TKP4140 Process Control

Department of Chemical Engineering NTNU

Autumn 2018 - Midterm Exam

12. October 2018

Student number: ______________________________

- Write your student number on **every** page in the indicated space.
- Write your answers on the enclosed pages.
- Use the last page for details if you have too little space.
- Do not separate the enclosed pages.
- Time: **100** minutes

Problem 1 (20 points)

Consider two flash tanks in series, as shown in Fig. 1, where the feed stream F is separated into gas product G_1 and liquid product L_1 in the first tank at pressure P_1. The liquid product of tank 1 is further heated, and then flashed in the second tank to gas product G_2 and liquid product L.

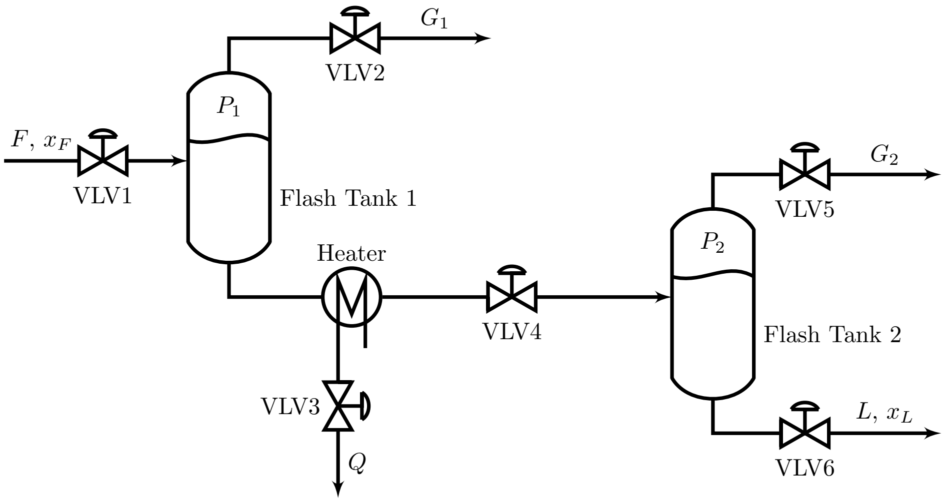

Figure 1: Two flash tanks in series

The control objectives are:

- Keep the composition of light component in the liquid product L at $x_L^s = 0.05$.
- Keep the process stable.
- Keep the pressures in both tanks at their setpoints: $P_1^s = 10$ bar and $P_2^s = 2$ bar respectively.
- Keep the liquid product flow L at a given value (this should be controlled tightly).

The available measurements are:

- Pressure in flash tank 1 and 2: P_1 and P_2.
- Level in flash tank 1 and 2: h_1 and h_2.
- Temperature of liquid product.
- Composition of liquid product L: x_L (with a large delay and unreliable).
- All flows (if needed).

(a) Identify:

CVs:

MVs:

(b) Propose a control structure based on feedback. Draw the proposed control structure in Fig. 1 (Show the MVs-CVs pairing on the flowsheet).

Problem 2 (5 points)

Draw the block diagram for the transfer function given by Eq. 1. Indicate signals $y_s(s)$, $e(s)$, $u(s)$, $y(s)$ and $d(s)$, and blocks $c(s)$, $g(s)$, $g_m(s)$ and $g_d(s)$ on your figure.

$$y(s) = \frac{g(s)c(s)y_s(s) + g_d(s)d(s)}{1 + g(s)g_m(s)c(s)} \tag{1}$$

Problem 3 (5 points)

SIMC tuning rules.

(a) Write the SIMC PI tuning rules for a first-order plus delay process ($g(s)$).

$g(s) =$

$K_c =$ $\tau_I =$

(b) Write the SIMC PID tuning rules (cascade form) for a second-order plus delay process ($g(s)$).

