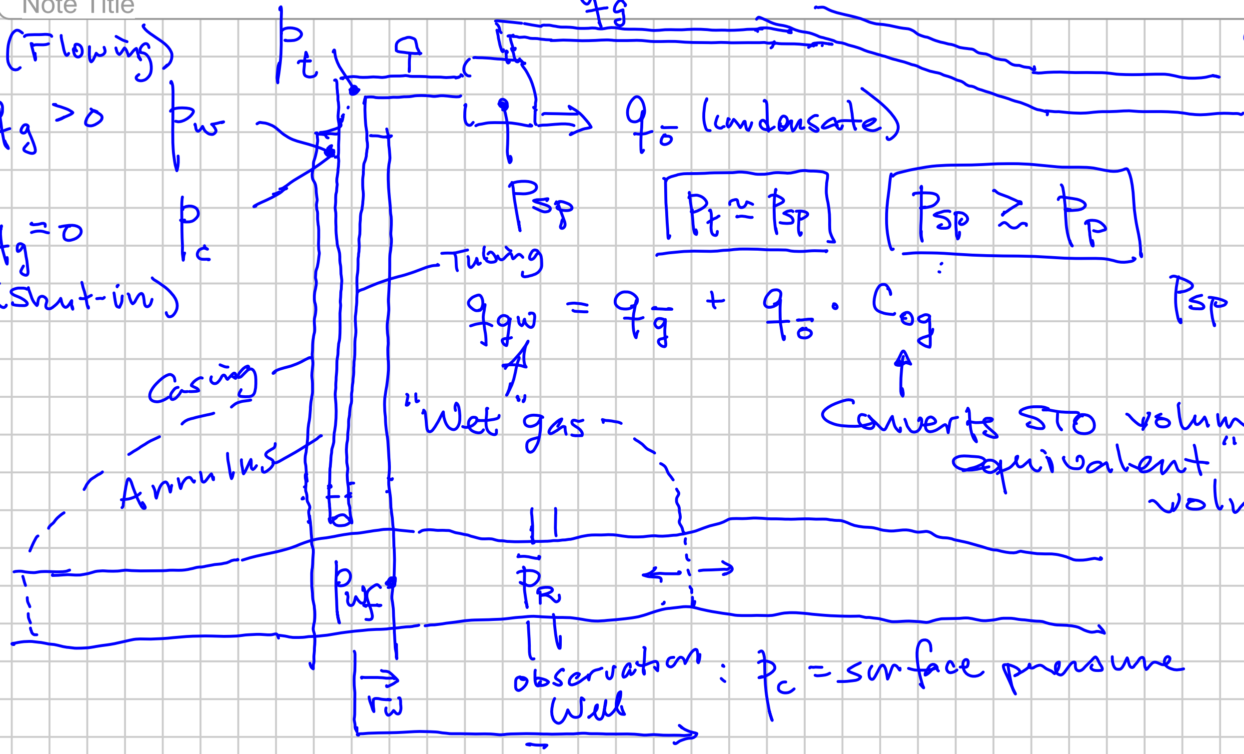
WELLHEAD BACKPRESSURE EQUATION



$p_t \simeq p_{sp}$

$p_{sp} \gtrsim p_p$

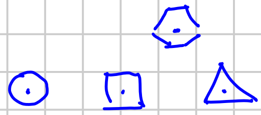
$p_{sp} < p_p$: Compression

$$q_{gw} = q_{\bar{g}} + q_{\bar{o}} \cdot C_{og}$$

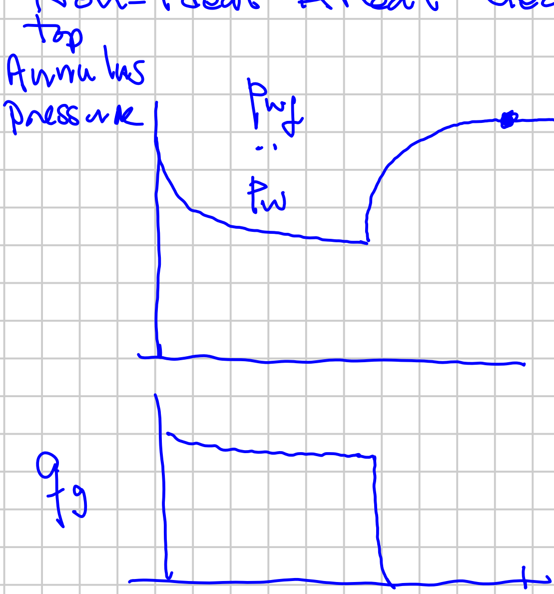
"Wet" gas

C_{og}: Converts STO volume to equivalent "surface gas" volume

$[\ln r_e/r_w - 3/4$



Non-Ideal Areal Geometries Drainage: s_G 0.x



$\bar{p}_R$, p_c } Related through a Static Gas Column

$$\frac{\bar{p}_R}{p_c} \simeq \frac{p_{wf}}{p_w} \sim \text{constant} \left(\frac{\bar{T} \quad \bar{Z}}{M_{\bar{g}} \quad TVD} \right)$$

