Note Title 2014-10-23

Natural Gas Petroleum Engineering $\longleftrightarrow$ "FLOW"

TASK (DRY)

① GAS RATE EQ Well $q_g \longleftrightarrow \Delta p$ Reservoir $\rightarrow$ Pipeline

@ STC

1 atm 60°F

SPE:

MMscf/D Mscf/D Sm^3/d scf/D

standard m^3/d

std m^3

$f(t)$

$\downarrow$

$\bar{p}_R$

(a) Reservoir Δp_R — q_g Given Today's $\bar{p}_e$

(b) "Tubing" Δp_T — q_g Calc q_{gw}

q_{gR} gas rate in the reservoir @ p, T_R

MULTIPOINT TESTING OF GAS WELLS

by

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Mscf/D

List our pressures

③ p_{wf} = wellbore flowing pressure

② $\bar{p}_R$ = volumetric average reservoir pressure

$$= \int_{V_{dw}} p(V)\, dV$$

Darcy +

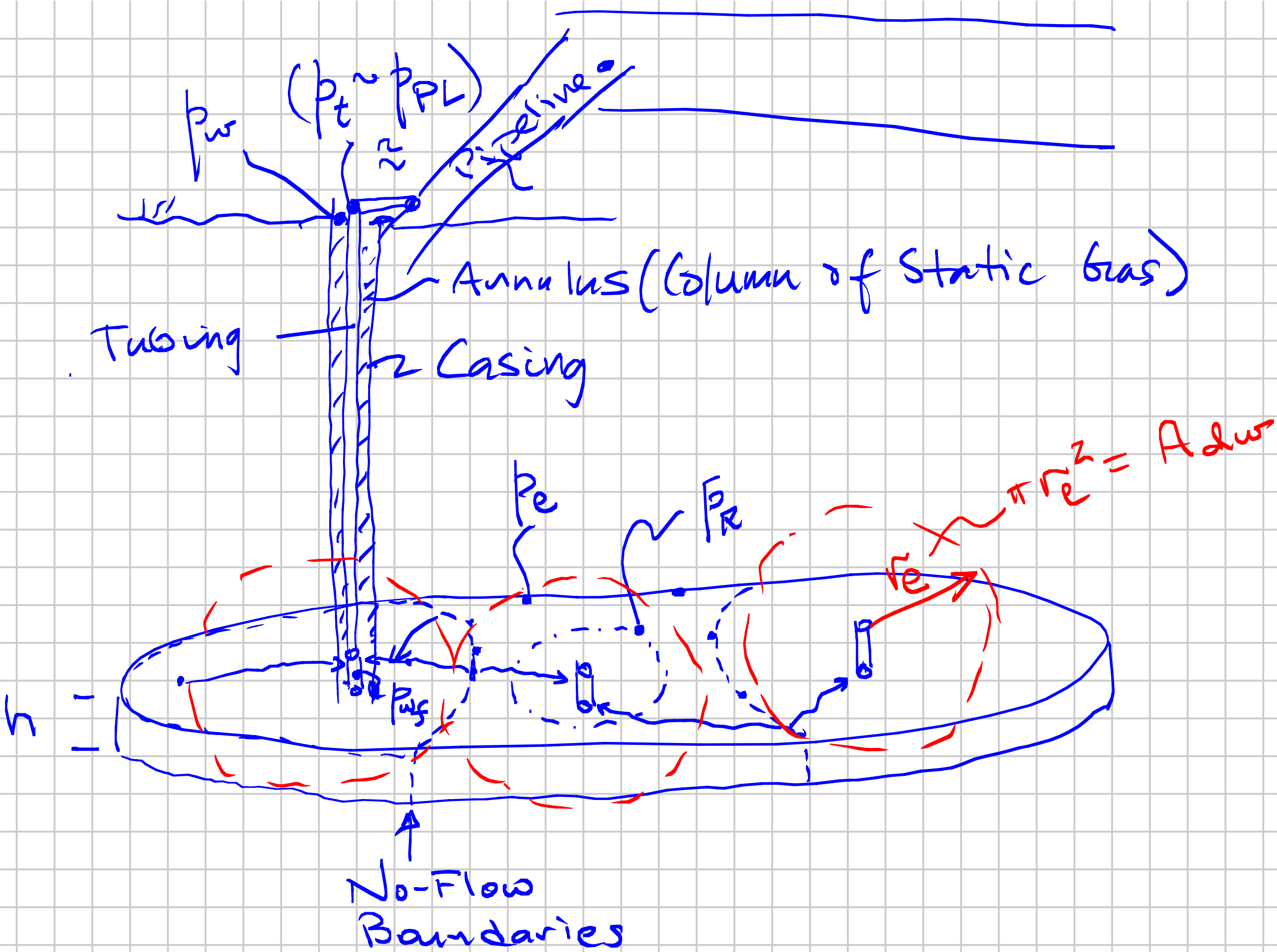
① p_e = pressure at the external outer boundary

p_t = tubing flowing pressure

p_w = annulus pressure flowing @ surface

Annulus

$p_{wf} \rightarrow p_t$: Tubing (Friction + Gravity) | $p_{wf} \rightarrow p_w$ (Gravity)



Homogeneous (ϕ, S_w, k) Reservoir

$$V_{dw} \propto \frac{q_{fw}}{\sum_{u=1}^{3} q_{fu}} = \frac{q_{fw}}{q_{fF}} = \frac{V_{dw}}{V_{dF}}$$

#1 Job of a Petroleum Engineer is

Forecast $q(t)$ G & O $\Rightarrow$ Revenues, NPV, Company Value

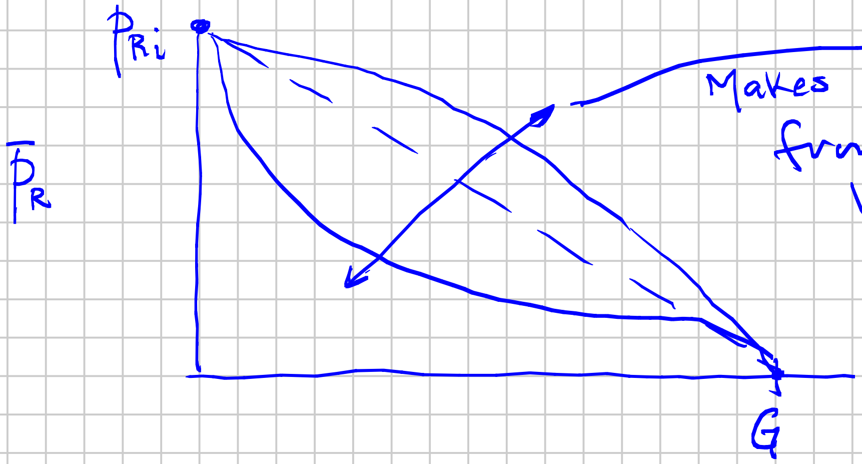
TASK

(2)

$$\underline{\underline{p_R(t)}} = f\left(\underbrace{\int_0^t q_{gF}\, dt}_{\underline{\underline{G_p}}} \right)$$

G_p = cumulative gas production

Gas Material Balance: $p_R(G_p, \ldots)$



Makes $p_R(G_p)$ deviate from simple straight line

G_p = Cum. Gas Produced

IGIP = Initial Gas ($\bar{g}$) in Place

Society of Petroleum Engineers

SPE 22921

APPLICATION OF A GENERAL MATERIAL BALANCE FOR HIGH-PRESSURE GAS RESERVOIRS

by M. J. Fetkovich, D. E. Reese, and C. H. Whitson, Phillips Petroleum Co.

TASK 3 PRODUCTION DECLINE PERFORMANCE

- of individual wells and/or
- Entire Field

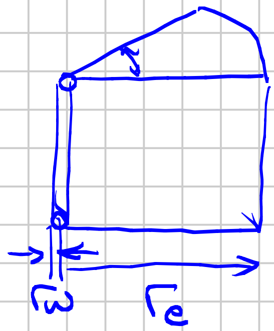
"DECLINE CURVE ANALYSIS" (DCA)

Father of DCA : MJ Fetkovich

Reservoir Gas Rate Equation $q_g \leftrightarrow p_{wf},\ p_R\ (p_e)$

PVT

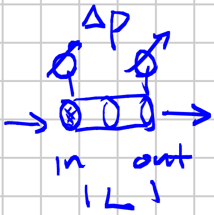
$$\boxed{q_g = \frac{(kh)(p_{pR} - p_{pwf})}{T_R \cdot \underbrace{\left[\ln\frac{r_e}{r_w} - \frac{3}{4}\right]}_{\sim 8-10}}}$$



Darcy Velocity

Darcy's Law: $v = \frac{k}{\mu}\cdot\frac{\Delta p}{L}$

≠ pore velocity



$q = v\cdot A$

bulk Area ⊥ to flow

$A = \pi\left(\frac{d_{core}}{2}\right)^2$

$$\underline{p_{pR}} \equiv 2\cdot\int_0^{p_R} \frac{p'}{\mu Z}\,dp'$$

$\left(\frac{\rho}{\mu}\right)$

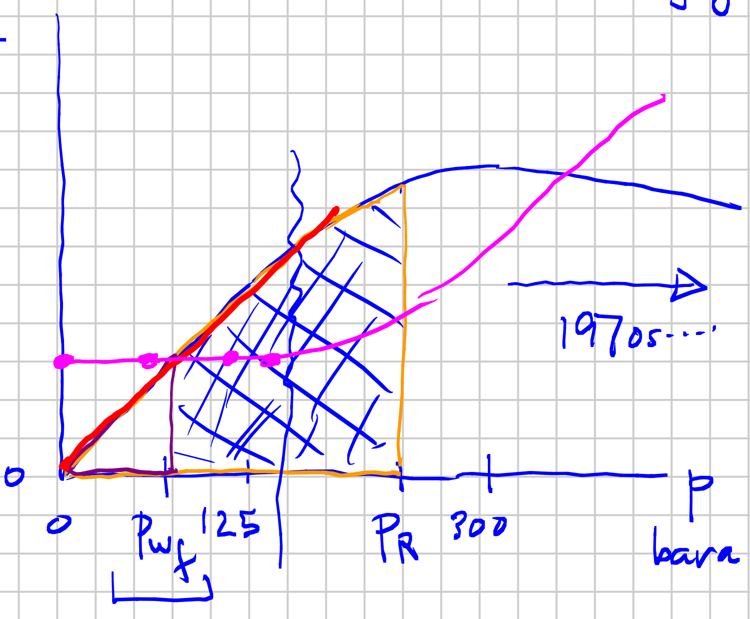
$-$

$$p_{pwf} = 2\cdot\int_0^{p_{wf}} \underline{\frac{p}{\mu Z}}\,dp$$

$2\frac{p}{\mu Z}$

$\frac{1}{\mu Z}$

Given Gas (γ_g, y_i)



WE Control

$p_{pR} - p_{pwf}$ = Driving Potential for Darcy

History Lesson[1966]: Al-Hussainy Ramey & Crawford

<1960s+ $\underline{p_{Ri} \le 150 \text{ bara}}$

$\frac{p}{\mu Z} = m\cdot p$ straight line

$\boxed{p_p} = 2\int_0^p \frac{p}{\mu Z}$

m(p): OLD SPE

Low-Pressure Gas Rate Equation

$$q_g = \frac{(kh)\cdot 2\cdot(P_R^2 - P_{wf}^2)}{\underbrace{T_R\,(\mu Z)^*}_{\text{const}}\left[\ln\frac{r_e}{r_w} - \frac{3}{4}\right]}$$

* At P_R & T_R or P_{sc}

$$q_g = C\,(P_R^2 - P_{wf}^2)$$

MJF : $\int \frac{1}{\mu_g B_g}\,dp = \underbrace{\frac{T_{sc}}{P_{sc} T_R}}\int \frac{p}{\mu Z}$

ARC : $2\int \frac{p}{\mu Z}\,dp$

$$B_g = \frac{P_{sc}}{T_{sc}}\cdot\frac{Z T_R}{p} \qquad \frac{1}{B_g} = \frac{T_{sc}}{T_R P_{sc}}\,\frac{p}{Z}$$

Field Units:

q_g	scf/D
k	md
h	ft
p	psia
T	°R
μ	cp

$$q_g = \frac{0.703\,kh\,(P_R^2 - P_{wf}^2)}{T_R\,(\mu Z)^*\left[\ln\frac{r_e}{r_w} - 3/4\right]}$$

