Sequential mixed-integer dynamic optimization for integrated design and control

M. Alizadeh
M. Ramezani
Supervisor:
Dr. Sahlodin

Summer 2022

Superstructure[1]

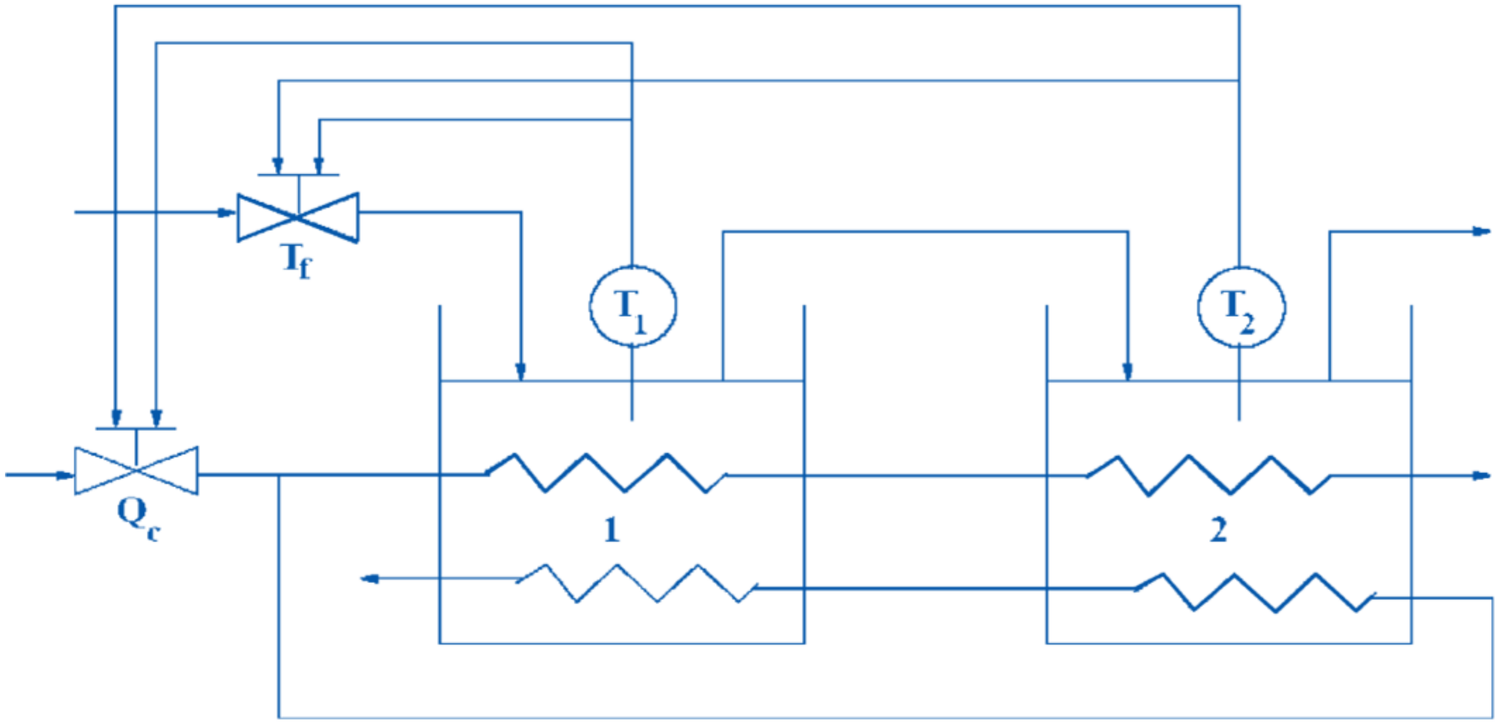


Fig1. Superstructure of processing alternatives[1]

1-Flores-Tlacuahuac, A., & Biegler, L. T. (2007). Simultaneous mixed-integer dynamic optimization for integrated design and control. Computers and Chemical Engineering, 31(5–6), 588–600.

Optimization Problem(cont'd)

$$\boxed{\min \frac{1}{t_f}\left(\int_0^{t_f}\left(T_2^{sp}-T_2\right)^2 dt+\int_0^{t_f}\left(T_1^{sp}-T_1\right)^2 dt\right)}$$

-10% Step change for Setpoints

$$C_f = C_f^{nominal} + \alpha_d(e^{-\lambda t} - 1)$$

$$T_{c1}^{in} = T_{cf}y_c + (1 - y_c)T_{c2}$$

$$T_{c2}^{in} = T_{c1}y_c + (1 - y_c)T_{cf}$$

$$Q_c = Q_c^{bias} - (1 - y_i)\left(K_{p_1}P_1 + K_{i_1}I_1\right) - y_i \times \left(K_{p_2}P_2 + K_{i_2}I_2\right)$$

$$T_f = T_f^{bias} + y_i \times \left(K_{p_1}P_1 + K_{i_1}I_1\right) + (1 - y_i)\left(K_{p_2}P_2 + K_{i_2}I_2\right)$$

Mass and Energy Equations

$$I_1 = \int P_1 \, dt$$

$$I_2 = \int P_2 \, dt$$

Processing constraints

Optimization Problem(cont'd)

$$\min \frac{1}{t_f}\left(\int_0^{t_f}\left(T_2^{sp}-T_2\right)^2 dt+\int_0^{t_f}\left(T_1^{sp}-T_1\right)^2 dt\right)$$

-10% Step change for Setpoints

$$C_f = C_f^{nominal} + \alpha_d(e^{-\lambda t} - 1)$$

$$T_{c1}^{in} = T_{cf}y_c + (1 - y_c)T_{c2}$$

$$T_{c2}^{in} = T_{c1}y_c + (1 - y_c)T_{cf}$$

$$Q_c = Q_c^{bias} - (1 - y_i)\left(K_{p_1}P_1 + K_{i_1}I_1\right) - y_i \times \left(K_{p_2}P_2 + K_{i_2}I_2\right)$$

$$T_f = T_f^{bias} + y_i \times \left(K_{p_1}P_1 + K_{i_1}I_1\right) + (1 - y_i)\left(K_{p_2}P_2 + K_{i_2}I_2\right)$$

