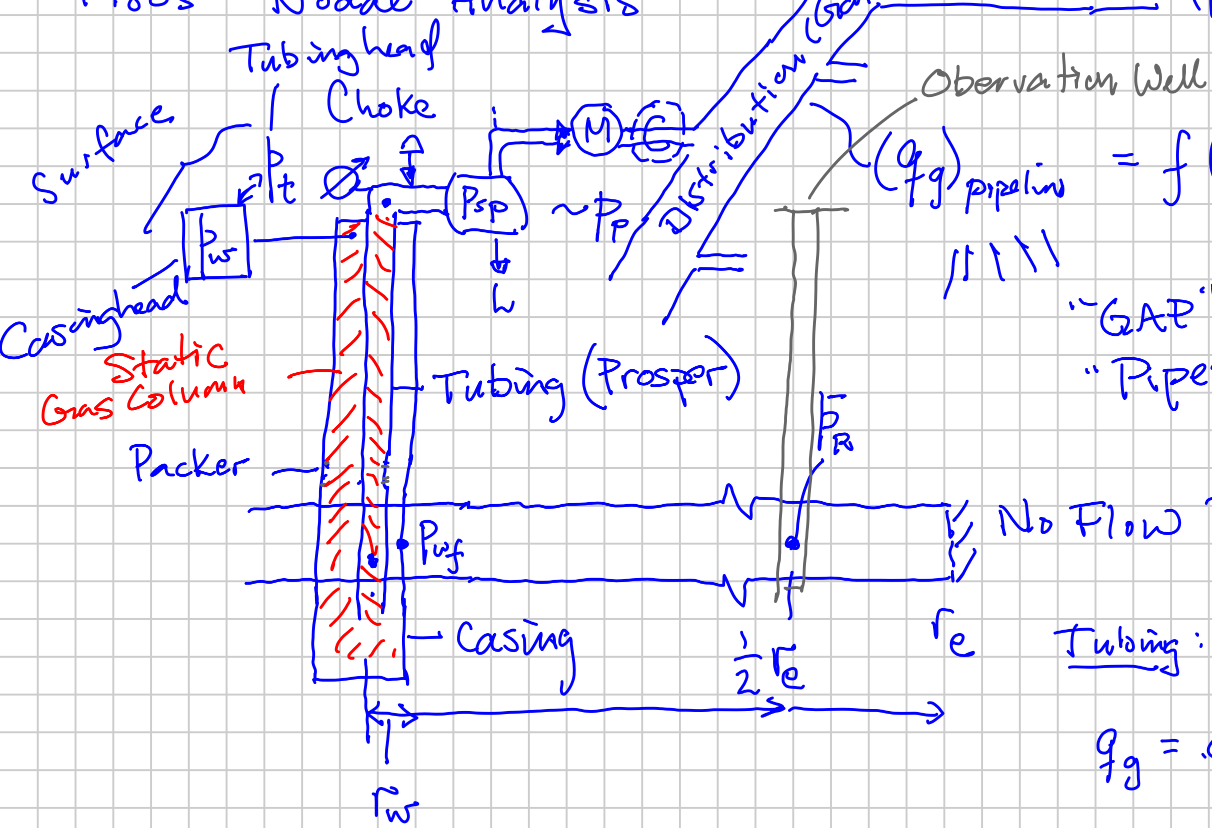
Note Title 4/7/2016

1980s "Nodal Analysis"



(P_{pexit}) (q_g) Gather Line

$$(q_g)_{pipeline} = f(\Delta p)_{line}$$

"GAP" (Petex)

"Pipesim" (SLB)

Tubing: @Surface

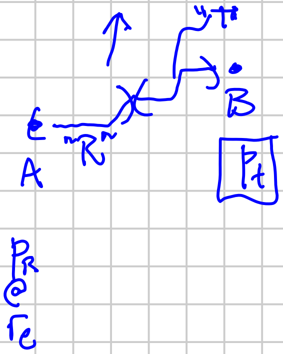
$$q_g = C_T \left(p'^2_{wf} - p_t^2\right)^{0.5}$$

Pressures at different points (NODE) in the system

- Some measured
- Some not

} All have flow equations

$$\boxed{q_g} = f(\Delta p)$$



Pipeflow of Gas

① ~ Primarily friction dominated

② ~ "Lower" pressures : PVT simplified : $\mu_g \sim$ const.

