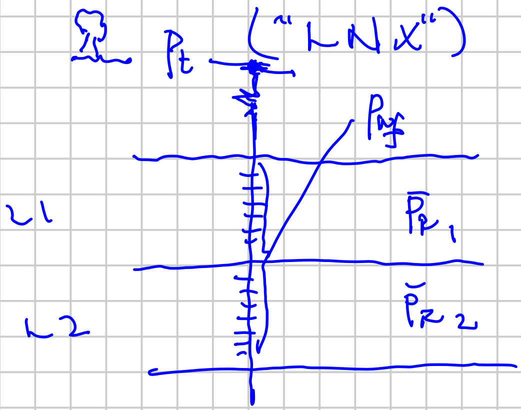
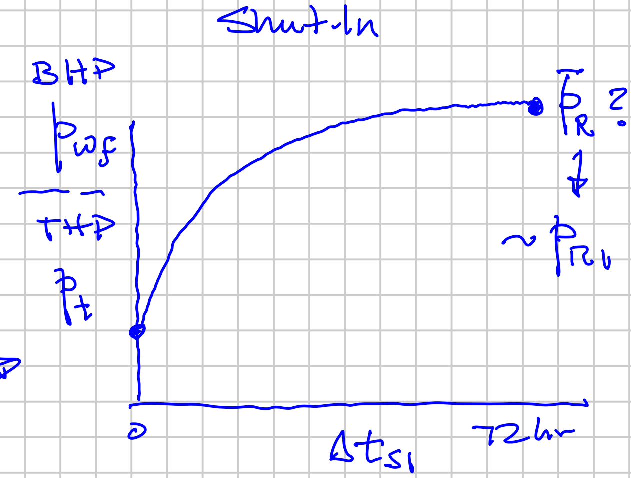
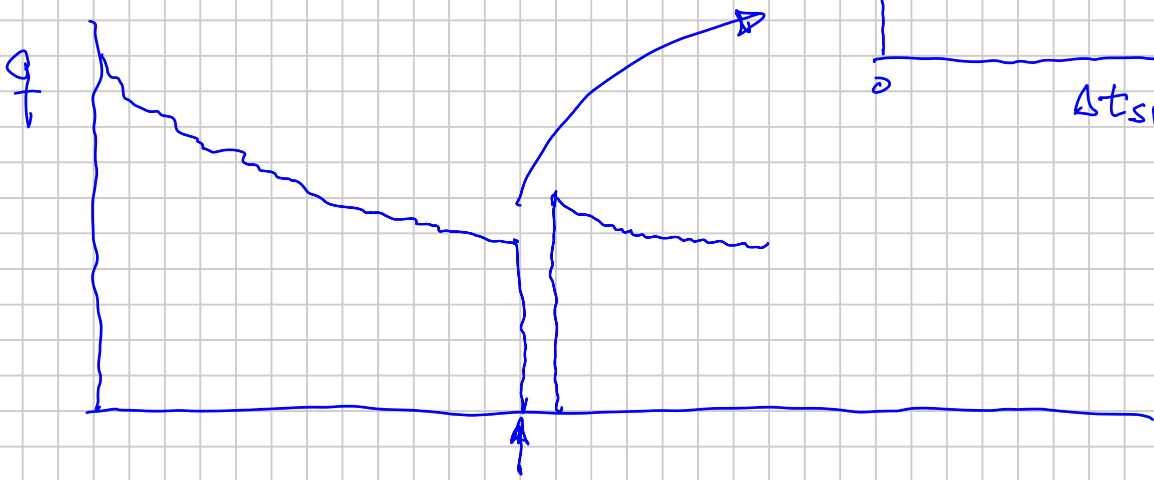
LAYERED NO-CROSSFLOW RESERVOIRS

("LNX")