Mass and Energy Equations

$$\frac{dc_1}{dt} = \frac{C_f - C_1}{\theta} + r_{A1}$$

$$\frac{dT_1}{dt} = \frac{T_f - T_1}{\theta} + \beta r_{A1} - \alpha(T_1 - T_{c_1})$$

$$\frac{dc_2}{dt} = \frac{C_1 - C_2}{\theta} + r_{A2}$$

$$\frac{dT_2}{dt} = \frac{T_1 - T_2}{\theta} + \beta r_{A2} - \alpha(T_2 - T_{c_2})$$

$$\frac{dT_1}{dt} = \frac{Q_c(T_{c1}^{in} - T_{c1})}{V_c} + \alpha(T_1 - T_{c_1})$$

$$\frac{dT_2}{dt} = \frac{Q_c(T_{c2}^{in} - T_{c2})}{V_c} + \alpha(T_2 - T_{c_2})$$

$$I_1 = \int P_1\, dt$$

$$I_2 = \int P_2\, dt$$

Processing constraints

Optimization Problem

$$\boxed{\min \frac{1}{t_f}\left(\int_0^{t_f}\left(T_2^{sp}-T_2\right)^2 dt+\int_0^{t_f}\left(T_1^{sp}-T_1\right)^2 dt\right)}$$

-10% Step change for Setpoints

$$C_f = C_f^{nominal} + \alpha_d(e^{-\lambda t}-1)$$

$$T_{c1}^{in} = T_{cf}y_c + (1-y_c)T_{c2}$$

$$T_{c2}^{in} = T_{c1}y_c + (1-y_c)T_{cf}$$

$$Q_c = Q_c^{bias} - (1-y_i)\left(K_{p_1}P_1 + K_{i_1}I_1\right) - y_i \times \left(K_{p_2}P_2 + K_{i_2}I_2\right)$$

$$T_f = T_f^{bias} + y_i \times \left(K_{p_1}P_1 + K_{i_1}I_1\right) + (1-y_i)\left(K_{p_2}P_2 + K_{i_2}I_2\right)$$

Mass and Energy Equations

$$I_1 = \int P_1\, dt$$

$$I_2 = \int P_2\, dt$$

Processing constraints

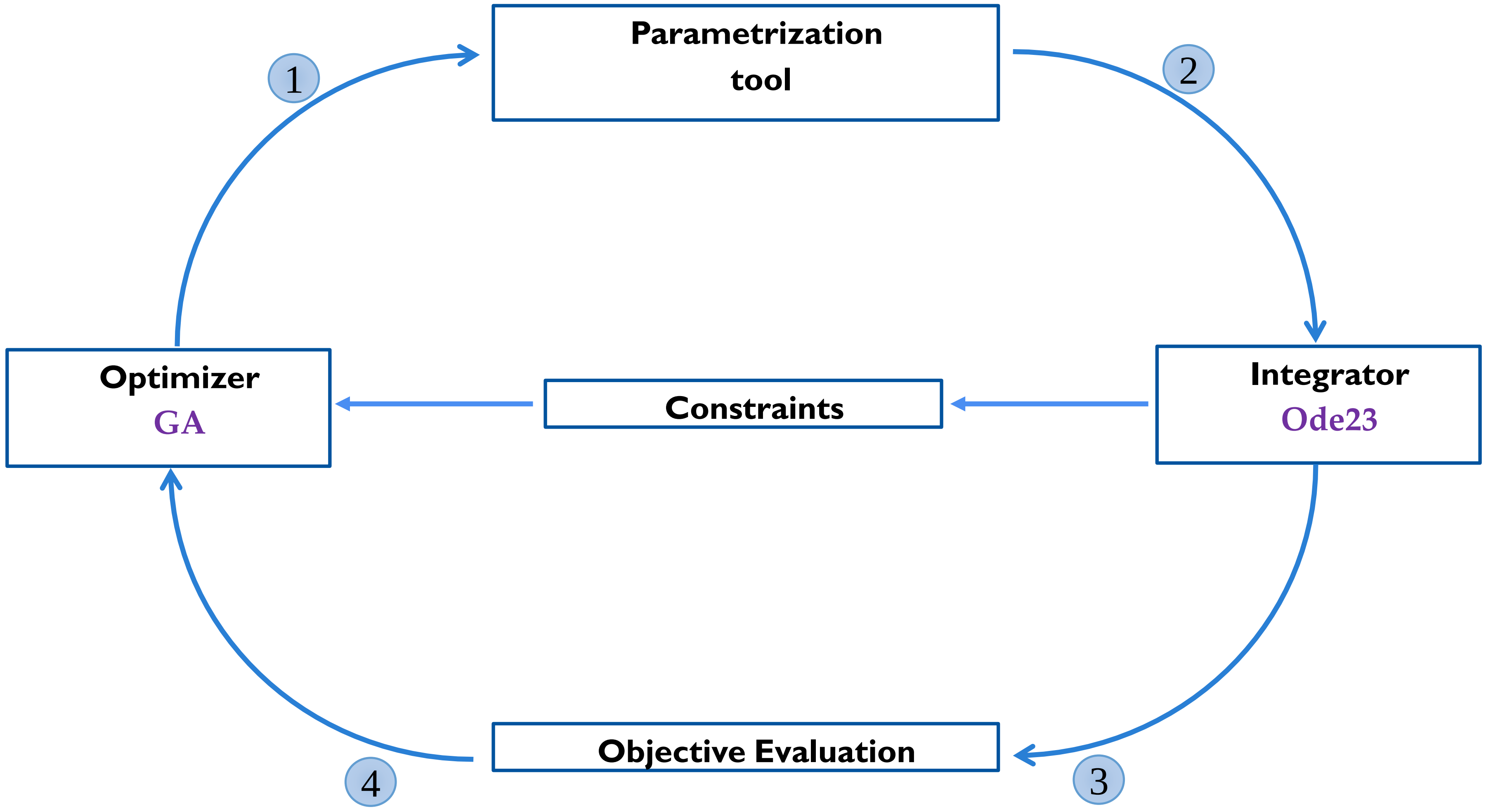
$$\int \max(0, T_F - 60)dt \le tol$$

$$\int \max(0, -(T_F))dt \le tol$$

$$\int \max(0, Q_c - 8)dt \le tol$$

$$\int \max(0, -Q_c)dt \le tol$$

Single shooting method (sequential)



Optimum parameters

yc= 0 → Counter-Current flow

yi=1 → $(T_2\text{-}Q_c)$ (T_1,T_f)

