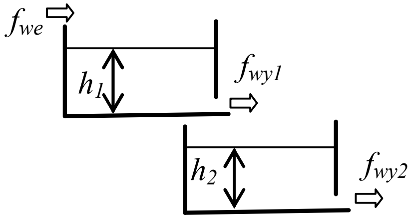
Kaskada niewspółdziałająca



$$\begin{cases} A_1\dot{h}_1(t) = f_{we}(t) - f_{wy1}(t) \\ A_2\dot{h}_2(t) = f_{wy1}(t) - f_{wy2}(t) \end{cases}$$

$$f_{wy1}(t) = A_{w1}\sqrt{2gh_1(t)}$$

$$f_{wy2}(t) = A_{w2}\sqrt{2gh_2(t)}$$

$$\begin{cases} A_1\dot{h}_1(t) = f_{we}(t) - A_{w1}\sqrt{2gh_1(t)} \\ A_2\dot{h}_2(t) = A_{w1}\sqrt{2gh_1(t)} - A_{w2}\sqrt{2gh_2(t)} \end{cases}$$

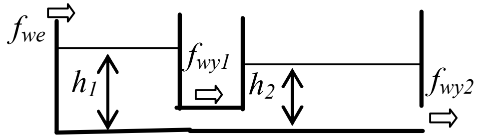
$$\begin{cases} 0 = f_{we} - A_{w1}\sqrt{2gh_1} \\ 0 = A_{w1}\sqrt{2gh_1} - A_{w2}\sqrt{2gh_2} \end{cases}$$

$$f_{we} = A_{w1}\sqrt{2gh_1} = A_{w2}\sqrt{2gh_2}$$

$$h_1 =$$

$$h_2 =$$

Kaskada współdziałająca



$$\begin{cases} A_1\dot{h}_1(t) = f_{we}(t) - f_{wy1}(t) \\ A_2\dot{h}_2(t) = f_{wy1}(t) - f_{wy2}(t) \end{cases}$$

$$f_{wy1}(t) = A_{w1}\sqrt{2g\left(h_1(t) - h_2(t)\right)}$$

$$f_{wy2}(t) = A_{w2}\sqrt{2gh_2(t)}$$

$$\begin{cases} A_1\dot{h}_1(t) = f_{we}(t) - A_{w1}\sqrt{2g\left(h_1(t) - h_2(t)\right)} \\ A_2\dot{h}_2(t) = A_{w1}\sqrt{2g\left(h_1(t) - h_2(t)\right)} - A_{w2}\sqrt{2gh_2(t)} \end{cases}$$

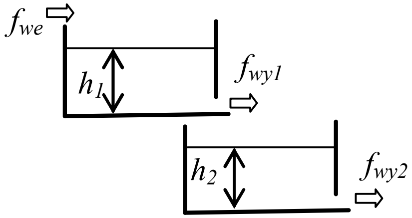
$$\begin{cases} 0 = f_{we} - A_{w1}\sqrt{2g\left(h_1 - h_2\right)} \\ 0 = A_{w1}\sqrt{2g\left(h_1 - h_2\right)} - A_{w2}\sqrt{2gh_2} \end{cases}$$

$$f_{we} = A_{w1}\sqrt{2g\left(h_1 - h_2\right)} = A_{w2}\sqrt{2gh_2}$$

$$h_1 =$$

$$h_2 =$$

Kaskada niewspółdziałająca

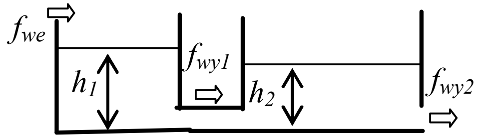


$$\begin{cases} A_1\dot{h}_1(t) = f_{we}(t) - f_{wy1}(t) \\ A_2\dot{h}_2(t) = f_{wy1}(t) - f_{wy2}(t) \end{cases}$$