$k_v = 0$

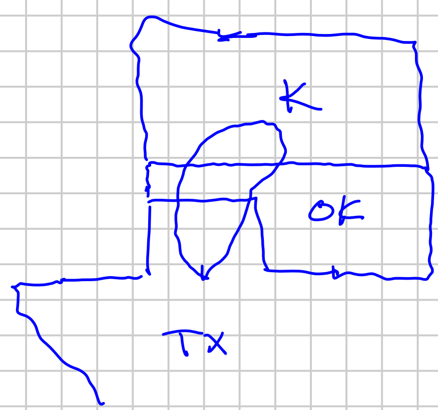




Hugoton | W. Texas

Three Geologic Zones

H K W



99%

LNX ⇒ Differential Depletion

$$\underbrace{\frac{k_1}{V_1}} > \underbrace{\frac{k_2}{V_2}} \qquad p_{R1} \neq p_{R2}$$

"VR" *

$$\frac{\{J^\circ \mid C_R\}}{\{IFIP \mid HCPV\}} \qquad \left[\frac{\{kh, s\}_{N_w}}{HCPV}\right]_{RFU} \sim \text{Rate of Drainage Factor}$$

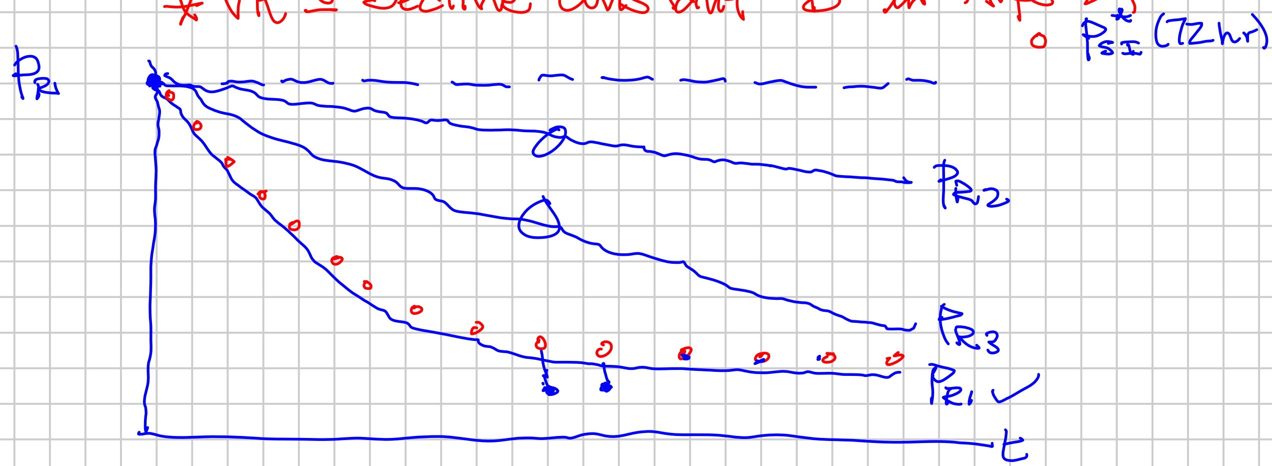
"Voidage Ratio"

RFU	VR
1	210
2	35
3	100

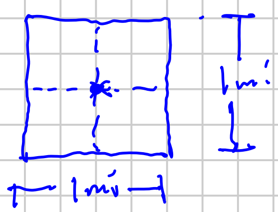
⇒ Rank High-to-Low VR

RFU	VR	To Equalize VR N_w
1	210	5
3	100	10
2	35	30

* VR ≃ Decline Constant "D" in Arps's Eq.



640 acres / section



Section

1 mi ≈ 5280 f ~ 1600 m

43560 ft / acre

10 ft² ~ 1 m²

4360 m² / acre

Drilling Spacing Unit.