$V_1 = 1079.996$

$V_2 = 720.000$

$K_{c1} = 1.32260$

$K_{i1} = 0.0036670$

$K_{c2} = 0.3321133$

$K_{i2} = 0.0004051$

Simulation

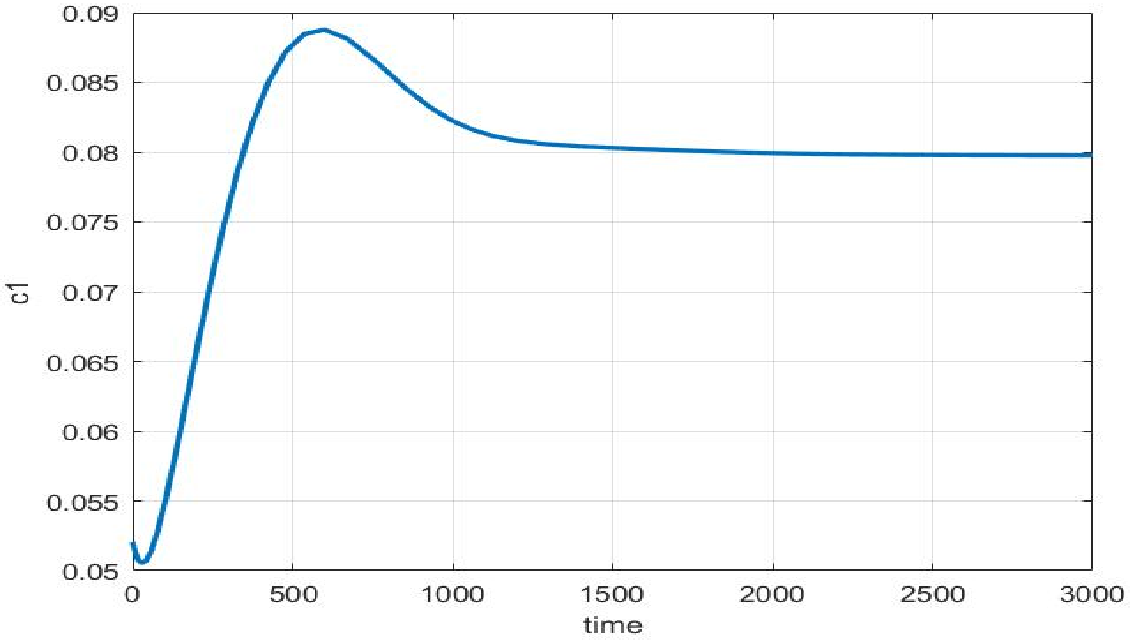


Fig2. C1 vs Time

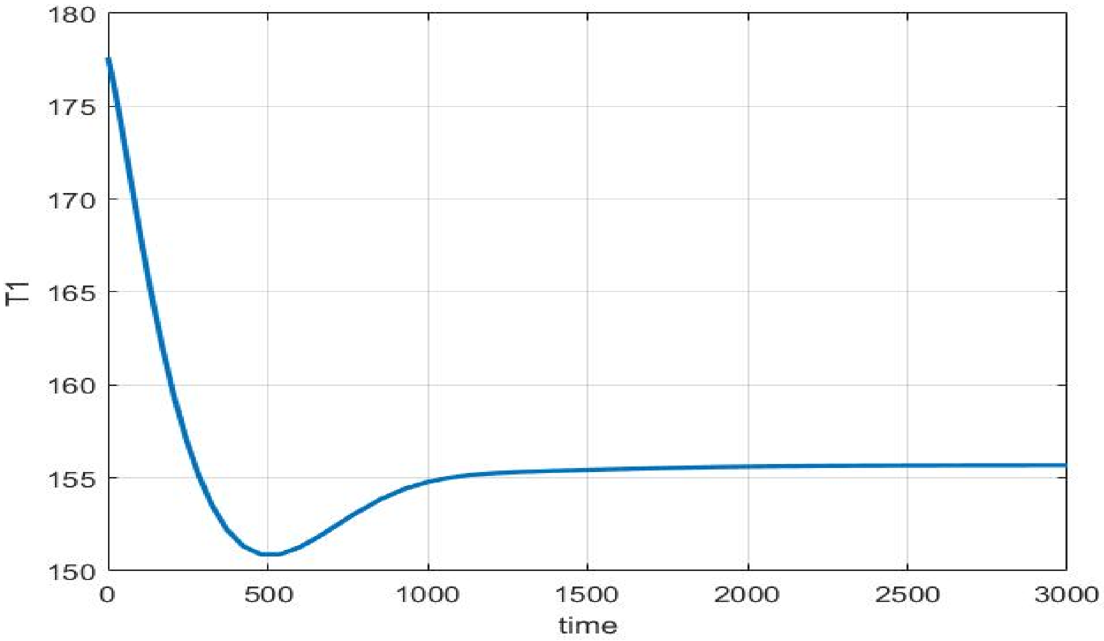


Fig2. T1 vs Time

Simulation (cont'd)

