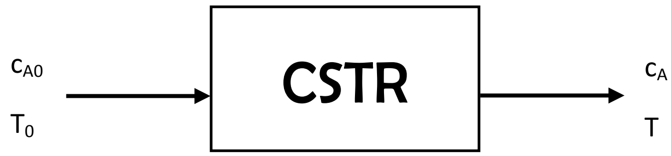
6. Control Elements

a. Transfer function



1. Unsteady-state component balances for species A (slurry)

$$V\frac{dc_A}{dt} = qc_{A0} - qc_A - Vkc_A \qquad (1)$$

Where V = tank volume

q = mass flow rate

c_{A0} = inlet concentration

c_A = product concentration

2. Rearrange equation (1) into:

$$\frac{dc_A}{dt} = c_{A0}\left(\frac{q}{V}\right) - c_A\left(\frac{q-Vk}{V}\right)$$

$$\frac{dc_A}{dt} + c_A\left(\frac{q-Vk}{V}\right) = c_{A0}\left(\frac{q}{V}\right)$$

$$\frac{dc_A}{dt} + c_A\left(\frac{1}{\tau}\right) = c_{A0}\left(\frac{q}{V}\right) \qquad (2)$$

Where $\tau = \frac{V}{q-Vk}$ is the time constant of the tank.

3. By taking Laplace transform,

$$sC_{A(s)} + C_{A(s)}\left(\frac{1}{\tau}\right) = C_{A0(s)}\left(\frac{q}{V}\right)$$

$$C_{A(s)}\left(s + \frac{1}{\tau}\right) = C_{A0(s)}\left(\frac{q}{V}\right)$$

$$\frac{C_{A(s)}}{C_{A0(s)}} = \frac{\left(\frac{q}{V}\right)}{\left(s+\frac{1}{\tau}\right)} \qquad (3)$$

4. By multiplying the numerator and denominator of equation (4) with τ, the transfer function can be expressed as,

$$\frac{C_{A(s)}}{C_{A0(s)}} = \frac{\left(\frac{q}{V}\right)\tau}{\left(s+\frac{1}{\tau}\right)\tau} = \frac{\left(\frac{q}{V}\right)\tau}{(\tau s+1)} = \frac{\left(\frac{q}{V}\right)\tau}{(\tau s+1)} = \frac{\frac{q}{V}\times\frac{V}{q-Vk}}{\tau s+1}$$

$$\frac{C_{A(s)}}{C_{A0(s)}} = \frac{\left(\frac{q}{q-Vk}\right)}{(\tau s+1)}$$

$$\frac{C_A(s)}{C_{A0}(s)} = \frac{K_{P1}}{\tau s+1} \qquad (4)$$

Where $K_{P1} = \frac{q}{q+Vk}$ is the gain of the transfer function.

5. Energy balance of the tank,

$$\rho VC\frac{dT}{dt} = \rho qC(T - T_0) + (-\Delta H)Vkc_A \qquad (5)$$

Linearize (1) and (4), and note that $\frac{dc_A}{dt} = \frac{dc_A^{'}}{dt}$ and $\frac{dT}{dt} = \frac{dT^{'}}{dt}$

$$V\frac{dc_A^{'}}{dt} = qc_{A0}^{'} - qc_A^{'} - Vkc_A^{'} \qquad (6)$$

$$\rho VC\frac{dT^{'}}{dt} = \rho qCT^{'} - \rho qCT_0^{'} + (-\Delta H)Vkc_A^{'} \qquad (7)$$

From equation (5), Laplace transform it to get

$$V\frac{dc_A^{'}}{dt} + qc_A^{'} + Vkc_A^{'} = qc_{A0}^{'}$$

$$(V_s + q + Vk)C_A^{'}(s) = qC_{A0}^{'}$$

$$C_A^{'}(s) = \frac{qC_{A0}^{'}}{(V_s+q+Vk)} \qquad (8)$$

From equation (6), Laplace transform it to get

$$\rho VC\frac{dT^{'}}{dt} - \rho qCT^{'} = -\rho qCT_0^{'} + (-\Delta H)Vkc_A^{'}$$

$$(\rho VC - \rho qC_s)T^{'}(s) = -\rho qCT_0^{'} + (-\Delta H)Vkc_A^{'}$$

$$T^{'}(s) = \frac{-\rho qCT_0^{'}+(-\Delta H)Vkc_A^{'}}{(\rho VC-\rho qC_s)} \qquad (9)$$

Therefore, the transfer function is

$$\frac{T'(s)}{C_A'(s)} = \frac{(-\rho qC T_0' + (-\Delta H)Vk c_A')(V_s + q + Vk)}{(\rho VC - \rho q C_s)q C_{A0}'} \qquad (10)$$

b. <u>Order of reaction</u>

The reaction is a first order reaction.

c. <u>Variables</u>

i. Controlled variables: Concentration of outlet, outlet temperature
ii. Manipulated variables: Biomass inlet flow rate (feed), heating rate of heaters
iii. Disturbance variables: Tank pressure, presence of catalyst.

d. <u>Type of control algorithm</u>

PID controller because it improves the closed loop stability. The effect of derivative action is to increase the damping in the response and generally improve the stability by reducing the settling time. Therefore, it is useful in reducing the oscillation caused by the integral action in the system response.