$$f_{wy1}(t) = A_{w1}\sqrt{2gh_1(t)} \approx a_1 h_1(t)$$

$$f_{wy2}(t) = A_{w2}\sqrt{2gh_2(t)} \approx a_2 h_2(t)$$

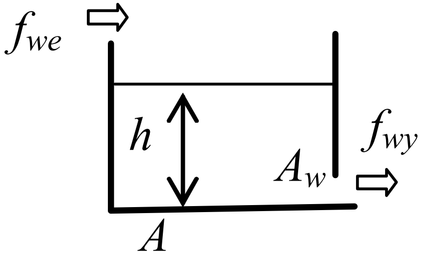
Kaskada współdziałająca

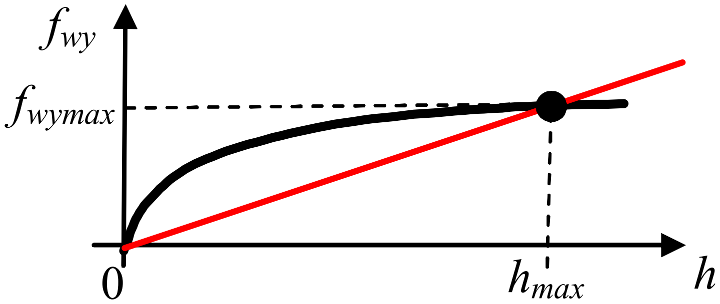


$$\begin{cases} A_1\dot{h}_1(t) = f_{we}(t) - f_{wy1}(t) \\ A_2\dot{h}_2(t) = f_{wy1}(t) - f_{wy2}(t) \end{cases}$$

$$f_{wy1}(t) = A_{w1}\sqrt{2g\left(h_1(t) - h_2(t)\right)} \approx a_1\left(h_1(t) - h_2(t)\right)$$

$$f_{wy2}(t) = A_{w2}\sqrt{2gh_2(t)} \approx a_2 h_2(t)$$





$$f_{wy} = A_w\sqrt{2gh} \approx ah$$

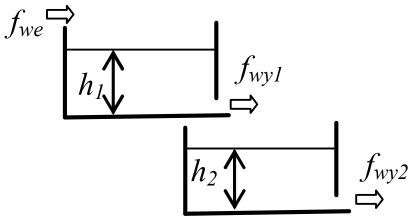
$$f_{wymax} = A_w\sqrt{2gh_{max}} \quad \rightarrow a$$

Kiedy $h=h_{max}$?

Jaką maksymalną wartość może mieć przepływ f_{we}, żeby ciecz nie wylewała się ze zbiornika?

Otwarte układy hydrauliczne (modele zlinearyzowanie)

Kaskada niewspółdziałająca



$$\begin{cases} A_1 \dot{h}_1(t) = f_{we}(t) - a_1 h_1(t) \\ A_2 \dot{h}_2(t) = a_1 h_1(t) - a_2 h_2(t) \end{cases}$$

$$f_{we} = a_1 h_1 = a_2 h_2 \quad \rightarrow \quad \begin{matrix} h_1 = f_{we} / a_1 \\ h_2 = f_{we} / a_2 \end{matrix}$$

$$\begin{cases} (A_1 s + a_1) h_1(s) = f_{we}(s) \\ (A_2 s + a_2) h_2(s) = a_1 h_1(s) \end{cases}$$

$$\begin{cases} M_1 h_1(s) = f_{we}(s) \\ M_2 h_2(s) = a_1 h_1(s) \end{cases}$$

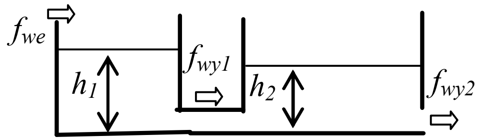
$$h_1(s) = \frac{1}{M_1} f_{we}(s)$$

$$h_2(s) = \frac{a_1}{M_1 M_2} f_{we}(s)$$

$$M_1 M_2 = (A_1 s + a_1)(A_2 s + a_2) = 0$$

$$A_1 A_2 s^2 + (A_1 a_2 + A_2 a_1) s + a_1 a_2 = 0$$

Kaskada współdziałająca



$$\begin{cases} A_1 \dot{h}_1(t) = f_{we}(t) - a_1 \left(h_1(t) - h_2(t)\right) \\ A_2 \dot{h}_2(t) = a_1 \left(h_1(t) - h_2(t)\right) - a_2 h_2(t) \end{cases}$$

$$f_{we} = a_1 (h_1 - h_2) = a_2 h_2 \quad \rightarrow \quad \begin{matrix} h_1 = f_{we} (a_1 + a_2)/(a_1 a_2) \\ h_2 = f_{we} / a_2 \end{matrix}$$

$$\begin{cases} (A_1 s + a_1) h_1(s) = f_{we}(s) + a_1 h_2(s) \\ (A_2 s + a_1 + a_2) h_2(s) = a_1 h_1(s) \end{cases}$$

$$\begin{cases} M_1 h_1(s) = f_{we}(s) + a_1 h_2(s) \\ M_2 h_2(s) = a_1 h_1(s) \end{cases}$$

