<u>Simulación y Control de Procesos</u>

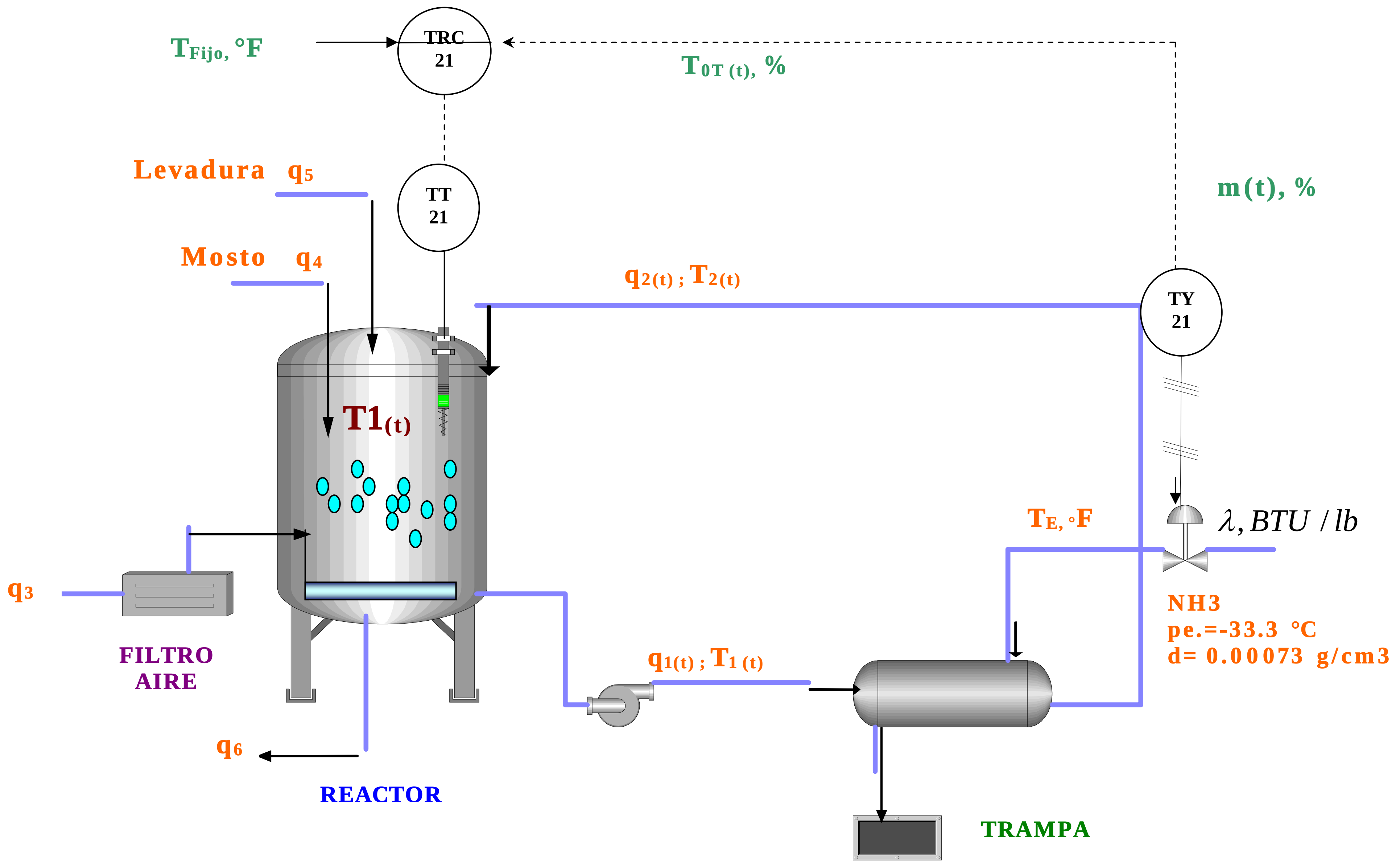
Análisis Dinámico para Control de Temperatura en corriente lateral, en la Fermentación de Levaduras de Cerveza

Análisis al Reactor:

Balance General
Balance por componente y Linealizacion
Balance de Energía

Análisis al Intercambiador:

Balance de Energía e instrumentación



TFijo, °F
TRC
21
T0T (t), %
Levadura q5
TT
21
Mosto q4
q2(t) ; T2(t)
m(t), %
TY
21
T1(t)
TE, °F
λ, BTU / lb
q3
NH3
pe.=-33.3 °C
d= 0.00073 g/cm3
FILTRO
AIRE
q1(t) ; T1 (t)
q6
REACTOR
TRAMPA

