PSS (BD)

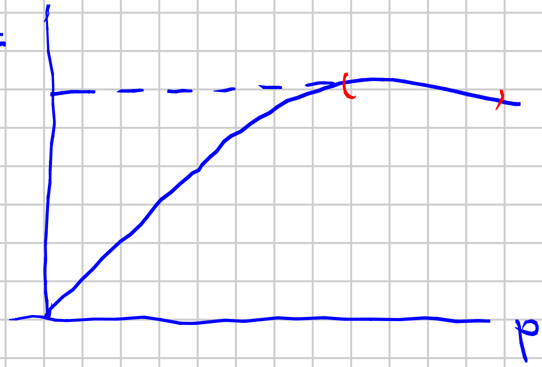
$t > t_{pss}$ ($k > 1$–10 md)

$$q_g^{(t)} = \frac{\boxed{kh\,(p_{pR}^{(t)} - p_{pwf})}}{\boxed{T_R \cdot \left[\ln \frac{r_e}{r_w} - \frac{3}{4} + s\right]}} \quad (1)$$

Darcy's Law

← Constant $t > 0 \ldots$

$$p_p \equiv 2 \cdot \int_0^p \frac{p}{\mu Z}\, dp$$



"IA": Radial Flow

$$q_g = \frac{\boxed{kh}\,(\overset{\text{const}}{p_{pi}} - p_{pwf}^{(t)})}{\boxed{T_R\left[p_D^{(t)} + s\right]}} \quad (2)$$

Const.

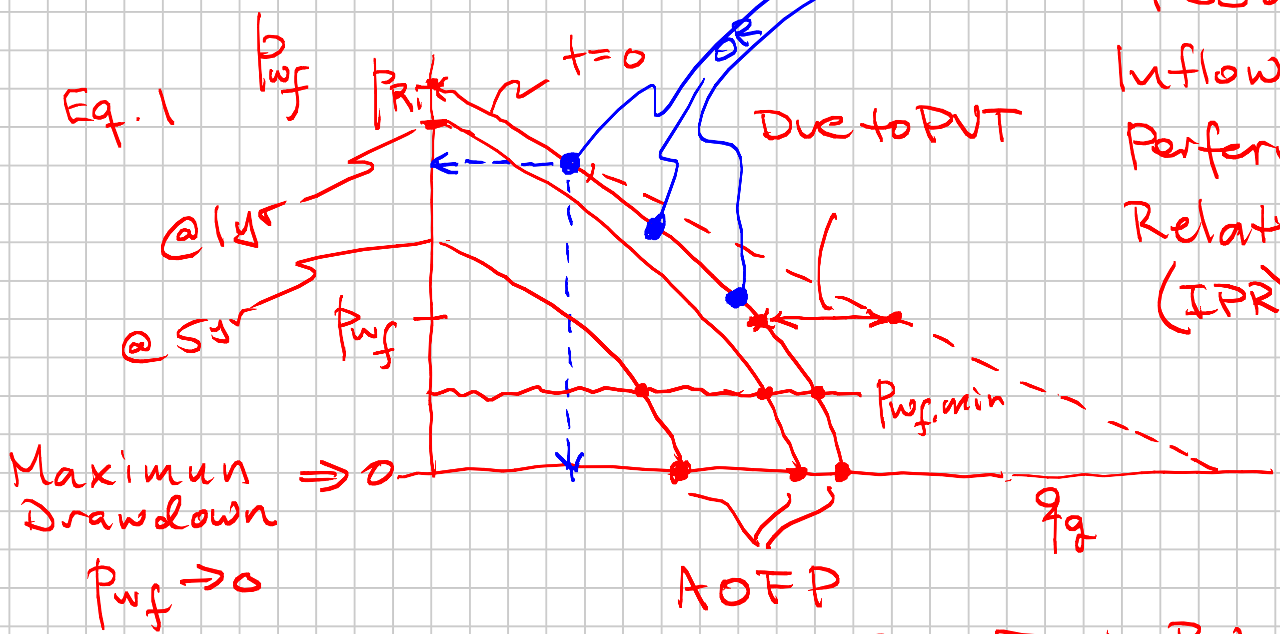
Darcy's Law

← $f(t)$ until t_{pss}

$$p_D = \frac{1}{2}\left[\ln t_D + 0.809\right]$$

Single-Rate Test $\frac{kh}{T_R\left[\ln \frac{r_e}{r_w} + s\right]}$ PSS: BD

Inflow Performance Relation (IPR)