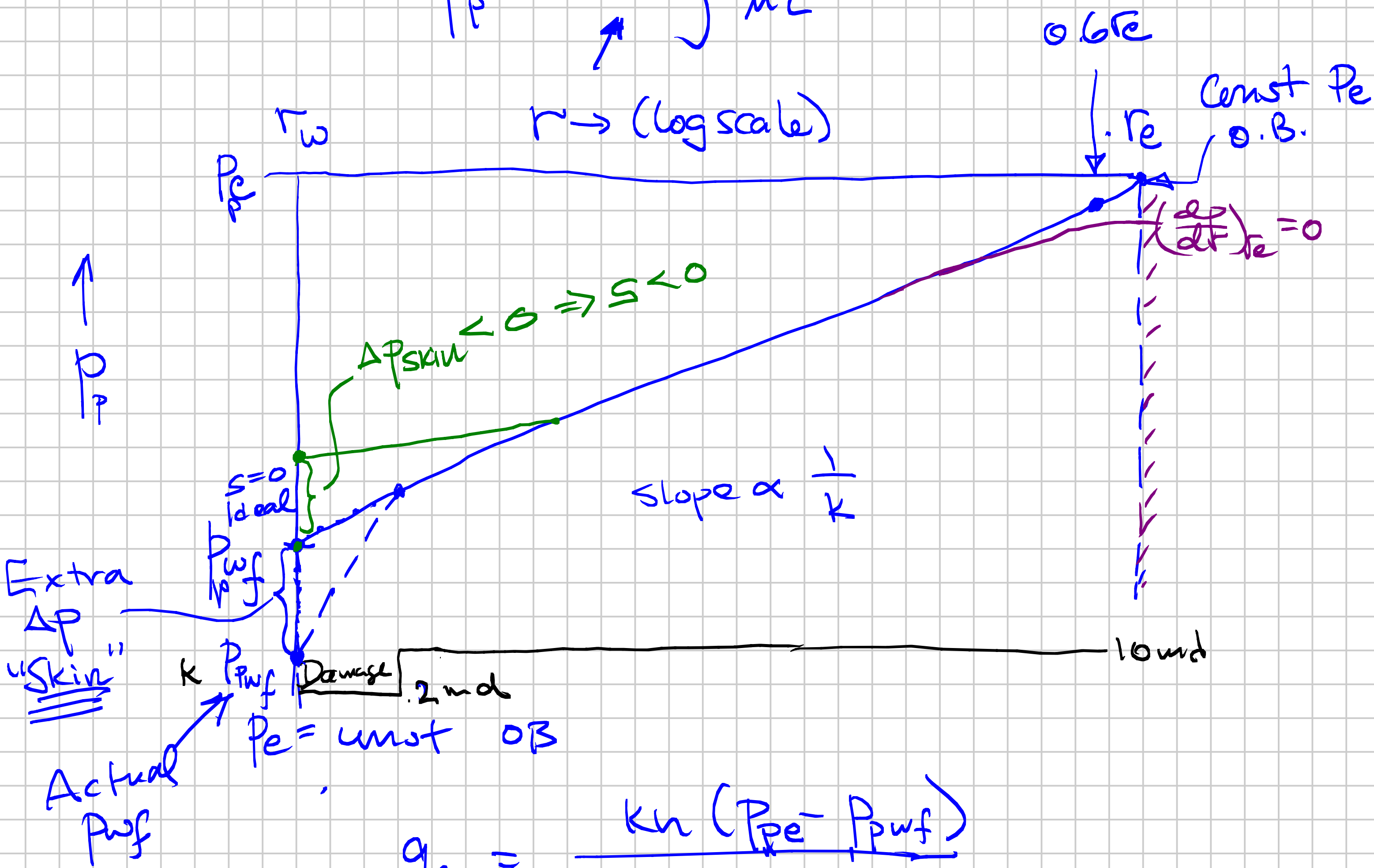
Assuming Steady State Flow : q_{mass} = const @ all r

$$q_g = \frac{0.703\, kh\,(p_{pR} - p_{pwf})}{T_R\left[\ln\frac{r_e}{r_w} - \frac{3}{4}\right]}$$

No-Flow O.B.

because "p_{pR}"

$$p_p = 2 \cdot \int \frac{p}{\mu Z}\, dp$$



$$q_g = \frac{kh\,(p_{pe} - p_{pwf})}{T_R\left[\ln\frac{r_e}{r_w}\right]}$$

$$q_g = \frac{kh\,(p_{pR} - p_{wf})}{T_R\left[\ln\frac{r_e}{r_w} - 0.60\right]}$$