REACCION QUIMICA

Levadura (c)

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + Calor$$

MOSTO (s) ETANOL (p)

BALANCE DE MASA EN EL REACTOR

$$\rho_4 q_4 + \rho_5 q_5 + \rho_3 q_{3(t)} + \rho_2 q_{2(t)} - \rho_1 q_{1(t)} - \rho_6 q_6 = \frac{\partial M_t}{\partial t}$$

$$\rho_3 q_{3(t)} + \rho_2 q_{2(t)} - \rho_1 q_{1(t)} = 0$$

$$\rho_1 = \rho_2 = \rho$$

en estado estacionario :

$$\rho_3 \bar{q}_3 + \rho \bar{q}_2 - \rho \bar{q}_1 = 0$$

restando y aplicando la place :

$$\frac{\rho_3}{\rho} Q_{3(s)} + Q_{2(s)} - Q_{1(s)} = 0 \quad ; \qquad K' = \frac{\rho_3}{\rho}$$

$$Q_{1(s)} = Q_{3(s)} + Q_{2(s)}$$

Balance por componentes (Reactor)

levadura : c

Mosto : s

Etanol : p

BALANCE POR COMPONENTE: LEVADURA:

$$\mu_{\max}\left(1 - \frac{c_p}{c\,p^*}\right)^{0.52} \frac{c_s c_c}{k_s + c_s} - k_\partial c_c = \frac{\partial c_c}{\partial T} \qquad ....(I)$$

en estado estacionario :

$$\mu_{\max}\left(1 - \frac{\bar{c}_p}{c\,p^*}\right)^{0.52} \frac{\bar{c}_s \bar{c}_c}{k_s + \bar{c}_s} - k_\partial \bar{c}_c = 0 \qquad ...(II)$$

linealizando los términos variables :

$$\left(1 - \frac{c_p}{c\,p^*}\right)^{0.52} \frac{c_s c_c}{k_s + c_s} = \left(1 - \frac{\bar{c}_p}{c\,p^*}\right)^{0.52} \frac{\bar{c}_s \bar{c}_c}{k_s + \bar{c}_s} - \frac{0.52}{\left(1 - \frac{\bar{c}_p}{c\,p^*}\right)^{0.48} c\,p^*} \cdot \frac{\bar{c}_s \bar{c}_c}{k_s + \bar{c}_s} . C_p + \left(1 - \frac{\bar{c}_p}{c\,p^*}\right)^{0.52} \frac{\bar{c}_s}{k_s + \bar{c}_s} . C_c$$

$$+ \left(1 - \frac{\bar{c}_p}{c\,p^*}\right)^{0.52} \left[\frac{\bar{c}_c}{k_s + \bar{c}_s} - \frac{\bar{c}_c}{(k_s + \bar{c}_s)^2}\right] . C_s$$

donde:

$$\mathrm{C_p} = c_{p(t)} - \overline{c_p}$$

$$\mathrm{C_c} = c_{c(t)} - \overline{c_c}$$

$$\mathrm{C_s} = c_{s(t)} - \overline{c_s}$$

$$(I)-(II):$$

$$\frac{0.52\mu_{\max}}{\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.48}}\cdot\frac{\overline{c}_s\overline{c}_c}{k_s+\overline{c}_s}\mathrm{C_p}+\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.52}\frac{\mu_{\max}\overline{c}_s}{k_s+\overline{c}_s}\mathrm{C_c}+\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.52}\mu_{\max}\left[\frac{\overline{c}_c}{k_s+\overline{c}_s}-\frac{\overline{c}_c}{\left(k_s+\overline{c}_s\right)^2}\right]\mathrm{C_s}-k_\partial.\mathrm{C_c}=\frac{\partial \mathrm{C_c}}{\partial t}$$

$$\frac{\partial \mathrm{C_c}}{\partial t}+\left[k_\partial-\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.52}\frac{\mu_{\max}\overline{c}_s}{k_s+\overline{c}_s}\right]\mathrm{C_c}=\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.52}\mu_{\max}\left[\frac{\overline{c}_c}{k_s+\overline{c}_s}-\frac{\overline{c}_c}{\left(k_s+\overline{c}_s\right)^2}\right]\mathrm{C_s}-\frac{0.52\mu_{\max}}{\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.48}}\cdot\frac{\overline{c}_s\overline{c}_c}{k_s+\overline{c}_s}\mathrm{C_p}$$