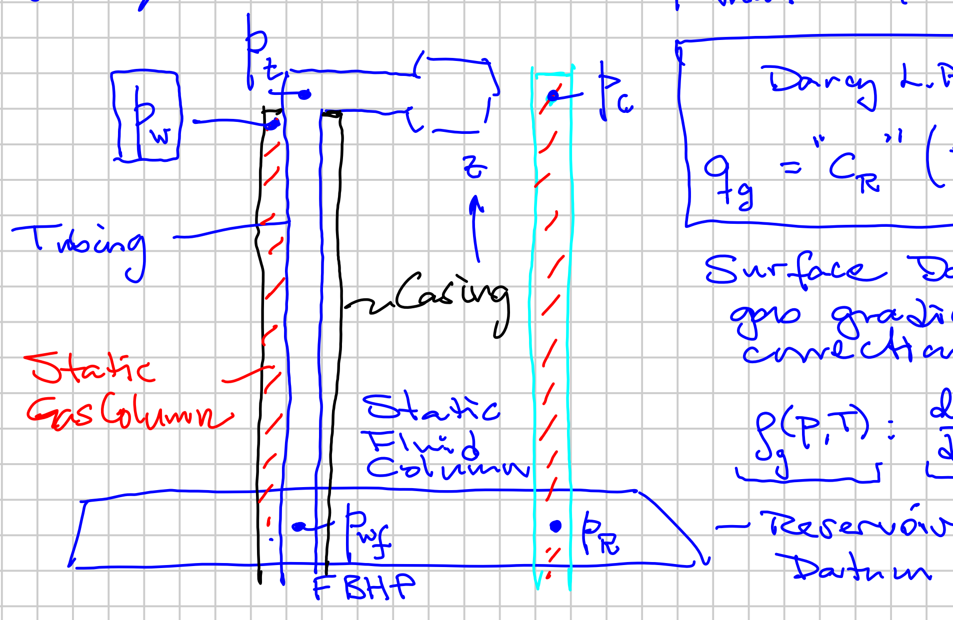
1 gas well / section

1000 m² / mål

4 mål = 1 acre

$P_{wf} - P_t =$
(1) gravity
(2) friction

$P_{wf} - P_w =$
(1) gravity



Darcy L.P. Gas

$$q_g = \text{"}C_R\text{"}\left(P_R^2 - P_{wf}^2\right)$$

Surface Datum using gas gradient correction BH→Surf.

$\underline{\rho_g(p,T)}$: $\underline{\frac{dp}{dz} = \rho_g g}$

⇓

$\frac{P_{wf}}{P_w} = \text{const}$

The standard backpressure equation for a well producing from a single layer reservoir is given by Fetkovich (1975). $\approx \frac{p_R}{p_c}$

$$\boxed{q_g = C_R(p_c^2 - p_w^2)} \qquad (1)$$

$p_R \quad p_{wf}$

The backpressure constant, C_R, is defined as:

$$C_R = \frac{4.18 kh e^S}{T_R\left(\ln\frac{r_e}{r_w} - \frac{3}{4} + s\right)\mu_g z} \qquad (2)$$

with q_g in std m3/d, p in bar, k in md, h in m, T_R in K, and μ_g in cp. The gravity term, S, is defined as:

"Static"

$$\boxed{S = \frac{0.0684\gamma_g D}{\bar{T}\bar{z}}} \qquad (3)$$

656 TVD

This S must not be confused with the skin factor, s.

The surface datum pressures, p_c and p_w, are converted to bottomhole pressures through the gravity term. The different pressure datums are shown in **Fig. 1**.

$$p_R = e^{S/2}p_c\,; \quad p_{wf} = e^{S/2}p_w \qquad (4) \quad *$$

$$\frac{p_R}{p_c} \approx \frac{p_{wf}}{p_w} \approx e^{S/2}$$

p_c "p_R"

p_w "p_{wf}"

$$q_g = \underbrace{C_R}(p_c^2 - p_w^2)$$

Same Eq. for 1-layer or n-layer system

LNX

$$\bar{C}_R \quad \Big| \quad \bar{p}_c$$

$$\bar{C}_R = \sum_{l=1}^{N_l} C_{Rl}$$

$$\underbrace{\bar{p}_c^{\,2}(t)} = \frac{\sum_{l=1}^{N_l} C_{Rl} \cdot \bar{p}_{cl}^{\,2}(t)}{\bar{C}_R}$$

