TPG 4105 Makeup Hour Wed. Oct. 18, 15-16

Well Flow Equations (Rate)

Assumption: "Pseudo Steady State"
"Steady State"

Darcy's Law:

$$v = \frac{k}{\mu} \cdot \frac{dp}{dr} \qquad \text{("Darcy Velocity")}$$

k = absolute perm. $[L^2]$ md, D

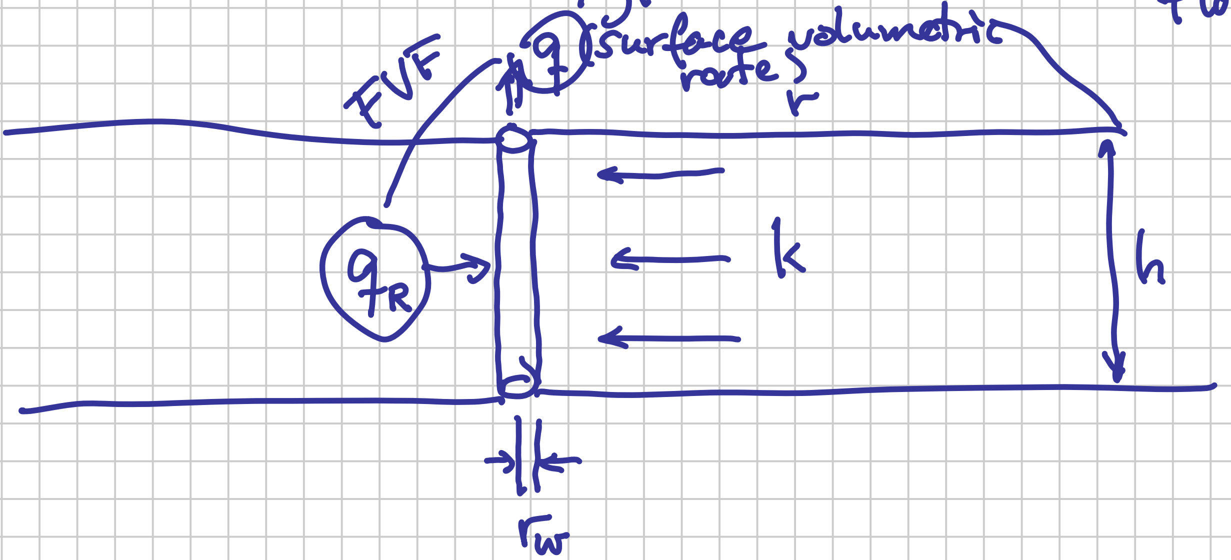
md $\uparrow$ 10^{-3} D ; D $\uparrow$ $\sim 10^{-12}\ m^2$, $1\ \mu m^2$

μ = dynamic viscosity $[mPa \cdot s]$ ''' cp

p : $[\Phi = p + \rho g z]$

r : or x, y, z ;

horizontal flow: p instead of Φ



wellbore radius $\sim$ 0.1 m

$$v = \frac{k}{\mu} \frac{dp}{dr}$$

B.C.

$\Rightarrow$ Steady State

$p = p_e$ @ $r = r_e$ (Const. outer boundary)

$p = p_{wf}$ @ $r = r_w$

Assume:

$\mu, k \sim$ constant

Cylindrical, Radial Flow Geometry

$$\Rightarrow q_R = 2\pi r h \cdot v$$

$$B \equiv FVF = \frac{q_R}{q}$$ $\leftarrow$ surface vol. rate

$$q = \frac{q_R}{B} = \frac{2\pi r h v}{B}$$

$B(p)$: $B_g \propto \frac{1}{p}$

$B_o \sim$ kinda const. || Liquid Flow

$$q_o = 2\pi h \cdot \frac{r}{B_o} \cdot \frac{k}{\mu} \cdot \frac{dp}{dr}$$

SS Assumption: $q(r) =$ constant

$$\int_{r_w}^{r_e} \frac{1}{r}\, dr = \underbrace{\frac{2\pi k h}{q_o \mu_o B_o}}_{\sim \text{const for liquid flow}} \int_{p_w}^{p_e} dp$$

$$\ln \frac{r_e}{r_w} = \frac{2\pi k h}{q_o \mu_o B_o} (p_e - p_{wf})$$

$$\boxed{q_o = \frac{2\pi k h\, (p_e - p_{wf})}{\mu_o B_o \cdot \ln \frac{r_e}{r_w}}}$$