$g(s) =$

$K_c =$ $\tau_I =$ $\tau_D =$

Problem 4 (5 points)
PID Controller

Two commonly used representations of a PID controller are

- Series/cascade form: $c(s) = K_c \left(\frac{\tau_I s+1}{\tau_I s}\right)(\tau_D s + 1) = \frac{K_c}{\tau_I s}\left(\tau_I \tau_D s^2 + (\tau_I + \tau_D)s + 1\right)$
- Ideal/parallel form: $c(s) = K_c' \left(\frac{1}{\tau_I' s} + \tau_D' s + 1\right) = \frac{K_c'}{\tau_I' s}\left(\tau_I' \tau_D' s^2 + \tau_I' s + 1\right)$

Given the controller settings K_c, τ_I and τ_D for a PID controller in series form, what are the corresponding values of K_c', τ_I' and τ_D' for the ideal form? Derive the relationship.

Problem 5 (25 points)
Given the transfer function in Eq. 2:

$$g(s) = \frac{2}{(5s+1)(3s+1)} \tag{2}$$

(a) Find the first order plus delay (FOPD) approximation using the Half rule.

(b) Find PI controller tuning parameters using the SIMC rules. Select $\tau_C = 2$.

(c) Find PID controller tuning parameters using the SIMC rules. Select $\tau_C = 1.5$.

(d) Sketch in Fig. 2 the closed-loop response for a step in setpoint for both the PI and PID controllers with the obtained tuning parameters.

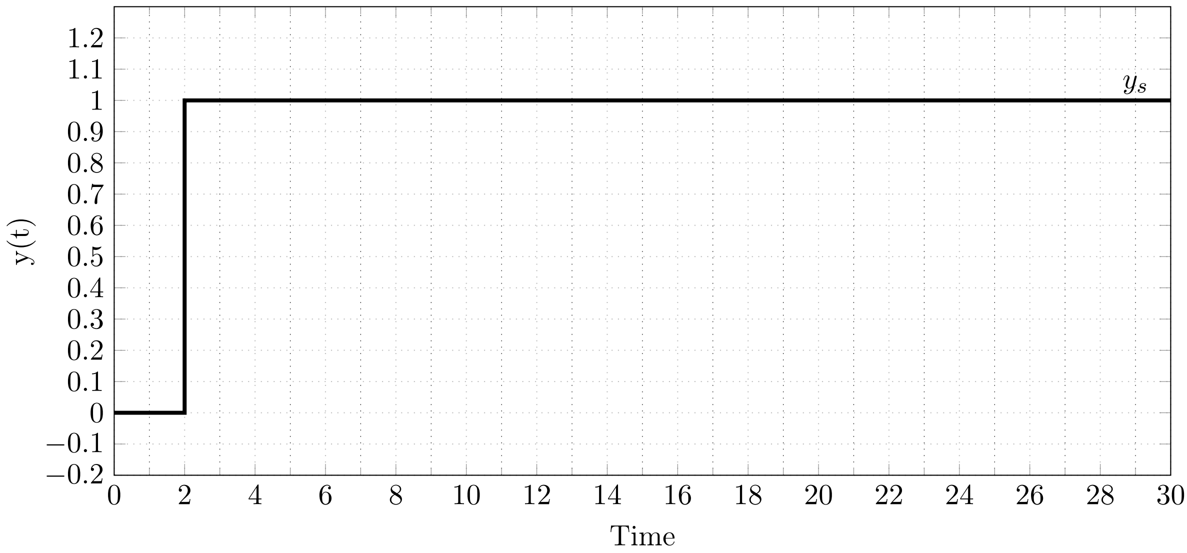

Figure 2: Closed-loop responses for setpoint changes for PI and PID

(e) For the PID controller, find also the tunings for the ideal form.

(f) Consider a disturbance $d(s)$ at the plant output (i.e.$g_d = 1$). Find the closed-loop transfer function $T_d(s)$ from $d(s)$ to $y(s)$ with the obtained PID tuning parameters

Problem 6 (10 points)

Consider a disturbance d at the plant output, with the following closed-loop transfer function from $d(s)$ to $y(s)$: $T_d(s) = \frac{1.5s}{1.5s+1}$

Sketch in Fig. 3 the closed-loop response in y for a unit step change in the disturbance d at time $t = 0$. Also show in Fig. 3 the response in y for a unit step change in the disturbance d without control.

