suddenly from 500 to 400 kg/min and remains at the new value. Determine an expression for $x(t)$.

PTO

Q2. (a) Why do we need to develop the mathematical model of a process we want to control?

(b) Derive the following expression for an underdamped response:

$$\text{Decay ratio} = \exp\left(\frac{-2\pi\zeta}{\sqrt{1-\zeta^2}}\right)$$

[3+3+3+3=12]

(c) With an example of first-order system, show how the time constant is correlated with storage capacitance and resistance to heat flow.

(d) How the system responds when the real part of its complex poles is zero? Mathematically prove it.

Q3. The governing equation for the capillary tube viscometer is the well known Hagen-Poiseuelle equation:

$$Q = \frac{\pi D^4}{128\eta L}\Delta p$$

(i) If Q, L, D, p are measured with an uncertainty of $\pm 1\%$, how accurately is η known?

(ii) If the uncertainty in the measurement of D is reduced to $\pm 0.1\%$, what is the improvement achieved in the uncertainty of η? **[2.5+1]**

Q4. A mercury thermometer with a capillary tube of 0.025 cm diameter is being designed to measure temperature of water around 25 °C. The bulb is spherical and is made of a zero-expansion material. What volume must the bulb have if a sensitivity of 0.25 cm/°C is required? Assume that the volumetric expansion coefficient of mercury around 25 °C is 0.00018 cm^3/cm^3 °C. You must derive the expression for the sensitivity of the thermometer.

[2]

Q5. Derive the relationship between the output pressure and the displacement for a flapper-nozzle system. **[2]**