$s_G \sim +2.x$

Purpose : Control p_t $\Rightarrow$ How much gas rate ? q_{fg}

How : Combine R pressure drops together with the T pressure drop

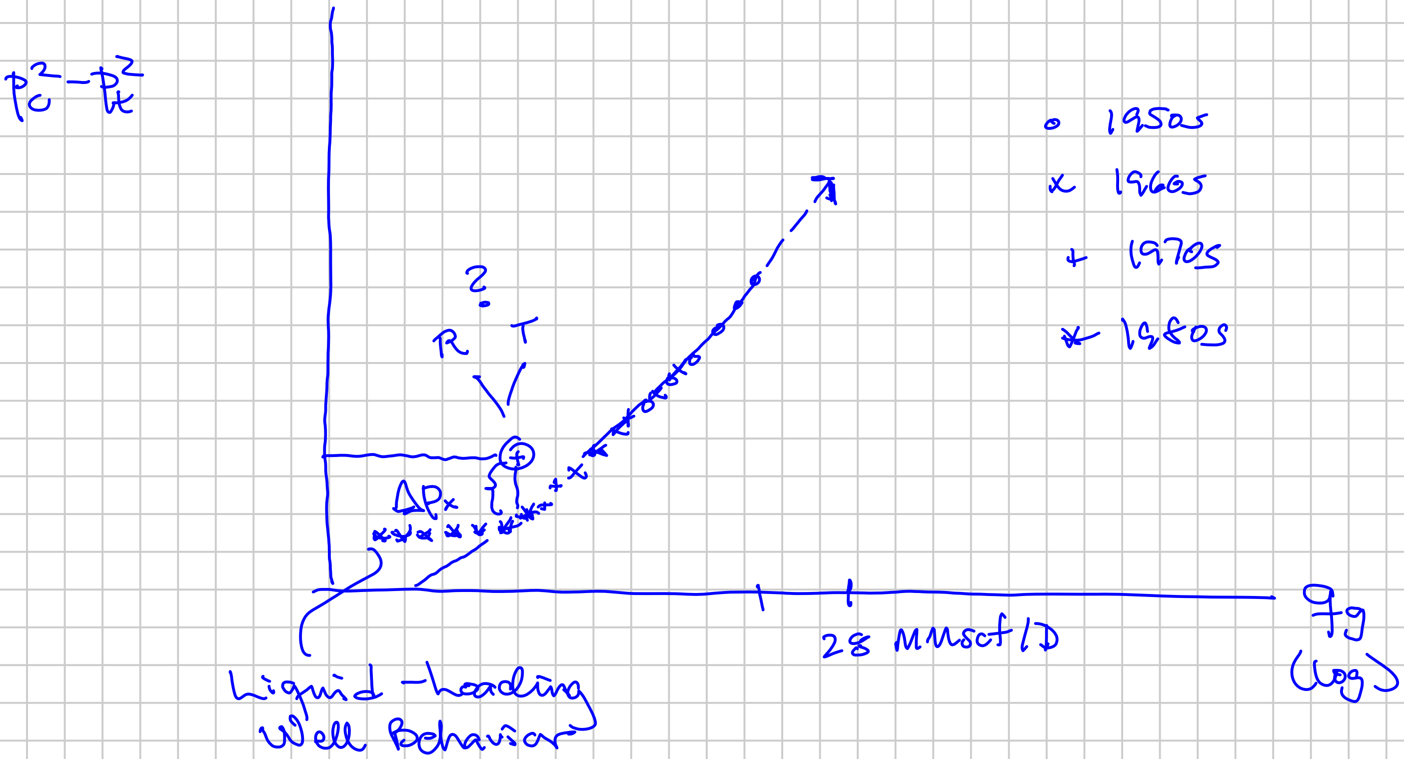
$$p_c^2 - p_t^2 = A' q_{fg} + B' q_{fg}^2$$

p_c ↑ Known @ Given time

p_t ⇕

$q_{fg}(p_t)$ @ a given "time" (p_c)

