Note Title 10/17/2018

* New Required Reading paper:

1973 – Fetkovich – DCA (JPT–1980) {supplement to lectures}

* IPR Eq. for "Wellbore Backflows" in LNX systems during a shut-in period $q_t = 0 = \underset{<0}{q_1} + \underset{>0}{q_2}$

(1) $q = J(p_R - p_x) + J_x(p_x^2 - p_{wf}^2) \quad | \quad p_{wf} < p_x < p_R$

(2) $q = J(p_R - p_{wf}) \quad | \quad p_{wf} > p_x$

(3) $q = J_x(p_R^2 - p_{wf}^2) \quad | \quad p_R < p_x$

How to handle $p_R < p_{wf}$?

$q < 0$

$$J_x = \frac{J}{2 p_x}$$

DECLINE CURVE ANALYSIS (DCA)

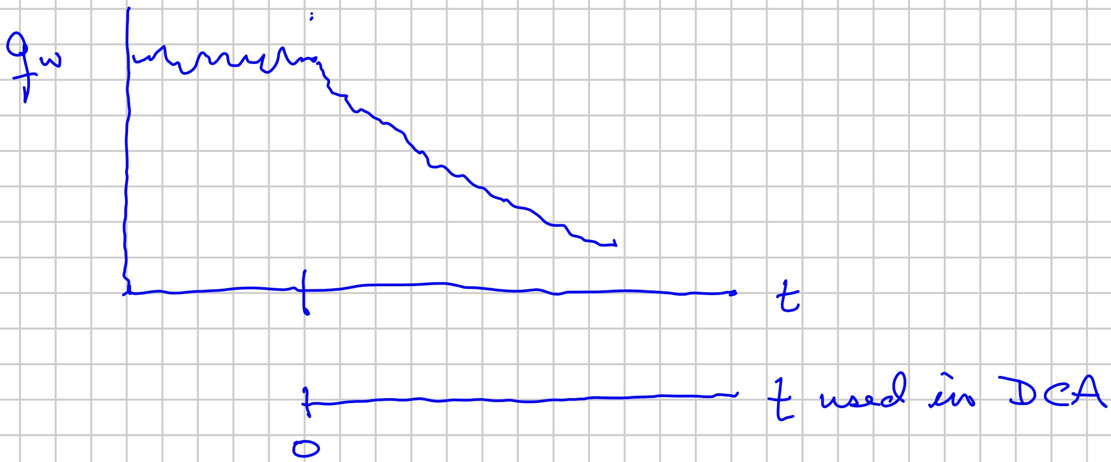
(RTA)

① Arp's Eq

$$q = \frac{q_i}{\left[1 + bDt\right]^{1/b}} \qquad 0 < b < 1$$

$$q = q_i \cdot e^{-Dt} \qquad b = 0$$

Applies after a well goes on decline



② Fetkovich (1973)

(a) Arps 3 parameters q_i D b are expressed in physical terms

(i) $q_i = q$ for PSS (BD) flow with a constant FBHP at the start of decline ($p_R \le p_{Ri}$)

e.g. $q = J(p_R - p_x) + J_x(p_x^2 - p_{wf}^2)$

k h r_e r_w s μ B p_x

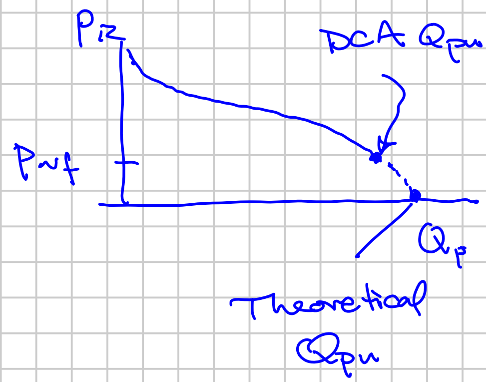
(iii) D = "decline constant"

