Homework 1

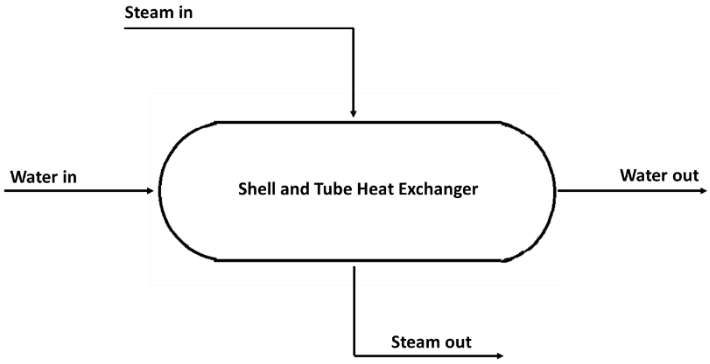
Instructions:

- Total of 8 questions:
- HW1 will count for 5% of the overall marks.
- Grading here will be out of 70 marks
- The HW should be submitted on MS Team. The deadline is Friday 21st Jan 2022 Midnight.
- TA help session can be arranged based on your requests.

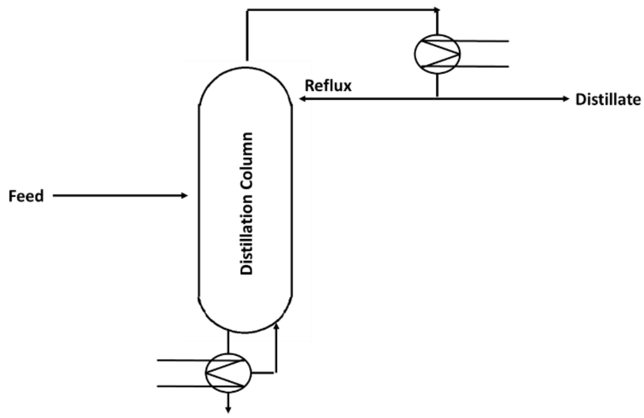
1. **Marks: [5]**

Propose a feedback control method and feedforward control method with schematics diagrams for the following: Choose appropriate MV. You can just choose 1 MV for each question.

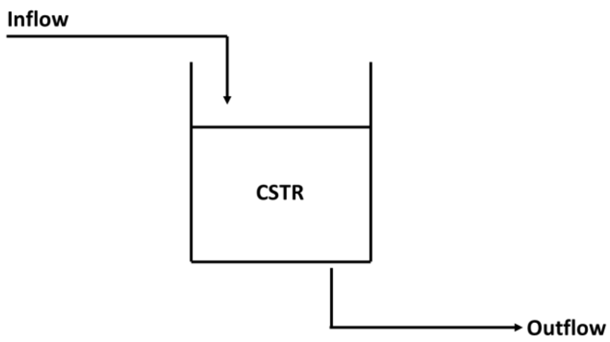
a) To maintain the exit temperature of water **(water out)** in the shell and tube heat exchanger.



b) To maintain the production of distillate (**composition**) with the required percentage of the product.



c) To maintain the height of liquid column in the CSTR. Choose appropriate MV.



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2. Marks: [10]

Tutorial 2 covered the derivation of 2.4.6 "The Continuous Stirred-Tank Reactor (CSTR)" equations. The following equations were derived:

$$V\frac{dc_{\mathrm{A}}}{dt} = q(c_{\mathrm{Ai}} - c_{\mathrm{A}}) - Vkc_{\mathrm{A}} \qquad 1$$

$$V\rho C\frac{dT}{dt} = wC(T_{\mathrm{i}} - T) + (-\Delta H_{\mathrm{R}})Vkc_{\mathrm{A}} + UA(T_{\mathrm{c}} - T) \qquad 2$$

Where the reaction constant is Arrhenius function of temperature, i.e.

$$k = k_0 e^{-E/RT} \qquad 3$$

a) Explain each term present in equations 1 and 2 along with their units. [2]
b) Is this linear or non-linear model? [1]
c) Solve example 2.5 (Page no. – 27,4th edition) by simulating the system using ode15s using the values given in Table 2.3. [7]