$$\tau_1=\frac{1}{k_\partial-\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.02}\frac{\overline{c}_s\mu_{\max}}{k_s+\overline{c}_s}}$$

$$k_1=\frac{\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.52}\left[\frac{\overline{c}_c}{k_s+\overline{c}_s}-\frac{\overline{c}_c}{\left(k_s+\overline{c}_s\right)^2}\right]\mu_{\max}}{k_\partial-\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.52}\cdot\frac{\overline{c}_s}{k_s+\overline{c}_s}}$$

$$k_2=\frac{\frac{0.52\mu_{\max}}{\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.48}c_p^{*}}\cdot\frac{\overline{c}_s\overline{c}_c}{k_s+\overline{c}_s}}{k_\partial-\left(1-\frac{\overline{c}_p}{c_p^{*}}\right)^{0.52}\cdot\frac{\overline{c}_s}{k_s+\overline{c}_s}}$$

$$\tau_1 \frac{\partial C_c}{\partial t} + C_c = k_1 C_s - k_2 C_p$$
$$\tau_1 s C_{c(s)} + C_{c(s)} = k_1 C_{s(s)} - k_2 C_{p(s)}$$
$$C_{c(s)} = \frac{k_1}{\tau_1 s + 1} . C_{s(s)} - \frac{k_2}{\tau_1 s + 1} . C_{p(s)}$$

MOSTO:

$$Y_{p/c} . Y_{s/p} \mu_{max} \left(1 - \frac{c_p}{c_p^*}\right)^{0.52} . \frac{c_c c_s}{k_s + c_s} - m c_c = \frac{\partial c_s}{\partial t} \quad ...(III)$$

en estado estacionario :

$$Y_{p/c} . Y_{s/p} \mu_{max} \left(1 - \frac{\bar{c}_p}{c_p^*}\right)^{0.52} . \frac{\bar{c}_c \bar{c}_s}{k_s + \bar{c}_s} - m \bar{c}_c = 0 \quad ...(IV)$$

linealizando los terminos variables :

$$Y_{p/c} . Y_{s/p} \left(1 - \frac{c_p}{c_p^*}\right)^{0.52} \mu_{max} . \frac{c_c c_s}{k_s + c_s} = \left(1 - \frac{\bar{c}_p}{c_p^*}\right)^{0.52} . \frac{\bar{c}_c \bar{c}_s}{k_s + \bar{c}_s} - \frac{0.52 Y_{p/c} . Y_{s/p} \mu_{max}}{\left(1 - \frac{\bar{c}_p}{c_p^*}\right)^{0.48} c_p^*} . \frac{\bar{c}_s \bar{c}_c}{k_s + \bar{c}_s} . C_p$$

$$+ \left(1 - \frac{\bar{c}_p}{c_p^*}\right)^{0.52} \mu_{max} . \frac{Y_{s/p} \bar{c}_s . Y_{p/c}}{k_s + \bar{c}_s} . C_c + Y_{p/c} . Y_{s/p} \mu_{max} \left(1 - \frac{\bar{c}_p}{c_p^*}\right)^{0.52} \left[\frac{\bar{c}_c}{k_s + \bar{c}_s} - \frac{\bar{c}_c}{(k_s + \bar{c}_s)^2} \right] . C_s$$

$$(III) - (IV) : \; Y_{p/c} . Y_{s/p} . \mu_{max} = w$$

$$\frac{0.52 w}{\left(1 - \frac{\bar{c}_p}{c_p^*}\right)^{0.48} c_p^*} . \frac{\bar{c}_s \bar{c}_c}{k_s + \bar{c}_s} . C_p + \left(1 - \frac{\bar{c}_p}{c_p^*}\right)^{0.52} . \frac{\bar{c}_s w}{k_s + \bar{c}_s} . C_c + \left(1 - \frac{\bar{c}_p}{c_p^*}\right)^{0.52} w . \left[\frac{\bar{c}_c}{k_s + \bar{c}_s} - \frac{\bar{c}_c}{(k_s + \bar{c}_s)^2} \right] . C_s - m C_c = \frac{\partial C_s}{\partial t}$$

