Note Title 2014-10-30

$$q_g = \frac{kh\left[p_{pR} - p_{pwf}\right]}{T_R \cdot \left[\ln\frac{r_e}{r_w} - 3/4 + s\right]}$$

$p_R(t)$

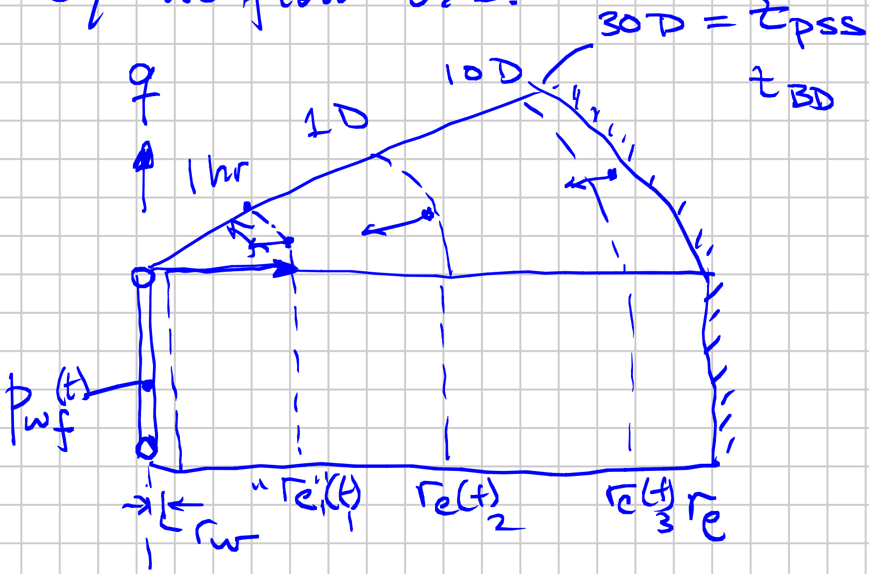
Control

scf/D

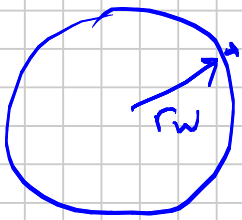
Fix p_{wf}: $q_g(t) \downarrow$

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

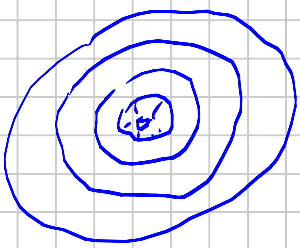
Pseudosteady State (PSS) Flow w/ no-flow B.B.



$\underbrace{\underline{\Delta p(r) > \epsilon}\ \text{(mbar)}\ \text{(1 psi)}}$



$\frac{r_e(t)}{r_w} \gtrsim 1$



$\underbrace{\text{"Transient" Before reaching } \underline{\text{PSS}}}_{\text{Infinite Acting}}$

Boundary Dominated

"Well Testing" $\rightsquigarrow$ PTA (Pressure Transient Analysis)

Hank Ramey

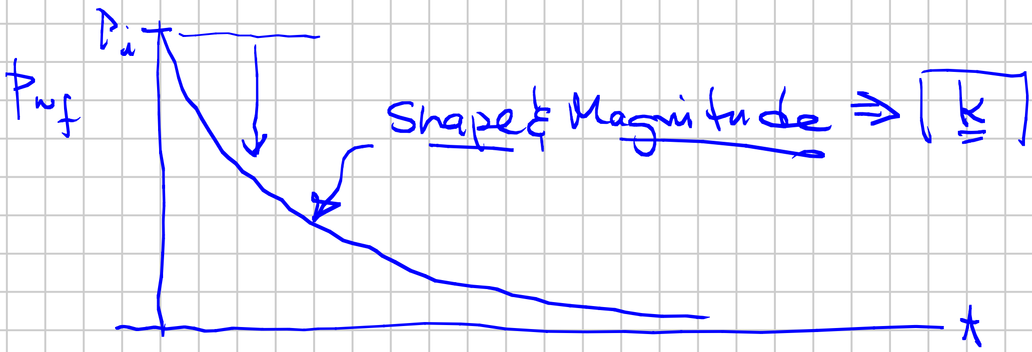
[q = constant (controlled)]