$\rho_g \sim \frac{pM}{RTZ}$

Turbulent

$$\boxed{q_g = C\left(p_{in}^2 - p_{out}^2\right)^{0.5}}$$

p_{in} & p_{out} at the Same Vertical Datum

$$\Delta p^2 = \frac{1}{C^2} \cdot q_g^2$$

Sm^3/d

MM scf/D

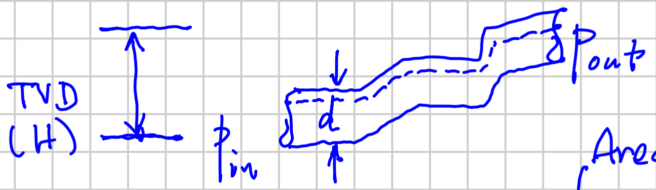
kg/s

lbmol/d

Surface Vol. Rate

Mass Rate

Molar Rate



$p_{out} \Rightarrow p'_{out} = p_{out} \cdot$ const

$\tilde{d}$

Area ⊥ to flow

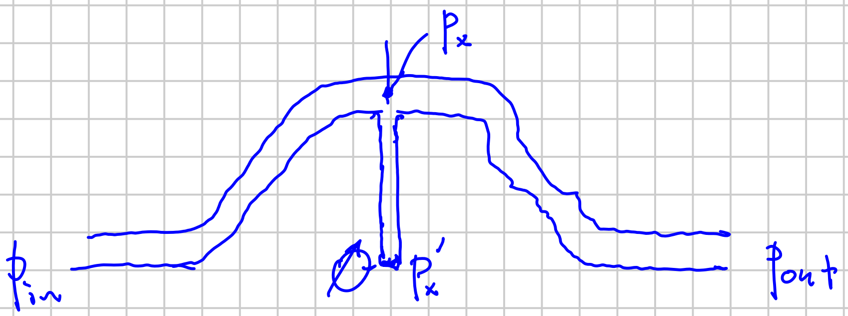
$$d = \sqrt{A \cdot \frac{4}{\pi}}$$

$$C = f\left(d^{2.6}, L_f, \epsilon, \gamma_g\right)$$

d: Inner flow diameter; L_f: flow path length; ϵ: pipe roughness

* What about Vertical elevation differences between "in" & "out"

- Simplest and usually accurate correction is to convert <u>all</u> pressures used in the pipeflow equation (p_{in} & p_{out}) to a common reference vertical "position" (depth) — Fetkovich Ref. = Surface



$p_x : p'_x$

?

$$\Delta p^2 = p_{in}^2 - p_x^2 \neq \frac{1}{C_L^2} \cdot q_g^2$$

$$\frac{1}{C_R^2} q_g^2 \neq p_x^2 - p_{out}^2$$

$$\Delta p^2 = \underbrace{p_{in}^2 - p_{out}^2}_{} = \frac{1}{C^2} q_g^2$$

$$= \underbrace{\frac{1}{C_L^2} q_g^2}_{p_{in}^2 - p_x'^2} + \underbrace{\frac{1}{C_R^2} q_g^2}_{p_x'^2 - p_{out}^2}$$

$$p_{wf}' = p_w$$

Surface-converted version of p_{wf}

"in"

Tubing Rate Eq.

$$\boxed{q_g = C_T \left(p_w^2 - p_t^2\right)^{0.5}}$$

a constant

"p_{wf}'"

Convert pressures along a $\overset{\text{static}}{\text{vertical}}$ gas column?

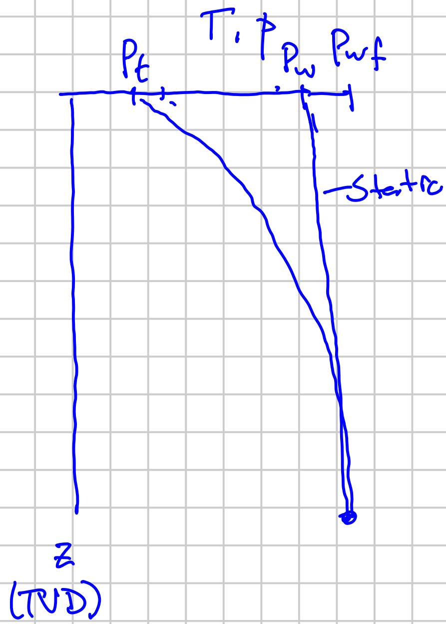
$z \uparrow$

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

$$\rho_g = \frac{p M_g}{R T Z(p,T,M_g)} \sim \left(\frac{M_g}{R \bar{T} \bar{Z}}\right) \cdot p$$

constant

$$\bar{T} = \int_{Top}^{Bot} T(z)\, dz$$



$$\int_{p_{wf}}^{p_w} \frac{1}{p}\,dp = \underbrace{\left(\frac{M_g}{R\bar{T}\bar{Z}}\right)}_{>0} g \int_H^0 dz$$

$$\ln \frac{p_w}{p_{wf}} = \left(\quad \right)(0-H) = -\frac{M_g\, g}{R\bar{T}\bar{Z}} H$$

$$p_w = p_{wf} \cdot e^{-\frac{M_g\, g H}{R\bar{T}\bar{Z}}}$$

$$p_w^2 = p_{wf}^2 \cdot e^{-\left(2 \cdot \overbrace{\frac{M_g\, g H}{R\bar{T}\bar{Z}}}^{\text{Constant "S"}}\right)}$$

$$S = \frac{\gamma_g \cdot M_{air} \cdot H}{R\ \bar{T}\bar{Z}} = \underset{\uparrow}{(\text{number})}\ \underset{\uparrow}{\underbrace{\left(\frac{\gamma_g\, H}{\bar{T}\bar{Z}}\right)}}$$