$$\frac{\partial C_s}{\partial t} - w\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}\cdot\left[\frac{\bar{c}_c}{k_s+\bar{c}_s} - \frac{\bar{c}_c}{(k_s+\bar{c}_s)^2}\right].C_s = \left[\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}\cdot\frac{\bar{c}_s}{k_s+\bar{c}_s} - m\right].C_c$$

$$-\frac{0.52}{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.48} c_p^*}\cdot\frac{\bar{c}_s\bar{c}_c}{k_s+\bar{c}_s}.C_p$$

$$\tau_2 = \frac{1}{-w\left[\frac{\bar{c}_c}{k_s+\bar{c}_s} - \frac{c_c}{(k_s+\bar{c}_s)^2}\right]\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}}$$

$$k_3 = \frac{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}\cdot\frac{\bar{c}_s}{k_s+\bar{c}_s} - m}{-\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}\left[\frac{\bar{c}_c}{k_s+\bar{c}_s} - \frac{\bar{c}_c}{(k_s+\bar{c}_s)^2}\right]}$$

$$k_4 = \frac{\frac{0.52}{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.48} c_p^*}\cdot\frac{\bar{c}_s\bar{c}_c}{(k_s+\bar{c}_s)}}{-\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}\left[\frac{\bar{c}_c}{k_s+\bar{c}_s} - \frac{\bar{c}_c}{(k_s+\bar{c}_s)^2}\right]}$$

$$\tau_2\frac{\partial \mathrm{C_s}}{\partial t} + \mathrm{C_s} = k_3\mathrm{C_c} - k_4\mathrm{C_p}$$

$$\tau_2 s\mathrm{C_{s(s)}} + \mathrm{C_{s(s)}} = k_3\mathrm{C_{c(s)}} - k_4\mathrm{C_{p(s)}}$$

$$\mathrm{C_{s(s)}} = \frac{k_3}{\tau_2 s+1}.\mathrm{C_{c(s)}} - \frac{k_4}{\tau_2 s+1} - \mathrm{C_{p(s)}}$$

ETANOL:

$$Y_{p/c}.\mu_{max}\left(1-\frac{c_p}{c_p^*}\right)^{0.52}\frac{c_c c_s}{k_s+c_s}=\frac{\partial c_p}{\partial T} \qquad ...(V)$$

En estado estacionario :

$$Y_{p/c}.\mu_{max}\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}.\frac{\bar{c}_c\bar{c}_s}{k_s+\bar{c}_s}=0 \qquad ...(VI)$$

linealizando :

$$\left(1-\frac{c_p}{c_p^*}\right)^{0.52}\frac{c_c c_s}{k_s+c_s}=$$

$(V)-(VI)$:

$$\frac{Y_{p/c}.\mu_{max}0.52}{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.48}c_p^*}.\frac{\bar{c}_s\bar{c}_c}{k_s+\bar{c}_s}.C_p+Y_{p/c}.\mu_{max}\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}.\frac{\bar{c}_s}{k_s+\bar{c}_s}.C_c+Y_{p/c}.\mu_{max}\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}\left[\frac{\bar{c}_c}{k_s+\bar{c}_s}-\frac{\bar{c}_c}{(k_s+\bar{c}_s)^2}\right].C_s$$

$$=\frac{\partial C_p}{\partial t}$$

$$\tau_3=\frac{1}{\frac{Y_{p/c}.\mu_{max}0.52}{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.48}c_p^*}.\frac{\bar{c}_s\bar{c}_c}{k_s+\bar{c}_s}} \qquad k_5=\frac{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}.\frac{\bar{c}_s}{k_s+\bar{c}_s}}{\frac{0.52}{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.48}c_p^*}.\frac{\bar{c}_s\bar{c}_c}{k_s+\bar{c}_s}}$$

$$k_6=\frac{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.52}\left[\frac{\bar{c}_c}{k_s+\bar{c}_s}-\frac{\bar{c}_c}{(k_s+\bar{c}_s)^2}\right]}{\frac{0.52}{\left(1-\frac{\bar{c}_p}{c_p^*}\right)^{0.48}c_p^*}.\frac{\bar{c}_s\bar{c}_c}{k_s+\bar{c}_s}}$$

$$_3\frac{\partial C_p}{\partial t} + C_p = K_5 C_c + K_6 C_s$$

$$\tau_3 C_{p(S)} + C_{p(S)} = K_5 C_{c(S)} + K_6 C_{s(S)}$$

$$C_{p(S)} = \frac{K_5}{\tau_3 s + 1} C_{c(S)} + \frac{K_6}{\tau_3 s + 1} C_{s(S)}$$