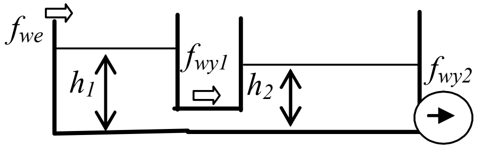
$$h_1(s) = \frac{M_2}{M_1 M_2 - a_1^2} f_{we}(s)$$

$$h_2(s) = \frac{a_1}{M_1 M_2 - a_1^2} f_{we}(s)$$

$$M_1 M_2 - a_1^2 = (A_1 s + a_1)(A_2 s + a_1 + a_2) - a_1^2 = 0$$

$$A_1 A_2 s^2 + (A_1 a_1 + A_1 a_2 + A_2 a_1) s + a_1 a_2 = 0$$

Kaskada z pompą



$$\begin{cases} A_1\dot{h}_1(t) = f_{we}(t) - a_1\big(h_1(t) - h_2(t)\big) \\ A_2\dot{h}_2(t) = a_1\big(h_1(t) - h_2(t)\big) - f_{wy2}(t) \end{cases}$$

$$f_{we} = a_1\left(h_1 - h_2\right) = f_{wy2}$$

$$f_{we} = f_{wy2} \;\rightarrow\; h_1 - h_2 = f_{we} / a_1$$

$$f_{we} \neq f_{wy2} \;\rightarrow$$

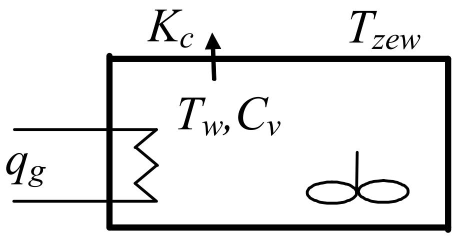
$$\begin{cases} (A_1 s + a_1)h_1(s) = f_{we}(s) + a_1 h_2(s) \\ (A_2 s + a_1)h_2(s) = a_1 h_1(s) - f_{wy2}(s) \end{cases}$$

$$\begin{cases} M_1 h_1(s) = f_{we}(s) + a_1 h_2(s) \\ M_2 h_2(s) = a_1 h_1(s) - f_{wy2}(s) \end{cases}$$

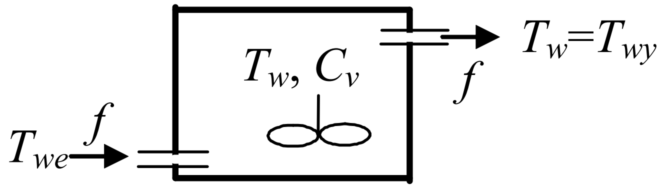
$$h_1(s) = \frac{M_2}{M_1 M_2 - a_1^2} f_{we}(s) - \frac{a_1}{M_1 M_2 - a_1^2} f_{wy2}(s)$$

$$h_2(s) = \frac{a_1}{M_1 M_2 - a_1^2} f_{we}(s) - \frac{M_1}{M_1 M_2 - a_1^2} f_{wy2}(s)$$

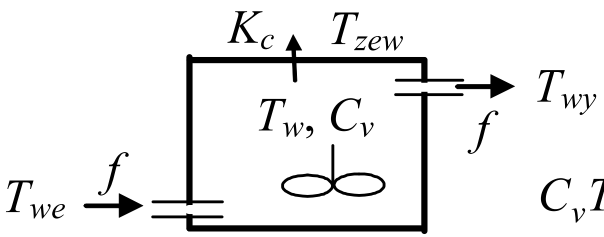
$$M_1 M_2 - a_1^2 = (A_1 s + a_1)(A_2 s + a_1) - a_1^2 = s\left(A_1 A_2 s + A_1 a_1 + A_2 a_1\right) = 0$$



$$C_v \dot{T}_w(t) = q_g(t) - K_c\left(T_w(t) - T_{zew}(t)\right)$$



$$C_v \dot{T}_w(t) = c_p \rho\, f(t) T_{we}(t) - c_p \rho\, f(t) T_w(t)$$



$$C_v \dot{T}_w(t) = c_p \rho\, f(t) T_{we}(t) - c_p \rho\, f(t) T_{wy}(t) - K_c\left(T_w(t) - T_{zew}(t)\right)$$