Same all wells everywhere

Different all wells around the world

$$S = 0.0375\ \overset{\gamma_g}{G}H/(T_a\ Z_a)$$

Combining Reservoir & Tubing Rate Eqs

$\Rightarrow$ "Wellhead Gas Rate Eq"

$$q_g = f\left(\underbrace{p_R^2 - p_t^2}\right)$$

$$\underbrace{R\left(r_e \rightarrow 0.47 r_e \rightarrow r_w^{+} \rightarrow r_w\right)}_{A \,\&\, B \;\big|\; (C \,\&\, n)} \rightarrow \underbrace{T\left(\text{bottom} \rightarrow \text{top}\right)}_{C_T}$$

This analysis assume $\underbrace{R}$ ~ p^2

$p_R^2 - p_t^2$

Different Vertical Datum

Measured : SSIP in the well itself

p_R' @ surface datum $\equiv$ "p_c"

Obervation SI well

p_{wf}' — " — $\equiv$ "p_w"

$$p_R = p_c \cdot e^{S/2} \qquad p_R^2 = p_c^2 \cdot e^{S}$$

$$p_{wf} = p_w \cdot e^{S/2} \qquad p_{wf}^2 = p_w^2\, e^{S}$$

$(p_c^2 - p_w^2)$ = Total Reservoir Pressure Drop

$(p_w^2 - p_t^2)$ = Total Friction Drop in Tubing

$$(p_c^2 - p_t^2) = \underset{R}{(p_c^2 - p_w^2)} + \underset{T}{(p_w^2 - p_t^2)}$$

= Total Well Pressure Drop

RESERVOIR

$$e^{-S}(p_R^2 - p_{wf}^2) = (B q_g^2 + A q_g) e^{-S}$$ Forchheimer Eq.

$$\underbrace{e^{-S} p_R^2}_{p_c^2} - \underbrace{e^{-S} p_{wf}^2}_{p_w^2} = B e^{-S} q_g^2 + A e^{-S} q_g$$

$$p_c^2 - p_w^2 = B' q_g^2 + A' q_g$$

$$B' = \underset{\uparrow \atop D \text{ or } \beta}{B} \cdot e^{-S} \qquad A' = \underset{\uparrow \atop kh,\ S,\ \ln r_e/r_w \ldots}{A} \cdot e^{-S}$$

$$\boxed{\begin{aligned} (p_c^2 - p_w^2) &= B' q_g^2 + A' q_g \\ (p_w^2 - p_t^2) &= \frac{1}{C_T^2} q_g^2 \end{aligned}}$$

