1. (20) A steam-heated evaporator used to concentrate a feed stream by evaporating water is shown in the figure. The mass fraction of solute in the exit stream $x$ is measured and controlled by adjusting the steam flow rate, $S$.

![Evaporator Diagram]

a) (4) What is the MV? CV?

b) (4) What are the possible DV's (up to 4)?

c) (4) What is the sign of the process gain? Explain your reasoning.

d) (4) Should the control valve be fail-open or fail-close? Why?

e) (4) What should be the sign of $K_c$?
2. (40) An integrating process for a tank with a pump in the exit line has

\[ G_p = \frac{-2}{s} \quad G_d = \frac{2}{s} \]

The process is to be controlled by a proportional controller, \( G_c = K_c \)

where \( K_c = -4 \quad K_m = G_m = 2.0 \quad G_v = K_v = 0.5 \)

a) (8) Determine the closed-loop transfer function for a set-point change \( (Y/Y_{sp}) \). What is the offset for a step change in set-point of magnitude M?

b) (10) Sketch the closed-loop response for a step change in set point of magnitude 2. Explain the important features of the response, such as the offset and the time scale.

c) (8) Determine the closed-loop transfer function for a disturbance change. What is the offset for a step change in disturbance of magnitude M in this case?

d) (10) Sketch the closed-loop response for a unit step change in the disturbance \( \frac{1}{s} \). Show the important features of the response (offset and time scale).

e) (4) Comment on the need for integral action in the controller to remove offset for this process in parts (a) and (c).

3. (10) A chemical reactor is forced with changes in flow rate. The steady state volumetric flow rate is 0.5 m³/hr and the steady state exit concentration (controlled variable) is 2.0 mol/L. For a change in flow rate of +0.1 m³/hr, the exit concentration decreases to 1.96. For a flow rate change of -0.1 m³/hr, the exit concentration increases to 2.08.

a) Calculate the process gain (with units) for each change.

b) Discuss why the gains may be different, especially in the context of process linearity (or nonlinearity).
4. (10) Contrast the accuracy and relative cost for the three flowmeter types: 
   (e.g., rank order as low/medium/high)
   a) (4) orifice
   b) (3) venturi
   c) (3) coriolis

5. (20) For the transfer function

   \[ G(s) = \frac{320(1 - 4s)e^{-3s}}{24s^2 + 28s + 4} \]

   a) (6) Calculate the gain, time delay, and time constants.
   b) (6) Does the step response exhibit inverse response, oscillation, or instability? Explain.
   c) (8) Sketch the unit step response, including an approximate time axis. Show all salient features. Use deviation variables.