Measure

$$p_R^2(t) = \frac{\sum_{l=1}^{N_l} C_{Rl} \cdot p_{Rl}^2}{C_R}$$

Note Title 10/9/2018

LNX DEPLETION CHARACTERISTICS

(1) Differential Depletion of RFUs

$$(\bar{P}_R)_{RFU1}(t) \neq (\bar{P}_R)_{RFU2\ldots}(t)$$

$$D_{RFU1} \neq D_{RFU2\ldots}$$

Requires Voidage Ratio (VR)

"D"

Arp's Decline Eq. $q = \dfrac{q_i}{[1 + bDt]^{b}}$

$$\frac{(kh)_1}{HCPV_1} = \frac{(100\ md)(\cancel{100}\ ft)}{\cancel{100}\ ft}$$

$$D \equiv \frac{q_i}{Q_{pu}(1-b)}$$

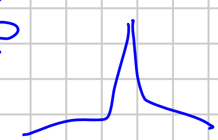
@start decline

$$\frac{(kh)_2}{HCPV_2} = \frac{(100\ md)(10\ ft)}{10\ ft}$$

$$q_i = \frac{kh(\bar{P}_R - P_{wf})}{\left[\ln\frac{r_e}{r_w} + s\right]}$$

$$\underbrace{\left(\frac{k_1}{k_2}\right)} \Rightarrow \frac{VR_1}{VR_2} = \frac{D_1}{D_2}$$

$$Q_{pu} = \underbrace{\frac{HCPV}{B_i}}_{IFIP} \cdot RF_u$$



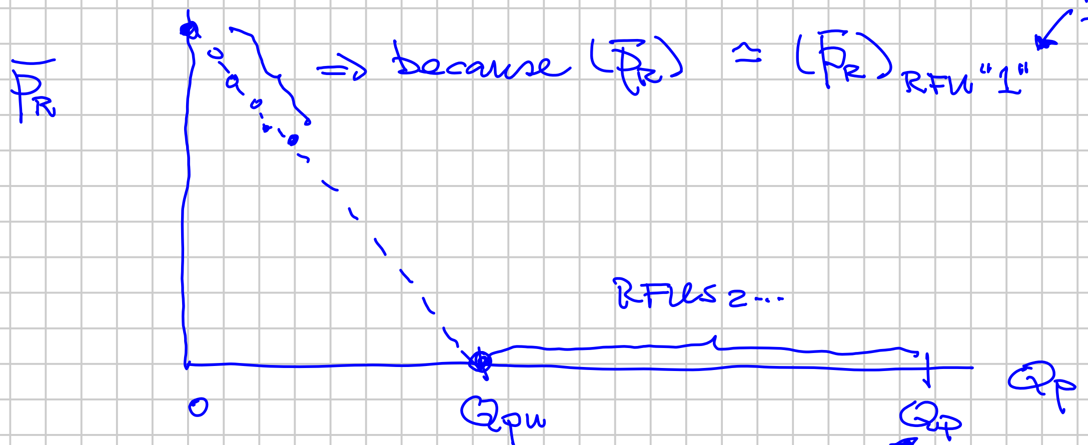
Oils 5–35%

Gas 60–98%

SGD (15–25%)

(2) Difficult to "see" Differential Depletion from conventional data used in material balance and rate (PTA, RTA)