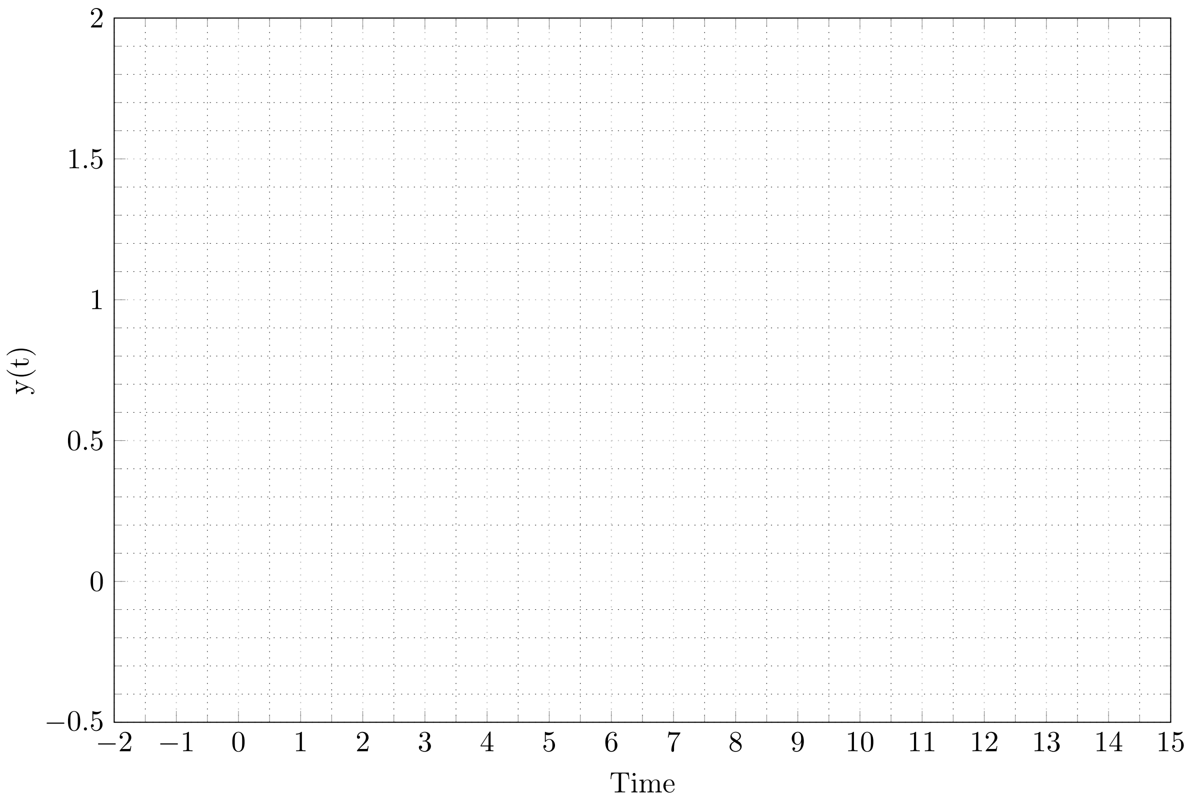

Figure 3: Closed-loop response for disturbances for PI controller.

Problem 7 (5 points)

Given a system with the transfer function in Eq. 3, obtain the controller setting for a PI controller using the SIMC tuning rule.

$$g(s) = \frac{3e^{-2s}}{s}. \tag{3}$$

Problem 8 (10 points)

Laplace Transforms

(a) Prove that $\mathcal{L}\{e^{-at}\} = \frac{1}{s+a}$.

(b) Given $g(s) = \frac{1}{5s+1}$, derive $y(t)$ (time domain) for:

i. $u(s) = 1$

ii. $u(s) = \frac{1}{s}$

Problem 9 (10 points)

