CPN321 – T1

2019

Before attempting this tutorial, read Seborg et al 1.1-1.3, 2.1-2.3

1 Pool control

From Seborg et al, problem 1.8 I M Appelpolscher, supervisor of the process control group of the Ideal Gas Company, has installed a $25\,\mathrm{m}\times 40\,\mathrm{m}\times 5\,\mathrm{m}$ swimming pool in his backyard. The pool contains level and temperature sensors used with feedback controllers to maintain the pool level and temperature at desired values. Appelpolscher is satisfied with the level control system, but he feels that the addition of one or more feedforward controllers would help maintain the pool temperature nearly constant. As a new member of the process control group, you have been selected to check Appelpolscher's mathematical analysis and to give your advice. The following information may or may not be pertinent to your analysis:

- Appelpolscher is particular about cleanliness and thus has a high-capacity pump that continually recirculates the water through an activated charcoal filter.
- The pool is equipped with a natural gas-fired heater that adds heat to the pool at a rate $Q(t)$ that is directly proportional to the output signal from the controller $p(t)$.
- There is a leak in the pool, which Appelpolscher has determined is constant and equal to a volumetric flowrate F. The liquid-level control system adds water from the city supply system to maintain the level in the pool exactly at the specified level. The temperature of the water in the city system is T_W, a variable.
- A significant amount of heat is lost by conduction to the surrounding ground, which has a constant, year-round temperature T_G. Experimental tests by Appelpolscher showed that essentially all of the temperature drop between the pool and the ground occurred across the homogeneous layer of gravel that surrounds the pool. The gravel thickness is Δx_G and the overall thermal conductivity is k_G.

- The main challenge to Appelpolscher's modelling ability was the heat loss term accounting for convection, conduction, radiation and evaporation to the atmosphere. He determined that the heat losses per unit area of open water could be represented by
$$\frac{Q_l}{A} = U(T_P - T_a)$$
where T_P and T_a are the temperatures of the pool and the air respectively and U is an overall heat transfer coefficient in suitable units.

Appelpolscher's detailed model included radiation losses and heat generation due to added chemicals, but he determined that these terms were negligible.

1. Draw a schematic diagram for the pool and all control equipment. Show all inputs and outputs, including all disturbance variables.
2. What additional variables would have to be measured to add feedforward control to the existing pool temperature feedback controller?
3. Write a steady-state energy balance. How can you determine which of the disturbance variables you listed in part 1 are most/least likely to be important?

2 Compressible liquid

From Luyben, problem 3.7. Consider the isothermal hydraulic system sketched in Figure 1. A slightly compressible polymer liquid is pumped by a constant-speed, positive displacement pump so that the mass flow rate W_1 is constant. Liquid density is given by
$$\rho = \rho_0 + \beta(P - P_0),$$
where ρ_0, β and P_0 are constant, ρ is the density and P is the pressure.

Liquid is pumped through three resistances where the pressure drop is proportional to the square of the mass flow ($\Delta P = RW^2$). A surge tank of volume V is located between R_1 and R_2 and is full of liquid. The pressure downstream of R_3 is atmospheric.

1. Derive the differential equation that gives the pressure P in the tank as a function of time and W_1.
2. Find the steady state value of the tank pressure P.

3 Air-conditioning system

Consider a typical split-unit air-conditioning system used to regulate temperature in a (closed) room on a hot day. The system consists of a "cold side" or evaporator unit installed inside a room, and a "hot side" or compressor unit installed outside. For the purposes of this question you may neglect the inner workings of these units and assume that the cold side unit moves heat from the room to refrigerant and the hot side moves heat from the refrigerant to the outside air.

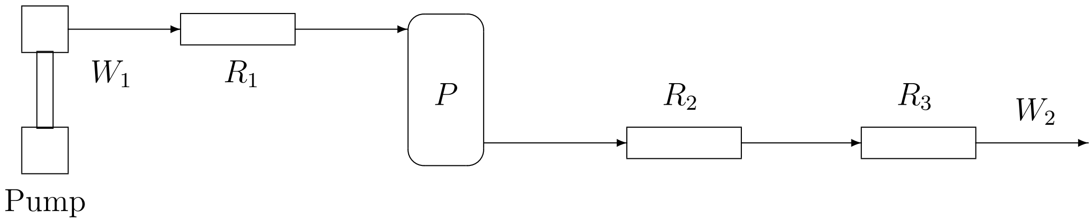


Figure 1: System with compressible liquid

- Sketch a diagram showing the room with the hot and cold side units. Add the symbols you will use for modelling the system to your diagram.
- Develop a rough model (use $f(x)$ liberally) of the interactions between variables.
- Identify the control objectives, the available measurements, and the manipulated variables. What are the external disturbances for such a system? Is this a SISO (Single Input Single Output) system?
- Develop a feedback control configuration to achieve your control objectives. Determine which variables to control, measure and manipulate.