t $\quad \bar{p}_{SI}$ / $\bar{p}_R$ $\quad (Q_p)_{Field}$



$\Downarrow$

$IFIP \ll (IFIP)$ Logs / Geo

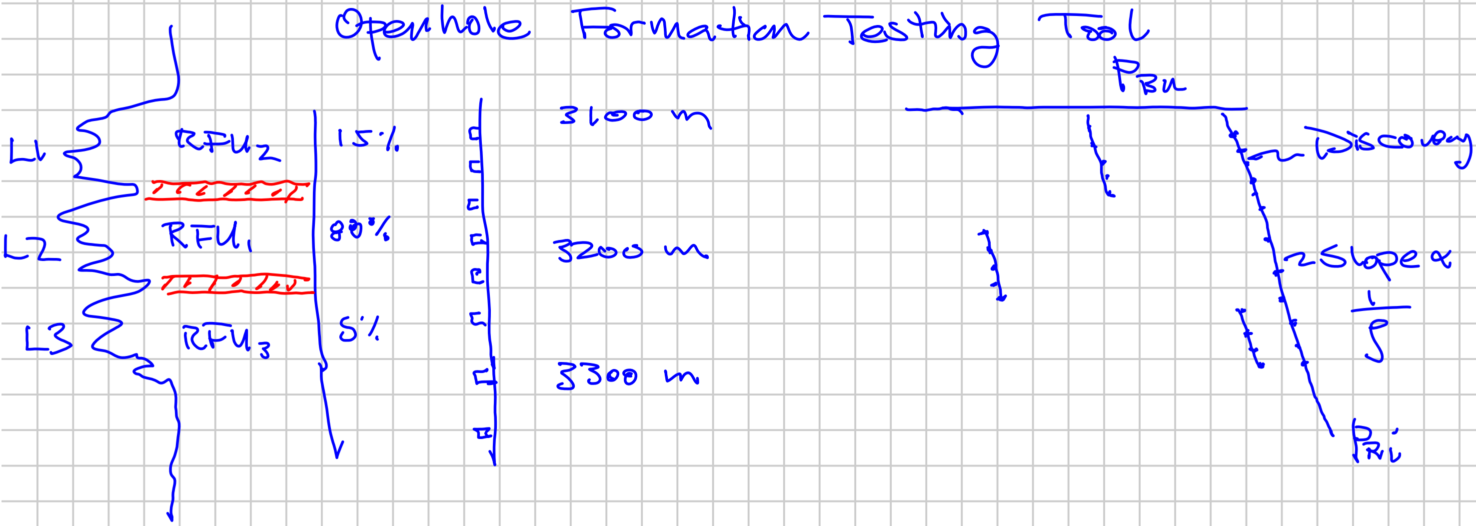
$\approx$

$(IFIP)_{RFU1}$

③ How to Verify Differential Depletion?

- "Late" Infill Wells with "MDT" (SLB)

Openhole Formation Testing Tool



④ What happens during a well shutin?

Metered Surface $q = 0$

$q_1 \neq 0$ $\quad P_{R1}$

$q_2 \neq 0$ $\quad \underbrace{p_{wf}(\Delta t_{s1}) < p_{R2} \quad P_{R3}}_{\text{Wellbore Storage}}$

$q_3 \neq 0$

Thereafter (hours)

$$\underbrace{\bar{p}_{R3} > \bar{p}_{R1}}_{\text{Producing into Wellbore L1 \& L3}} > \underbrace{p_{wf} > \bar{p}_{R2}}_{\text{Injection into L2 from Wellbore}}$$

$$\Sigma (q)_{RFU} = \underset{\text{Surface}}{q = 0}$$

"Backflow"

"Wellbore Crossflow"