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3. **Laplace Transform: [10 (3+3+4)]**

a. Let $f(s) = \frac{(s-1)(s+1)}{s(s+3)(s-4)}$. Find $f(t=0)$.

b. Find the solution of the following set of equations:

$$\frac{dx_1}{dt} = 2x_1 + x_2 + 1; \;\; x_1(0) = 0$$

$$\frac{dx_2}{dt} = 2x_1 + 3x_2 + e^t; \;\; x_2(0) = 0$$

c. Solve the following equation for $x(t)$

$$\frac{dx}{dt} = \int_0^t x(t)dt - t$$

$$x(0) = 3$$

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4. **Marks: 35**

For the given system (Figure 1) of the tank, answer the following questions. Where F_{in} and F_{out} are volumetric flow rate.

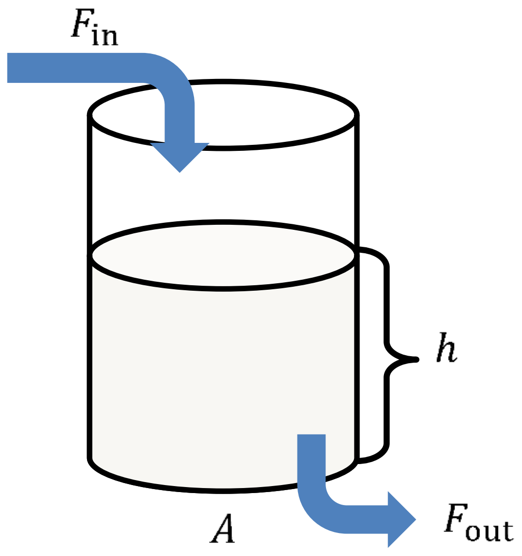

Figure 1

System#1 F_{out} is constant:

a. What will be the steady state model for the tank system? [1]

b. What will be the dynamic model for the tank system if the density of the fluid is assumed to be constant? [2]

c. For $A = 1\mathrm{m}^2$, $F_{\mathrm{in}} = 1\mathrm{m}^3/\mathrm{h}$ and $F_{\mathrm{out}} = 1.1\mathrm{m}^3/\mathrm{h}$, when will be the tank become empty if it is initially filled up to $1\mathrm{m}$. Find the solution analytically. [2]

<u>System#2 F_{out} is linear function of height ($F_{\mathrm{out}} = \alpha_1 h$)</u>

d. If $\mathrm{F}_{\mathrm{out}} = \alpha_1 h$ where $\alpha_1 = 0.001$, **[10 marks, provided the plot is good]**
   i. Find the analytical solution of the model equation. What is the time constant.
   ii. Using ode15s, find the numerical solution and plot both the profiles on the same plot (time axis for the plot should be at least 8 times the time constant).
   iii. What will be the steady state value of height of the tank? Does analytical solution agree with the numerical solution? If not, check your calculations.

   Instructions for plotting: Plots should be neat with proper axis labels and tiles along with legends. Unfinished/unreadable plots will lead to **0 marks** for the entire questions d.

<u>System#3 F_{out} is nonlinear function of height ($F_{\mathrm{out}} = \alpha_1 h$)</u>

e. If $\mathrm{F}_{\mathrm{out}} = \alpha_2\sqrt{h}$ where $\alpha_2 = 0.0005$, **[9 marks, provided the plot is good and correct]**
   i. Is it possible to get analytical solution of the model equation? [-]
   ii. Using ode15s, find the numerical solution and plot both the profiles on the same plot (time axis for the plot should be at least 8 times the time constant).
   iii. What will be the steady state value of height of the tank? Does analytical solution agree with the numerical solution? If not, check your calculations.

