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
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](image)

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 \( \tau \) and delay \( \theta \) for this process (with \( T_0 \) as input and \( T \) as output).

<table>
<thead>
<tr>
<th>parameter</th>
<th>symbol</th>
<th>value</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass flow</td>
<td>( F )</td>
<td>10</td>
<td>kg s(^{-1})</td>
</tr>
<tr>
<td>water density</td>
<td>( \rho )</td>
<td>1000</td>
<td>kg m(^{-3})</td>
</tr>
<tr>
<td>pipe area</td>
<td>( A )</td>
<td>0.01</td>
<td>m(^2)</td>
</tr>
<tr>
<td>pipe length</td>
<td>( L )</td>
<td>100</td>
<td>m</td>
</tr>
<tr>
<td>tank volume</td>
<td>( V )</td>
<td>0.2</td>
<td>m(^3)</td>
</tr>
</tbody>
</table>

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 $\tau_I$ [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 ($K_c = 0$ which gives $u = 0$). Note: Should be the same as in Task 2. Complete the green line in Figure 3a.

9. P-control (keep $\tau_I = 99999$ at a large value so the I-action is off). Use $K_c = 0.5$. Complete the green line in Figure 3c.

10. P-control. Try increasing $K_c$. At what value of $K_c$ does the system go unstable? Can you explain this?

11. PI-control. Use SIMC rule with $\tau_{uc} = \text{delay}$. Complete the green line in Figure 3d.
Start Simulink by writing the following in the Matlab command window:

```matlab
>> tunepid1_ex1  %Alternatively double click the Simulink (.mdl) file
>> Kc=0;tau1=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.

![Figure 3: Step response plots](image-url)