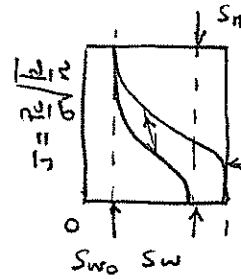
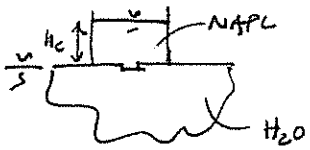
Darcy's Law: Volume: $Q = v^d A = -AK\,dh/dx$; Velocity: $v^a = \frac{v^d}{n} = -\frac{K}{n}\frac{dh}{dx}$ } $\frac{K}{\rho g} = \frac{k}{\mu}$; $k = \frac{b^3}{12s}$

Multiphase Behavior (Static):



Wetting	Non-Wetting
Water	Air
Water	Oil / DNAPL / LNAPL
Oil/Napl	Air

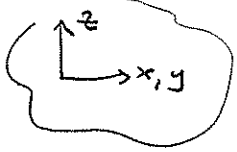


Buoyant with air:

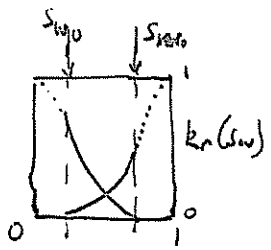
$h_{min} = \frac{h_c}{(1 - \rho_w/\rho_{nw})}$

Capillary models: $h_c = \left\{ \frac{4\sigma}{d\gamma_w},\ \frac{2\sigma}{b\gamma_w} \right\}$ Also Brooks-Corey and van Genuchten (P_c vs S_w)

Permeability Relations (Rate of movement)

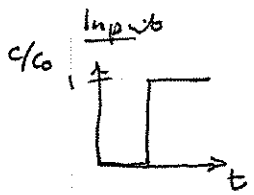


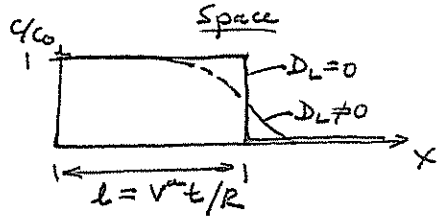
$$v_{ix} = -k_r \frac{k_i}{\mu_i}\left(\frac{dp_i}{dx} + 0\right)$$
$$v_{iz} = -k_r \frac{k_i}{\mu_i}\left(\frac{dp_i}{dz} + \rho_i g 1\right)$$
$$\Big\} \quad v_{ij} = -k_r \frac{k_i}{\mu_i}\left(\frac{dp_i}{dx_j} + \rho_i g \frac{\partial z}{\partial x_j}\right)$$

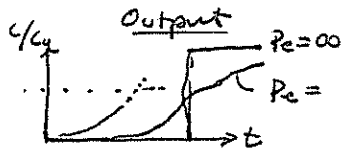


$k_r = \frac{k(S)}{k(S=1)}$; Heads: $v_{ix} = -k_r \frac{k_i}{\mu_i}\frac{d}{dx_j}\left(\frac{p_i}{\rho_i g} + \frac{\rho_i g\, z}{\rho_i g}\right)\rho_i g = -k_r K \frac{dh}{dx_j}$

Transport (miscible phases): Diffusion/Dispersion: $F_d = -D\,\partial c/\partial x$; Advection: $F_a = v_x^a n c$ } $\frac{dc}{dt} = \frac{D_L}{R}\frac{\partial^2 c}{\partial x^2} - \frac{v_x^a}{R}\frac{\partial c}{\partial x}$







$R_a = \left(1 + \frac{\rho_b K_D}{\theta}\right)$

$D_L = D_d^* + \alpha_L V^a$

$D_T = D_d^* + \alpha_T V^a$

$\alpha_L \sim L/10$; $\alpha_T \sim \alpha_L/3$

$K_D = K_{oc} f_{oc}$ $\quad f_{oc} > 0.1\%$

$K_{oc} = \int \frac{f(k_{ow})}{f(S)}$

$S_e = X_i S_i$

$M_T = C n V_T R$

$V_a = -\frac{K}{R_n}\frac{dh}{dx}$

$C_w = \frac{(C_{total} * \rho_b)}{(K_D \rho_b + \theta_w)}$ } $C_w > S_{ei}$: possible NAPL presence; $C_w < S_{ei}$: NAPL absence

Vadose Zone: $C_w = X_i S_i$; $C_g = H C_w$; $C_s = K_D C_w$ } $R_g = [1 + \frac{\theta_w}{\theta_g}\frac{1}{H} + \frac{\rho_b}{\theta_g}\frac{K_D}{H}]$; $H = \frac{C_g}{C_w}$

$V_g^a = V_{air}^a / R_g$; Rate of removal order; $H = \frac{H'}{(RT)}$

Water Flux: $q_w^a = q_{inf}/\theta_w$; $q_m = \theta_w V_w^m C_w$

Site Characterization: Direct: Coring/Augers/Trenches/Cable tool ... Sampling
Indirect: Geophysics — Surface + Borehole.

Restoration: