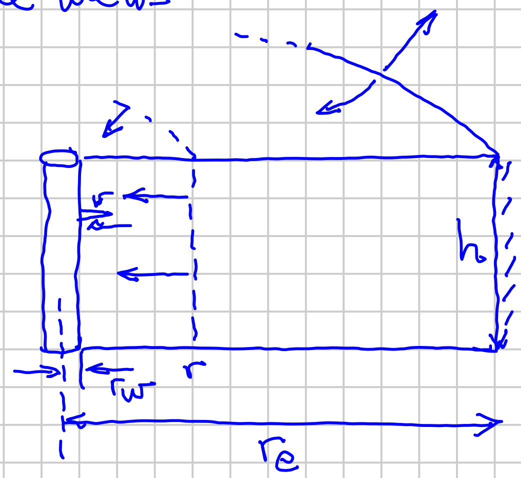
RESERVOIR RATE EQ. FOR GAS WELLS (Steady State)

- Radial Cylindrical Flow in Vertical wells



Darcy's Law:

$$\frac{q}{A_\perp} \equiv v = \frac{k}{\mu}\frac{dp}{dr}$$

* Use to develop

Forcheimmer's Eq.

$$\frac{dp}{dr} = \frac{\mu}{k} v + \underbrace{\rho \beta v^2}_{\text{Nearest Wellbore } r \to r_w}$$

$$A = 2\pi r h \qquad \left(v \;\tilde{\propto}\; \frac{1}{r} \right)$$

$$\beta \propto \frac{1}{k}$$

Ramey

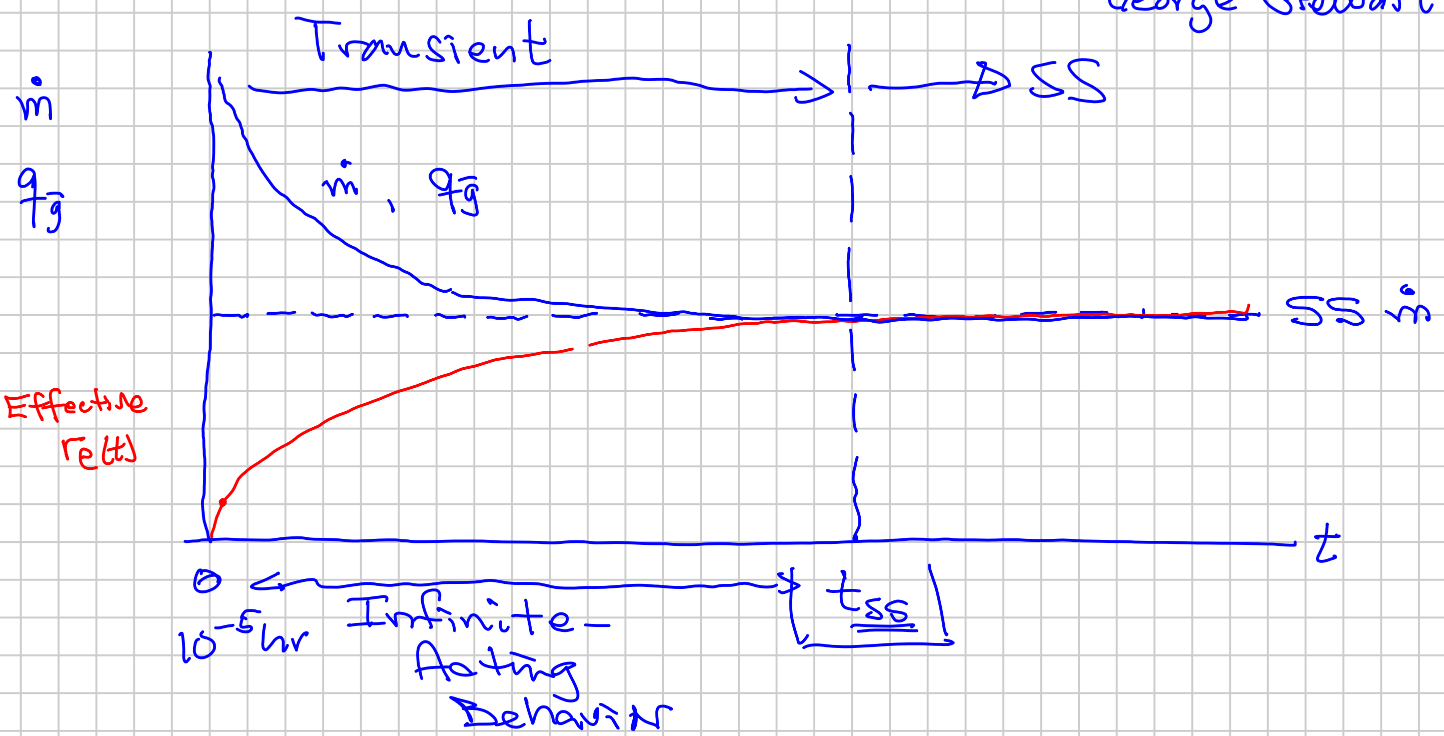
$$\beta_{core} \neq \beta_{well\ tests}$$

