[3 Hours] **[Total Marks: 80]**

N.B:

1) Question 1 is compulsory. Answer any three questions from the remaining.
2) Assume data if necessary and specify the assumptions clearly
3) Draw neat sketches wherever required
4) Answer to the sub-questions of an individual question should be grouped and written together.

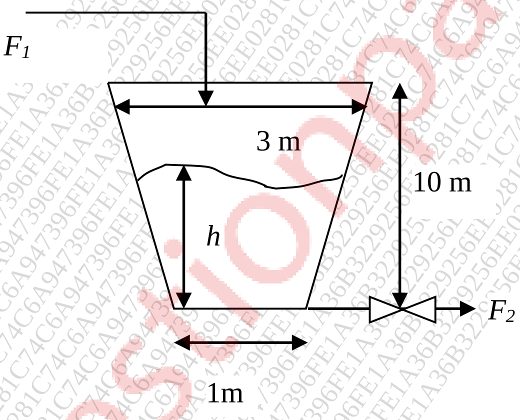
Q.1.a) A liquid surge tank has the following transfer function of [05]

$$\frac{H(s)}{Q_i(s)} = \frac{20}{(100s+1)}$$

The system is operating at the steady state with q_{is}=0.4m^3/s, and h_s=4m when the inlet flow rate fluctuates as a sine wave with an amplitude of 0.1m^3/s and a period of 500 sec. what is the maximum and minimum value of the level after 10 min?

Q.1.b) Explain Phase Margin and Gain Margin? [05]

Q.1.c) Derive the transfer function between liquid level and the inlet stream for the figure mentioned below and outlet flowrate is given by $F_2 = h/5$? [05]



Q.1.d) Consider the Nyquist plot of the following system [05]

$$G_{OL} = \frac{3.5K_c}{s^2+s-2}$$

for what value of Kc will the point -1 be encircled? Will it be clockwise direction? Will the closed loop system be stable?

Q.2.a) The variation of liquid level in a spherical tank with the inlet flowrate q_i and outlet discharging through the valve can be described as

$$\frac{dh}{dt} = \frac{1}{\pi(D-h)h} q_i - C_v\sqrt{h}$$

Derive the transfer function relating the changes in the liquid level h to the changes in the inlet flow rate q_i. The diameter of the tank is D and C_v is the constant of the valve in the outlet line. [10]

Q.2.b) Two streams w_1 and w_2 each at a constant density of 900 kg/m^3, and carrying solute of mass fraction x_1 and x_2 respectively, enter a continuous stirred tank of 2m^3 capacity. At steady-state, w_{1s}=700 kg/min, w_{2s}=300 kg/min, x_{1s}=0.4, and x_{2s}=0.75. Suddenly the inlet flow rate w_2 decreases to 100 kg/min and remains there. Determine an expression for the mass fraction of the solute *x(t)*. Assume that liquid hold up is constant. [10]

Q.3.a) A unit feedback control system has: $G(s) = \frac{80}{s(s+2)(s+20)}$ Generate Bode plot and comment on the stability. [10]

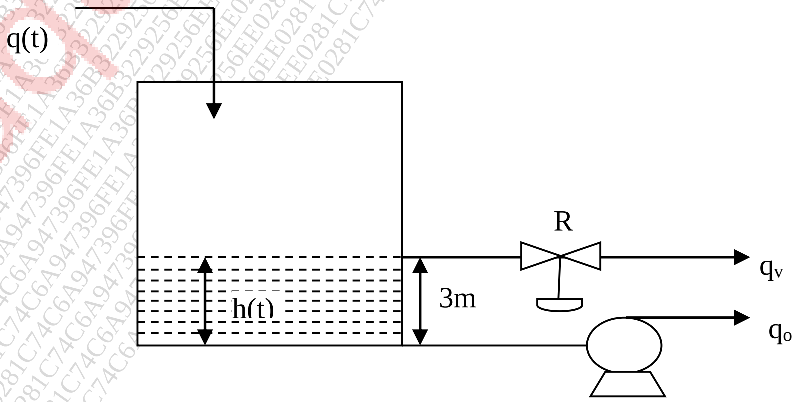
Q.3.b) Consider the following transfer function of a process: [10]

$$G_p(s) = \frac{5e^{-0.2s}}{(2s^2+s+1)}$$

Design a PI controller for the negative feedback loop of the process, based on the Zeigler and Nicholos tuning rules.