		Range min	Range max	Unit	O.M. $= \log\left(\frac{max}{min}\right)$
1	k	0.001	10 000	md	7
	h	1	1000	m	3
	kh	0.01	10^6	md-m	8
	p_e	10	1000	bara	2
	p_{wf}	1	100	bara	2
	$(p_e - p_{wf})$	10	1000	bar	2
	μ_o *	0.1	10 000	cp	5
	B_o	1.	3	vol/vol	0.x
	$\ln \frac{r_e}{r_w}$	5	8		0.0x
	r_e	100	10 000	m	

* Norway: 0.1–10 cp

Non-Ideal (Real Life) Situations:

✓ ① Pressure dependent μ, B $\mu(p)$, $B(p)$

✓ ② Two-phases flowing (e.g. $\underline{\underline{g+o}}$; $o+w$; $g+w$)
k_{rp}

✓ ③ Irregular Well Geometries, S_G

✓ ④ $P_e \neq$ constant, i.e., depletion ($P_e(t)$)

✓ ⑤ Near wellbore "damage" (Skin Effect)

✓ ⑥ Darcy's Law too optimistic:
"turbulent" flow at high velocities

$$\frac{dp}{dr} = \underbrace{\frac{\mu}{K} v}_{\substack{\text{Darcy} \\ \text{"Laminar"}}} + \underbrace{\beta \rho v^2}_{\substack{\text{non-Darcy} \\ \text{"Turbulent"}}}$$

rock property

density

✓ ⑦ Low-permeability (low-diffusivity; $\frac{K}{\phi \mu c}$)

Steady-state (Pseudo Steady State) assumption is not valid.

"system" (rock+fluid) isothermal compress.

Diffusivity Eq.

$p(x,y,z,t)$ for $q = \text{constant}$

$\dots\ v(x,y,z,t) = \frac{k}{\mu}\frac{dp}{dx}$

2 terms:

(1) $\frac{kh}{\mu B}$

(2) $\frac{k}{\phi \mu c_t} \cdot z$

$\bar{P}_R(Q)$ Depletion

Cum. Prod. $= \int q\, dt$

$$q_p = \frac{kh}{[X + s]} \cdot \int_{P_{wf}}^{\bar{P}_R(t)} \frac{k_{rp}}{\mu_p B_p}\, dp$$

Usually: $P_e \simeq$ voluteric average pressure $\simeq \bar{P}_R$

$\underbrace{\text{because using}}$ $\bar{P}_R$ instead of P_e

Ided: $X = \ln(r_e/r_w) - 0.5$

$s = \text{skin} = 0$

$k_{rp} = 1$

$\mu_p, B_p \sim \text{constant}$

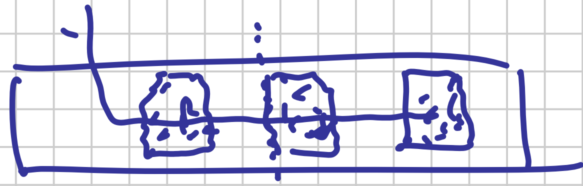
Well Geometry:

$$\underbrace{\ln\frac{r_e}{r_w}}_{8} + s$$

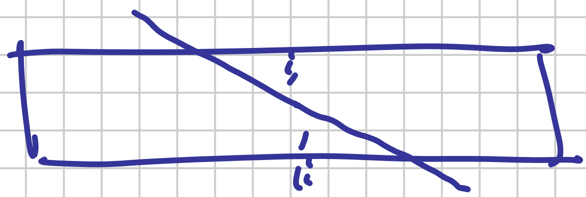
s

$s = s_G$

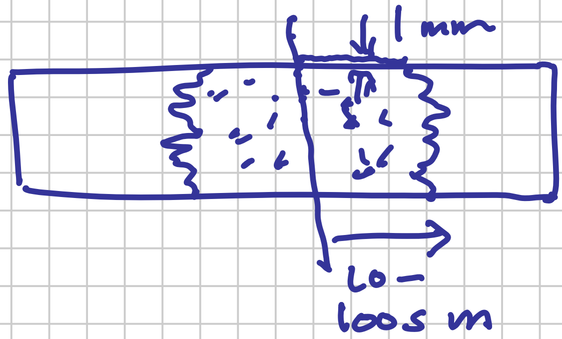
-4 to -7 • Horizontal Well



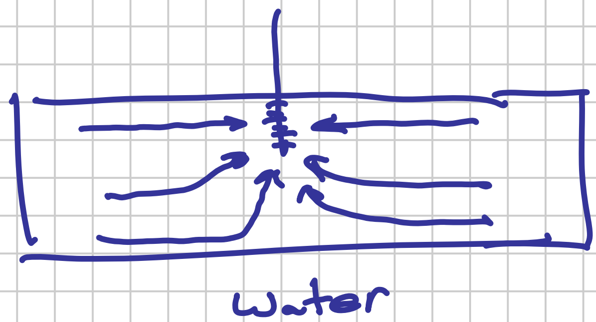
-1 to -3 • Inclined Well



-3 to -5 • Stimulated, Fractured



+2 to +20 • Partial Penetration

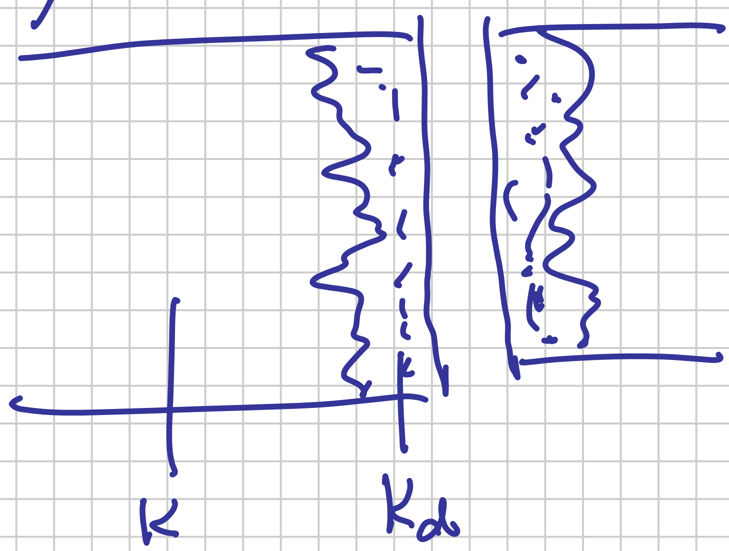


+1 to +100 Damage:

$$s = s_d \sim \left(\frac{k}{k_d} - 1\right) \ln\frac{r_d}{r_w}$$

0.1 - 1 m

0.8 to 0.01



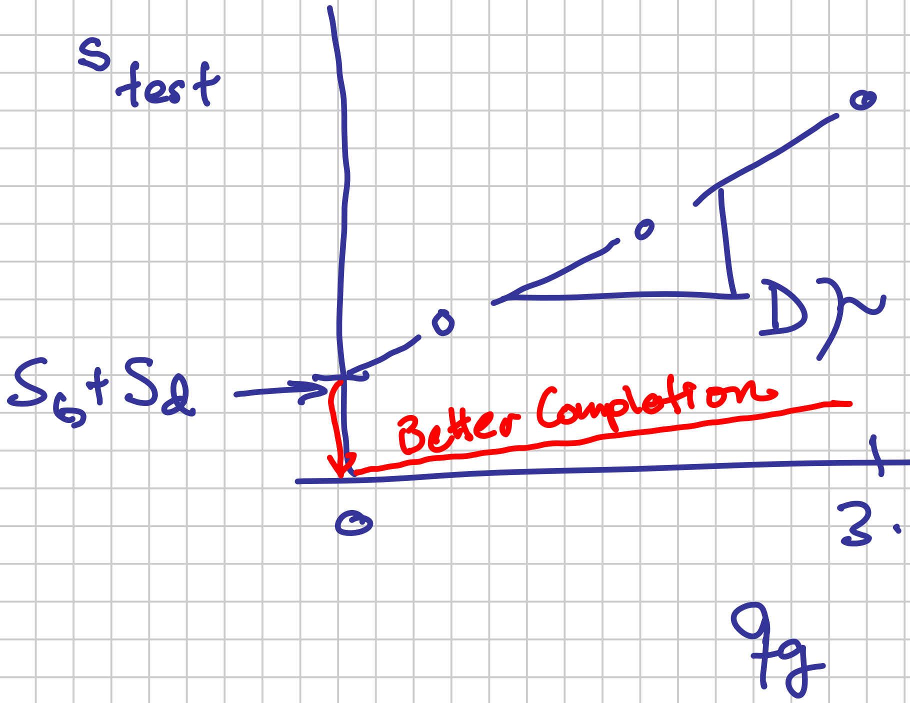
Non-Darcy Flow (Forcheimmer Eq.)

