Process control – Exercise 1

1 Control of mixer and reactor process

The process flowsheet is shown in Figure 1. Before feeding to the reactor, reactant A needs to be diluted with water to a specified concentration. The mixing with water releases a lot of heat. The main dilution is done in the mixing tank which is also cooled. The conditions in the mixing tank make it difficult to install a concentration sensor here. The mixture is further cooled in a heat exchanger before the concentration is "fine tuned" (and measured) before entering the reactor. The reactor temperature should be kept constant. The flowrate of reactant A is measured.

a) Classify the variables (CVs, MVs and important DV)

b) Suggest a control structure, which includes use of two ratio controllers

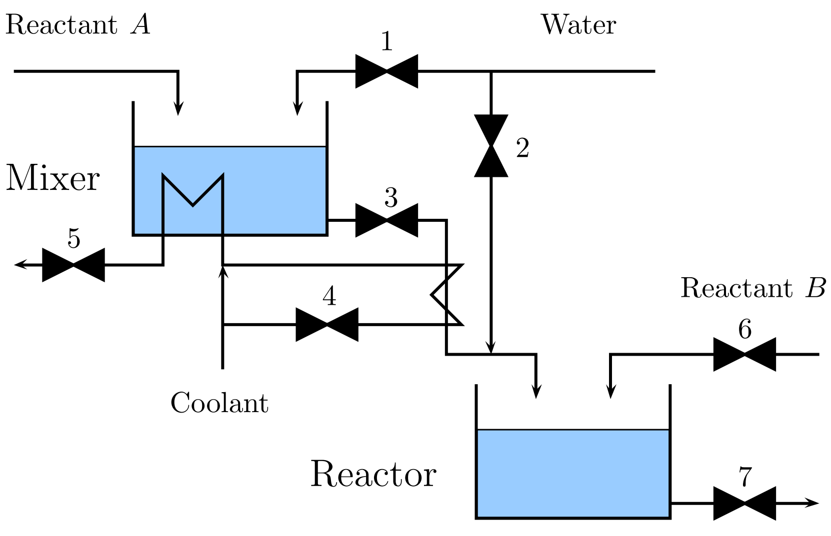


Figure 1: Control of mixer/reactor process

2 Temperature control in a tank (similar to control of shower)

The feed to a continuous process enters through a long pipeline, see Figure 2. We assume perfect mixing and constant volume in the tank. The heat loss is neglected. We want to consider how the tank temperature (T) changes when the inlet temperature T_0 varies. Note: *Green line* means that you should also plot your result by hand by extending the green line in the figures below.

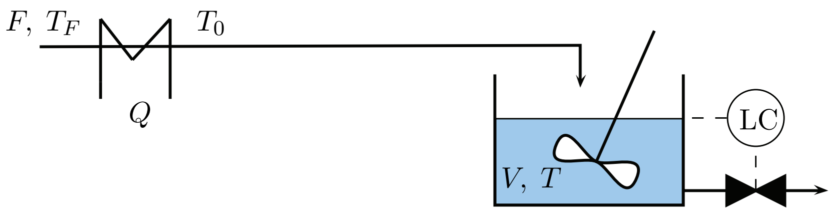


Figure 2: Pipe and tank process

2.1 Dynamics

1. Formulate the (dynamic) energy balance for the tank (without the pipeline).
2. Sketch the time response in T to a step change in T_0 (including the pipeline). Complete the green line in Figure 3a.
3. Find the gain (k), time constant (τ) and delay (θ) for this process (with T_0 as input and T as output).

Table 1: Data

parameter	symbol	value	unit
mass flow	(F)	10	$\mathrm{kg\,s^{-1}}$
water density	(ρ)	1000	$\mathrm{kg\,m^{-3}}$
pipe area	(A)	0.01	$\mathrm{m^2}$
pipe length	(L)	100	m
tank volume	(V)	0.2	$\mathrm{m^3}$

2.2 Control

4. In practice, we can adjust T by use of an electrical heater (Q). Make a flow sheet and show how to control the temperature in the tank ($y = T$) using the heater with a single feedback controller.
5. The time delay due to the long pipe can be a problem for good control of T. Suggest an improved control structure (with cascade) based on measuring also T_0. (Comment: The outer cascade is intended, for example, to correct for possible heat loss in the pipe and in the tank).

6. Consider a step disturbance in T_F (at $t = 100$ s for example).
   - What is the best possible control (ideal control) one can get for T for this system using feedback based on measuring T? Complete the green line in Figure 3b.
   - What if we can measure T_0?
7. What if we can measure $T_F(d)$ and use feedforward control; what is the best possible?

2.3 Simulation (Extra: will be demonstrated in class in week 2)

Simulate case 4 with $y = T$ for a step disturbance (d) in T_F using a PI controller with gain K_c and integral time τ_I [s]. The input is the scaled heat input, $u = \Delta Q/(FC_p)$.