BALANCE DE ENERGIA EN EL REACTOR:

$$\rho_3 C_{p3} T_{3(t)} q_{3(t)} + \rho_2 C_{p2} T_{2(t)} q_{2(t)} - V\Delta H_{rxn}(r_g - r_d) - \rho_1 C_{p1} T_{1(t)} q_{1(t)} = V\rho Cv \frac{\partial T_{(t)}}{\partial T}$$

$$\rho_1 = \rho_2 = \rho$$

$$C_{p1} = C_{p1} = C_p$$

$$\Delta H_{rxn} = cte$$

$$q_1 = q_2 = q$$

$$\rho_3 C_{p3} T_{3(t)} q_{3(t)} + \rho C_p T_{2(t)} q_{2(t)} - V\Delta H_{rxn}(r_g - r_d) - \rho C_p T_{1(t)} q_{1(t)} = V\rho Cv \frac{\partial T_{(t)}}{\partial T}$$

$$\rho_3 C_{p3} T_{3(t)} q_{3(t)} + \rho C_p T_{2(t)} q_{2(t)} - V\Delta H_{rxn}\left[\mu_{\max}\left(1 - \frac{C_p}{C_p^*}\right)^{0.52} \frac{C_c C_s}{K_s + C_s} - K_\partial C_c\right] - \rho C_p T_{1(t)} q_{1(t)} = V\rho Cv \frac{\partial T_{(t)}}{\partial T} \text{.......}(V)$$

<u>Linealizando los Términos variables:</u>

$$\left(1 - \frac{C_p}{C_p^*}\right)^{0.52} \frac{C_c C_s}{K_s + C_s} = \left(1 - \frac{\overline{C_p}}{C_p^*}\right)^{0.52} \frac{\overline{C_s}\,\overline{C_c}}{K_s + \overline{C_s}} - \frac{0.52}{\left(1 - \frac{\overline{C_p}}{C_p^*}\right)^{0.48} C_p^*} \cdot \frac{\overline{C_c}\,\overline{C_s}}{K_s + \overline{C_s}} Cp + \left(1 - \frac{\overline{C_p}}{C_p^*}\right)^{0.52} \frac{\overline{C_s}\,\overline{C_c}}{K_s + \overline{C_s}} Cc$$

$$+ \left(1 - \frac{\overline{C_p}}{C_p^*}\right)^{0.52} \left[\frac{\overline{C_c}}{K_s + \overline{C_s}} - \frac{\overline{C_c}}{\left(K_s + \overline{C_s}\right)^2}\right] . Cs$$

$$Donde:$$

$$C_p = C_{p(t)} - \overline{C_p}$$

$$C_c = C_{c(t)} - \overline{C_c}$$

$$Cs = C_{s(t)} - \overline{C_s}$$

Linealizando los Términos variables:

$$T_{i(t)}q_{i(t)} = \overline{T_i}\,\overline{q_i} - \overline{T_i}q_i + \overline{T_i}Q_{i(t)}$$

$$T_{i(t)} = T_{i(t)} - \overline{T_i}$$

$$Q_{i(t)} = q_{i(t)} - \overline{q_i}$$

En estado Estacionario:

$$\rho_3 C_{p3}\overline{T}_{3(t)}\overline{q}_{3(t)} + \rho C_p \overline{T}_{2(t)}\overline{q}_{2(t)} - V\Delta H_{rxn}\left[\mu_{max}\left(1-\frac{\overline{C_p}}{C_p^*}\right)^{0.52}\frac{\overline{C_c}\,\overline{C_s}}{K_s+\overline{C_s}} - K_\partial C_c\right] - \rho C_p \overline{T}_{1(t)}\overline{q}_{1(t)} = 0 ....(VI)$$

(V) – (VI)

$$\rho_3 C_{p3}\overline{q}_{3(t)}\mathrm{T}_{3(t)} + \rho_3 C_{p3}\overline{T}_{3(t)}Q_{3(t)} + \rho C_p \overline{q}_{2(t)}\mathrm{T}_{2(t)} + \rho C_p \overline{T}_{2(t)}Q_{2(t)} + \frac{M.0.52}{\left(1-\frac{\overline{C_p}}{C_p^*}\right)^{0.48} C_p^*}\frac{\overline{C_c}\,\overline{C_s}}{K_s+\overline{C_s}}Cp_{(p)}$$