"study" $p_{wf}(t)$ $\Rightarrow$ Estimate k, s, p_R, ... r_e, shape

Single Phase "Slightly (constant)" Compressibility System

$$q = \frac{kh\,[p_i - p_{wf}(t)]}{\mu B\,\left[\ln \frac{r_e(t)}{r_w}\right]}$$

constant

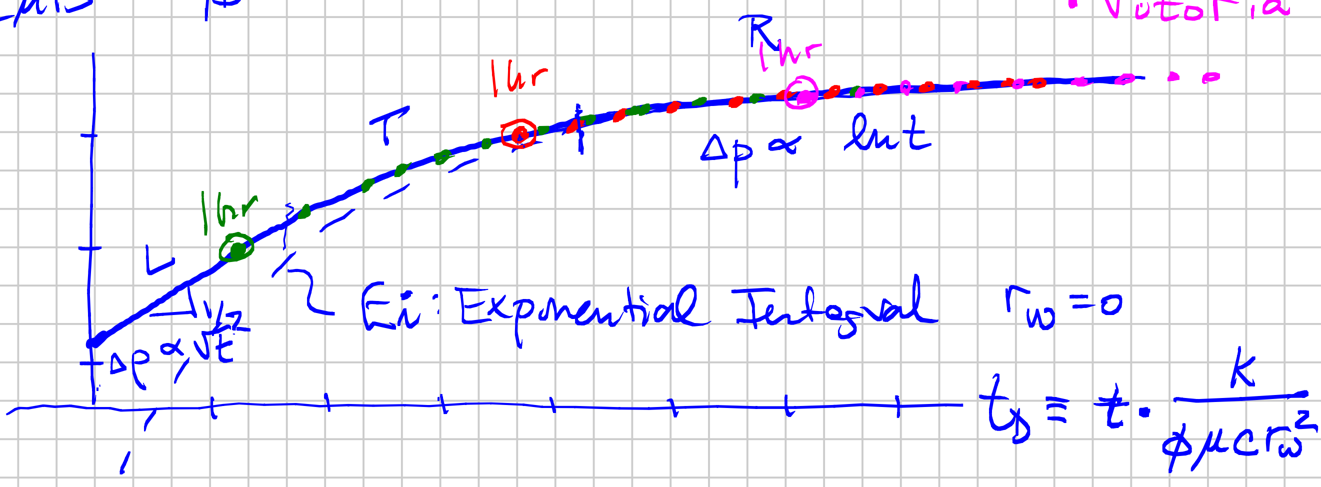


Every well w/ h = const, q = const, ... (assumptions)

Same shape of $p_i - p_{wf}(t) \equiv \Delta p(t)$

- OKC
- Shiraz
- Vitoria

$$\Delta p \cdot \frac{kh}{q\mu B} \equiv p_D = \text{dimensionless pressure drop}$$