AOFP

Absolute Open Flow Potential

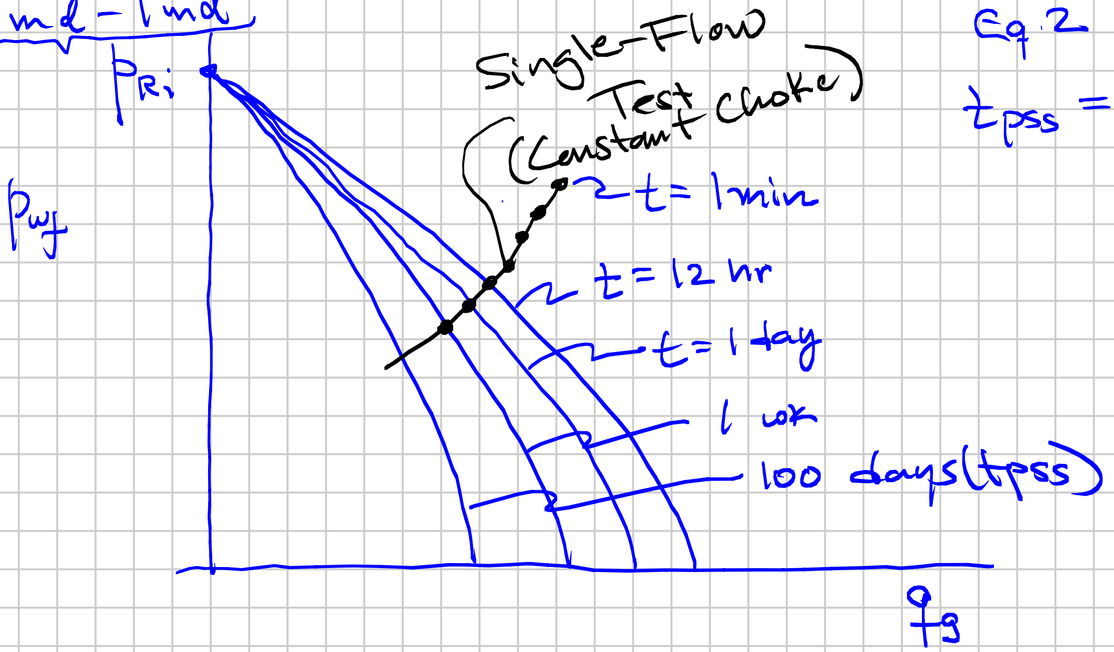
$q_{g\,max}$

Lower Perm: t_{pss} can be "Large" (days-wks-months)

$k \lesssim 0.1\ md - 1\ md$

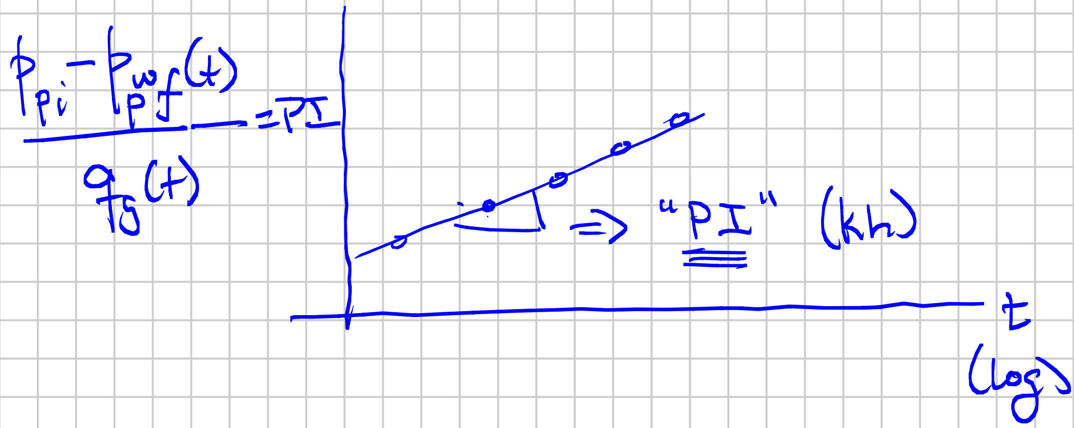
Eq. 2

$t_{pss} = 100$ days



To find "$kh/[\bar{r}_R(\ln\frac{r_e}{r_w}+s)]$" PI

Run a transient test $q(t)$ & $p_{wf}(t) \Rightarrow$ "PI"(t)



Flow in Porous Media with "High" Velocities ("non-Darcy")
("Turbulent")
("High-Velocity Flow")

$$\frac{dp}{dx} = \underbrace{\frac{\mu}{k} v}_{\text{Darcy}} + \underbrace{\beta \rho v^2}$$