A' & B' are constants through the life of the well



$P_c^2 - P_t^2$
o 1950s
x 1960s
+ 1970s
* 1980s
?
R
T
ΔP_x
28 MMscf/D
q_g
(log)
Liquid-Loading
Well Behavior

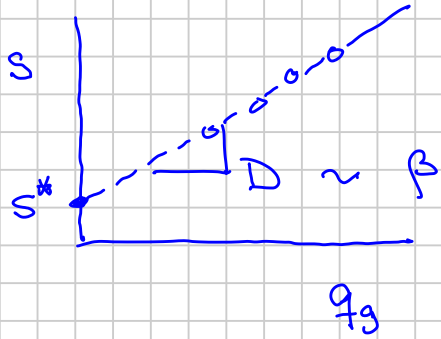
Reservoir Gas Rate Eq.

$$p_{pR} - p_{pwf} = A\, q_g + B\, q_g^2$$

$$A_R = \frac{T_R}{7.73\, kh}\left[\ln\frac{r_e}{r_w} - \frac{3}{4} + s^*\right]$$

$$B_R = \frac{T_R}{7.73\, kh} \cdot D$$

$\sim \beta$



$$p_R^2 - p_{wf}^2 = A_R' q_g + B_R' q_g^2 \quad ; \quad p_R \lesssim 3{,}000\ \text{psia}$$

200 bar

$$A_R' = \frac{T_R\,(\mu Z)^*}{7.73\, kh}\left[\quad\right]$$

$$B_R' = \frac{T_R\,(\mu Z)^*}{7.73\, kh}\, D$$

Tubing Gas Flow:

(1) Fully turbulent flow

(2) Assume $(v_g)_T$ sufficient to lift (carry) small liquid volumes - as droplets and/or thin liquid film along tubing.

- Valid "early" most of the well's life
- Eventually will be violated

$$q_g = C_T \cdot \underbrace{(p_w^2 - p_t^2)}_{\text{Friction Only}}{}^{0.5}$$

$$\Delta p_T = \cancel{\Delta p_G} + \Delta p_F$$

$$p_{wf} \rightarrow p_w$$

$$\frac{p_{wf}}{p_w} = \text{constant}$$

$$\frac{p_c^2}{p_R^2} = e^{-S}$$

$$p_w^2 - p_t^2 = \underbrace{\frac{1}{C_T^2}}_{B_T} q_g^2$$

Tubing Friction Pressure Drop

$$e^{-S}(p_R^2 - p_{wf}^2) = (B_R' q_g^2 + A_R' q_g)$$

$$(p_c^2 - p_w^2) = (\qquad\qquad) e^{-S}$$

$$p_c^2 - p_w^2 = B_R'' q_g^2 + A_R'' q_g$$

Convert $p_{wf} \rightarrow p_w$; $p_R \rightarrow p_c$

DE for a static fluid column : $\uparrow \underline{z}$ D

$$\frac{dp}{dz} = \rho_g g$$

$$B_R'' = B_R' \cdot e^{-S}$$

$$\rho_g = \left(\frac{M_g}{R T Z_g}\right) p$$

$$A'' = A_R' e^{-S}$$

$$\frac{dp}{dz} = \left(\frac{M_g g}{R \bar{T} \bar{Z}}\right) p$$

$$\int_{p_c}^{p_R} \frac{1}{p} dp = \left(\frac{M_g g}{R \bar{T} \bar{Z}}\right) \int_{0\ (\text{Top})}^{\text{TVD (Bottom)}} dz$$

$$\ln \frac{p_R}{p_c} = \left(\frac{M_g\, g \cdot TVD}{R \bar{T} \bar{Z}} \right)$$

$$\frac{p_R}{p_c} = \exp \left(\underbrace{\frac{M_g\, g\, TVD}{R \bar{T} \bar{Z}}}_{\equiv S/2} \right)$$

$$\frac{p_R^2}{p_c^2} = \exp \left(\underbrace{2 \frac{M_g\, g\, TVD}{R \bar{T} \bar{Z}}}_{\equiv S} \right)$$

$$S = 0.0375\, GH/T_a\, Z_a$$

$* \; G = \gamma_g = M_g / M_{air}$

$* \; H = TVD$ [ft]