Steady state: $\dot{m}(r) =$ constant

$$p(r = r_w) = p_{wf} = \text{const}$$

$$p(r = r_e) = p_e = \text{constant}$$

George Stewart



$$\dot{m} = q\rho = \text{const}$$

$$= v A \rho$$

$$= \frac{k}{\mu_g}\frac{dp}{dr} 2\pi r h \, \rho_g$$

q_g
Gas Rates always
Sm^3/d
scf/D

$$q_{\bar{g}} = \dot{m}\, \rho_{\bar{g}}^{-1} = \text{constant}$$

$$\dot{m} = q_{\bar{g}} \rho_{\bar{g}}$$

$$q_{\bar{g}} \rho_{\bar{g}} = \frac{k}{\mu_g} 2\pi r h \rho_g \frac{dp}{dr}$$

$$\rho_g = \frac{p M_g}{R T_R Z_g} \quad \Big| \quad \rho_{\bar{g}} = \frac{p_{sc}}{T_{sc}} \frac{M_g}{R\,(1)} \quad \Big| \quad \frac{\rho_g}{\rho_{\bar{g}}} = \frac{(p/Z_g)}{(p_{sc}/T_{sc})\,T_R}$$

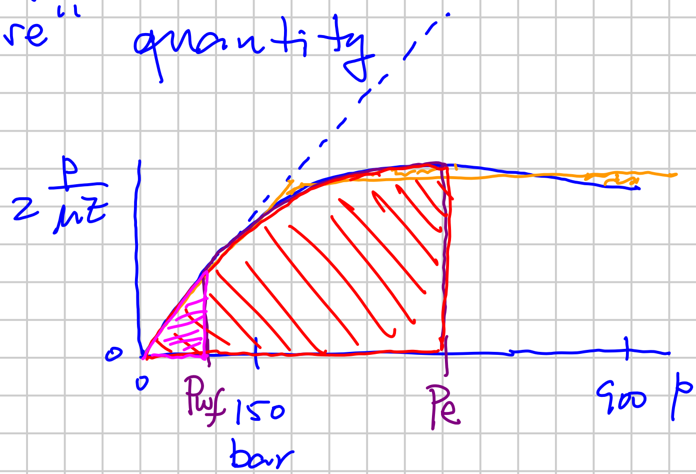
$$q_{\bar{g}} = \frac{2\pi kh}{(p_{sc}/T_{sc})\,T_R} \cdot r \cdot \frac{p}{\mu_g Z_g} \frac{dp}{dr}$$

$$q_{\bar{g}} \underbrace{\int_{r_w}^{r_e} \frac{1}{r}\,dr}_{\ln r_e/r_w} = \frac{2\pi kh}{(p_{sc}/T_{sc})\,T_R} \underbrace{\int_{p_{wf}}^{p_e} \frac{p}{\mu_g Z_g}\,dp}_{\int_{p_0}^{p_e} - \int_{p_0}^{p_{wf}}}$$