F, R, R, F

Forchheimer

Becomes important for "Reynold's" number $\gtrsim 1$

$$Re \equiv \frac{\rho v_p \bar{d}_g}{\mu}$$

$\phi = 0.2$

$h = 20 \text{ m}$

$q_g = 1000000 = 10^6 \text{ Sm}^3/d$

$B_g = 0.01 \text{ m}^3/\text{Sm}^3$ @ 100bar

$r = 0.5 \text{ m}$

$$v_p = \frac{q}{A\phi} = \frac{[10^6(0.01)]}{2\pi(0.5)20} \cdot \frac{D}{(3600 \cdot 24 \text{ s})(0.2)}$$

$2\pi r h$

e.g. gas $\rho = 100 \frac{\text{kg}}{\text{m}^3}$

$\bar{d}_g = 50 \ \mu\text{m}$

$\mu = 0.02 \text{ mPa.s}$

$v_p = 0.01 \text{ m/s}$

$$Re = \frac{(100)(0.01)(50 \cdot 10^{-6})}{0.00002}$$

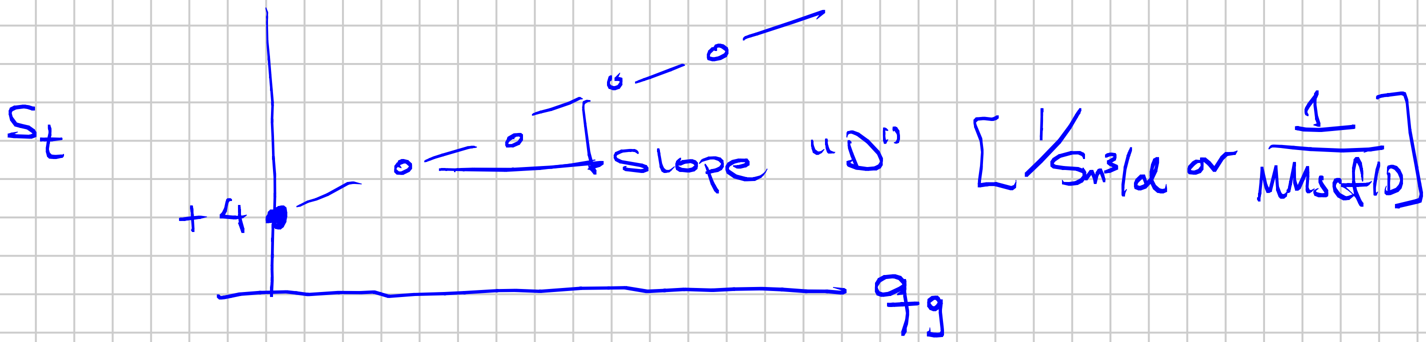
$$Re = 2.5 > 1$$

$$q_g = \frac{(kh)\left[p_{pR} - p_{pwf}\right]}{(T_R)\left[\underbrace{\ln\frac{r_e}{r_w} - \frac{3}{4}}_{p_D} + \underbrace{(s + D q_g)}_{\text{Dimensionless } \Delta p}\right]}$$

Damage
Geometry
⋮

$$S_t = s + \underbrace{D q_g}_{\text{Rate-dependent skin contribution}}$$

$$\boxed{D \propto \beta}$$



$$\left(\frac{p_{pR} - p_{pwf}}{q_g}\right) = A + B q_g$$

$$p_{pR} - p_{pwf} = \overbrace{q_g \cdot \frac{T_R}{kh}\left[\ln\frac{r_e}{r_w} - \frac{3}{4} + s\right]}^{A} + q_g^2 \underbrace{\frac{T_R}{kh} \cdot D}_{B}$$

$$p_R^2 - p_{wf}^2$$

$$\boxed{0 = B q_g^2 + A q_g - (p_{pR} - p_{pwf})}$$

How to determine A & B:

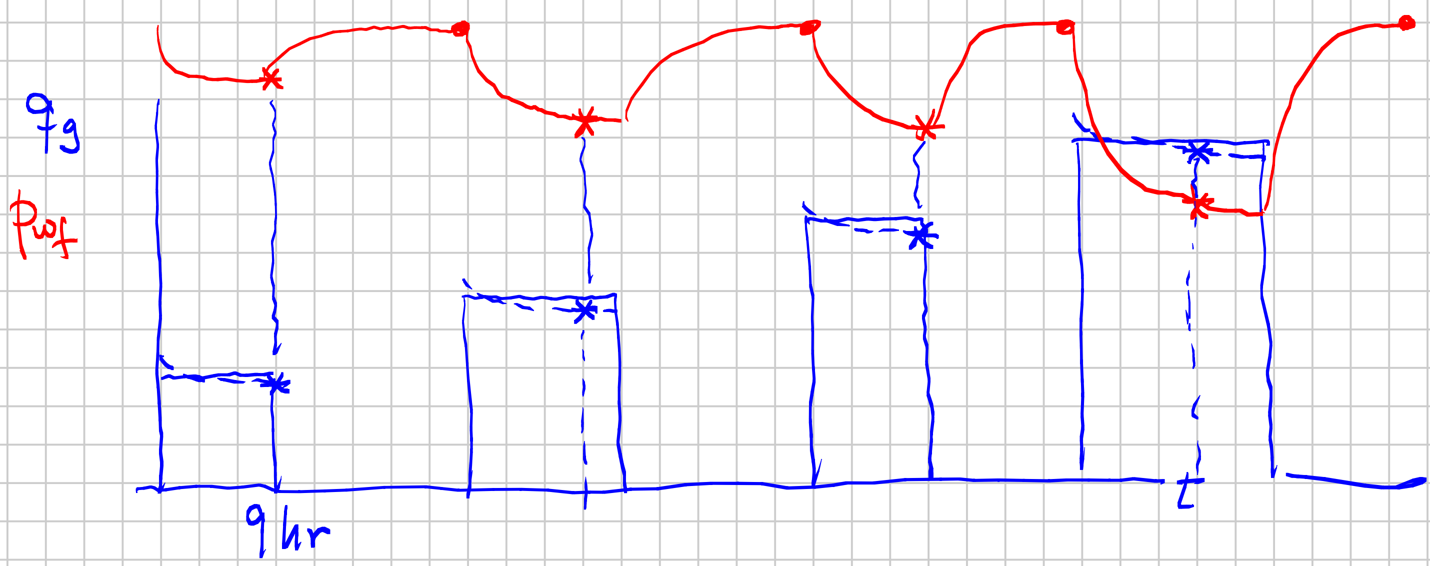
minimum 2 flow rates (q_g, P_{wf}) measurements

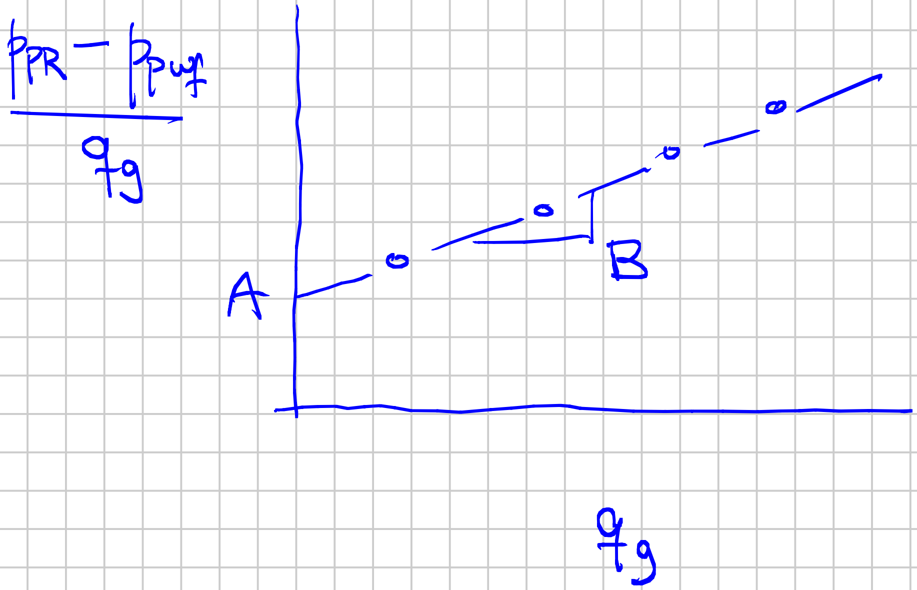
Industry standard is (3 →) 4 different flow tests (i.e. 4 chokes)

⇒ "Multi-Point Testing of Gas Wells"

Isochronal Test

- Each flow period is
  - same duration - e.g. 6 hr
  - Collect the (P_{wf}, q_g) "point" at the same production time
- Should be a shut-in between each flow period ⇒ $\bar{p}_R$ to be reached (same each time)





$\frac{P_{PR} - P_{Pwf}}{q_g}$
A
B
q_g