$$D \equiv \frac{q_i}{Q_{pu}^{DCA}} \cdot \frac{1}{1-b}$$

$$Q_{pu} = \int_0^\infty q \, dt$$

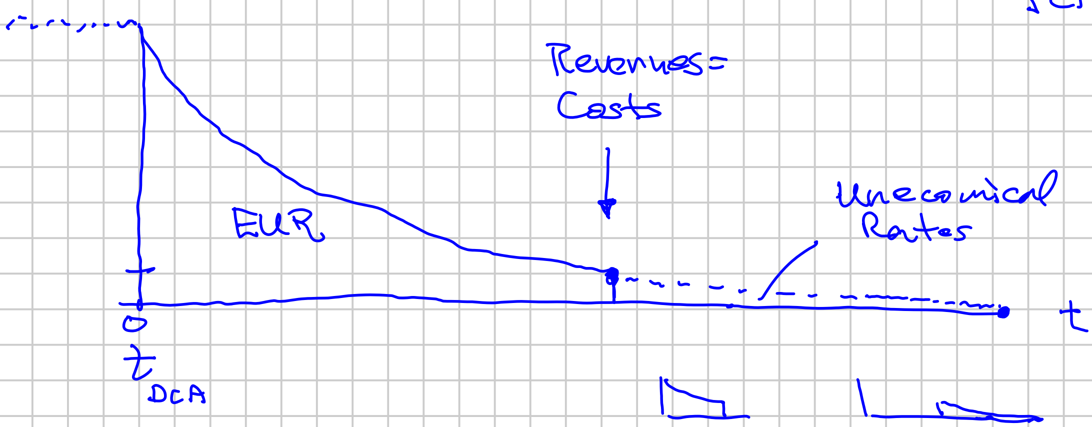
$$p_R^\infty = p_{wf}$$

$$q^\infty = 0$$



EUR = Est. Ultimate Recovery

Sm^3
STB
Scf



$$Q_{pu}^{DCA} = EUR + \text{Non-Econ}$$

$$EUR \le Q_{pu}^{DCA} \le Q_{pu}$$

$p_R \to p_{wf,min}$ $\qquad$ $p_R \to 0$

(iii) b : reflects the shapes of IPR & MB

$q(p_{wf})$ $\quad$ $\bar{p}_R(Q_p)$

Single-phase vs Multiphase Flow

