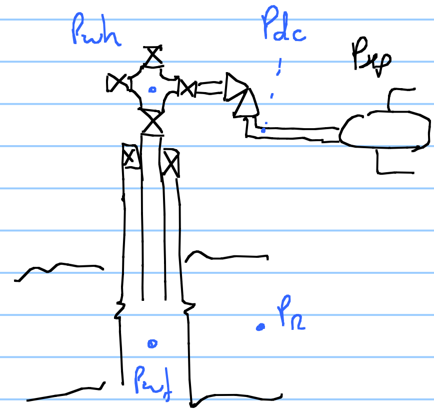
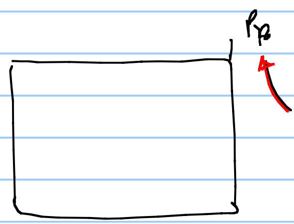
Notes for Youtube video nr. 6

Simplified dry gas production system



Reservoir model



Dry gas material balance

$$P_R = P_{Ri} \frac{z_R}{z_i} \Big(1 - \underbrace{\frac{G_p}{G}}_{R_F} \Big)$$

$f(q_g)$ $q_g = f(t)$

uncertain value

R_F recovery factor

gas deviation factor

$z \; f(P_r, T_r)$ $\frac{T_R}{T_c}$

$\frac{P_R}{P_c} \rightsquigarrow f(\text{gas composition})$

MB dry gas equation is implicit

- Given RF, assume P_R
- with P_R compute z_R
- verify that $\varepsilon = P_R - P_{Ri} \frac{z_R}{z_i} \left(1 - R_F \right) = 0 \leq$ Tolerance
- if not,

3.3.2 Z-Factor Correlations. Standing and Katz[4] present a generalized Z-factor chart (**Fig. 3.6**), which has become an industry standard for predicting the volumetric behavior of natural gases. Many empirical equations and EOS's have been fit to the original Standing-Katz chart. For example, Hall and Yarborough[21,22] present an accurate representation of the Standing-Katz chart using a Carnahan-Starling hard-sphere EOS,

$$Z = \alpha p_{pr}/y, \quad (3.42)$$

Equation approximation to Z chart

where $\alpha = 0.06125\, t \exp[-1.2(1-t)^2]$, where $t = 1/T_{pr}$.

The reduced-density parameter, y (the product of a van der Waals covolume and density), is obtained by solving

$$f(y) = 0 = -\alpha p_{pr} + \frac{y + y^2 + y^3 - y^4}{(1-y)^3}$$
$$- (14.76t - 9.76t^2 + 4.58t^3)y^2$$
$$+ (90.7t - 242.2t^2 + 42.4t^3)y^{2.18+2.82t}, \quad (3.43)$$

with
$$\frac{df(y)}{dy} = \frac{1 + 4y + 4y^2 - 4y^3 + y^4}{(1-y)^4}$$
$$- (29.52t - 19.52t^2 + 9.16t^3)y$$
$$+ (2.18 + 2.82t)(90.7t - 242.2t^2 + 42.4t^3)$$
$$\times y^{1.18+2.82t}. \quad (3.44)$$

The derivative $\partial Z/\partial p$ used in the definition of c_g is given by

$$\left(\frac{\partial Z}{\partial p}\right)_T = \frac{\alpha}{p_{pc}}\left[\frac{1}{y} - \frac{\alpha p_{pr}/y^2}{df(y)/dy}\right] \quad (3.45)$$

to predict T_c, P_c we will use Sutton correlations

Sutton[7] suggests the following correlations for hydrocarbon gas mixtures.

$$T_{pcHC} = 169.2 + 349.5\gamma_{gHC} - 74.0\gamma_{gHC}^2 \quad (3.47a)$$

and
$$p_{pcHC} = 756.8 - 131\gamma_{gHC} - 3.6\gamma_{gHC}^2. \quad (3.47b)$$

$$\gamma_g = \frac{Mw_{gas}}{Mw_{air}\,(28.97)}$$

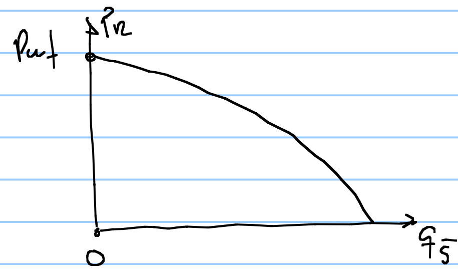
$$Mw_{gas} = \sum_{i=1}^{N} z_i Mw_i$$

$P_R \rightarrow P_{wf}$ IPR equation low pressure dry gas equation

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

← backpressure exponent
laminar $n \sim 1$
turbulent $n \to 0.5$

inflow coefficient $\{T_R, k, h, s$ (skin factor)



