Process Control, 3P4

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Note:

- You may bring in any printed materials to the midterm; any textbooks, any papers, *etc*.
- You may use any calculator during the midterm.
- **To help us with grading, please start each question on a new page, but use both sides of each page in your booklet**.
- You may answer the questions in any order on all pages of the answer booklet.
- This exam requires that you apply the material you have learned here in 3P to new, unfamiliar situations, which is the level of thinking we start to require from students that will be graduating or working in co-ops in a year from now.
- Any ambiguity or lack of clarity in a question may be resolved by making a suitable and justifiable assumption, and continuing to answer the question with that assumption(s).
- **Total marks**: 66 marks, 12.5% of course grade.
- Total time: 2 hours (nominally), though you have "infinite" time to complete it. There are 4 pages on the exam, please ensure your copy is complete.

Question 1 [11 = 1 + 5 + 2 + 3]

1. The Laplace transform and its inverse are:
   (a) the same
   (b) unique functions
   (c) defined at values for $t < 0$
   (d) only defined for complex functions of s
2. Give the time-domain solution for $h(t) = \ldots$ for the following differential equation system

$$\tau \frac{dh}{dt} = Km(t) - h(t) \qquad \text{where } m(t) = \begin{cases} 0 & \text{for}\, t < 2 \\ 3 & \text{for}\, t \geq 2 \end{cases}$$

   You may assume that $h(t)$ and input $m(t)$ are deviation variables.
3. Give an example of a process with zero gain.
4. Sketch a rough time-domain plot of $y(t)$ for the following expression written in Laplace transform. The plot must include suitable numeric values on the axes.

$$y(s) = \frac{6e^{-4s}}{s\,(9s+1)}$$

Question 2 [11 = 3 + 5 + 2 + 1]

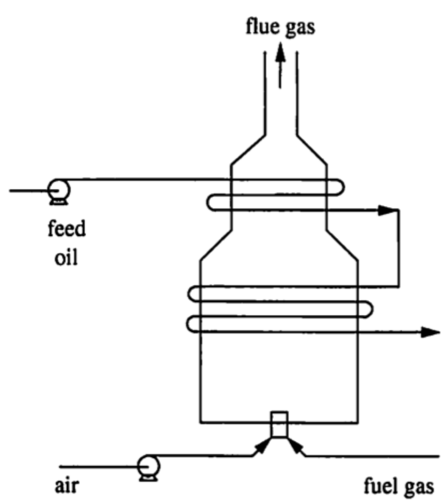
An exothermic stirred tank reactor has an inlet feed, given by flow F. The outlet temperature, T_{out} shows a first order dynamic response when increasing this flow.

Downstream from the reactor is a heat exchanger, but the pipe connection from the stirred tank to the heat exchanger has approximately θ seconds of delay. The heat exchanger operates by using chilled water, which enters at a constant flow rate of q. The hot stream from the reactor enters the heat exchanger and then this exits with temperature, T. The dynamics relating the hot stream inlet temperature to the outlet temperature, T, are also first order.

1. Draw a rough engineering diagram of the system (e.g. a piping an instrumentation diagram) with all the relevant symbols.
2. Draw a block diagram of the system, using one block per unit operation, starting from the feed flow rate F as the input, up to the exiting temperature, T. In your block diagram enter all the transfer function and dynamic information you know, using appropriate symbolic representation learned in the course so far.
3. Write a single symbolic transfer function relating the incoming flow, F to the exiting temperature, T.
4. What will be the order of the transfer function in part 3?

Question 3 [8 = 4 + 4]

Below is a diagram of fired heater used to pre-heat an oil stream before it is used in a different part of the process.