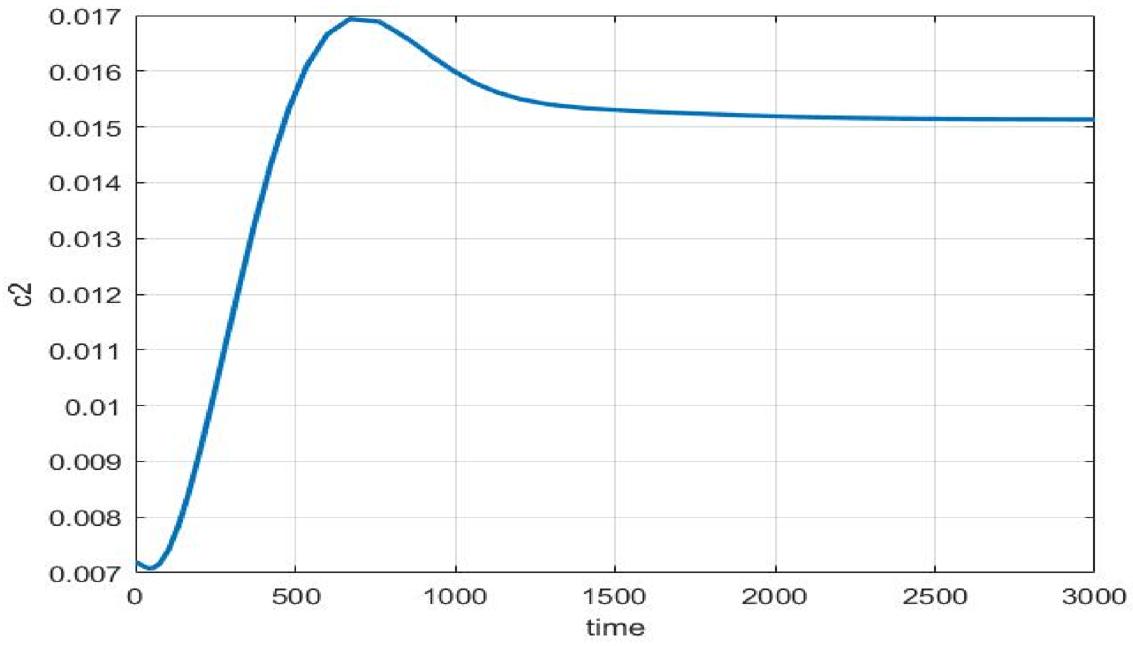


Fig3. C2 vs Time

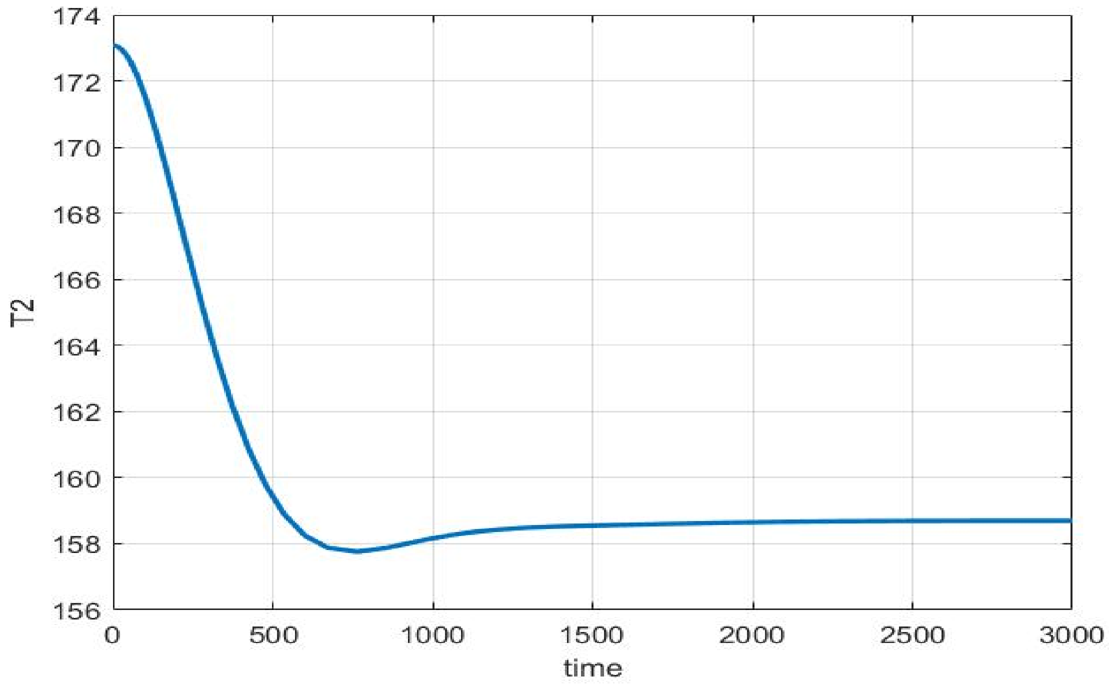


Fig4. T2 vs Time

Simulation (cont'd)