Sketch the step response for

(a) $g_1(s) = 2e^{-3s} + \frac{3}{2s+1}$

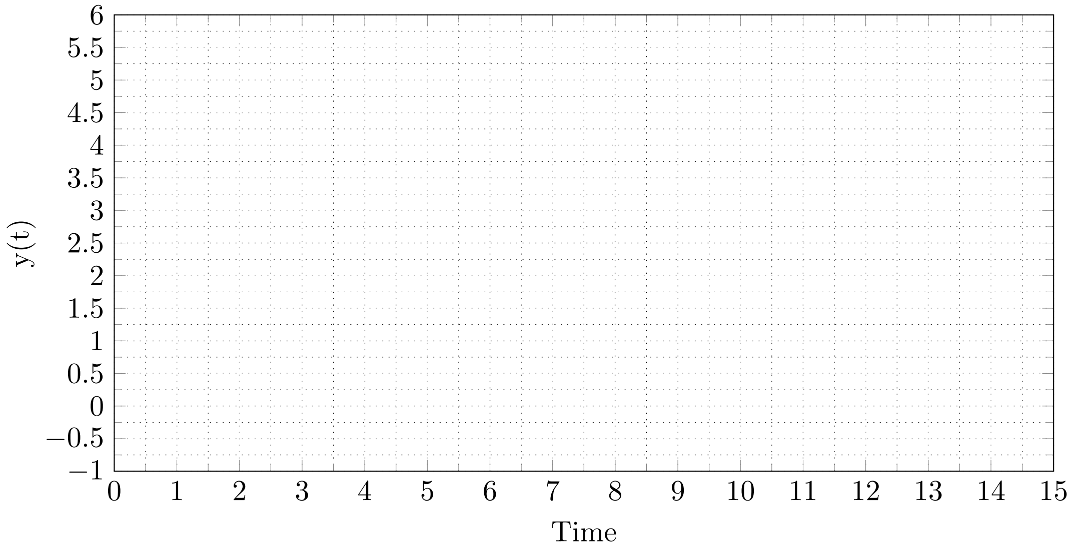

Figure 4: Step Response g_1

(b) $g_2(s) = \frac{2s-1}{(4s+1)(s+1)}$

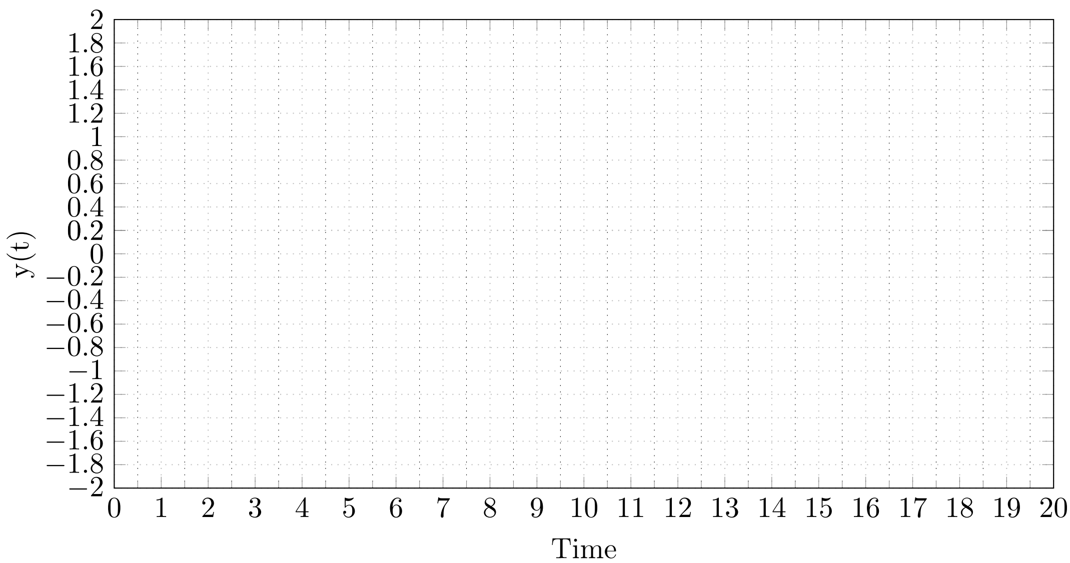

Figure 5: Step Response g_1

Problem 10 (5 points)

Given the plot in Fig. 6 for a second order transfer function and the formulas in Eq. 4:

