$$R = (1 - E)^n \qquad t_F = \frac{\mu \alpha' \rho_C}{2\Delta P^{1-s}} \left(\frac{V_F}{A}\right)^2$$

$$t_W = 2t_F nf$$

$$f = V_R / V_F$$

$$n = V_W / V_R \qquad t_F = \beta t_C$$

$$J = k \cdot \ln(c_G / c_F)$$

$$\frac{c_G}{c_F} = \exp\left[\frac{J}{k}\right]$$

$$k = \frac{D}{\delta}$$

Turbulent Flow (Re > 4000)

$$Sh = 0.023(Re)^{0.8}(Sc)^{0.33}$$

Laminar Flow (Re < 1800)

$$Sh = 1.86(Re)^{0.33}(Sc)^{0.33}(d_h/L)^{0.33}$$

$$Sh = \frac{kd_h}{D}$$

$$Re = \frac{d_h v_B \rho}{\mu}$$

$$Sc = \frac{\mu}{\rho D}$$

Constant Pressure Filtration (with $\mathbf{V} = 0$ at $t = 0$)

$$\frac{t}{\mathbf{V}/A} = \frac{\mu\alpha\rho_C}{2\Delta P}\left(\frac{\mathbf{V}}{A}\right) + \frac{\mu R_M}{\Delta P}$$

Constant Pressure Filtration (with $\mathbf{V} = \mathbf{V}_S$ at $t = t_S$)

$$\frac{(t - t_S)}{(\mathbf{V} - \mathbf{V}_S)} = \frac{\mu\alpha\rho_C}{2A^2\Delta P}(\mathbf{V} + \mathbf{V}_S) + \frac{\mu R_M}{A\Delta P}$$

Constant Rate Filtration

$$\Delta P = \alpha\mu\rho_C v^2 t + \mu R_M v$$

Constant Rate then, after t_S, Constant Pressure Filtration

Phase I: constant rate

$$\Delta P = \mu\,\alpha\rho_C v^2 t + \mu R_M v \qquad (t < t_S)$$

$$\mathbf{V} = Q_I t = \text{constant} \qquad (\mathbf{V} \le \mathbf{V}_S)$$

Phase II: constant pressure

$$\Delta P = \Delta P_S = \text{constant} \qquad (t \ge t_S)$$

$$\frac{(t - t_S)}{(\mathbf{V} - \mathbf{V}_S)} = \frac{\mu\alpha\rho_C}{2A^2\Delta P}(\mathbf{V} + \mathbf{V}_S) + \frac{\mu R_M}{A\Delta P} \qquad (\mathbf{V} > \mathbf{V}_S)$$