4 CSTRs

Consider a system of two continuous stirred tank reactors in series, as shown in Figure 2, where the following endothermic reaction takes place:

$$\mathrm{A} + \text{catalyst} \rightarrow \mathrm{B}$$

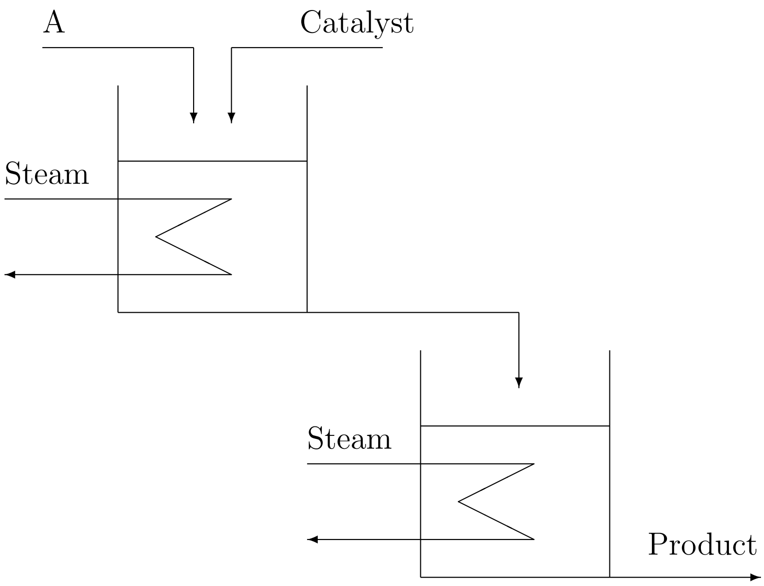


Figure 2: CSTRs in series

1. Identify the control objectives for the operation of the two CSTRs.

2. Classify the variables of the system into inputs and outputs and subsequently classify the inputs into disturbances and manipulated variables and the outputs into measured and unmeasured outputs.

3. Develop a control configuration that would satisfy the control objectives stated using a composition analyser at the exit stream of the second CSTR

4. Set up the equations describing the behaviour of the open loop system (ie the system without any control). Confirm that your model is correctly specified.

5 Degrees of freedom

Consider the example process given on the next page. If we disregard the assignment of symbols as parameters, inputs or outputs we find that there are 27 symbols and 11 equations, so that there are 16 degrees of freedom.

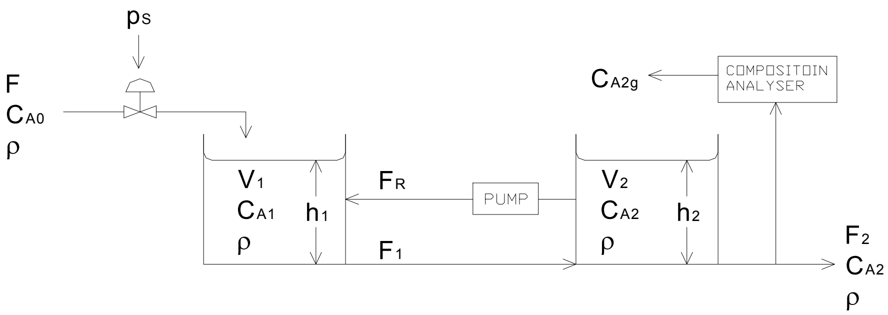
Answer the following questions, showing your work

1. How many different ways are there to assign these degrees of freedom? For example, if we have three symbols A, B and C and we have two degrees of freedom, there are 3 ways of specifying the values so that the degrees of freedom are zero (A and B; B and C; or A and C). Remember we can calculate this using combination.

2. Not all of these specifications are consistent. For example, if $A + B = C$, we cannot specify A, B and C independently. Write down as many consistent specifications as you can for the big model – at least three.

3. Symbols that cannot change once the system has been built are called parameters. In the example, there are 14 parameters (F_R is assumed to be a fixed property of the pump). Once they have been specified, this leaves 2 degrees of freedom. In how many ways can the remaining degrees of freedom be specified consistently?

PRO FORMA SUMMARY OF A PROCESS MODEL



No.	Output variables (11)	Process equations **(using 27 symbols)**	**Process parameters (14)**	**Specified input variables (2)**
1	$V_1(t)$	$F(t)-F_1(t)+F_R=\frac{d}{dt}[V_1(t)]$	F_R	
2	$V_2(t)$	$F_1(t)-F_R-F_2(t)=\frac{d}{dt}[V_2(t)]$		
3	C_{A1} (t)	$F(t)C_{A0}(t)+F_RC_{A2}(t)-F_1(t)C_{A1}(t)-k_RV_1(t)C_{A1}(t)=\frac{d}{dt}[V_1(t)C_{A1}(t)]$	k_R	$C_{Ao}(t)$
4	$C_{A2}(t)$	$F_1(t)C_{A1}(t)-F_RC_{A2}(t)-F_2(t)C_{A2}(t)-k_RV_2(t)C_{A2}(t)=\frac{d}{dt}[V_2(t)C_{A2}(t)]$		
5	$h_1(t)$	$V_1(t)=A_1h_1(t)$	A_1	
6	$h_2(t)$	$V_2(t)=A_2h_2(t)$	A_2	
7	$F(t)$	$F(t)=k_V\sqrt{x(t)}\sqrt{\frac{\Delta p}{\rho}}$	k_v , Δp, ρ	
8	$F_1(t)$	$F_1(t)=k_{F1}\sqrt{\rho g(h_1(t)-h_2(t))}$	k_{F1} , g	
9	$F_2(t)$	$F_2(t)=k_{F2}\sqrt{\rho g(h_2(t))}$	k_{F2}	
10	x(t)	$\tau^2\frac{d^2x(t)}{dt^2}+2\zeta\tau\frac{dx(t)}{dt}+x(t)=K_Pp_s(t)$	τ, ς, K_p,	$p_s(t)$
11	$C_{A2g}(t)$	$C_{A2g}=C_{A2}(t-t_{DT})$	t_{DT}	
TOTAL:	**Unknowns: 11**	**Equations: 11**		