- pseudo-steady state regime (boundary dominated flow) page 37 of compendium

- $P_{wf} \rightarrow P_{wh}$ Dry gas tubing equation

$$q_g = C_T \left(\frac{P_{wf}^2}{e^S} - P_{wh}^2 \right)^{0.5}$$

tubing coefficient (friction losses)

elevation coefficient (hydrostatic losses)

$q_g = 0 \quad P_{wf} = P_{wh} \, e^{S/2}$

Page 156, Appendix A of compendium

$$q_{sc} = \left(\frac{\pi}{4}\right) \cdot \left(\frac{R}{M_{air}}\right)^{0.5} \cdot \left(\frac{T_{sc}}{p_{sc}}\right) \cdot \left(\frac{D^5}{f_M \cdot L \cdot \gamma_g \cdot Z_{av} \cdot T_{av}}\right)^{0.5} \cdot \left[\left(p_{wf}^2 - p_t^2 \cdot e^S\right) \cdot \left(\frac{S}{e^S - 1}\right)\right]^{0.5}$$

$$C_T = \left(\frac{\pi}{4}\right) \cdot \left(\frac{R}{M_{air}}\right)^{0.5} \cdot \left(\frac{T_{sc}}{p_{sc}}\right) \cdot \left(\frac{D^5}{f_M \cdot L \cdot \gamma_g \cdot Z_{av} \cdot T_{av}}\right)^{0.5} \cdot \left(\frac{S \cdot e^S}{e^S - 1}\right)^{0.5}$$

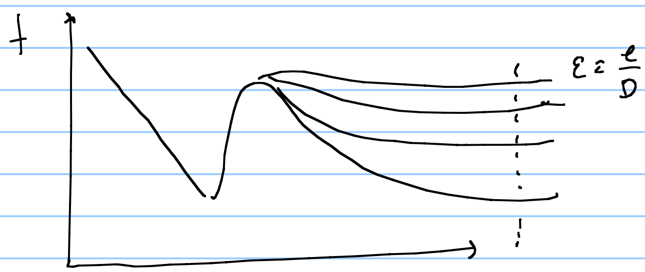
$$S = 2 \cdot L \cdot C_a = 2 \cdot \frac{M_g}{Z_{av} \cdot R \cdot T_{av}} \cdot L \cdot g \cdot \cos(\alpha)$$

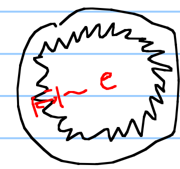
Comments about tubing equation

to compute C_T $\quad T_{av} \rightarrow \dfrac{T_{wf} + T_{wh}}{2}$ $\quad$ An estimate of T_{wh} is needed

$$Z_{av} \sim \frac{Z_{wf} + Z_{wh}}{2}$$

f_M friction factor





$$Re = \frac{v \rho D}{\mu}$$

μ_g is $<< \mu_L$

$Re_g >>$

always in fully turbulent regime

$v = f(q_{local})$

q_{local} $f(\rho)$

for gas $v \uparrow\uparrow$ $\quad \rho$ is low compared to liquid

liquid $v \sim [0.5 - 4]$ m/s

gas $v \sim [5 - 40]$ m/s

$f_M = f(\varepsilon)$ $\quad$ however $e = f(D)$ due to manufacturing

Lowe equation for dry gas: (page 166)

"opening" tuning factor

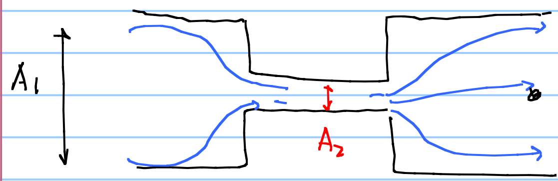
$$q_{\bar{g}} = \frac{p_1 \cdot T_{sc} \cdot A_2 \cdot C_d}{p_{sc}} \cdot \sqrt{2 \cdot \frac{R}{Z_1 \cdot T_1 \cdot M_w} \cdot \frac{k}{k-1} \cdot \left(y^{\frac{2}{k}} - y^{\frac{k+1}{k}}\right)}$$