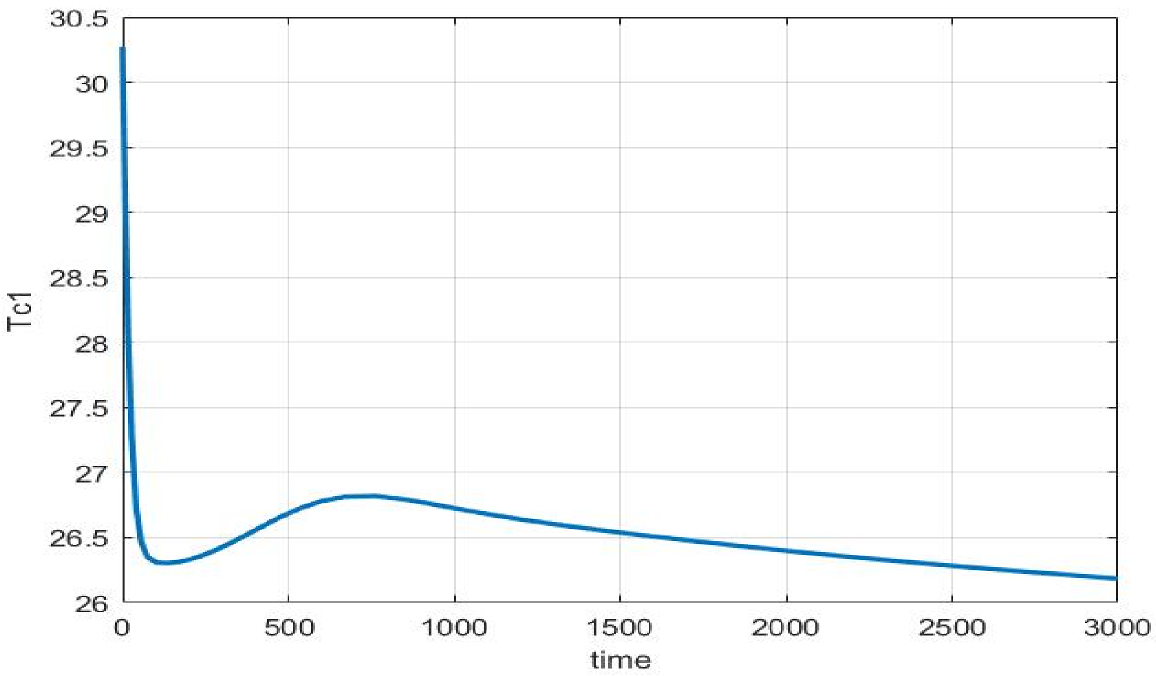


Fig5. Tc1 vs Time

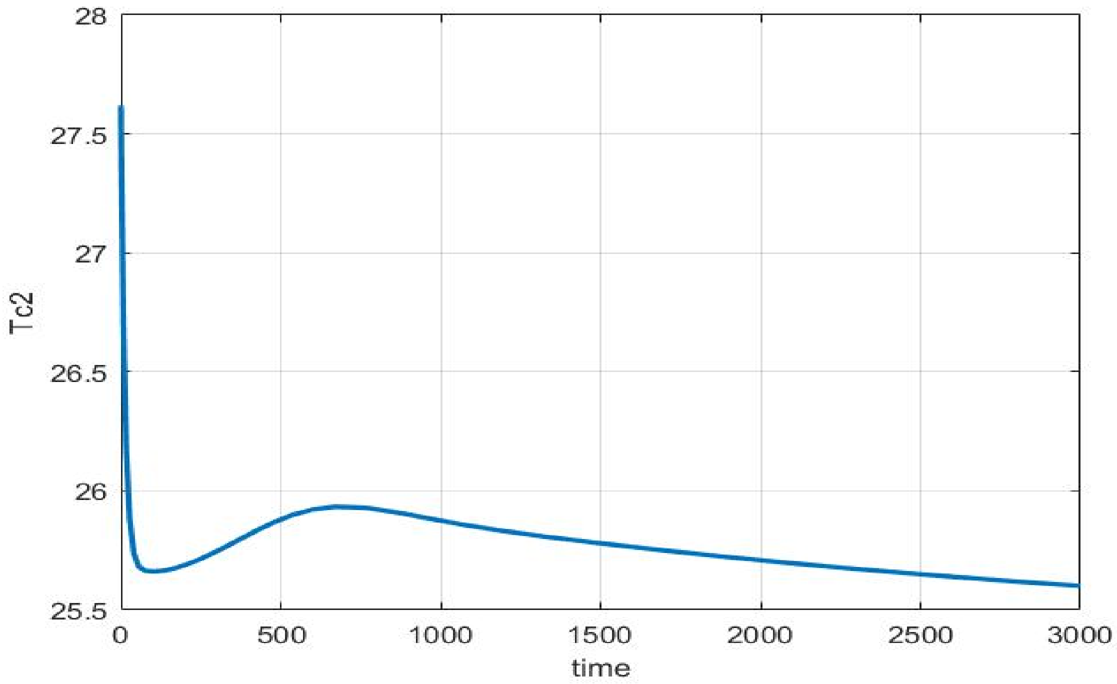


Fig6. Tc2 vs Time

Simulation (cont'd)