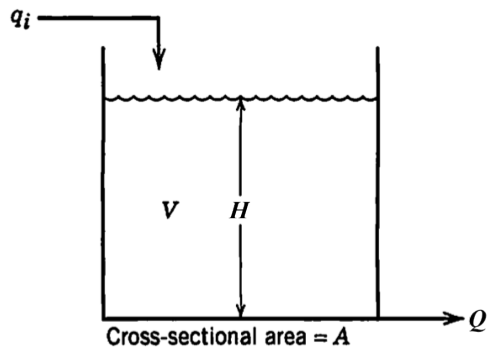


1. State 2 control objectives that would be considered when designing and forming the control loops for this process.
2. For one of your chosen objectives, very clearly specify what the manipulated variable and what the controlled variable would be, and justify (explain) your choice clearly.

Question 4 [14 = 5 + 2 + 7]

The Laplace transfer function for the tank height, H, when the outlet flow, Q, is varied is given by:

$$\frac{H'(s)}{Q'(s)} = -\frac{100}{20s + 1}$$



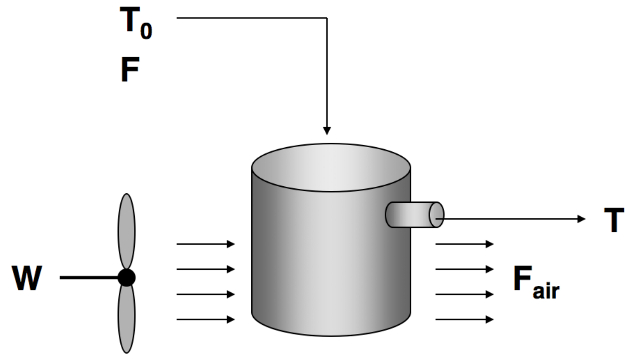
The height is measured in inches, and the outlet flow, Q is measured in liters per minute, and the inlet flow is q_i, a constant value. The variables Q' and H' are deviation variables.

1. What is the gain of the process, including units? In your answer, explain why the gain's value makes sense.
2. What is the time constant of the process, including units?
3. A step change, of unit magnitude is made to the outlet flow. What **change** in height will be observed in the tank after:
   (a) 0 minutes
   (b) 20 minutes
   (c) 40 minutes
   (d) 60 minutes
   (e) 80 minutes
   (f) 100 minutes?

   Draw a plot of the tank's height response, $H'(t)$, based on your numeric values above. Mark where the 6 points are on your plot.

Question 5 [19 = 5 + 1 + 10 + 3]

A metallic stirred tank has a hot stream flowing into it, at temperature T_0; the stream leaving has a temperature, T. We want to judge how effective it will be to cool the tank when using a fan; since the inlet temperature is always varying, and we have to control the outlet temperature.



1. Show the ODE describing the temperature leaving the tank is:

$$V\rho C_p \frac{dT}{dt} = F\rho C_p(T_0 - T) - UA(T - T_{\text{amb}})$$

   where the heat capacity is C_p, the liquid density in the tank is ρ, the constant volume in the tank is V, the area available for heat transfer is A, the heat transfer coefficient is U, and the (assumed constant) ambient temperature is T_{amb}. The inlet flow, F is also assumed constant.

   In your derivation, be clear on which assumptions you are making.

2. What are the units for each term in the ODE?

3. The motor powering the fan has a DC coil, so we can adjust the voltage, which will affect the amount of heat transfer. It has been found to be of the form $U = aW^{0.5}$, where W is the voltage, and a is a constant.

   As a step towards our goal, show how you would linearize the term: $UA(T - T_{\text{amb}})$.

4. We want to design a control system that will solve the goals of this problem.

   (a) What will be the manipulated variable?

   (b) What will be the controlled variable?

   (c) What will be considered the disturbance?

Question 6 [3]

You are working at a waste-water treatment plant, and the operator is complaining that the amount of oxygen in the water (dissolved oxygen level) is too low, below the required amount. He said: “the feedback control system is broken; please fix it”.

What **list of specific instructions** will you give to your summer student to go investigate whether the control system actually is broken?

The end.