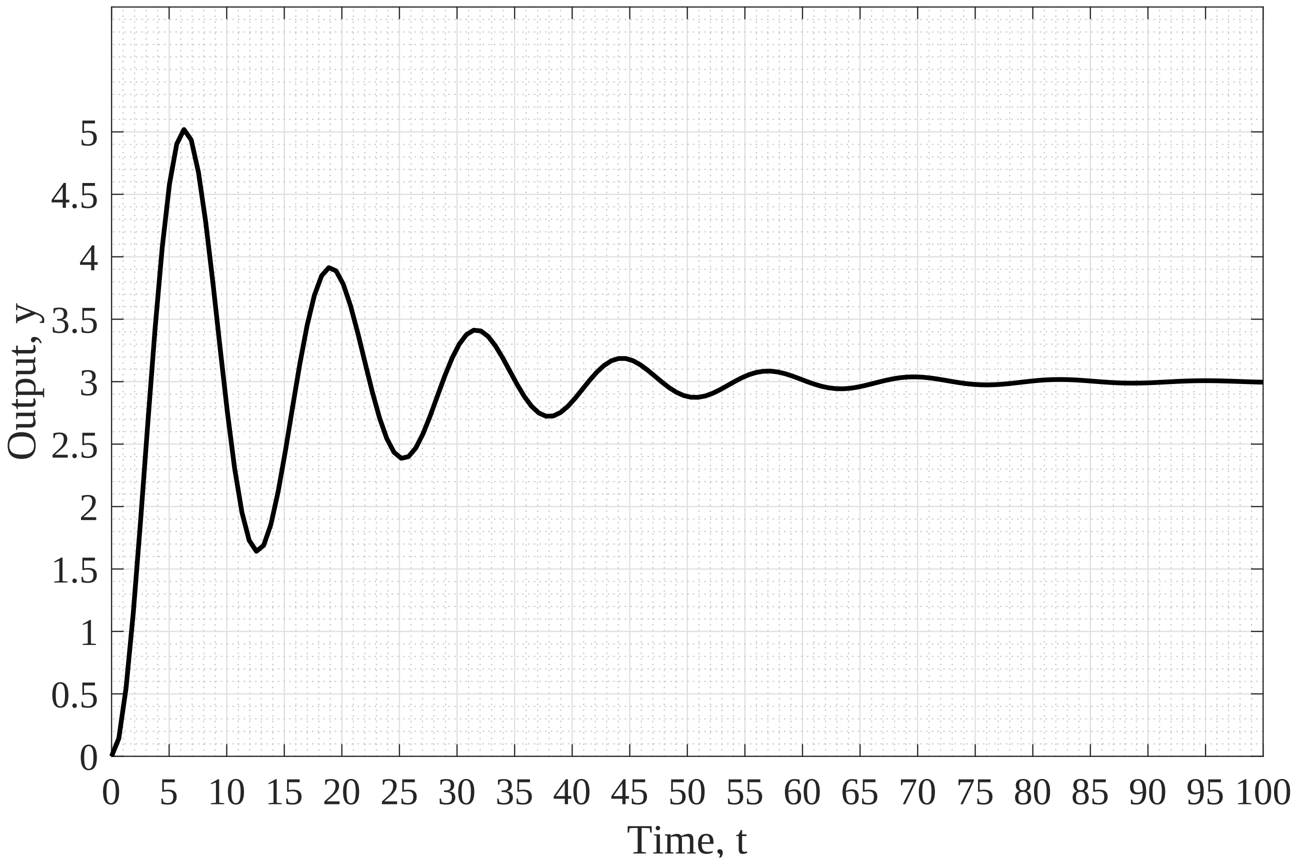

Figure 6: Step response for $g(s)$

$$t_p = \frac{\pi\tau}{\sqrt{1-\zeta^2}} \approx \pi\tau; \qquad \frac{a}{b} = exp\Big(\frac{-\pi\zeta}{\sqrt{1-\zeta^2}}\Big) \approx exp(-\pi\zeta) \tag{4}$$

where, t_p is the time to first peak and $\frac{a}{b}$ is the overshoot. These approximations hold for a small ζ, and can be used in this case.

(a) Show a, b in Fig.6.

(b) Find the transfer function $g(s)$.

Extra space

Please indicate clearly which problem the solution belongs to.