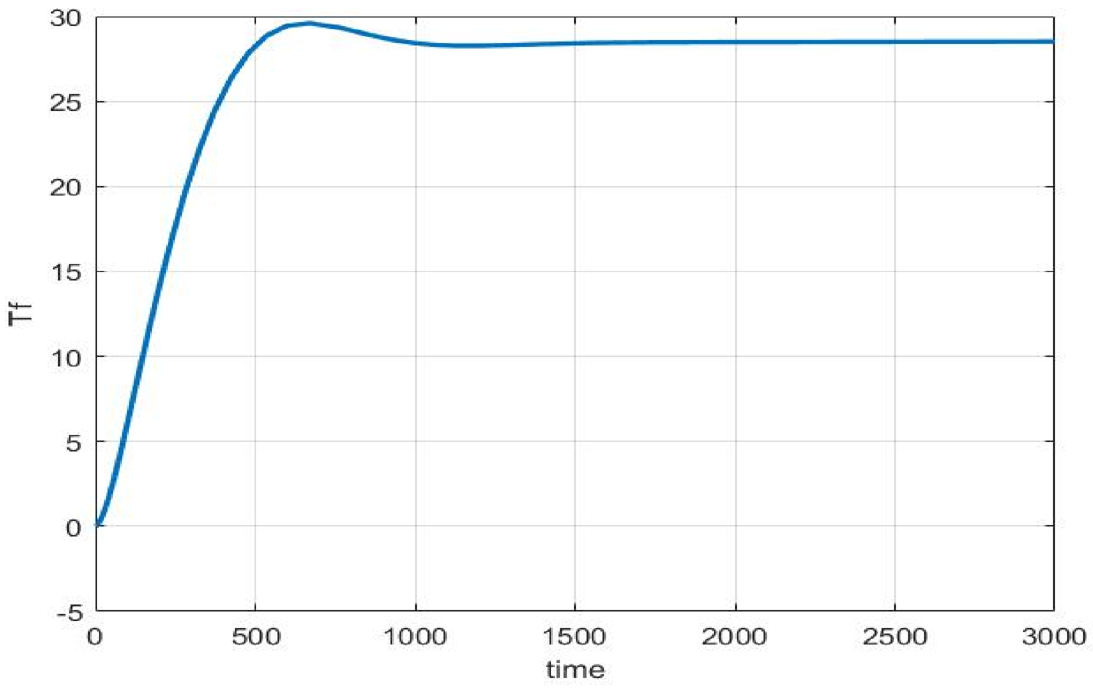


Fig7. Tf vs Time

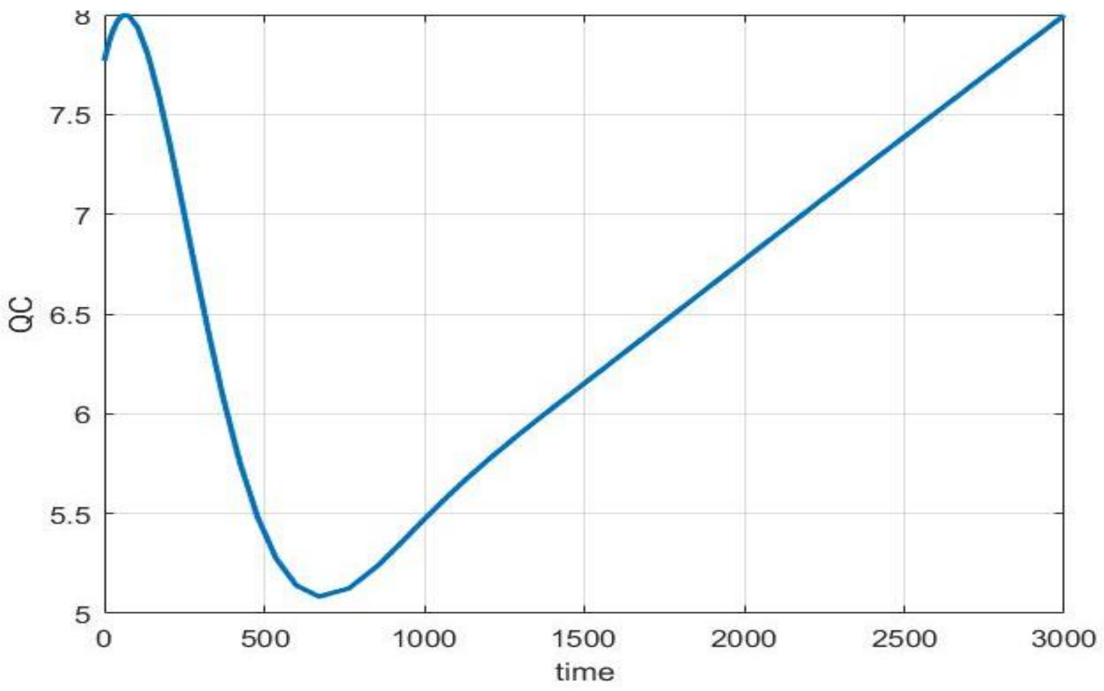


Fig8. Qc vs Time

Simulation (cont'd)

Setpoint Kick issue!

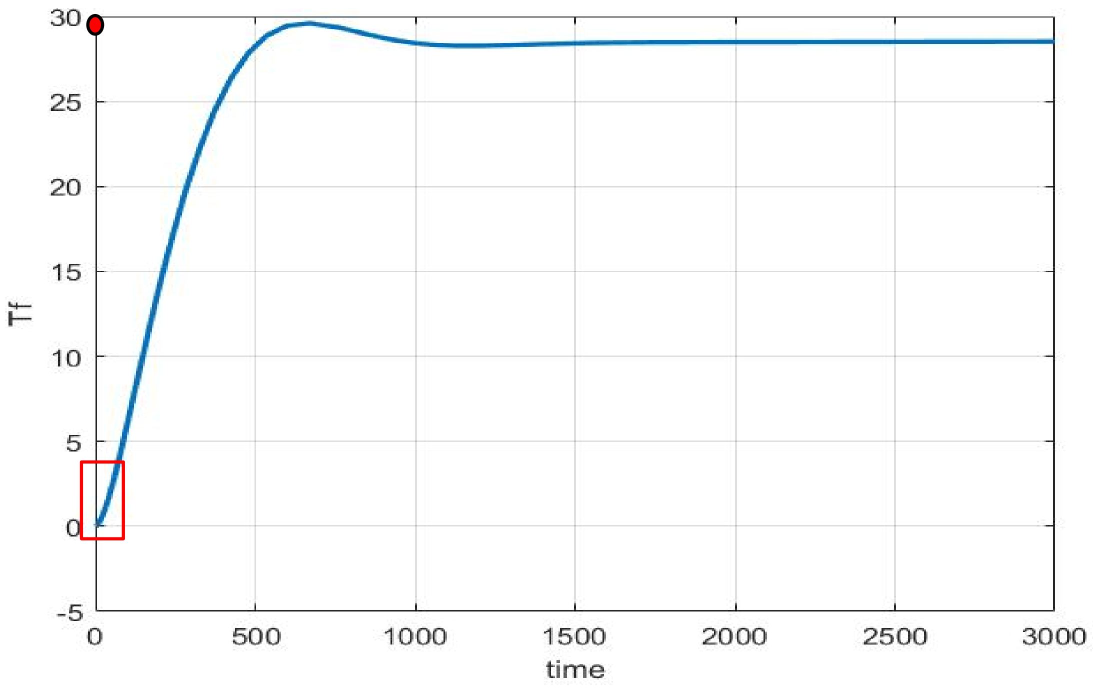


Fig7. Tf vs Time

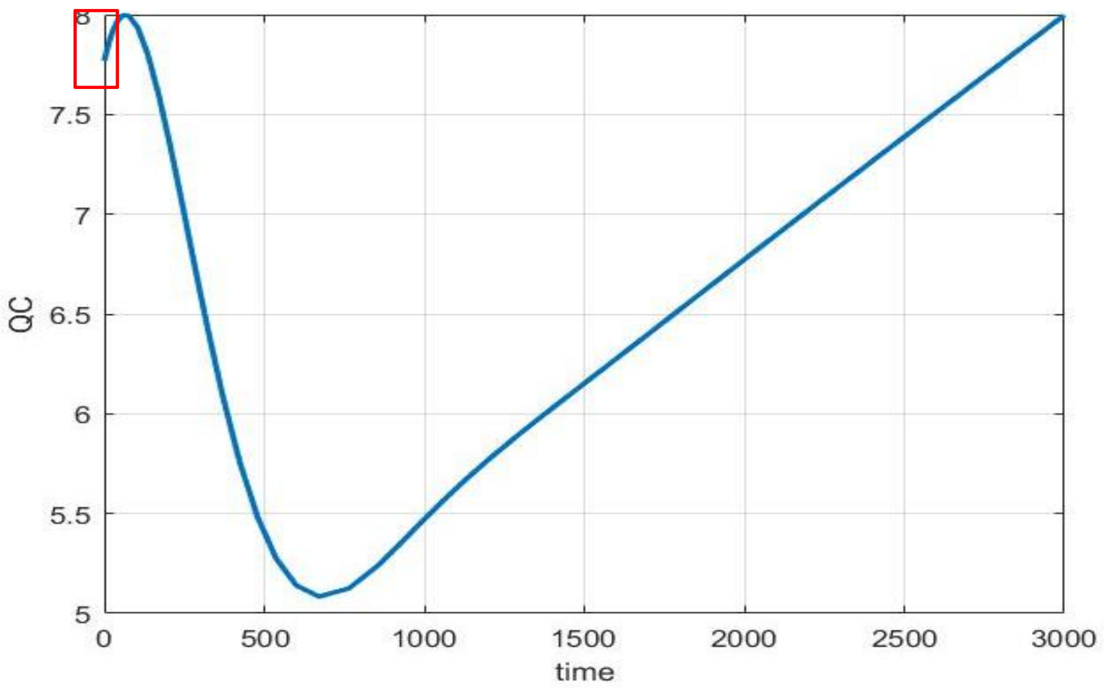
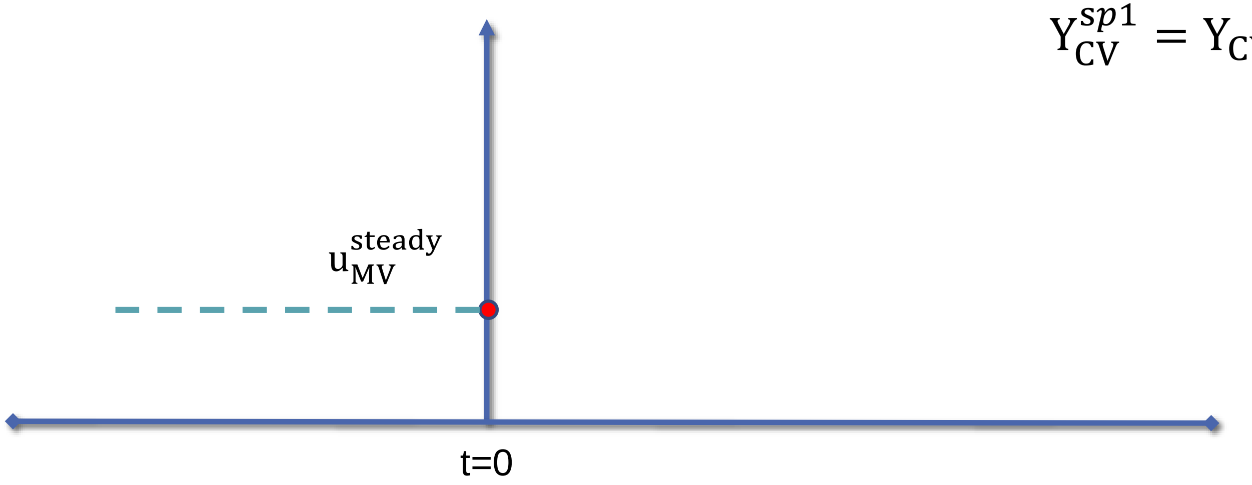