Introduce "pseudopressure" quantity

$$m(p) = p_p = 2\int_{p_0}^{p} \frac{p}{\mu_g Z_g}\,dp$$

p_0 ← Any pressure reference $p_{sc} = 1$ atm



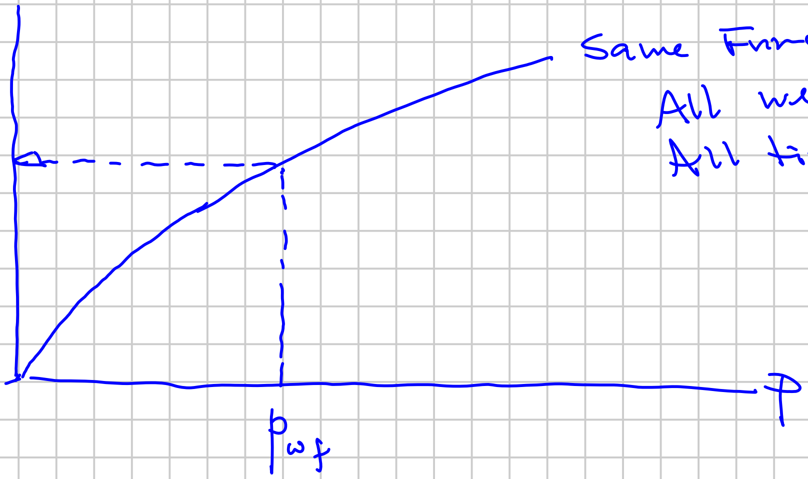
$$q_{\bar{g}} = \frac{\pi k h}{(p_{sc}/T_{sc}) T_R \left[\ln r_e/r_w\right]} \left(p_{pe} - p_{pwf} \right)$$

SS
Pure SI Units

$$p_{pe} = 2\int_{p_0}^{p_e} \frac{p}{\mu Z} dp \qquad p_{pwf} = 2\int_{p_0}^{p_{wf}} \frac{p}{\mu Z} dp$$

Pseudopressure

$m(p)$ $\quad p_p$



Same Function:
All wells in Field
All times

Infinite-Acting Period $\quad t < t_{ss}$

$\tilde{r}_e(t)$

$$\left[\ln \frac{\tilde{r}_e(t)}{r_w}\right] = p_D(t) =$$ dimensionless pressure (drop) function

