
The objectives for this assignment are:

1. to continue building your first-principles process modelling skills,
2. to continue building your MATLAB / Simulink skills for process simulation.

You may work together in groups to complete the assignment, but you must hand in your own assignment solution. **If you work with a group, please identify the people that you worked with on your solution**. Computer printout may be included with your solution as an appendix, but please do not provide these as your entire solution report.

In the last assignment, we considered brewing beer in a spherical kettle (see Figure **??**). After a batch of beer is brewed, the vessel must be thoroughly cleaned before it can be used to brew the next batch. This is done by flushing the kettle using a mixture of hot water and a special cleaning solution. Hot water enters the vessel at a rate of $F_w \; \frac{m^3}{hr}$ and the cleaning solution at $F_c \; \frac{m^3}{hr}$. The flow of cleaning solution is controlled by an equal percentage valve, which approximately follows the flow relationship:

$$F_c = k_c P_c^2,$$

where P_c is the position if the valve on the cleaning solution line given in the unit % *open*. The liquid leaves the tank via a draining line and the flow through this line follows a standard square-root law:

$$F_o = k_o \sqrt{h},$$

where h is the height of liquid in the tank (m) and F_o is the flow out of the tank ($\frac{m^3}{hr}$). Recall that the tank is 2 m in diameter. The cleaning solution concentration of the fluid leaving the tank is X_o, given as a weight fraction. Note that the density of the cleaning solution is $\rho_c = 1010 \; \frac{kg}{m^3}$.

The values of key process variables at steady-state operation, when the kettle is half full, are:

variable	steady-state value
F_w	150.0 m^3/hr
F_c	50 m^3/hr
h	1.0 m
P_c	50%

Please answer each of the following questions, showing all of your work:

1. (5 points) Classify the process variables.
2. (10 points) Develop a dynamic model of the process.
3. (10 points) Linearize your model about the given steady-state operation.
4. (5 points) Determine the *Degrees of Freedom* available in your model. What is the maximum number of input variables that you can specify to get a unique solution?
5. (20 points) Compare the transient response of the linear and nonlinear models of the liquid level and cleaning solution concentration in the tank for:
   a) a $\pm 10\%$ change in hot water flow-rate F_w. Comment on your results.
   b) a $\pm 1\%$ change in hot water flow-rate F_w. Comment on your results.
   c) a $\pm 25\%$ change in cleaner valve position P_c. Comment on your results.
   d) a $\pm 1\%$ change in cleaner valve position P_c. Comment on your results.

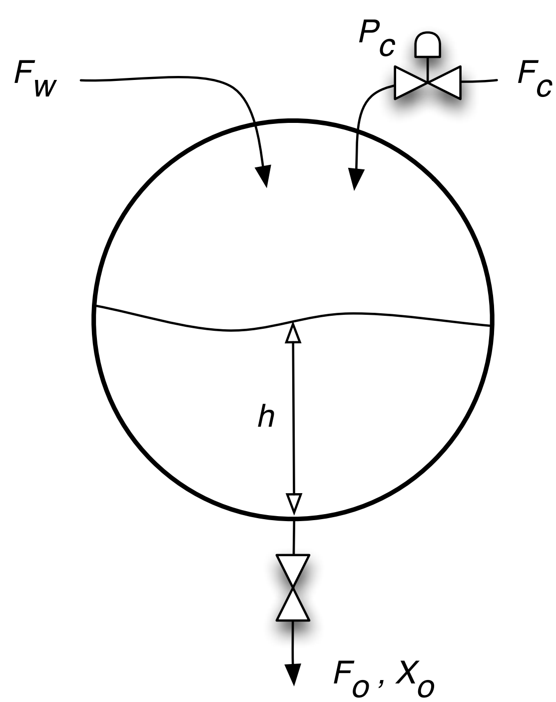

Figure 1: ACME beer brewing kettle