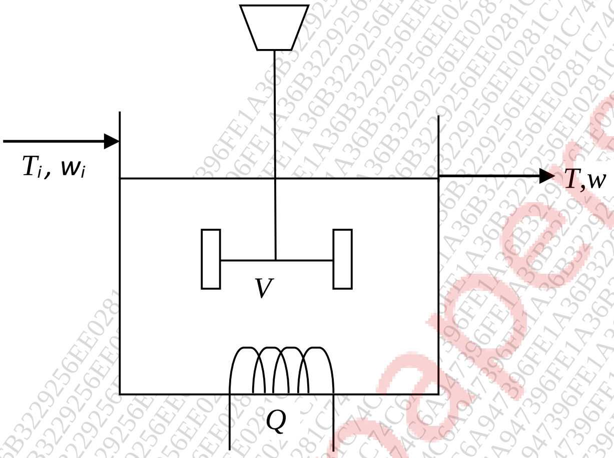
Q.4.a) A composition sensor is used to continually monitor the contaminant level in a liquid stream. The transfer function of the sensor is given by $\frac{C_m(s)}{C(s)} = \frac{1}{12s+1}$ where C is the deviation in the actual contamination, and C_m is the deviation in the measured value. The process is at steady state initially, with the contamination at 5 *ppm*, when the input start increasing as *c(t)*=5+0.2*t*, where *t* is in sec. An alarm sounds if the measured value exceeds the environmental limit of 7 *ppm*. After the actual contamination exceeds the limit, how long will it take for the alarm to sound? [10]

Q.4.b) Derive the transfer function *H*(s)/*Q*(s) for the liquid level system shown in the figure when the (i) The tank level operates about the steady state values of h_s=1 m, (ii) The tank level operates about the steady state value of h_s=3 m. The pump removes water at a constant rate of 10 m^3/min. The rate is independent of head. The cross sectional area (*A*) of tank 1 m^2 and resistance *R* is 0.5m /(m^3/min).[10]



Q.5.a) Using Routh Criteria determine the limits of K_c for the stability of the system with following open loop transfer function. $G(s) = \dfrac{K_c}{(s+1)(0.5s+1)(s/3+1)}$ [10]

Q.5.b) A continuous stirred-tank heating system shown in the figure below. The liquid inlet stream consists of a single component with a mass flow rate w_i and a inlet temperature T_i. The tank contents are agitated and heated using a electrical heater that provides a heating rate Q, density and specific heat capacity of the mixture is constant. Carry out the degrees of freedom analysis, also state the disturbance and manipulated variables, for following two cases (i) holdup is constant, (ii) holdup is varying [10]



Q.6.a) Consider a liquid phase, irreversible, first order reaction taking place in a CSTR, where the reactant A gets converted to product B. The reaction is cooled by coolant passing through a coil at a temperature T_c. Develop a state space model, assuming volume is constant, if both, the concentration of A and the reaction temperature T, are required to be monitored. Following is the mass & energy balance equations. [10]

volumetric flow rate of liquid: q m^3/hr
kinetic rate constant for first order:-k $1/hr$
density of liquid: ρ kg/m^3
volume of reactor: V m^3
concentration of reactant in feed: C_{Ai}, mol/m^3
heat capacity of liquid: C $J/kg.K$
heat transfer coeff. of the coil: U $J/m^2.hr.K$
surface area of cooling coil: A m^2

$$V\frac{dC_A}{dt} = q(C_{Ai} - C_A) - VkC_A$$

$$V\rho C_p\frac{dT}{dt} = wC(T_i - T) + (-\Delta H_R)VkC_A + UA(T - T_c)$$

Q.6.b) Obtain relation between $Y_{sp}(s)/Y(s)$? [10]