Use the Simulink file `tunepid1_ex1` (see example code at the bottom):

- Note that we consider deviation variables and we can write $\Delta T_0 = u + d$, where $d = \Delta T_F$ and $u = \Delta Q/(FC_p)$ (derived from energy balance for the heater).
- Some dynamics have been added for the heater (first-order response with time constant 1 s).
- Disturbances. d at $t = 100$ s: T_F goes up by 1 K.

Consider the following cases:

8. No control (`Kc=0` which gives $u = 0$). Note: Should be the same as in Task 2. Complete the green line in Figure 3a.
9. P-control (keep `taui=99999` at a large value so the I-action is off). Use `Kc=0.5`. Complete the green line in Figure 3c.
10. P-control. Try increasing `Kc`. At what value of `Kc` does the system go unstable? Can you explain this?
11. PI-control. Use SIMC rule with `tauc=delay`. Complete the green line in Figure 3d.

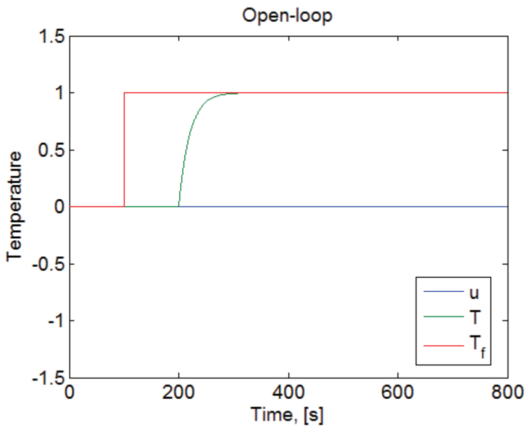
Start Simulink by writing the following in the Matlab command window:

```
>> tunepid1_ex1  %Alternatively double click the Simulink (.mdl) file
>> Kc=0;taui=99999;taud=0;  %This sets the PI controller parameters
>> sim('tunepid1_ex1')   % Alternatively press the start button
>> plot(time,Tf,'red',time,u,'blue',time,T,'green')
```

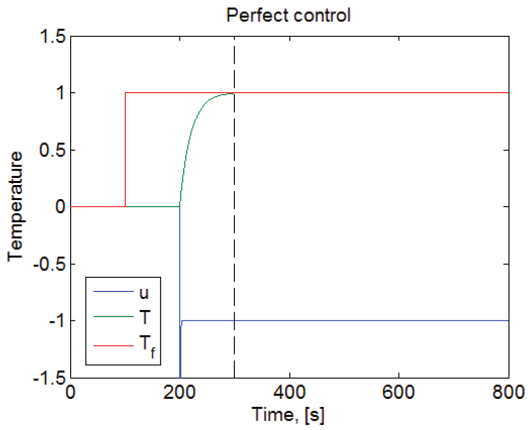
To change the step disturbance settings open the Simulink file and double click Step disturbance (d) block. In the pop-up window you can define the time and magnitude of the step.

2.4 Figures

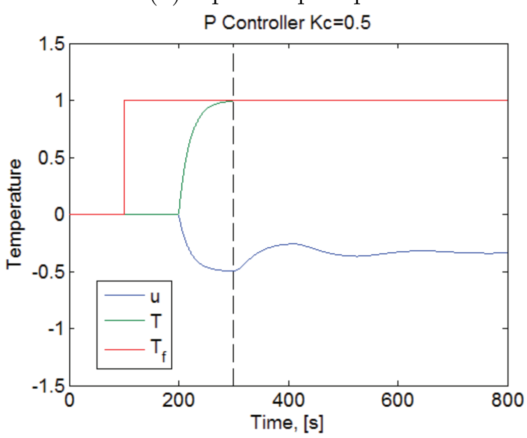
In the plots below (Figure 3), the input u (scaled heat input; blue line) and the disturbance T_f (red line) are given for the whole simulation, but the output T (green line) is given up to 300 s. Please sketch by hand the behavior of output T (green line) for the remaining time.



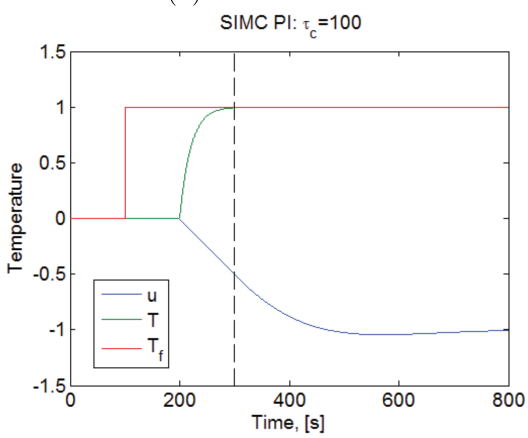
(a) Open-loop response



(b) Perfect control



(c) Proportional control



(d) Proportional-Integral control

Figure 3: Step response plots