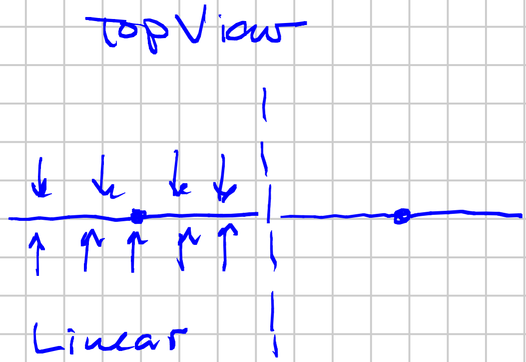


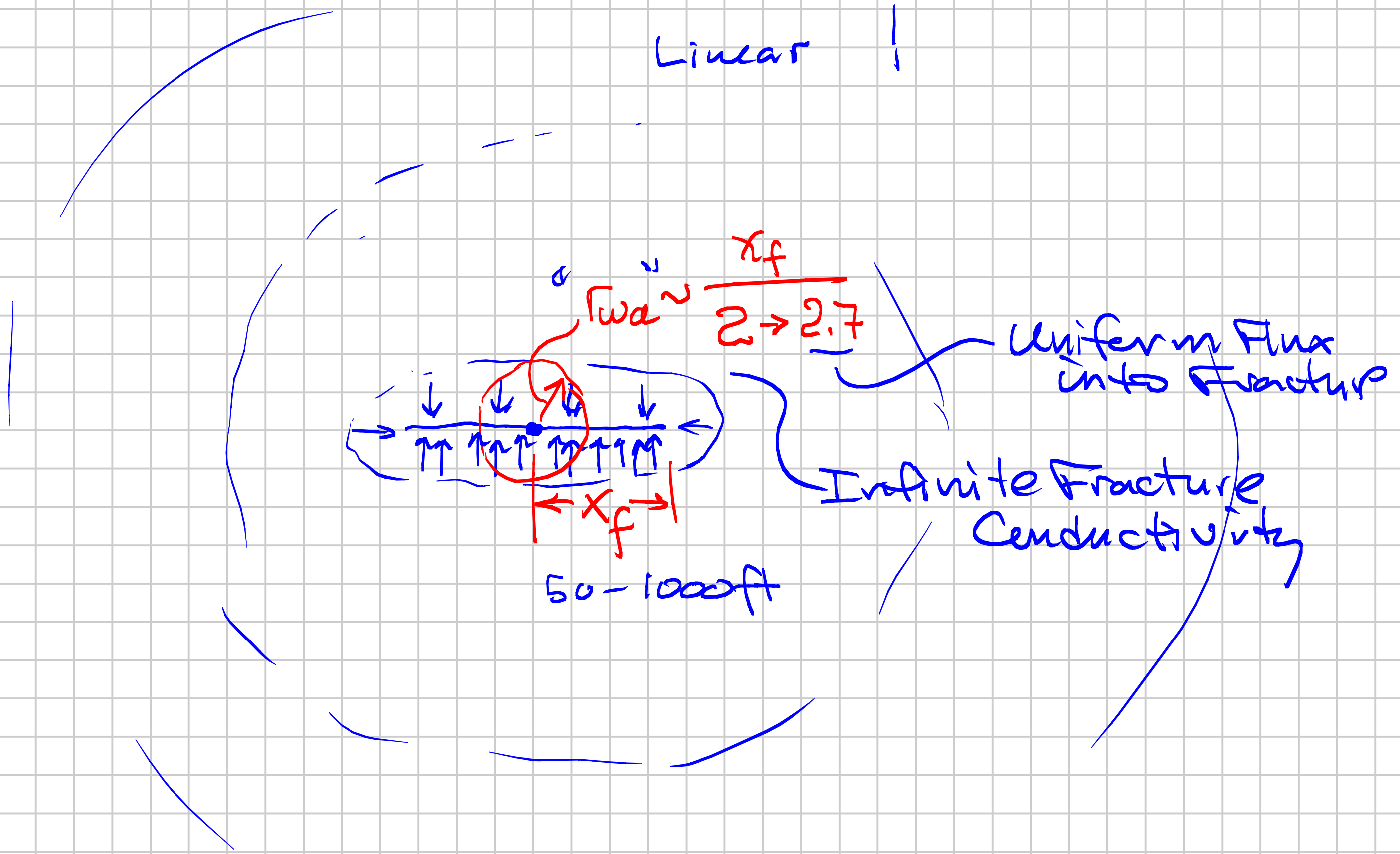
$$t_D \equiv t \cdot \frac{k}{\phi \mu c r_w^2}$$

Dimensionless Time

van Everdingen - Hurst

$$\frac{kh\,\Delta p}{\mu B q}$$





p_{wf} = constant (instead of q)