1) $T_{wy}(t) = T_w(t)$

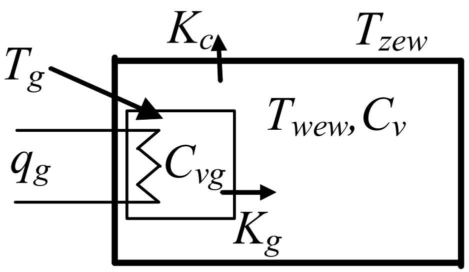
$$C_v \dot{T}_w(t) = c_p \rho\, f(t) T_{we}(t) - c_p \rho\, f(t) T_w(t) - K_c\left(T_w(t) - T_{zew}(t)\right)$$

2) $T_w(t) = \left(T_{we}(t) + T_{wy}(t)\right)/2$

$$C_v \frac{\dot{T}_{we}(t) + \dot{T}_{wy}(t)}{2} = c_p \rho\, f(t) T_{we}(t) - c_p \rho\, f(t) T_{wy}(t) - K_c\left(\frac{T_{we}(t) + T_{wy}(t)}{2} - T_{zew}(t)\right)$$

3) $T_{wy}(t) = 2T_w(t) - T_{we}(t)$

$$C_v \dot{T}_w(t) = c_p \rho\, f(t) T_{we}(t) - c_p \rho\, f(t)\left(2T_w(t) - T_{we}(t)\right) - K_c\left(T_w(t) - T_{zew}(t)\right)$$



$$\begin{cases} C_{vg}\dot{T}_g(t) = q_g(t) - K_g\left(T_g(t) - T_{wew}(t)\right) \\ C_{vw}\dot{T}_{wew}(t) = K_g\left(T_g(t) - T_{wew}(t)\right) - K_c\left(T_{wew}(t) - T_{zew}(t)\right) \end{cases}$$

wy: T_g, T_{wew} we: q_g, T_{zew}

$$\begin{cases} 0 = q_g 0 - K_g\left(T_g - T_{wew}\right) \\ 0 = K_g\left(T_g - T_{wew}\right) - K_c\left(T_{wew} - T_{zew}\right) \end{cases}$$

$$q_g = K_g\left(T_g - T_{wew}\right) = K_c\left(T_{wew} - T_{zew}\right)$$

$$T_{wew} = \frac{q_g}{K_c} + T_{zew}$$

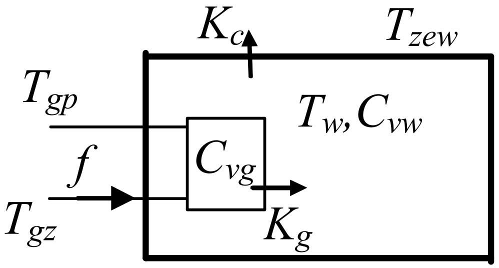
$$T_g = \frac{q_g}{K_g} + T_{wew} = \frac{q_g}{K_g} + \frac{q_g}{K_c} + T_{zew}$$

Identyfikacja parametrów (K_g, K_c)

$$q_{gN},\ T_{zewN},\ T_{wewN},\ T_{gN}$$

$$K_c = \frac{q_{gN}}{T_{wewN} - T_{zewN}}$$

$$K_g = \frac{q_{gN}}{T_{gN} - T_{wewN}}$$



$$T_{gśś}(t) = T_{gp}(t)$$

$$\begin{cases} C_{vg}\dot{T}_{gp}(t) = c_{pw}\rho_{pw} f(t) T_{gz}(t) - c_{pw}\rho_{pw} f(t) T_{gp}(t) - K_g\left(T_{gp}(t) - T_{wew}(t)\right) \\ C_{vw}\dot{T}_{wew}(t) = K_g\left(T_{gp}(t) - T_{wew}(t)\right) - K_c\left(T_{wew}(t) - T_{zew}(t)\right) \end{cases}$$

$$\begin{cases} C_{vg}\dot{T}_{gp}(t) = c_{pw}\rho_{pw} f(t)\left(T_{gz}(t) - T_{gp}(t)\right) - K_g\left(T_{gp}(t) - T_{wew}(t)\right) \\ C_{vw}\dot{T}_{wew}(t) = K_g\left(T_{gp}(t) - T_{wew}(t)\right) - K_c\left(T_{wew}(t) - T_{zew}(t)\right) \end{cases}$$

wy: T_{gp}, T_{wew}

we: T_{gz}, T_{zew}, f

$$\begin{cases} 0 = c_{pw}\rho_{pw} f\left(T_{gz} - T_{gp}\right) - K_g\left(T_{gp} - T_{wew}\right) \\ 0 = K_g\left(T_{gp} - T_{wew}\right) - K_c\left(T_{wew} - T_{zew}\right) \end{cases}$$

$$c_{pw}\rho_{pw} f\left(T_{gz} - T_{gp}\right) = K_g\left(T_{gp} - T_{wew}\right) = K_c\left(T_{wew} - T_{zew}\right)$$