$\frac{R_U}{MW_g}$ $k = \frac{c_p}{c_v}$

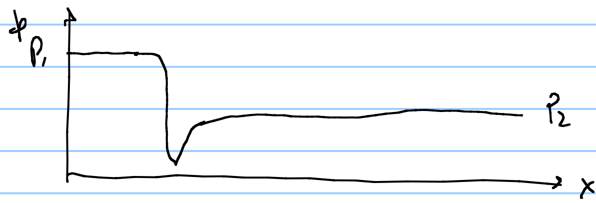
$p_{sc} = 1.01325$ bara

$T_{sc} = 15.56\,°C$

$y = \frac{P_2 \text{ (downstream)}}{P_1 \text{ (upstream)}}$



if $y > y_c \simeq (0.6)$, there is critical flow at the throat



if $y > y_c$ $q_{\bar{g}} = q_{\bar{g}_c} =$

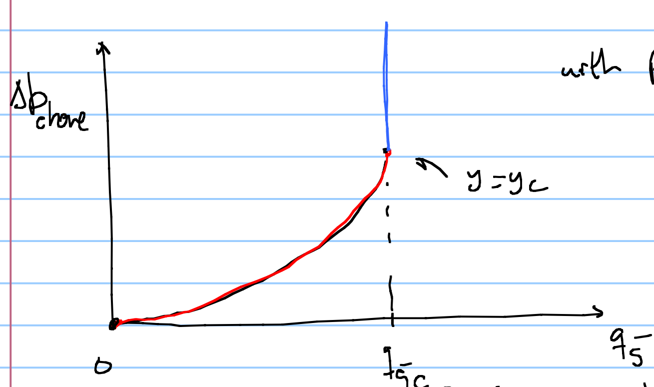
$$q_{\bar{g}} = \frac{p_1 \cdot T_{sc} \cdot A_2 \cdot C_d}{p_{sc}} \cdot \sqrt{2 \cdot \frac{R}{Z_1 \cdot T_1 \cdot M_w} \cdot \frac{k}{k-1} \cdot \left(y_c^{\frac{2}{k}} - y_c^{\frac{k+1}{k}}\right)}$$

in blue

if $y < y_c$

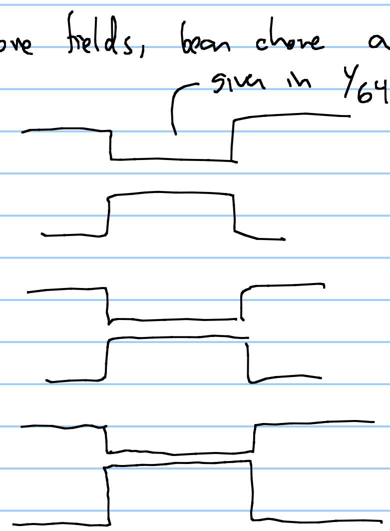
$$q_{\bar{g}} = \frac{p_1 \cdot T_{sc} \cdot A_2 \cdot C_d}{p_{sc}} \cdot \sqrt{2 \cdot \frac{R}{Z_1 \cdot T_1 \cdot M_w} \cdot \frac{k}{k-1} \cdot \left(y^{\frac{2}{k}} - y^{\frac{k+1}{k}}\right)}$$

in red



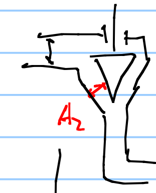
(flow is "choked", critical flow)

in onshore fields, bean choke are often used



offshore often adjustable chokes are used

needle choke



adjustable throat area

→ P_{sep} flowline → tubing equation can be used for flowline

horizontal flowline, the tubing equation simplifies to

$$q_{\bar{s}} = C_{FL}\left(P_{dc}^2 - P_{sep}^2\right)^{0.5}$$

$S=0$ (L'Hopital)

VBA   Visual basic for applications

for pipe equations in VBA   ① is upstream

② is downstream