Very Early Flow Behavior: Linear-Like Flow

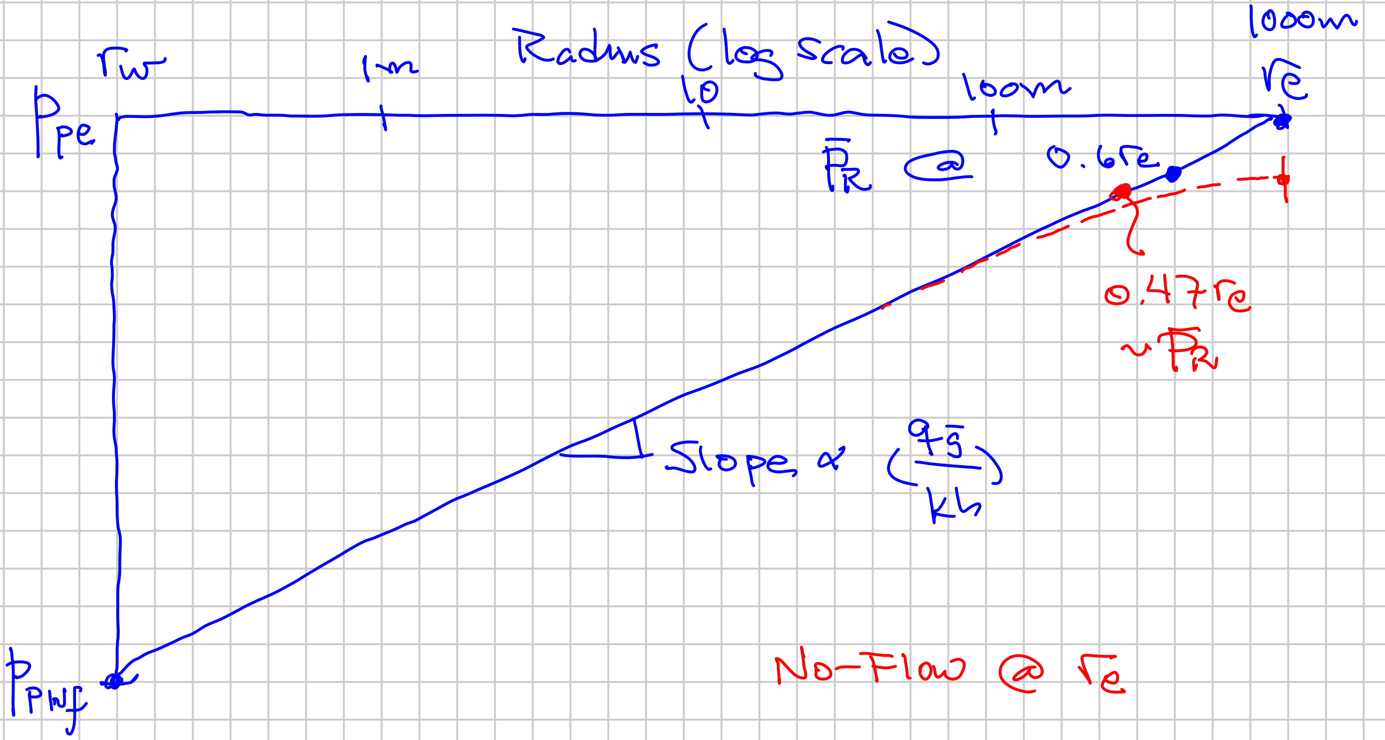
$p_D \propto \sqrt{t}$ $\quad$ 1970's: days → months

Most of IA period (when $\tilde{r} >> r_w$)

$p_D \propto \ln(t)$ $\quad$ radial-like flow

$$q_g = \frac{\pi k h}{(p_{sc}/T_{sc})\, T_R \left[\ln r_e/r_w\right]} \left(p_{pe} - p_{pwf}\right)$$

$$\Rightarrow \quad p_p(r) = p_{pwf} + \left(\frac{q_g}{kh}\right) \frac{(p_{sc}/T_{sc})\, T_R}{\pi} \cdot \left[\ln r - \ln r_w\right]$$



$\Rightarrow$ 80–90% $\Delta p = p_e - p_{wf}$ in first 10 m away from r_w

Volumetric Average Pressure $\bar{p}_R$ (not p_e)

$$\bar{p}_{pR} = \frac{\int_{r_w}^{r_e} p_p(r)\, r\, dr}{\int_{r_w}^{r_e} r\, dr}$$

Avg. Vol. Press

$$q_g = \frac{\pi k h}{(p_{sc}/T_{sc})\, T_R \underbrace{\left[\ln \frac{0.6 r_e}{r_w}\right]}_{\sim \ln \frac{r_e}{r_w} - \frac{1}{2}}} \left(\bar{p}_{pR} - p_{pwf}\right)$$