$\boxed{\text{IA Flow}}$

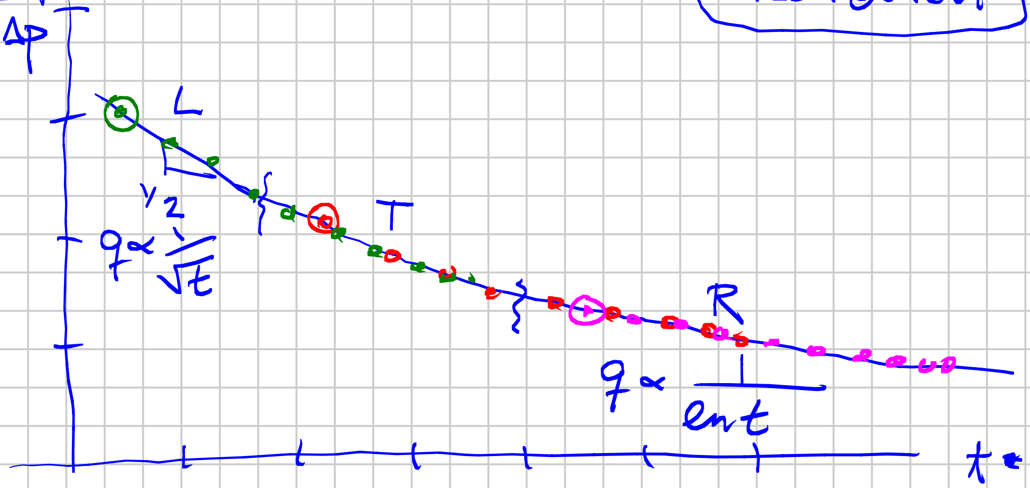
DCA

Decline Curve Analysis (Mike J. Fetkovich)

$$q(t) = \frac{kh\left[p_i - p_{wf}\right]}{\mu B\left[\ln \frac{r_e(t)}{r_w}\right]}$$

Tsarovich

$$q_D \equiv q \cdot \frac{\mu B}{kh\Delta p}$$