$$-\left[M\left(1-\frac{\overline{C_p}}{C_p^*}\right)^{0.52}\frac{\overline{C_s}}{K_s+C_s} - N\right]Cc_{(t)} - M\left(1-\frac{\overline{C_p}}{C_p^*}\right)^{0.52}\left[\frac{\overline{C_c}}{K_s+C_s} - \frac{\overline{C_c}}{(K_s+\overline{C_s})^2}\right]Cs_{(t)} - \rho C_p \mathrm{T}_{1(t)}\overline{q}_{1(t)}$$

$$-\rho C_p \overline{T}_{1(t)}Q_{1(t)} = V\rho Cv\frac{\partial T_{(t)}}{\partial T}$$

$$M = V\Delta H_{rxn}\mu_{max} \quad ; \quad N = V\Delta H_{rxn}$$

$$T_{i(t)} = T_{i(t)} - \overline{T_i}$$

$$Q_{i(t)} = q_{i(t)} - \overline{q_i}$$

$$C_{i(t)} = c_{i(t)} - \overline{C_i}$$

$$\tau_{3=}\ \frac{V\rho Cv}{\rho C_p \overline{q}_{1(t)}}$$

$$\tau_{3=}\ \frac{\partial T_1}{\partial T} + T_{1(t)}$$

$$\tau_3 = K_5 T_{3(t)} + K_6 Q_{3(t)} + K_7 T_{2(t)} + K_8 Q_{2(t)} + K_9 C_{p(t)} - K_{10} C_{c(t)} - K_{11} C_{s(t)} - K_{12} Q_{1(t)}$$

Donde:

$$K_5 = \frac{\rho_3 C_{p3} \overline{q_3}}{\rho C_p \overline{q_1}} \qquad K_7 = \frac{\rho C_p \overline{q_2}}{\rho C_p \overline{q_1}}$$

$$K_6 = \frac{\rho_3 C_{p3} \overline{T_3}}{\rho C_p \overline{q_1}} \qquad K_8 = \frac{\rho_3 C_3 \overline{T_2}}{\rho C_p \overline{q_1}}$$

$$K_9 = \frac{\dfrac{M\,0.52}{\left(1-\dfrac{\overline{C_p}}{C_p^*}\right)^{0.48} C_p^*} \cdot \dfrac{\overline{C_s}\,\overline{C_c}}{K_s + \overline{C_s}}}{\rho C_p \overline{q_1}} \qquad K_{10} = \frac{\left[M\left(1-\dfrac{\overline{C_p}}{C_p^*}\right)^{0.52} \dfrac{\overline{C_s}}{K_s+\overline{C_s}} - N\right]}{\rho C_p \overline{q_1}}$$

$$K_{11} = M\left(1-\frac{\overline{C_p}}{C_p^*}\right)^{0.52} \frac{\left[\dfrac{\overline{C_c}}{K_s+\overline{C_s}} - \dfrac{\overline{C_c}}{\left(K_s+\overline{C_s}\right)^2}\right]}{\rho C_p \overline{q_1}} \qquad K_{12} = \frac{\rho C_p \overline{T_1}}{\rho C_p \overline{q_1}}$$

Aplicando LaPlace:

$$T_{1(s)} = \frac{K_5}{\tau_3 s+1}T_{3(s)} + \frac{K_6}{\tau_3 s+1}Q_{3(s)} + \frac{K_7}{\tau_3 s+1}T_{2(s)} + \frac{K_8}{\tau_3 s+1}Q_{2(s)} + \frac{K_9}{\tau_3 s+1}C_{p(s)} - \frac{K_{10}}{\tau_3 s+1}C_{c(s)} - \frac{K_{11}}{\tau_3 s+1}C_{s(s)} - \frac{K_{12}}{\tau_3 s+1}Q_{1(s)}$$

INTERCAMBIADOR DE CALOR:

Sensor y transmisor de temperatura.

El Sensor de temperatura se calibra para un rango de 22 a 122ºF y una constante de tiempo τ_r de 0.75 min

- Válvula de control

  La válvula de control se diseña con una sobrecapacidad de 100% y las variaciones en la caída de presión se pueden despreciar.