$T_{wew} =$

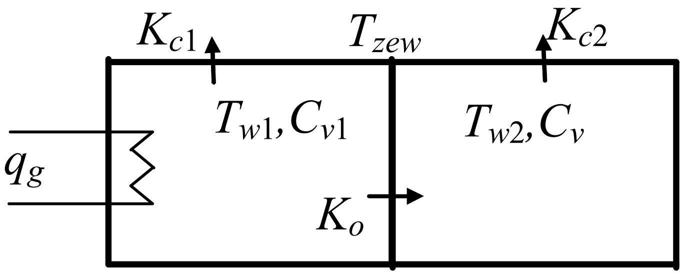
$T_{gp} =$

Identyfikacja parametrów (K_g, K_c)

1) $T_{zewN}, \; T_{wewN}, \; T_{gzN}, \; T_{gpN}, \; f_N$

2) $T_{zewN}, \; T_{wewN}, \; T_{gzN}, \; T_{gpN}, \; q_N$

$$c_{pw}\rho_{pw} f_N\left(T_{gzN} - T_{gpN}\right) = K_g\left(T_{gpN} - T_{wewN}\right) = K_c\left(T_{wewN} - T_{zewN}\right) = q_N$$



$$\begin{cases} C_{v1}\dot{T}_{w1}(t) = q_g(t) - K_{c1}\left(T_{w1}(t) - T_{zew}(t)\right) - K_o\left(T_{w1}(t) - T_{w2}(t)\right) \\ C_{v2}\dot{T}_{w2}(t) = K_o\left(T_{w1}(t) - T_{w2}(t)\right) - K_{c2}\left(T_{w2}(t) - T_{zew}(t)\right) \end{cases}$$

wy: T_{w1}, T_{w2}

we: q_g, T_{zew}

$$\begin{cases} 0 = q_g - K_{c1}\left(T_{w1} - T_{zew}\right) - K_o\left(T_{w1} - T_{w2}\right) \\ 0 = K_o\left(T_{w1} - T_{w2}\right) - K_{c2}\left(T_{w2} - T_{zew}\right) \end{cases}$$

$T_{w1} =$

$T_{w2} =$

Identyfikacja parametrów (K_o, K_{c1}, K_{c1})

$q_{gN}, \quad T_{zewN}, \quad T_{w1N}, \quad T_{w2}$

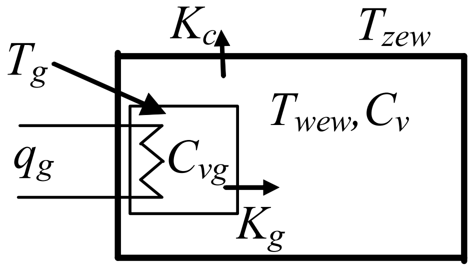
1) Konstrukcja zewnętrznych ścian jest taka sama,
ale pomieszczenie 2 ma o połowę mniejszą powieszchnię ścian

$$K_{c2} = aK_{c1}, a = 0.5$$

2) W warunkach nominalnych pomieszczenie z grzejnikiem
60% dostarczonego ciepła traci na zewnątrz

q_g	dostarczane ciepło
$K_{c1}\left(T_{w1} - T_{zew}\right)$	strata na zewnątrz
$K_o\left(T_{w1} - T_{w2}\right)$	strata do pomieszczenia2

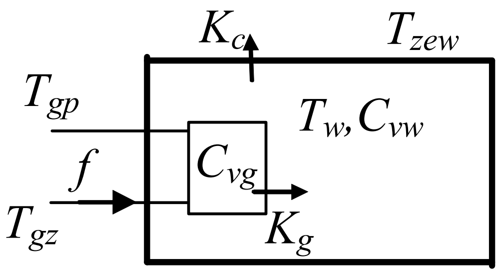
Obiekty cieplne



$$\begin{cases} C_{vg}\dot{T}_{gp}(t) = q_g(t) - K_g\left(T_g(t) - T_{wew}(t)\right) \\ C_{vw}\dot{T}_{wew}(t) = K_g\left(T_g(t) - T_{wew}(t)\right) - K_c\left(T_{wew}(t) - T_{zew}(t)\right) \end{cases}$$