$\ln \frac{r_e}{r_w}$ — 7 – 10

0.1 m

Pseudo-SS

No-Flow O.B. $\left.\frac{dp_p}{dr}\right|_{r=r_e} = 0$

$p_e(t)$ $\bar{p}_R(t)$

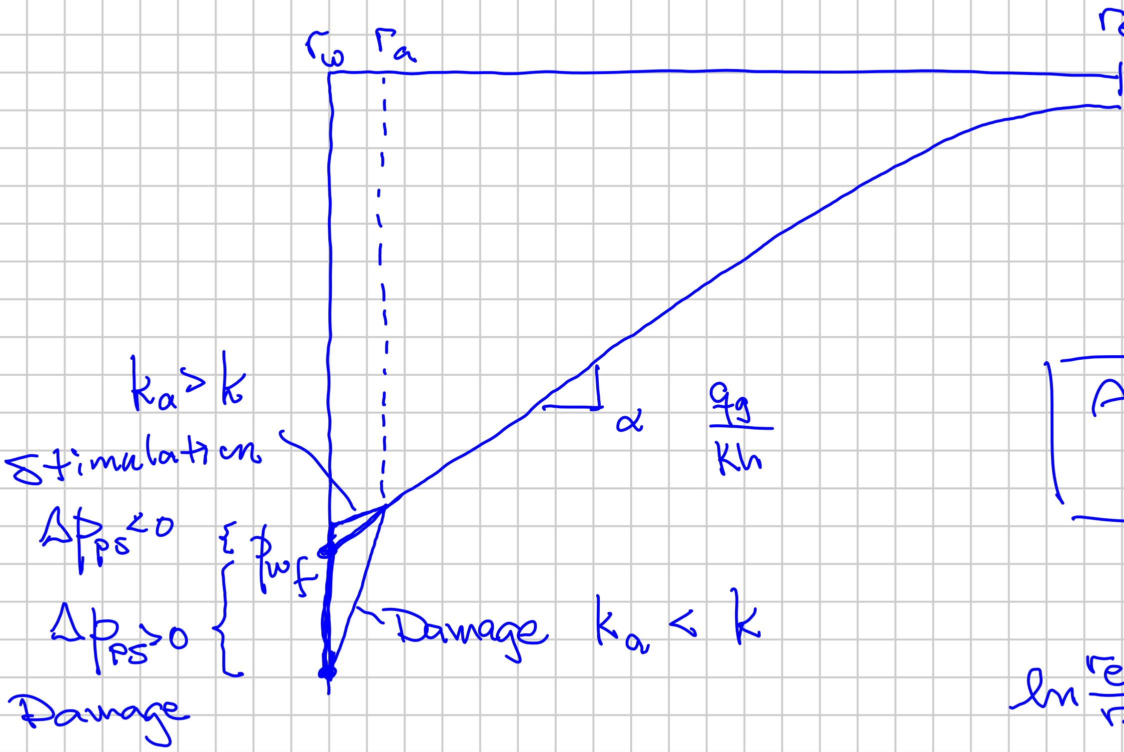
Avg. Vol. Press

$$q_g = \frac{\pi k h}{(p_{sc}/T_{sc})T_R\left[\ln \frac{0.472 r_e}{r_w}\right]}\left(\bar{p}_{pR} - p_{pwf}\right)$$

$\ln \frac{r_e}{r_w} - \frac{3}{4}$ ⟶ (No Flow O.B.)

$\left(\bar{p}_{pR} - p_{pwf}\right)$

Skin Effect: s (dimensionless pressure drop)



Assume: $r_a = r_w$

$\ln \frac{r_e}{r_w} - \frac{3}{4} + s$

$$s = \Delta \bar{p}_{ps} \cdot \frac{\pi k h}{(p_{sc}/T_{sc}) T_R \, q_{\bar{g}}}$$

"C" (units)

$$\left(q_{\bar{g}} = \frac{\pi k h \, (\bar{p}_{pR} - p_{pwf})}{(p_{sc}/T_{sc}) T_R \left[\ln \frac{r_e}{r_w} - \frac{3}{4} + s_t \right]} \right)$$

Total Skin:

s^* { damage, stimulation, geometry, ⋮ }

Forcheimmer:

$$s_t = (s^*) + \underbrace{D q_{\bar{g}}}_{>0}$$

Rate Dependent Skin

s^* rate independent

UNITS!

k [md]