$+ \beta \rho v^2$

$$s = s_G + s_d + D \cdot q$$

Constant

(β)

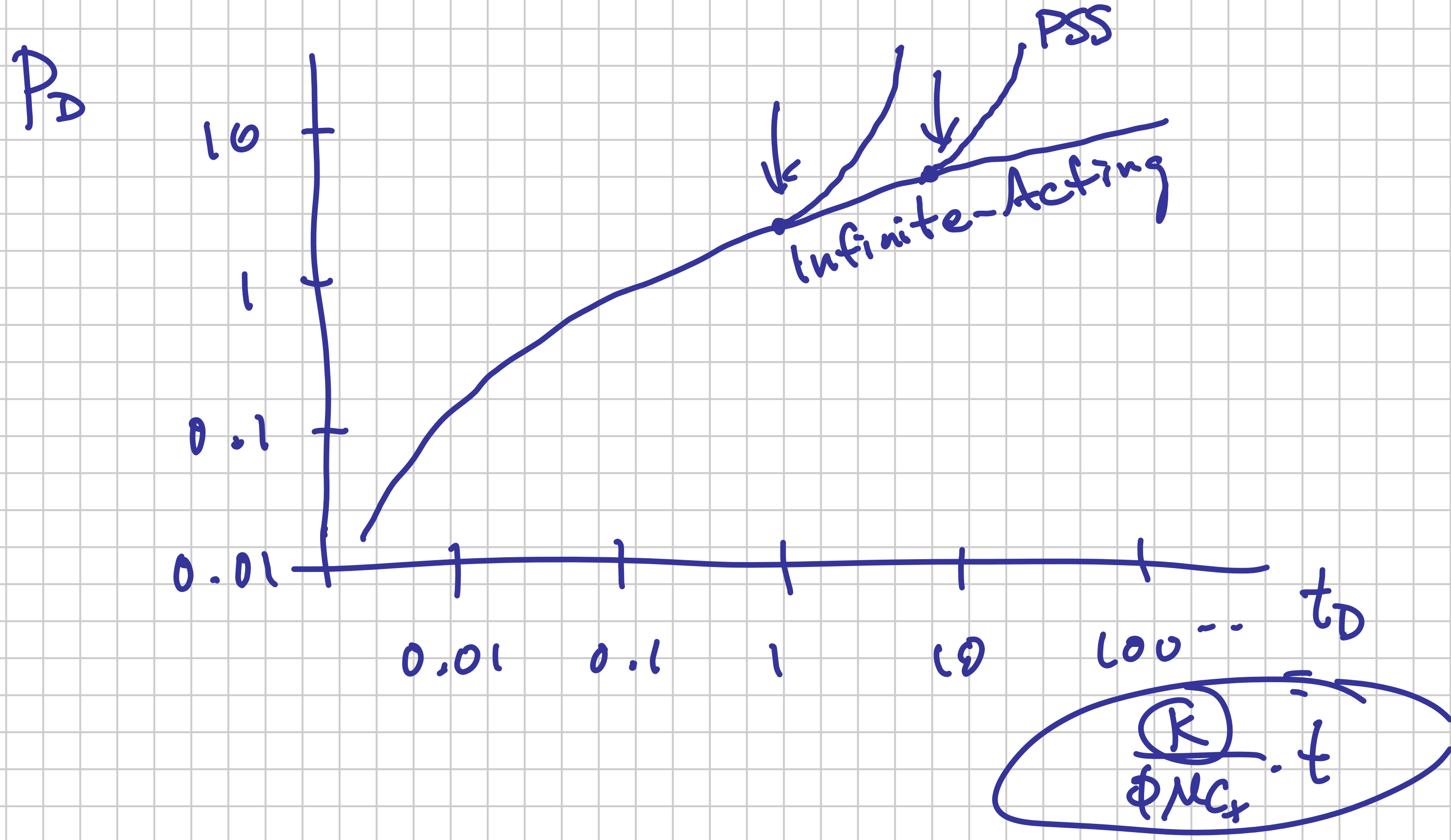


Troll: $D \sim \dfrac{1-2}{0.1 \cdot 10^6 \ Sm^3/d}$

Low-k, "Transient"
("Infinite-Acting")

$$X = p_D(t_D)$$

dimensionless "pressuredrop"



P_D
10
1
0.1
0.01
PSS
Infinite-Acting
0.01
0.1
1
10
100 ...
t_D
$= \frac{k}{\phi \mu c_t} \cdot t$