$$T_{wew}(s) = \frac{}{M} q_g(s) + \frac{}{M} T_{zew}(s)$$

$$T_g(s) = \frac{}{M} q_g(s) + \frac{}{M} T_{zew}(s)$$

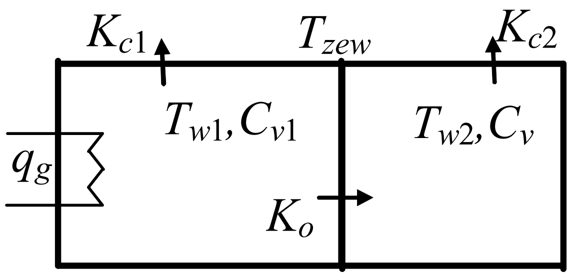


$$\begin{cases} C_{vg}\dot{T}_{gp}(t) = c_{pw}\rho_{pw} f(t)\left(T_{gz}(t) - T_{gp}(t)\right) - K_g\left(T_{gp}(t) - T_{wew}(t)\right) \\ C_{vw}\dot{T}_{wew}(t) = K_g\left(T_{gp}(t) - T_{wew}(t)\right) - K_c\left(T_{wew}(t) - T_{zew}(t)\right) \end{cases}$$

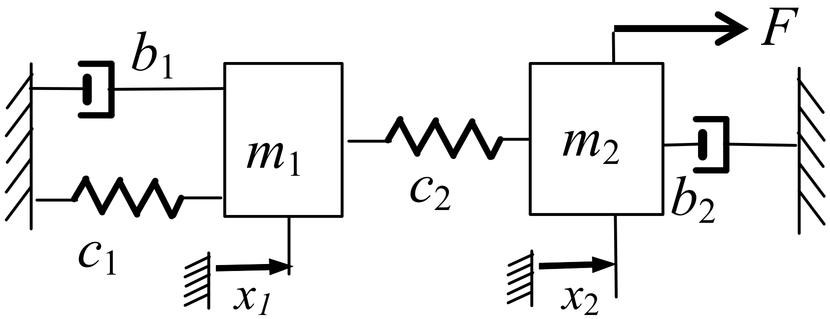
$$f(t) = const$$

$$T_{wew}(s) = \frac{}{M} T_{gz}(s) + \frac{}{M} T_{zew}(s)$$

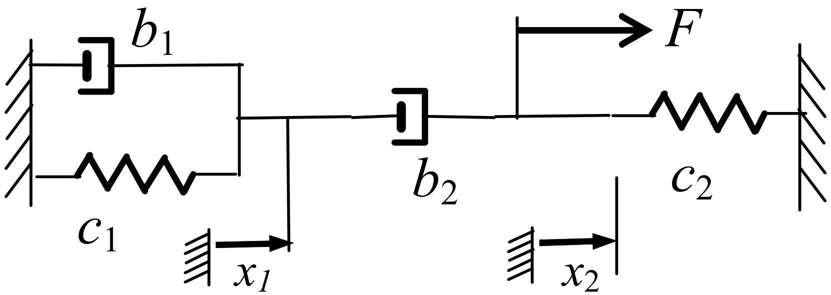
$$T_{gp}(s) = \frac{}{M} T_{gz}(s) + \frac{}{M} T_{zew}(s)$$



$$\begin{cases} C_{v1}\dot{T}_{w1}(t) = q_g(t) - K_{c1}\left(T_{w1}(t) - T_{zew}(t)\right) - K_o\left(T_{w1}(t) - T_{w2}(t)\right) \\ C_{v2}\dot{T}_{w2}(t) = K_o\left(T_{w1}(t) - T_{w2}(t)\right) - K_{c2}\left(T_{w2}(t) - T_{zew}(t)\right) \end{cases}$$



$$\begin{cases} F(t) = m_2\ddot{x}_2(t) + b_2\dot{x}_2(t) + c_2\left(x_2(t) - x_1(t)\right) \\ 0 = m_1\ddot{x}_1(t) + b_1\dot{x}_1(t) + c_1x_1(t) + c_2\left(x_1(t) - x_2(t\right. \end{cases}$$



$$\begin{cases} F(t) = b_2\left(\dot{x}_2(t) - \dot{x}_1(t)\right) + c_2x_2(t) \\ 0 = b_2\left(\dot{x}_1(t) - \dot{x}_2(t)\right) + c_1x_1(t) + b_1\dot{x}_1(t) \end{cases}$$