$\begin{cases} T_a = \bar{T} & [°R] \\ Z_a = \bar{Z} \end{cases}$

=

$$A_R'' = \frac{T_R (\mu Z)^*}{7.73\, kh\, e^s} \left[\ln \frac{r_e}{r_w} - \frac{3}{4} + s^* \right]$$

$$B_R'' = \frac{T_R (\mu Z)^*}{7.73\, kh\, e^s} D$$

T $\quad p_w^2 - p_t^2 = B_T\, q_g^2$

R $\quad p_c^2 - p_w^2 = B_R''\, q_g^2 + A_R''\, q_g$

TOTAL (T+R) $\quad p_c^2 - p_t^2 = (B_T + B_R'')\, q_g^2 + A_R''\, q_g$

$$B_T = \frac{1}{C_T^2} \qquad C_T(\underline{\underline{d_T^{2.6}}}, L_T)$$

$$(p_c^2 - p_t^2) = \overset{(R+T)}{B_{WH}} q_g^2 + \overset{(R)}{A_{WH}} q_g$$

$$Q = \underbrace{\left[\frac{31.62\, e^{s/2}}{\sqrt{(e^s - 1)\, F_r\, T_a\, Z_a}}\right]}_{C_T} (p_w^2 - p_t^2)^{0.5}$$

$$F_r = \frac{0.10797}{D^{2.612}}$$

Gas Reservoir with multiple wells draining a RESERVOIR UNIT: Flow – Pressure Communication

$\bar{p}_R$ ~ same for all wells @ time

$p_c(t)$

Each well has its own $\underbrace{A_{WH}, B_{WH}}$

(i) Predicted before production

A_R'' B_R'' B_T

reasonable estimates

DESIGN

Wells (time)

Platforms

Gathering Line d_{GP}

(2) Observed Values

t	q_g	p_t	p_c^{OBS}

: WHSIP

A_{WH} B_{WH}

~~Ini~~ Initial Test

Multirate Well Test

A^0_{WH} B^0_{WH}

High kh wells

$\Delta p_R \sim$ small

$\Delta p_T \sim$ large

} $\Delta p_T >> \Delta p_R \Rightarrow B_{WH} q_g^2$ dominate (log q_g)

(or if tubing is too small diameter)

(B_R'' & B_T)

Slope of WHBP on log-log ~ 2

$$q_g \cong \frac{1}{B_{WH}^{0.5}} (p_c^2 - p_{wt}^2)^{\sim 0.5}$$

WHBP Eq. A_{WH} B_{WH} = f(t)

① p_{Ri} > 2500 psia   Need p_p instead of p^2

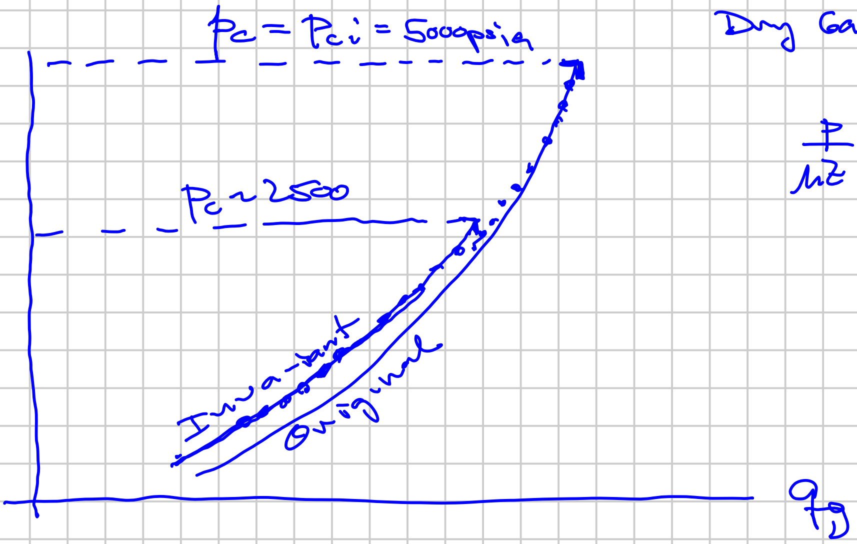
② Gas Condensate $p_R < p_d$ ⇒ GOR (CGR)

GOR (t : $p_R < p_d$)

(a) $A_R(t)$ ~ 20% → 55% → 100%

(b) $C_T(t)$ ~ 20%

$(p_c^2 - p_t^2)$



① Dry Gas, HP