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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.

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In the last assignment, we considered the conical surge tank that the ACME Chocolate Company uses in their production line where they make their truffles. In this assignment we will extend the model to include the steam jacket that is used to keep the chocolate warm and the valves that are used for flow control. The complete tank system is shown in Figure 1. In this process vessel, liquid chocolate is fed into the tank near the top of the tank at a rate of $F_{in}$ and a temperature $T_{in}$. The tank is heated using a steam jacket to ensure that the chocolate is at the proper temperature for coating the truffles. The warm chocolate exits the tank through a control valve at the bottom of the tank. The heating jacket is supplied with 30 *psig* saturated steam, which condenses and exits the jacket near the bottom of the tank through a condensate valve.

The tank is 2 $m$ in height and 2 $m$ in diameter at the tank top. Both valves are linear and as a result:

1. the outlet flow of the warm chocolate follows the relationship $F_{out} = k\ P_{out}\ \sqrt{h}$ (note that $P_{out}$ is the valve position for the exit chocolate stream),
2. the condensate flows the relationship $F_c = k_c\ P_c$ (note that $P_c$ is the valve position of the condensate valve).

The density of the warm chocolate is $\rho = 1100\ \frac{kg}{m^3}$. Heat capacity data is provided on the attached page.

The value of key process variables at normal steady-state operation for this surge tank is:

| variable | steady-state value |
|---|---|
| $F_{in}$ | 150.0 $l/min$ |
| $F_s$ | 68.75 $kg/hr$ |
| $h$ | 1.0 $m$ |
| $P_c$ | 50% |
| $P_{out}$ | 50% |
| $T_{in}$ | 30°$C$ |

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 normal 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 chocolate level in the tank and outlet temperature of the chocolate from the tank:
   a) a ±10% change in inlet flow rate $F_{in}$. Comment on your results.
   b) a ±1% change in inlet flow rate $F_{in}$. Comment on your results.
   c) a ±10% change in condensate valve position $P_c$. Comment on your results.
   d) a ±1% change in condensate valve position $P_c$. Comment on your results.

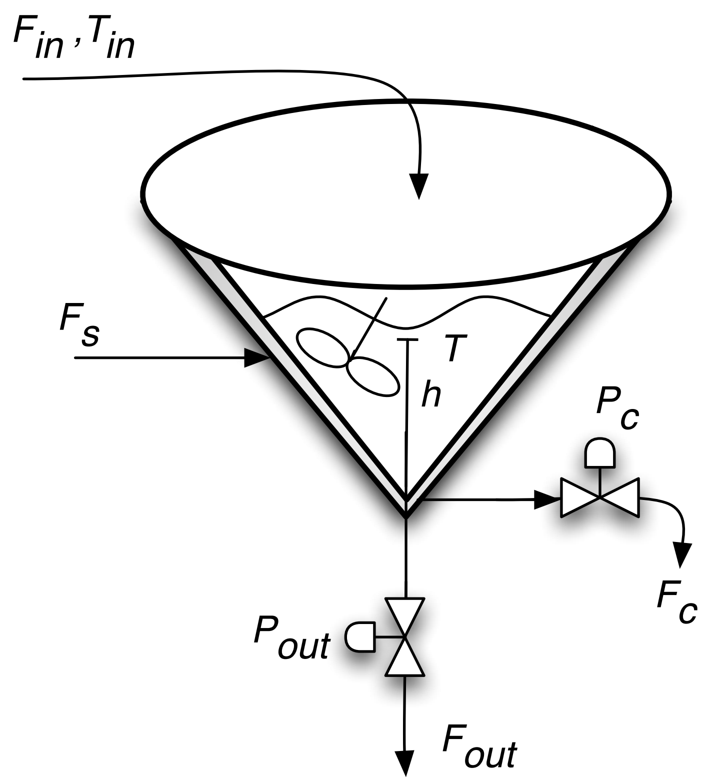



Figure 1: ACME jacketed surge tank

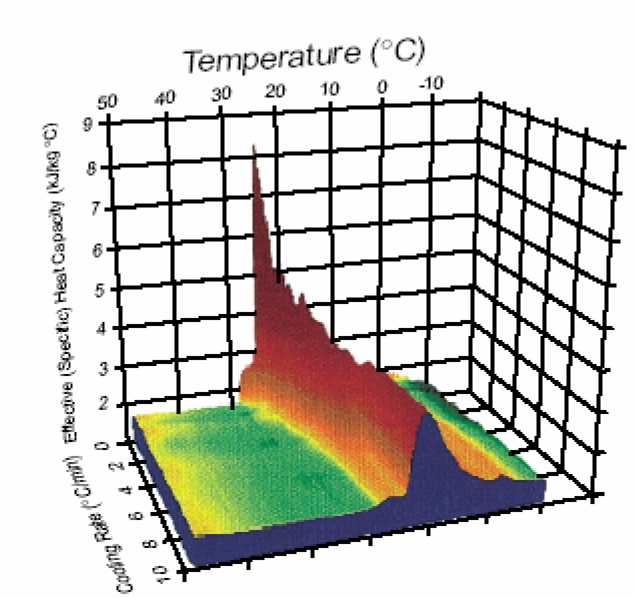
# Materials Science of Chocolate

Chocolate is a complex material, and its properties depend on its exact composition and the processing conditions (especially temperature and stress). This is the subject of a lot of research, as summarized in a recent article (P. Fryer and K. Pinschower, *MRS Bulletin*, 25 (December 2000).)

The melting point of chocolate is critical for the correct taste. If the melting point is too high (above the temperature of the mouth), the chocolate tastes gritty because of the residual solid component.

The heat capacity of milk chocolate cooled at different rates has been determined using differential scanning calorimetry (Figure 1). The effective heat capacity has a peak due to the chocolate melting (enthalpy of fusion), and this peak moves to lower temperatures as the cooling rate increases. Generally, the lower melting point is a good thing because it gives a better melt-in-the-mouth texture. However, milk chocolate melts at a lower temperature than dark chocolate, and the chocolatiers have to be sure not to lower the melting point so much that the milk chocolate product melts on the counter.

Figure 1: Effective heat capacity of milk chocolate as a function of temperature, after different cooling rates. From P. Fryer and K. Pinschower, *MRS Bulletin*, 25 (December 2000).




***Source:***

***Professor Mary Anne White (Dalhousie University)***
***CHEM/PHYC 3303 - Materials Science***
***http://myweb.dal.ca/mawhite/3303***