Integrated Design Project: Design of Tubular Reactor

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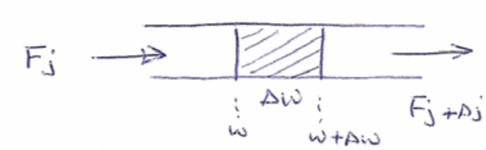
Design of tubular packed Reactor

$$r_j = \frac{\text{g-mol of j reacted}}{\text{time . g-catalyst}}$$



$$F_j\Big|_w - F_j\Big|_{w+\Delta w} + r_j^* \Delta w = \cancel{acc.}^{\,0}$$

$$\frac{dF_j}{dw} = -r_j^* \quad ; \quad w = \int_{F_j^0}^{F_j} -\frac{dF_j}{r_j^*}$$

For a chem. Rxn $\quad A + \frac{b}{a} B \longrightarrow \frac{c}{a} C + \frac{d}{a} D$

$$F_A = F_{A_0}(1-x)$$
$$F_B = F_{A_0}\left(\theta_B - \frac{b}{a}x\right) \quad ; \quad \theta_B = \frac{F_{B0}}{F_{A0}}$$
$$F_C = F_{A_0}\left(\theta_C + \frac{c}{a}x\right) \quad ; \quad \theta_C = \frac{F_{C0}}{F_{A0}}$$
$$F_D = F_{A_0}\left(\theta_B + \frac{d}{a}x\right) \quad ; \quad \theta_D = \frac{F_{D0}}{F_{A0}}$$

and $\quad F_{Tot.} = F_{T_0} + \delta F_{A_0} x$

where $\quad F_{T0} = \sum_{i=A}^{D} F_{i_0} = F_{A_0}(1+\theta_B+\theta_C+\theta_D)$

$$\delta = \frac{d}{a} + \frac{c}{a} - \frac{b}{a} - 1$$

For a volume change w/ chem. Rxn.

$$V = V_0 \frac{P_0}{P}\frac{T}{T_0}\frac{Z}{Z_0}\frac{N_T}{N_{T0}}$$

However, $\quad N_T = N_{T0} + \delta N_{A0} x$

and $\quad \frac{N_T}{N_{T0}} = 1 + \delta \frac{N_{A0}}{N_{T0}} x = 1 + \delta y_{A_0} x$

let $\quad \epsilon = \frac{\text{change in } N_T \text{ for Complete conversion}}{\text{Total } N_T \text{ fed to the Rxr.}}$

$$= \left(\frac{d}{a} + \frac{c}{a} - \frac{b}{a} - 1\right)\frac{N_{A0}}{N_{T0}} = \delta y_{A0}$$

$\therefore \quad V = V_0 \frac{P_0}{P}\frac{T}{T_0}\frac{Z}{Z_0}(1+\epsilon x)$

and $\quad v = v^0 \frac{P_0}{P}\frac{T}{T_0}\frac{Z}{Z_0}(1+\epsilon x) \quad ; \quad v = V/\text{Time}$

$$c_j = \frac{F_j}{v} = \frac{F_j}{v_0 (1+\epsilon x) \frac{P_0}{P} \frac{T}{T_0}} = \frac{F_j}{v_0 \frac{F_T}{F_{T0}} \frac{P_0}{P} \frac{T}{T_0}}$$

where $1+\epsilon x = \frac{N_T}{N_{T0}} \equiv \frac{F_T}{F_{T0}}$

$$\therefore \quad c_j = \frac{F_{A0}(\theta_j + \nu_j x)}{v_0 (1+\epsilon x) \frac{P_0}{P} \frac{T}{T_0}} \quad , \text{ but } \frac{F_{A0}}{v_0} = c_{A0}$$

$$= \frac{c_{A0}(\theta_j + \nu_j x)}{(1+\epsilon x)} \frac{P}{P_0} \frac{T_0}{T}$$

, ν_j is stoi. coef.
-ve for Rxnt
+ve for prod.

Now; for the Rxn $\alpha R\text{-}S + \beta H_2 \rightarrow R + H_2S$

or $\alpha A + \beta B \rightarrow C + D$

$$r^* = -k \, P_A^{\alpha} P_B^{\beta}$$
$$= -k \, c_A^{\alpha} c_B^{\beta} RT$$

and
$$F_{A0} \frac{dx}{dw} = kRT_0 \left[\frac{c_{A0}(1-x)}{(1+\epsilon x)} \frac{P}{P_0} \frac{T_0}{T} \right]^{\alpha} \cdot \left[\frac{c_{A0}(\theta_B - \frac{\beta x}{\alpha})}{(1+\epsilon x)} \frac{P}{P_0} \frac{T_0}{T} \right]^{\beta}$$

or
$$F_{A0} \frac{dx}{dw} = \frac{k \, c_{A0}^{\alpha} c_{A0}^{\beta}}{(1+\epsilon x)^{\alpha+\beta}} \left(\frac{P}{P_0} \frac{T_0}{T} \right)^{\alpha+\beta} (1-x)^{\alpha} (\theta_B - \tfrac{\beta}{\alpha} x)^{\beta}$$

assume isothermal condition, i.e $T = T_0$

$\alpha = \beta = 1$,

then
$$\boxed{F_{A0} \frac{dx}{dw} = \frac{k \, c_{A0}^2}{(1+\epsilon x)^2} \left(\frac{P}{P_0} \right)^2 (1-x)(\theta_B - x)} \quad --- (1)$$

This is an ODE with $x = f(w)$

You need another Equ. to obtain $P = f(w)$

use Eurgan Equation

Eurgun Equation

$$\frac{dP}{dz} = \frac{-G}{\rho g_c D_p}\left(\frac{1-\phi}{\phi^3}\right)\left[\frac{150(1-\phi)}{D_p}\mu + 1.7G\right]$$

where, z bed length

$g_c = 32.174 \frac{lbm\ ft}{s^2\ lb_f}$

ϕ : porosity

μ : viscosity

$G = \rho u$, u is the superfeacial veloaty

$= \frac{\text{volumetric flow rate}}{\text{cross-sectional area of pipe}} \left[\frac{ft}{hr}\right]$

to obtain Relation between ω & z

$\omega = (1-\phi) A_c z * \rho_c$ ← ρ of solid particle

$d\omega = (1-\phi) A_c \rho_c \, dz$

Also, $V_s = V_b(1-\phi)$,

solid vol. total vol.

$\dot{m}_o = \dot{m}$; $\rho_o v_o = \rho v$

∴ Eurgun Equation will become

$$\frac{dP}{d\omega} = -\frac{\alpha}{2}\frac{T}{T_o}\frac{P_o}{P/P_o}(1+\epsilon x) \quad , \quad \alpha = \frac{2\beta_o}{A_c \rho_c (1-\phi) P_o}$$

for isothermal condition, and for $\epsilon x \ll 1$

$$\frac{dP}{d\omega} = -\frac{\alpha}{2}\frac{P_o}{P/P_o} \quad , \quad \frac{P}{P_o} = \left(1 - \frac{2\beta_o z}{P_o}\right)^{1/2}$$

or $\frac{P}{P_o} = (1-\alpha\omega)^{1/2}$