$$t \cdot \frac{k}{\phi \mu c r_w^2} \equiv t_D$$

$$q_D(t_D)^{IA} \simeq \frac{1}{p_D(t_D)^{IA}}$$

q_D ~ same for radial well & vertically fractured well

L T R

$\sqrt{t} \longrightarrow \ln(t)$

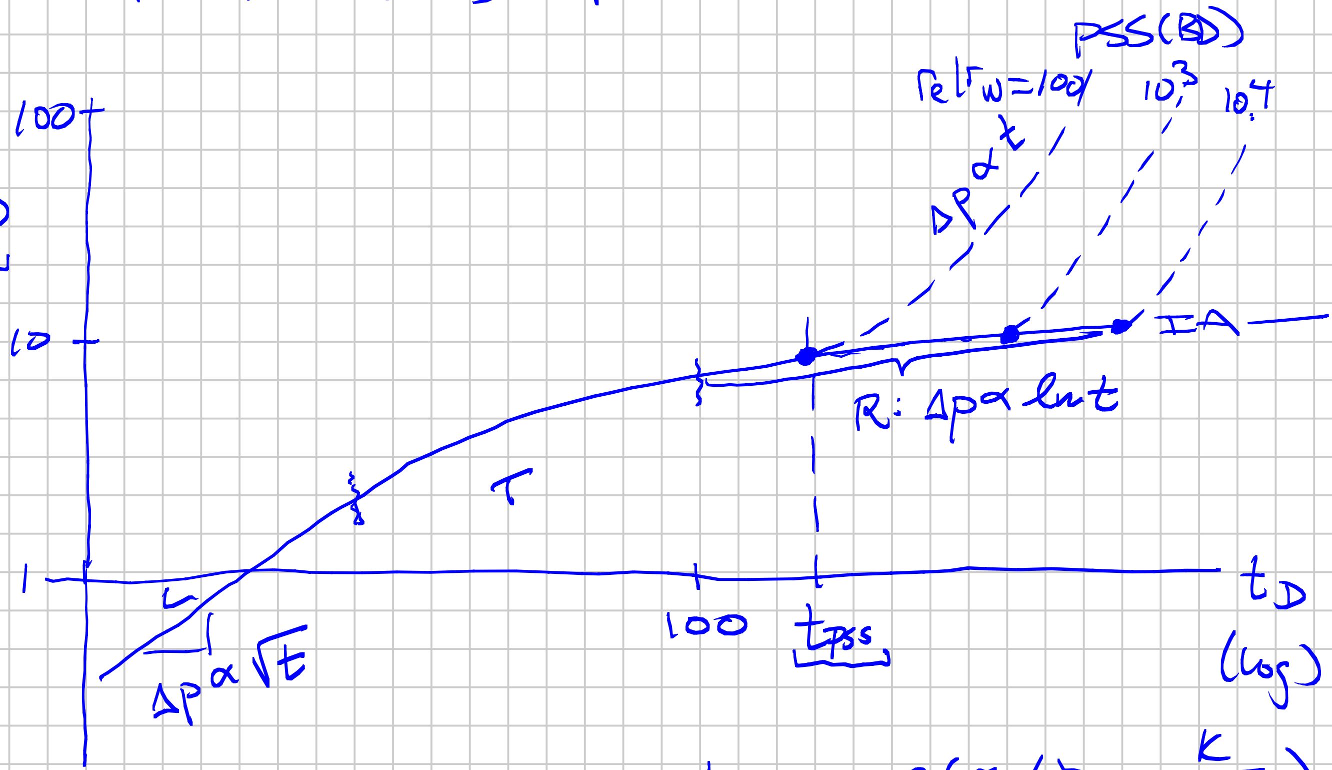
PTA Experts:

- Hank Ramey (Stanford)
- Raj Raghavan (Al Reynolds ++ U. Tulsa)
- Alain Gringarten (Imperial College)
- → Leif Larsen (U. Stavanger)
- Cinco-Ley
- Christine Economides (& Michael Economides)
- Earlougher (book)
- Mathews & Russel (book)
- → George Stewart (book)

- Roland Horne
- John Lee
- Kabir
- Bourdet $(d(\Delta p)/d\log t)$

DCA:

1st. IA → PSS (BD)   PTA



$P_D = \underline{P_i - P_{wf}(t)}$

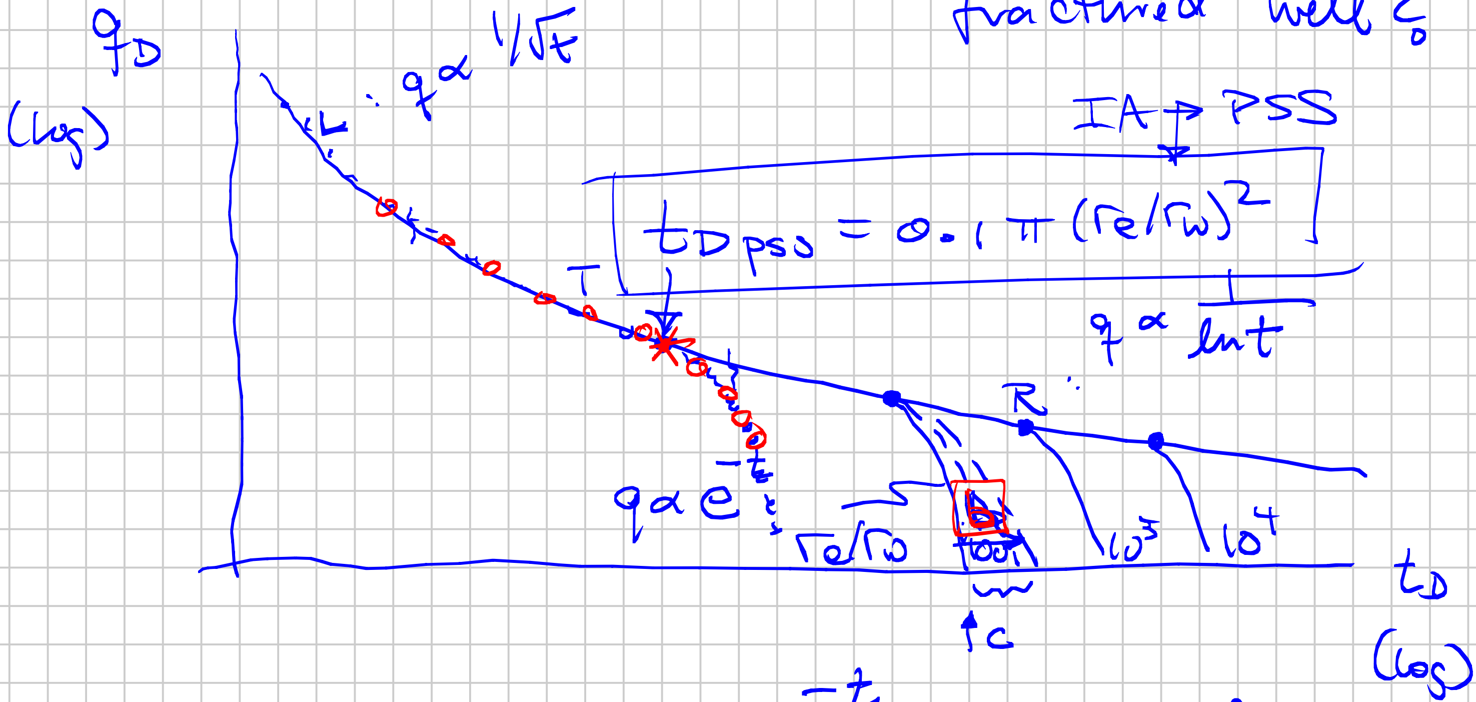
$$t_{pss} = f\left(r_e/r_w, \frac{k}{\phi \mu c r_w^2}\right)$$

$$f\left(\frac{k}{\phi \mu c r_e^2}\right)$$

p_{wf} = const ⇒ DCA ⇒ Δp = constant

IA : PSS (BD)

Radial solution for a vertically fractured well z_0



PSS (BD) : $q \propto e^{-t}$ Exponential

c : ~~small & constant~~ (b=0)

: Decline is less severe if higher compressibility during depletion.

Gas , SGD oil

DC Equations by ARPS (Before Fetkovich)

$$q = \frac{q_i}{\left[1 + bDt\right]^{1/b}}$$

b & q_i & D were best fit to data

$b = 0$: Exponential

$$q = q_i \, e^{-Dt}$$ (Analytical Solution to $q_D(t_D)$ PSS)

Fetkovich: b ~ "Recovery Efficiency"

$= 0$: Lowest (c ~ small)