$p_R > p_b$ $\qquad$ SGP $\quad p_R < p_b$

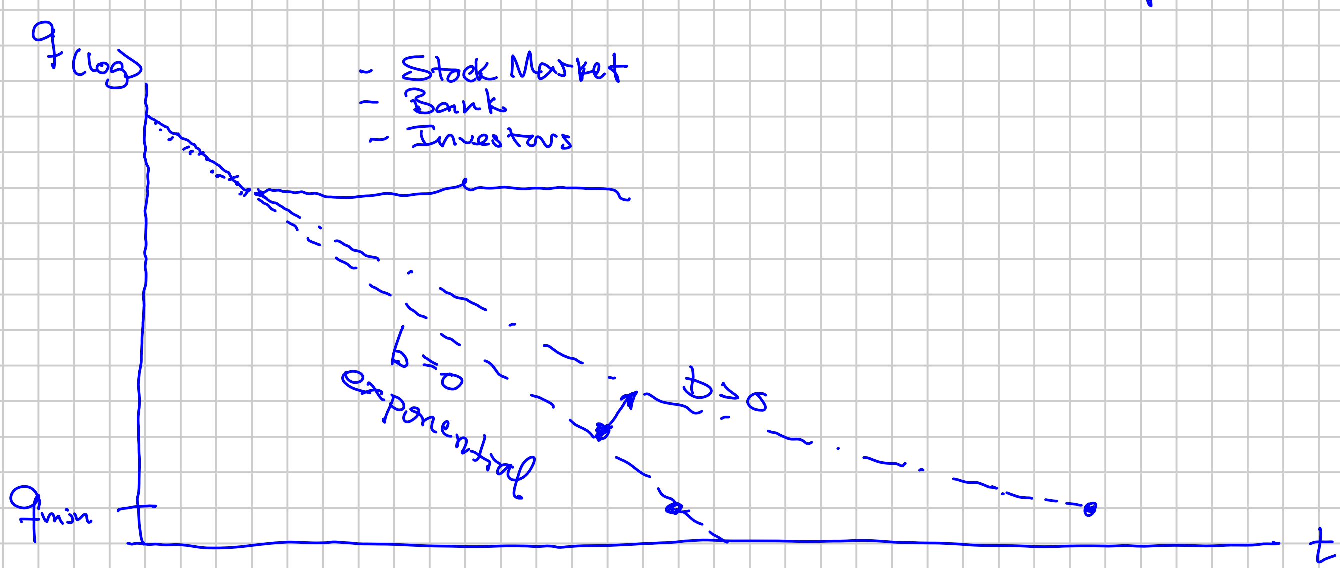
$p_{wf} > p_x$

Reservoir Flow and PVT behavior

1973 Single RFU : $\underline{0} < b < 0.5$

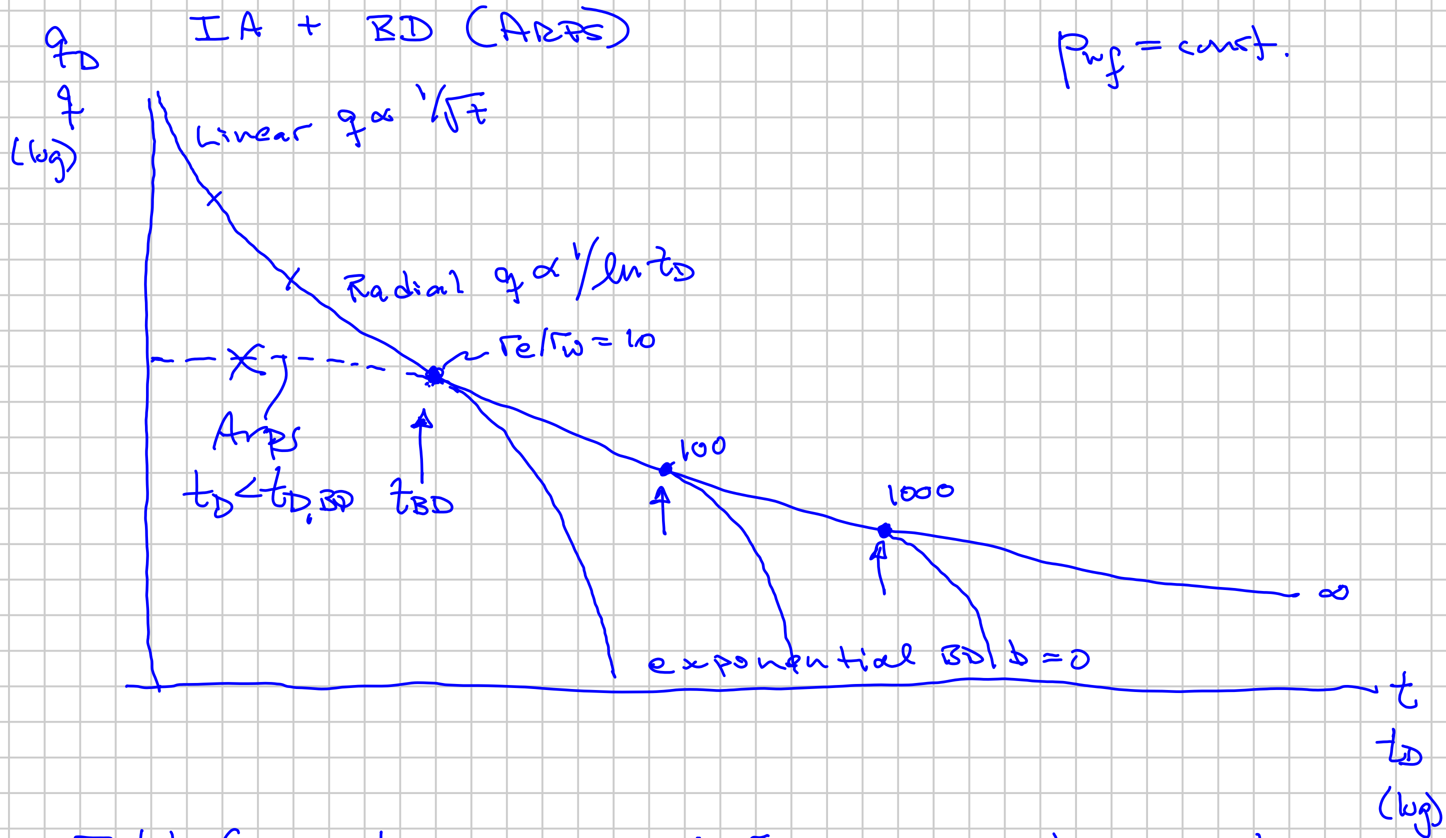
1990 Multiple RFUs (LNX) : $0.x \le b < 1$

RFUs have ~ same D ⇒ q_w "b" ~ q_{RFW} "b"



Fetkovich DCA

(b) Coupled the general flow theory in porous media (i.e. ~~not~~ not just PSS | BD flow) which is both "Infinite Acting" (IA) & BB behavior.