Fig8. Qc vs Time

$$u_{MV} = u_{MV}^{steady} + \left(K_{p_1}(Y_{CV}^{sp} - Y_{CV}) + K_{i_1} \int (Y_{CV}^{sp} - Y_{CV}) dt \right)$$

Initial Discontinuity / Setpoint Kick[1] (cont'd)

$$u_{MV} = u_{MV}^{steady} + \left(K_{p_1}(Y_{CV}^{sp} - Y_{CV}) + K_{i_1}\int (Y_{CV}^{sp} - Y_{CV})dt \right)$$



Before setpoint change:

$$Y_{CV}^{sp1} = Y_{CV}(t=0) = Y_{CV}^{steady}$$

1-https://jckantor.github.io/CBE30338/04.02-PID_Control_with_Setpoint_Weighting.html

Initial Discontinuity / Setpoint Kick[1] (cont'd)

$$u_{MV} = u_{MV}^{steady} + \left(K_{p_1}(Y_{CV}^{sp} - Y_{CV}) + K_{i_1} \int (Y_{CV}^{sp} - Y_{CV})dt \right)$$

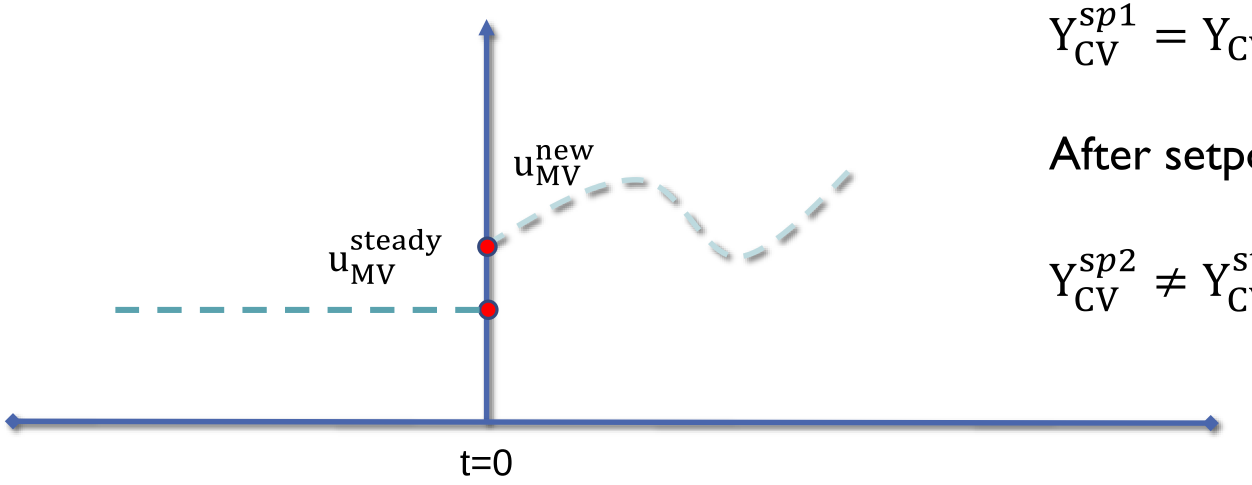


Fig9. schematic of the discontinuity at the initial time

Before setpoint change:

$$Y_{CV}^{sp1} = Y_{CV}(t = 0) = Y_{CV}^{steady}$$

After setpoint change:

$$Y_{CV}^{sp2} \neq Y_{CV}^{steady}$$

1-https://jckantor.github.io/CBE30338/04.02-PID_Control_with_Setpoint_Weighting.html

Initial Discontinuity / Setpoint Kick[1] (cont'd)

$$u_{MV} = u_{MV}^{steady} + \left(K_{p_1}(Y_{CV}^{sp} - Y_{CV}) + K_{i_1} \int (Y_{CV}^{sp} - Y_{CV})dt \right)$$