$\to 0.5$ e.g. SGD very favorable k_{rg} / k_{ro}

high S_{gc}

@ P_{wf} = const

$$q_i = \left[\frac{kh \, \Delta p}{\mu B \, \ln(r_e/r_w) + s} \right]$$

$$D = \frac{1}{1-b} \cdot \frac{q_i}{Q_{p\,ultimate}}$$ ~ similar for all wells

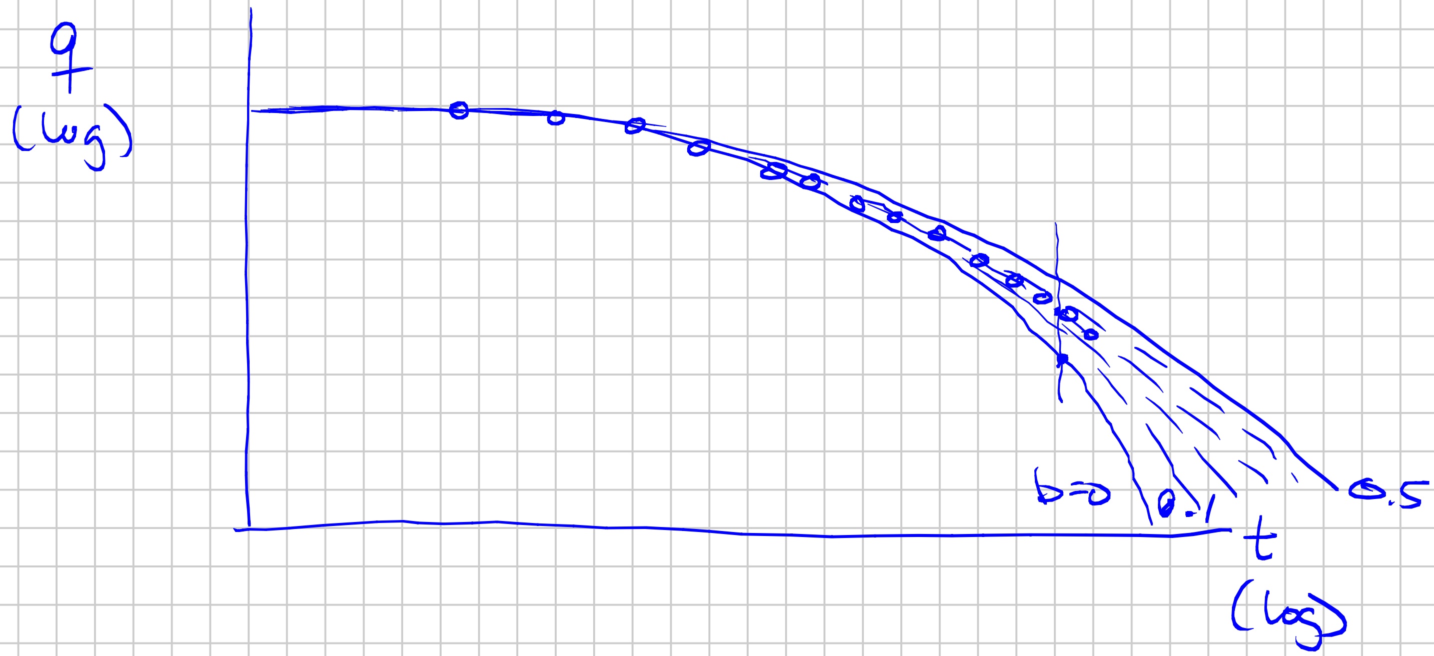
$$Q_p = \text{cum. production} = \int_0^t q \, dt$$

$Q_{p\,ult}$ @ $t = \infty$ ($q \to 0$)

$$= N \cdot RF_{ult}$$

$$\frac{k}{\phi \mu c r_e^2}$$

$$\left[\frac{\bar{h} \bar{\phi} A (1 - \bar{S}_w)}{B_{oi}} \right]$$



$t_D \sim t_{Dd} \sim D$

$q_i \quad q_D$

Fetkovich Generalized DC Analysis:

IA $\longrightarrow$ t_{pss} — Arps DC $\longrightarrow$

$$q = \frac{q_i}{\left[1+bDt\right]^{1/b}}$$

$$\left\{ \begin{array}{cc} q_i & D \\ \updownarrow & \updownarrow \\ q_D & t_D \end{array} \right\}$$

b: Recovery Efficiency

Proponent and Used :

Rate Normalization ($\underline{IA}$)