Tight Gas $t_{BD} \sim 0.5\,yr \rightarrow 5\,yr$ $p_{wf} \sim$ const

$\uparrow$

$\underline{\underline{k}}$ r_e

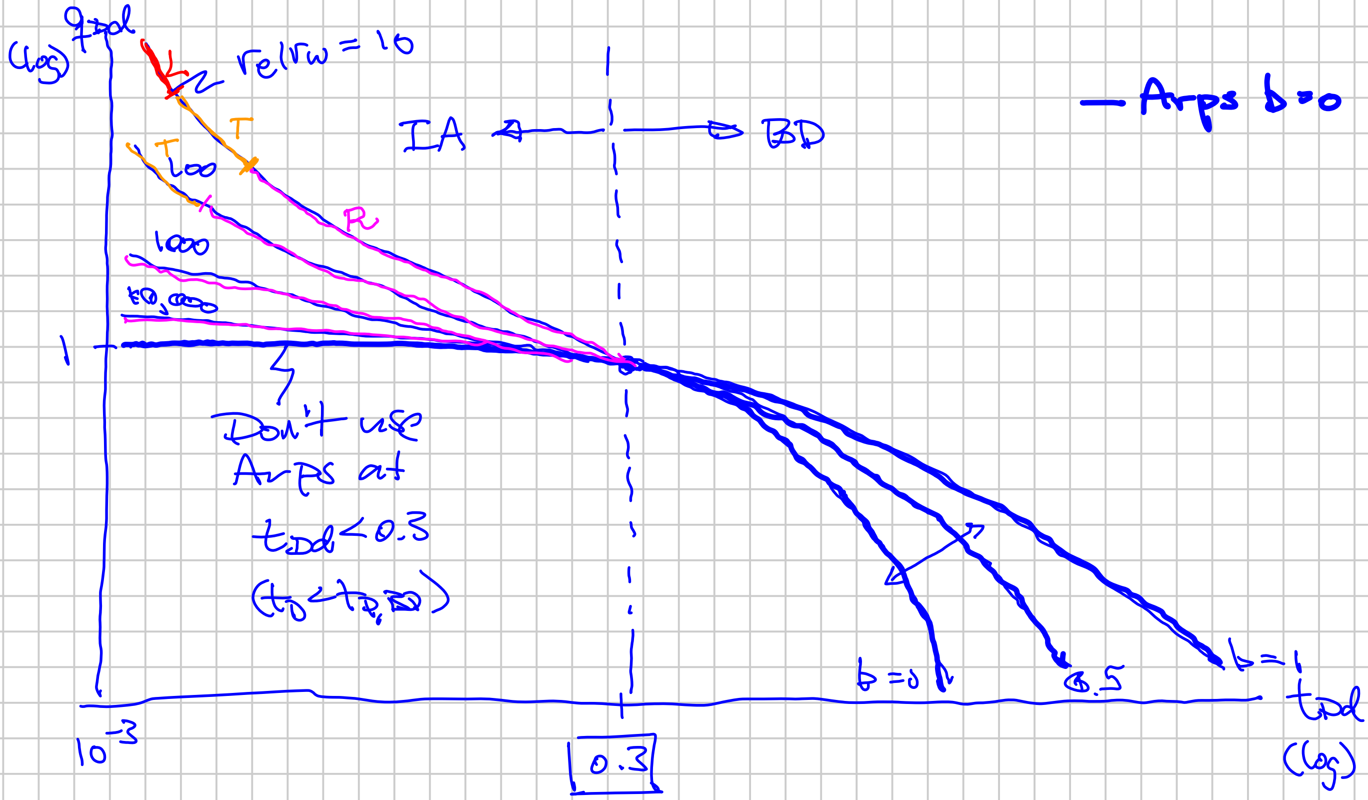
New Dimensionless variables

$$t_{Dd} \simeq \frac{t_D}{t_{D,BD}(r_e/r_w)} \quad (0.3) \quad \pi/16$$

$$q_{Dd} \cong \frac{q_D(t_D)}{q_D(t_{D,BD})}$$

Collapses all $q_D(t_D > t_{D,BD})$ to a single exponential curve

$$q_{Dd} = e^{-t_{Dd}}$$



Generalized Fetkovich Decline Type Curve (IA & BD)

$$\frac{q}{q_i} = q_{Dd} = \frac{1}{\left[1 + b\, t_{Dd}\right]^{1/b}}$$

$$\frac{q}{q_i} \equiv q_{Dd} = e^{-t_{Dd}}$$

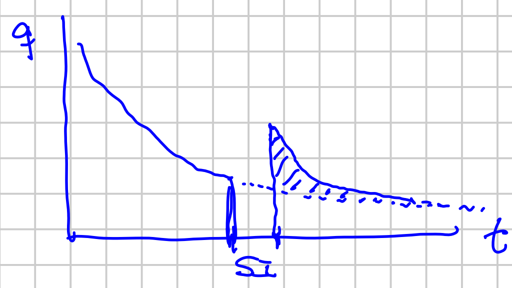
$$t_{Dd} \equiv D t$$

(c) $p_{wf}(t)$

(i) Rigorous Superposition - analogous to water influx

- Any $p_{wf}(t)$ variation

e.g. $q(t > \text{shut-in})$



(ii) Smoothly Varying $p_{wf}(t)$:

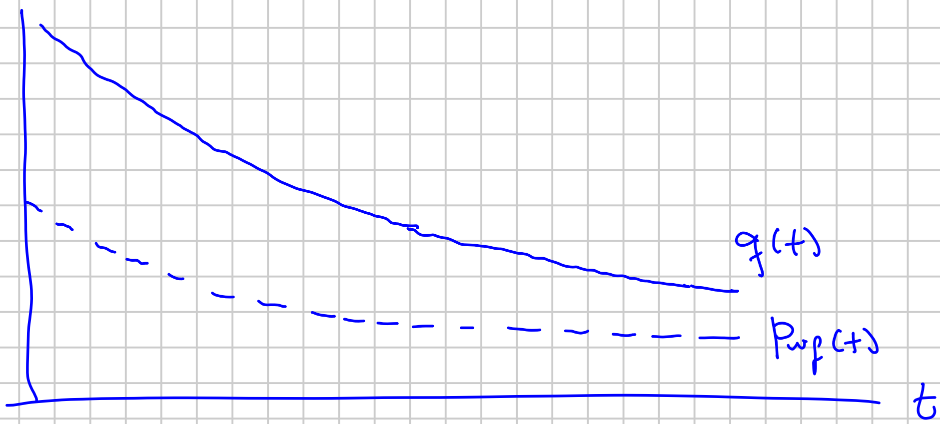
"Rate Normalization" (Winestock & Colpitts)

$\boxed{\underline{\underline{IA}}}$: $q_D(t_D) \simeq p_D^{-1}(t_D)$

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

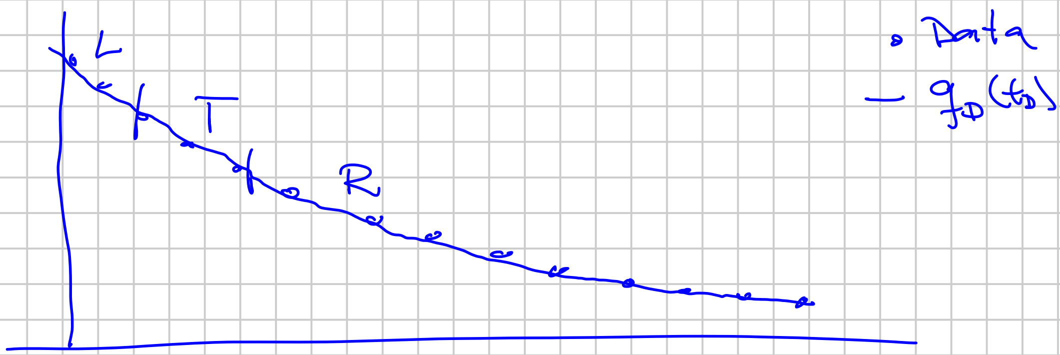
$$p_{wf}(t) \Rightarrow \frac{q(t)}{p_{Ri} - p_{wf}(t)} \simeq \frac{q(t)}{p_{Ri} - p_{wf}} : \frac{q_D(t_D)}{T}$$

const.



$$\left[\frac{q(t)}{P_i - P_{wf}(t)}\right]$$

$q_D(t_D)$



Rate Normalization

BD: ~~DOES~~ <u>NOT</u> WORK

$\underline{\text{Arp's}}$

$$q_D(t_D > t_{D,BD}) \propto e^{-t_D} \qquad b = 0$$

$$p_D^{-1}(t_D > t_{D,BD}) \propto \frac{1}{1 + t_D} \qquad b = 1$$

③ Past Fetkovich

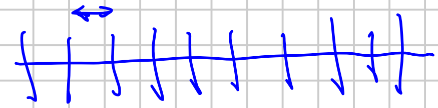
- nothing much new > 1990s LNX

~ 2005-ish "Unconventional 'Shales'" NA

$k \sim \underline{\underline{10}} - \underline{\underline{1000}}$ md

$10^{-5} - 10^{-3}$ md

$L_{ff} \sim 500$ ft $\rightarrow 20$ ft



$t_{BD} \sim \underbrace{2 \text{ yr} \rightarrow 20 \text{ yr}}$

(k, L_{ff})

$10^{-5} - 10^{-3}$ md

$t < t_{BD}$

"LFA" $\quad q \propto \frac{1}{\sqrt{t}}$

↓

BD

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

$b = 2$

$1 << bDt$

$$q \sim \frac{1}{\sqrt{t}}$$

Use Arp's $b=2$