   Instructions for plotting: Plots should be neat with proper axis labels and tiles along with legends. Unfinished/unreadable plots will lead to **0 marks** for the entire questions d.

f. Which of the system is self-regulating? [1]
   (System#1 (constant F_{out}), System#2, System#3)

g. For system#3, how does the height profile will change if we change the $\mathrm{F}_{\mathrm{in}} = \frac{1.1\mathrm{m}^3}{\mathrm{h}}$ (from its previous value of 1 m3/h) after it has reached the steady state? What will be the new steady state height? How much time (let's call it τ_{app}) does it take to reach the 63% of the difference in the steady state height? How much percentage difference in the heights will be covered after time $3\tau_{\mathrm{app}}$? [5]

h. For system#3, how does the height profile will change if, $\mathrm{F}_{\mathrm{in}} = 0.9\mathrm{m}^3/\mathrm{h}$ (from its previous value of F_{in} = 1 m^3/h)? What will be the new steady state height? How much time (let's call it τ_{app}) does it take to reach the 63% of the difference in the steady state height? How much percentage difference in the heights will be covered after time $3\tau_{\mathrm{app}}$? [5]

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5. **Marks: [4]**

Take the following question from the Seborg Book Chapter #2

2.3 Two tanks are connected together in the following unusual way in Fig. E2.3.

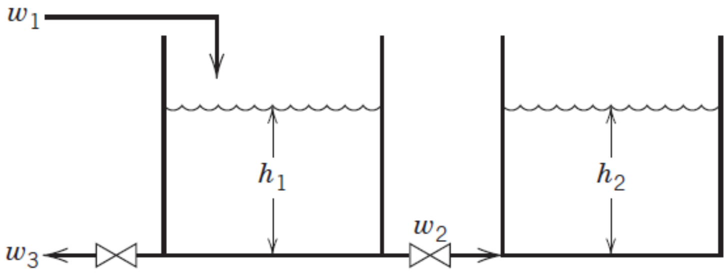

Figure E2.3

(a) Develop a model for this system that can be used to find h_1, h_2, w_2, and w_3 as functions of time for any given variations in inputs.

(b) Perform a degrees of freedom analysis. Identify all input and output variables.

Notes:

The density of the incoming liquid, ρ, is constant.
The cross-sectional areas of the two tanks are A_1 and A_2.
w_2 is positive for flow from Tank 1 to Tank 2.
The two valves are linear with resistances R_2 and R_3.

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Take the following questions from the Seborg Book Chapter #1

6. **Marks: [2]**

1.3 In addition to a thermostatically operated home heating system, identify two other feedback control systems that can be found in most residences. Describe briefly how each of them works; include sensor, actuator, and controller information.

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7. **Marks: [2]**

1.9 Two flow control loops are shown in Fig. E1.9. Indicate whether each system is either a feedback or a feedforward control system. Justify your answer. It can be assumed that the distance between the flow transmitter (FT) and the control valve is quite small in each system.

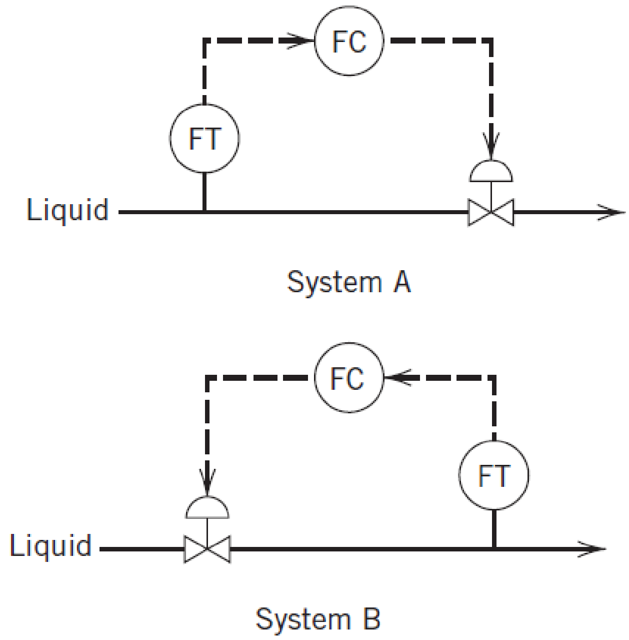

Figure E1.9

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8. Marks: [2]

1.10 In a thermostat control system for a home heating system,

(a) Identify the manipulated variable

(b) Identify the controlled variable

(c) How is the manipulated variable adjusted?

(d) Name one important disturbance (it must change with respect to time).

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