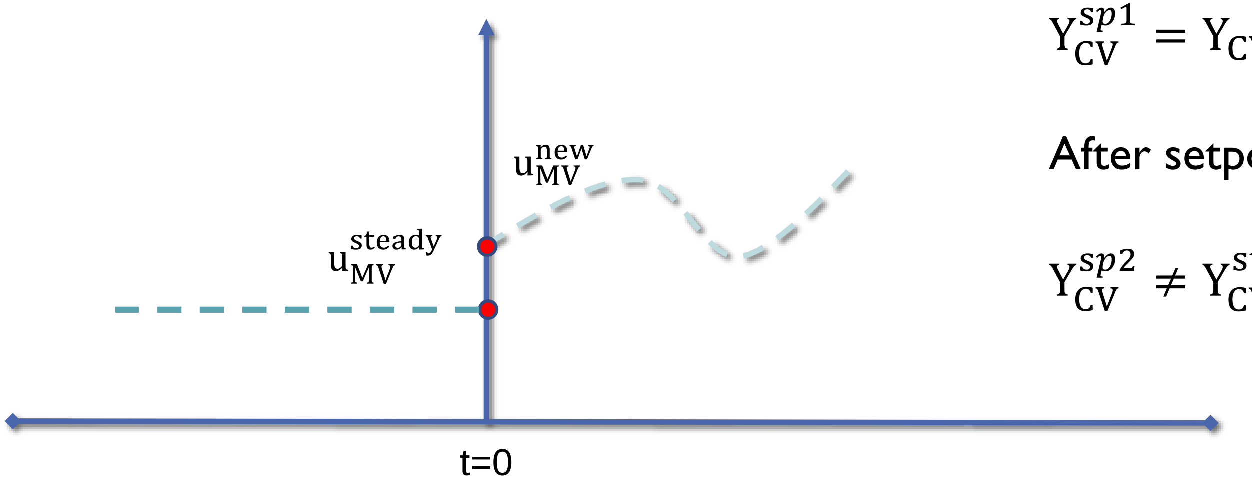


Fig9. schematic of the discontinuity at the initial time

Before setpoint change:

$$Y_{CV}^{sp1} = Y_{CV}(t=0) = Y_{CV}^{steady}$$

After setpoint change:

$$Y_{CV}^{sp2} \neq Y_{CV}^{steady}$$

Proposed Solution:

$$(u_{MV}^{steady} - u_{MV}(t=0))^2 \leq tol$$

Corrected optimum parameters

yc= 0 → Counter-Current flow

yi=1 → $(T_2\text{-}Q_c)$ (T_1,T_f)

$V_1 = 938.894$

$V_2 = 720.2794$

$K_{c1} = 0.0002030$
$K_{i1} = 2.9940214e\text{-}10$
$K_{c2} = 0.00018071$
$K_{i2} = 2.8542763e\text{-}06$

Initial Discontinuity / Setpoint Kick[1] (cont'd)

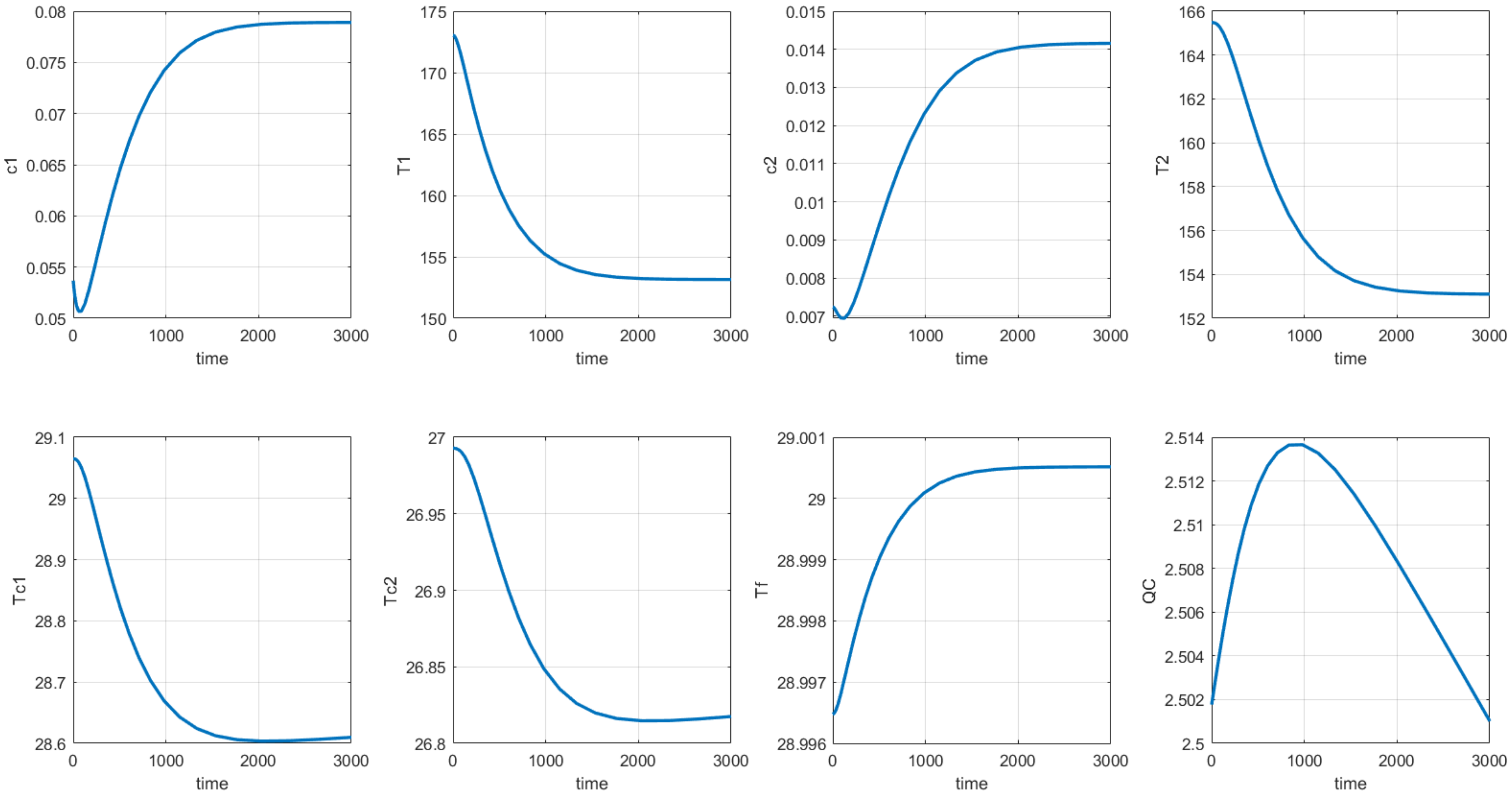


Fig9. schematic of the discontinuity at the initial time

1-https://jckantor.github.io/CBE30338/04.02-PID_Control_with_Setpoint_Weighting.html