Physically Δp_{skin} damage $r_d \rightarrow r_w$

Rate Equation, Δp_{skin} occurs AT r_w

$$q_g = \frac{0.703\, kh \left(p_{pR} - p_{pwf}\right)}{T_R \left[\underbrace{\left(\ln \frac{r_e}{r_w} - \frac{3}{4}\right)}_{\sim 8} + s\right]}$$

Dimensionless Quantity "Skin"

(Assume Pseudopressure p_p)

$$s = \Delta p_{p\,skin} \cdot \left(\frac{0.703\, kh}{q_g T_R}\right)$$

$$\Delta p_{p\,skin} = \underbrace{p_{p\,wf}}_{\text{Ideal } (s=0)} - p_{p\,wf,\,actual}$$

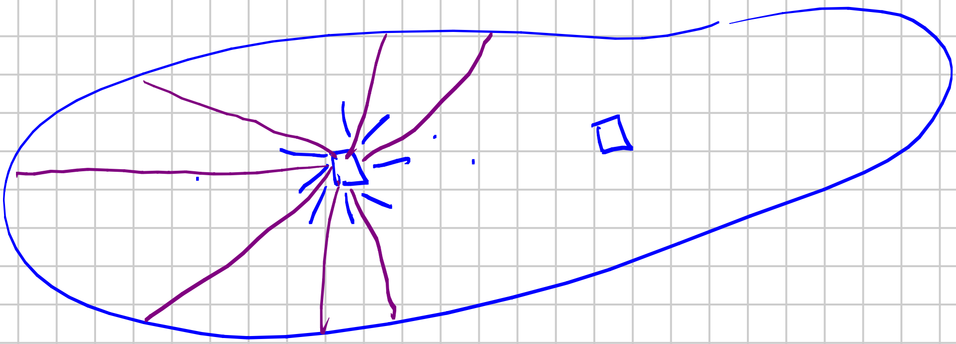
Magnitude of (Driller's) Damage Skin

$$s \sim 0 \rightarrow 5 \rightarrow 10 \rightarrow 50^{+}$$

Skin Effects:

- (Driller's) Damage $s > 0$ $\rightarrow 10-100$
- (Completion) Damage $s > 0$
- Flow Geometry Damage $1 - 10$ $\sim 1-2-3$

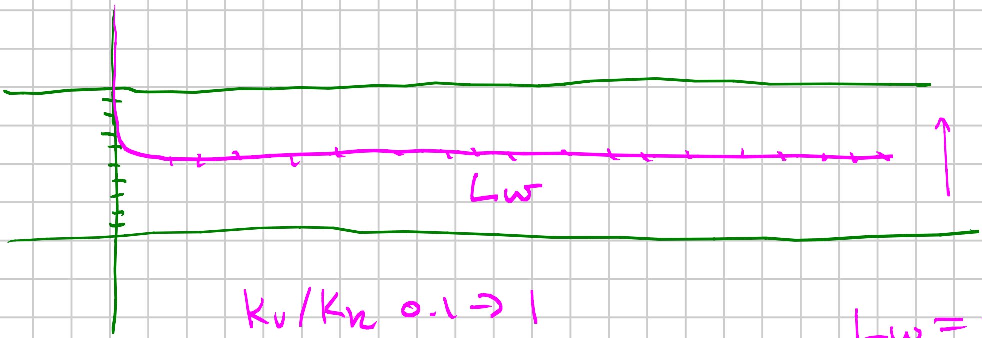
  ⋮



- Stimulation Skin $\sim -1 \rightarrow -5$
- Stimulation Flow Geometry Skin

$$10^6\ Sm^3/d = \frac{1}{8 + \underset{\uparrow\ 0}{S}} \cdot C \cdot \frac{1}{8}$$

$$2 \cdot 10^6\ Sm^3/d = C \cdot \frac{1}{8-4} = \frac{C}{4}$$



k_v/k_h 0.1 → 1

S_{HZ} $\overbrace{-5 \rightarrow -8}$

$S_{HZ} = f(L_w, k_v/k_h)$

$L_w = 1000$ m