$$\boxed{\text{Winestock \& Colpitts}}$$

$p_{wf}(t)$ smoothly varying

$$\frac{q(t)}{p_i - p_{wf}(t)} \Rightarrow \text{Behave according } q_D(t_D)$$

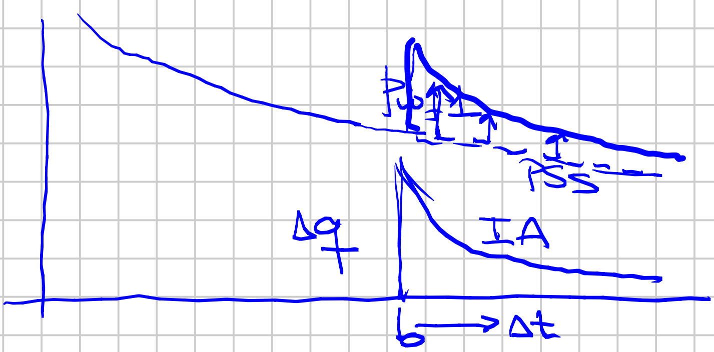
$p_{wf} = \text{const}$

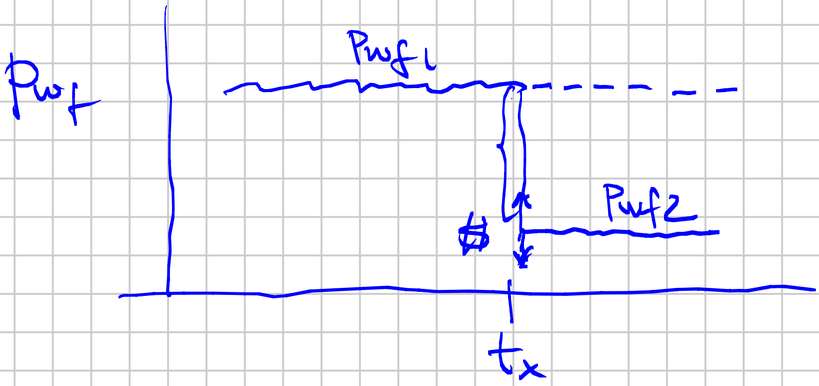
$$q_D(t_D) \propto \frac{1}{p_D(t_D)}$$

PTA using $\dfrac{p_i - p_{wf}(t)}{q(t)}$: $p_D(t_D)$

smoothly varying

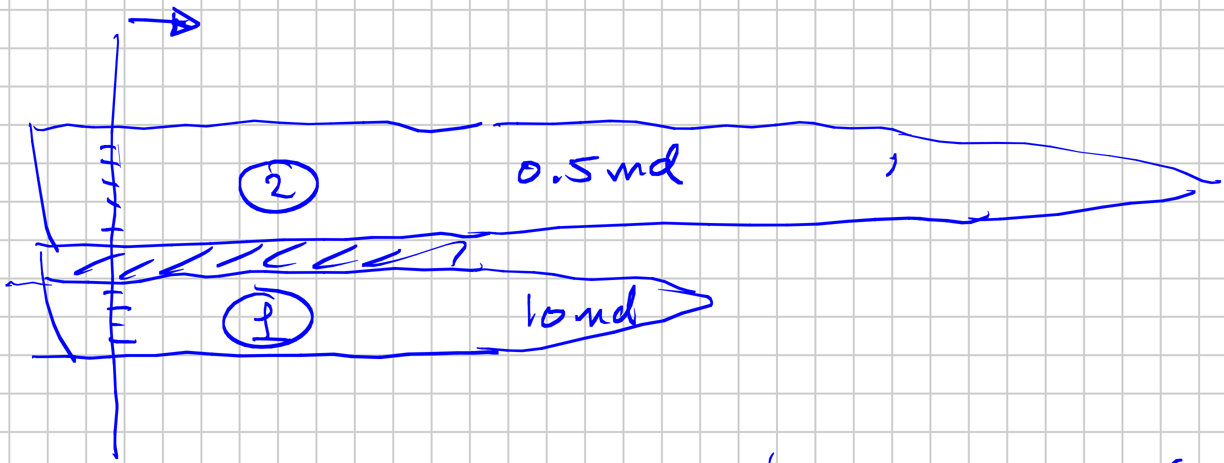
Proposed & Used Superposition of $q_D(t_D)$ for step changes in p_{wf} : compression in gas wells





$$q = \frac{kh}{\mu B}\left\{ q_D(t_D)\cdot(p_i - p_{wf1}) \right.$$
$$\left. q_D(t-t_x)_D\,(p_{wf1} - p_{wf2}) \right\}$$

Layered No-Crossflow Systems



$b_{①} = 0.2$

$b_{②} = 0.35$

Arp's $b_{well} > \underline{0.5 \rightarrow 0.9}$ (1)