C_T ← $d, L, \epsilon, \ldots$

Useful to do this graphically

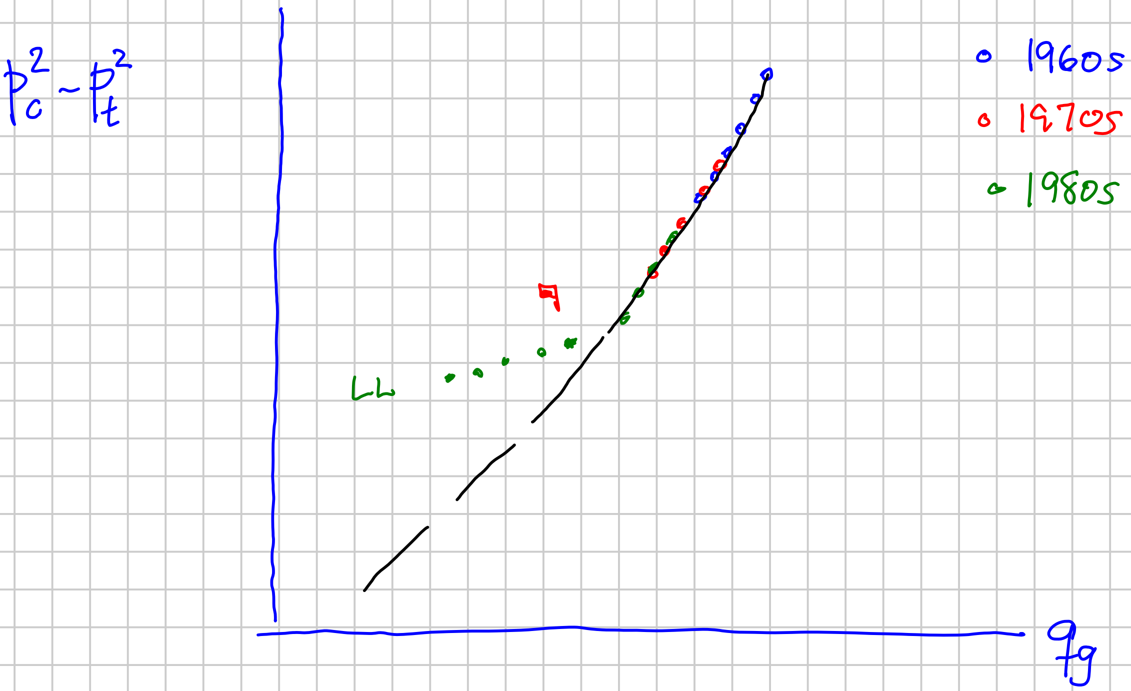
$\log \Delta p^2$ vs $\log q_g$

$$\boxed{(p_c^2 - p_t^2) = B_{wr} q_g^2 + A' q_g}$$

Should never change!

$$\boxed{B_{WH}} = \underbrace{B'}_{R} + \underbrace{\frac{1}{C_T^2}}_{T} = \underbrace{B \cdot e^{-S}}_{R} + \underbrace{\frac{1}{C_T^2}}_{T}$$

$$\left.\begin{matrix} A,\ B,\ C_T \\ (A',\ B',\ C_T) \end{matrix}\right\}$$ Should NEVER Change

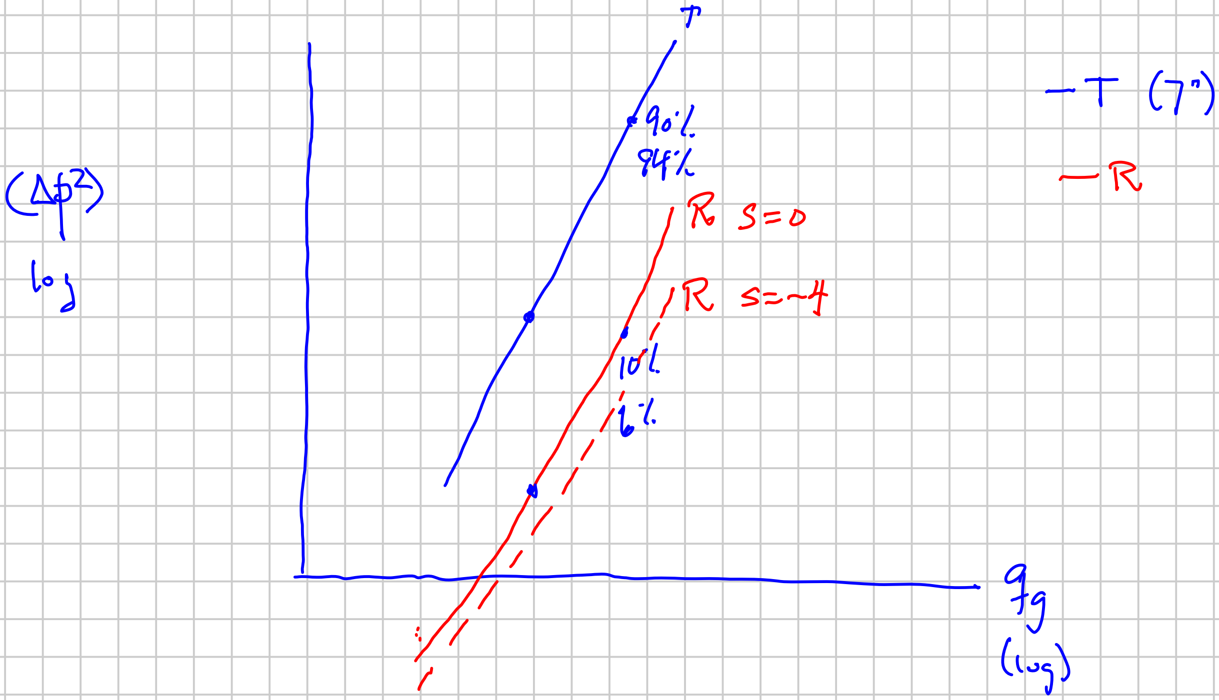


$(p_w^2 - p_t^2)$

% of total $(p_c - p_t)$ in the tubing ⇒ You control through d_T!

% of total $(p_c - p_t)$ in the Reservoir ⇒ You may control (Sure)

$(p_c^2 - p_w^2)$ Skin ↓



(Δφ²)
log
T
90%
94%
R s=0
R s=-4
10%
6%
q_fg
(log)
— T (7°)
— R