  La válvula es lineal la constante de tiempo del actuador es de 0.2min

Proceso

Del balance de energía al fluido de recirculación, si se supone que las perdidas de calor son despreciables, mezcla prefecta y las propiedades físicas son constantes. Resulta la siguiente ecuación.

$$\rho CpT_{1(t)}q_{1(t)} - UA[T_{2(t)} - T_{E(t)}] - \rho C_p T_{2(t)} q_{2(t)} - V\Delta H_{rxn}\left[\mu_{\max}\left(1-\frac{Cp}{Cp^*}\right)^{0.52}\frac{C_C C_S}{K_S + C_S} - K_d C_C\right] =$$

$$\rho v C_v \frac{dT_{2(t)}}{dt} \text{ ....(*)}$$

Linealizando los términos variables:

$$* \left(1-\frac{Cp}{Cp^*}\right)^{0.52}\frac{C_C C_S}{K_S + C_C} = \left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\frac{\overline{C_C}\,\overline{C_S}}{K_S + C_C} - \frac{0.52}{\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.48} Cp^*}\frac{\overline{C_C}\,\overline{C_S}}{K_S + C_S} \subset p + \left(1-\frac{Cp}{Cp^*}\right)^{0.52}\frac{\overline{C_S}}{K_S + C_C} \subset c$$

$$+ \left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\left[\frac{\overline{C_C}}{K_S + \overline{C_S}} - \frac{\overline{C_C}}{\left(K_S + \overline{C_S}\right)^2}\right] \subset s$$

Donde: $\subset_i = C_{i(t)} - \overline{C_i}$

$$T_{i.}q_{i(t)} = \overline{T_i}\,\overline{q_i} + \overline{q_i}\,\mathcal{T}_{i(t)} + \overline{T_i}\,\mathcal{Q}_{i(t)}$$

$$\mathcal{T}_i = T_{i(t)} - \overline{T_i}$$
$$\mathcal{Q}_i = q_{i(t)} - \overline{q_i}$$

- En estado estacionario:

$$\rho Cp\overline{T}_{1(t)}\overline{q}_{1(t)} - UA[\overline{T}_{2(t)} - \overline{T}_{E(t)}] - \rho C_p \overline{T}_{2(t)} \overline{q}_{2(t)} - V\Delta H_{rxn}\left[\mu_{\max}\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\frac{C_C C_S}{K_S + C_S} - K_d C_C\right] = 0$$

(*)-(**)

$$\rho Cp\left(\overline{q}_{1(t)}\mathcal{T}_{1(t)} - \overline{T}_1\mathcal{Q}_{1(t)}\right) - UA[\mathcal{T}_{2(t)} - \mathcal{T}_{E(t)}] - \rho C_p q_2 \mathcal{T}_{2(t)} - \rho C_p \mathcal{T}_2 \mathcal{Q}_{2(t)} + \frac{M\,0{,}52}{\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.48} Cp^*}\cdot\frac{\overline{C_C}\,\overline{C_S}}{K_S + \overline{C_S}}\cdot \subset p_{(t)}$$

$$\left[M\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\frac{\overline{C_S}}{K_S + \overline{C_S}} - N\right]\cdot \subset c_{(t)} - M\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\left[\frac{\overline{C_C}}{K_S + \overline{C_S}} - \frac{\overline{C_C}}{\left(K_S + \overline{C_S}\right)^2}\right] \subset s_{(t)} = \rho v C_v \frac{dT_{2(t)}}{dt}$$

M=V $\Delta H_{rxn}\mu_{\max}$

N=V $\Delta H_{rxn}Kd$

$$\rho v C_v \frac{dT_{2(t)}}{dt} + \left(\rho C_p \bar{q}_2 + UA\right)T_{2(t)} = \rho C_p \bar{q}_1 T_{1(t)} + \rho Cp\left(\bar{T}_1 Q_{1(t)}\right) - UAT_{E(t)} - \rho C_p \bar{T}_2 Q_{2(t)}$$

$$+\frac{M0{,}52}{\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.48} Cp^*} . \frac{\overline{C_C}\,\overline{C_S}}{K_S+\overline{C_S}} . \subset p_{(t)} - \left[M\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\frac{\overline{C_S}}{K_S+\overline{C_S}} - N\right] . \subset c_{(t)}$$

$$-M\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\left[\frac{\overline{C_C}}{K_S+\overline{C_S}} - \frac{\overline{C_C}}{\left(K_S+\overline{C_S}\right)^2}\right] . \subset s_{(t)}$$

$$\tau_4 \frac{dT_{2(t)}}{dt} + T_{2(t)} = K_{13}T_{1(t)} + K_{14}Q_{1(t)} + K_{15}T_{E(t)} - K_{16}Q_{2(t)} - K_{17}Cp_{(t)} + K_{18} \subset c_{(t)} - K_{19} \subset_{S(t)}$$