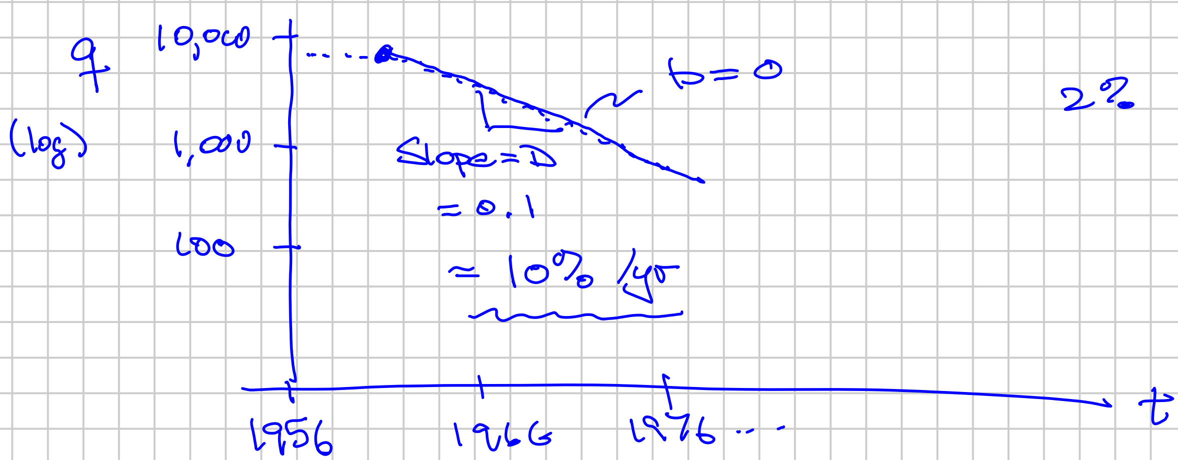
Shut-In

$$J_{L1}(\bar{p}_{R1} - p_{wf}) + J_{L3}(\bar{p}_{R3} - p_{wf}) = -J_{L2}(\bar{p}_{R2} - p_{wf})$$

$$= J_{L2}(p_{wf} - \bar{p}_{R2})$$

$p_{wf}^{SI}(\Delta t_{s1})$ satisfies this rate balance equation

⑤ Longer Well & Field Lives in LNK systems because Lower-"D" RFUs deplete slowly



Note Title "GENERAL" 10/10/2018

LNX M.B. + IPR PRODUCTION FORECAST STRATEGY

① Multiple RFUs

② All wells produce from all RFUs

③ Average well | Each RFU is "uniform" | Same p_{wf} all wells

④ Gas Reservoir $\underline{\text{or}}$ Oil Reservoir all RFUs
$\bar{g}$ $\bar{o}$

⑤ Discretize in time Δt (1 month | 1 year)

⑥ Specify Target Rate of Wells
(a) Lower FBHP p_{wf} constraint

As reservoir simulators work

(b) Specify $p_{wf}(t)$: Simpler

M.B. $R_p(p_R)$
SGD: $p_R(N_p)$

M.B. $r_p(p_R)$
GC: $p_R(G_p)$

RFU-1 : MB $p_R(Q_p)$ & IPR : $q_w(p_R, p_{wf})$

t	Target q_w	Min p_{wf}	Q_{pt}
$t_0 = 0$			
t_1			
t_2			
⋮			

$\boxed{\Delta t}$

* p_R	M.B. Q_p	IPR q_w	$\boxed{N_w} \cdot q_w$ q_t	$q_t \Delta t$ ΔQ_p	$\Sigma \Delta Q_p$ Q_p	*

$\underbrace{Q_p \quad q_w \quad q_t \quad \Delta Q_p \quad Q_p}_{=}$

*new columns

M.B. (SGD) : $Q_{pz} = G_p$

$R_p(p_R)$ $\Delta Q_{p(z)} = \Delta Q_p \bar{R}_p$ $\quad Q_{p(z)} = \Sigma \Delta Q_{p(z)}$

M.B (G.C) : $Q_{pz} = N_p$

$r_p(p_R)$ $\Delta Q_{p(z)} = \Delta Q_p \cdot \bar{r}_p$ $\quad Q_{p(z)} = \Sigma \Delta Q_{p(z)}$

simpler to specify p_{wf}

$\Rightarrow$ accept q_w, q_t

$N_{ts} \cdot N_{RFU}$

$N_{ts} \cdot N_{RFU} + N_{ts}$

$N_{ts}(N_{RFU} + 1)$

if q_w targets are given

: Variables (Unknown) : $p_R(t)$

Objective (Target) : Minimize

Q_p^{MB} : Q_p^{calc}

$$\sum_{i=1}^{N_{RFU}} \sum_{j=1}^{N_t} \left(\frac{Q_p^{calc} - Q_p^{MB}}{Q_{p\,ref}} \right)^2$$

(a) Q_p^{MB}

*(b) Q_{pu}