$$\tau_4 = \frac{\rho v C_v}{\left(\rho C_p \bar{q}_2 + UA\right)}; K_{13} = \frac{\left(\rho C_p \bar{q}_1 - UA\right)}{\left(\rho C_p \bar{q}_2 + UA\right)}; K_{14} = \frac{\rho C_p \bar{T}_1}{\left(\rho C_p \bar{q}_2 + UA\right)}; K_{15} = \frac{UA}{\left(\rho C_p \bar{q}_2 + UA\right)} - K_{16} = \frac{\rho C_p \bar{T}_2}{\left(\rho C_p \bar{q}_2 + UA\right)}$$

$$K_{17} = \frac{M \cdot 0{,}52 \cdot \overline{C_C} \cdot \overline{C_S}}{\left(\rho C_p \bar{q}_2 + UA\right)\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.48} Cp^*\left(K_S+\overline{C_S}\right)} + K_{18} = \frac{1}{\left(\rho C_p \bar{q}_2 + UA\right)}\left[M\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\frac{\overline{C_S}}{K_S+\overline{C_S}} - N\right]$$

$$K_{19} = \frac{1}{\left(\rho C_p \bar{q}_2 + UA\right)} M\left(1-\frac{\overline{Cp}}{Cp^*}\right)^{0.52}\left[\frac{\overline{C_C}}{K_S+\overline{C_S}} - \frac{\overline{C_C}}{\left(K_S+\overline{C_S}\right)^2}\right]$$

Aplicando Laplace:

$$T_{2(S)} = \frac{K_{13}}{\tau_4 s+1}T_{1(S)} + \frac{K_{14}}{\tau_4 s+1}Q_{1(S)} + \frac{K_{15}}{\tau_4 s+1}T_{E(S)} - \frac{K_{16}}{\tau_4 s+1}Q_{2(S)} - \frac{K_{17}}{\tau_4 s+1}Cp_{(S)} - \frac{K_{18}}{\tau_4 s+1} \subset c_{(S)} - \frac{K_{19}}{\tau_4 s+1} \subset_{S(S)}$$

Balance de energía. Si se supone que la tubería del intercambiador (metal) esta esencialmente a la misma temperatura que el agua de refrigeración:

$$UA[T_{2(t)} - T_{E(t)}] + \dot{W}_{(t)}\lambda = C_M \frac{dT_{E(t)}}{dT} ....(1)$$

Valvula: $\dot{W}_{(t)} = Kv \cdot vp_{(t)}\ldots\ldots\ldots\ldots(2)\quad Kv = W_{\max}$

$$vp_{(S)} = \frac{2}{\tau_v s+1}M_{(S)}.....................(3)$$; $M_{(S)}$:Señal de salida del controlador en porcentaje

Sensor- Transmisor (TT21)

Se puede representar mediante un retardo de 1º orden

$$\frac{T_{oT(S)}}{T_{2(S)}} = \frac{K_T}{\tau_T s + 1} \text{..........(4)}; \; T_{oT(S)} : \text{Transformada de Laplace de la}$$

señal de salida del transmisor, %

Controlador con retroalimentación (TRC21)

- La funcion de transferencia del controlador PID es:

$$G_{C(S)} = K_C \left(1 + \frac{1}{\tau_I s} + \tau_D s \right) = \frac{M_{(S)}}{R_{(S)} - T_{oT(S)}}$$

K_C : ganancia del controlador

τ_D : Tiempo de integración

τ_I : Tiempo de derivación

Aplicando Laplace:

(1) $$T_{E(S)} = \frac{1}{\tau_S s + 1} \cdot T_{2(S)} + \frac{K_{20}}{\tau_S s + 1} \cdot W_{(S)}$$

$$\tau_S = \frac{C_M}{UA}; \quad K_{20} = \frac{\lambda}{UA}$$

(2) $\dot{W}_{(t)} = W_{\max} \cdot vp_{(t)}$

Al combinar esta ecuación con la funcion de transferencia del actuador, se puede eliminar $vp_{(S)}$

$$\frac{W_{(S)}}{M_{(S)}} = \frac{2W_{\max}}{\tau_V s + 1} = \frac{K_V}{\tau_V s + 1}; \quad Kv = 2\,W_{\max}$$

Ganancia del transmisor: $K_T = \dfrac{100 - 0}{120 - 32} = 1{,}13 \,\%/{}^{o}F$

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