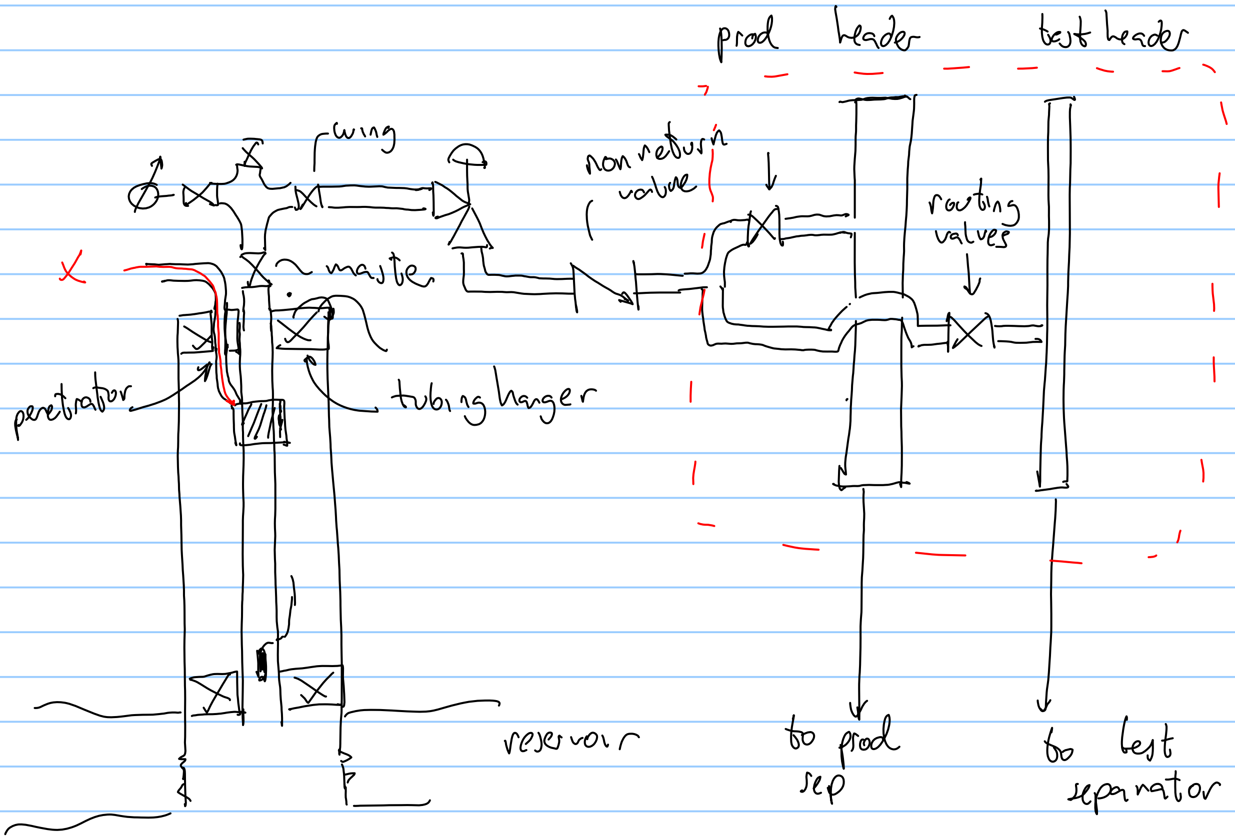
Day 2:

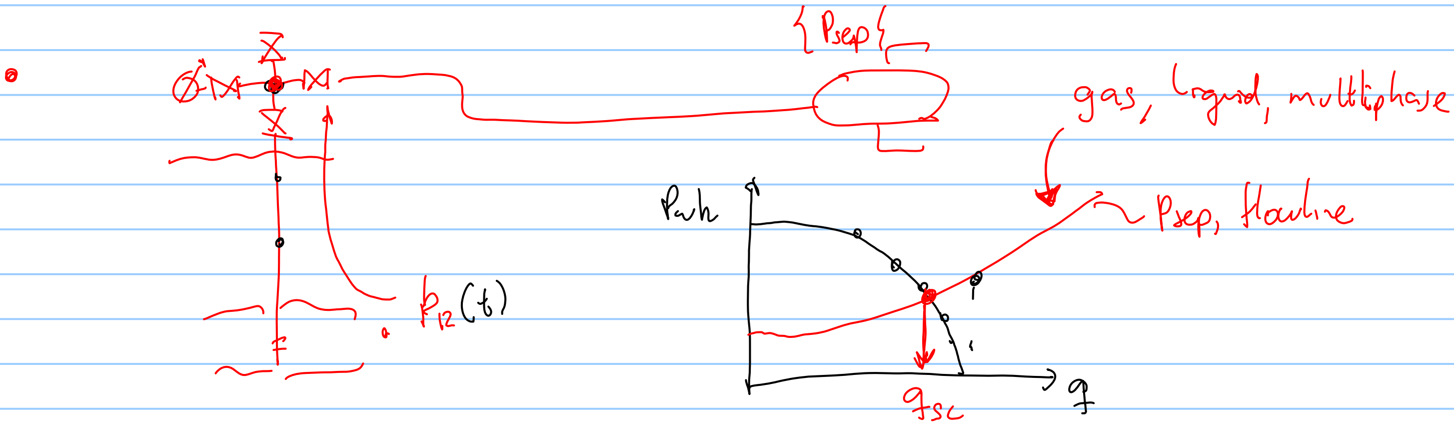


Christmas Tree Systems


Onshore tree

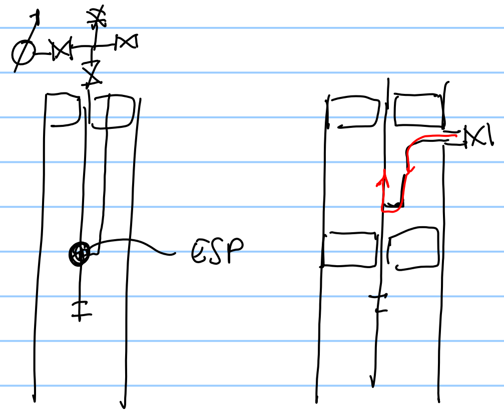

Offshore tree

Subsea tree



Selection of equilibrium point → bottom hole
- Design artificial lift
  - ESP
  - gas lift
- • Study IPR

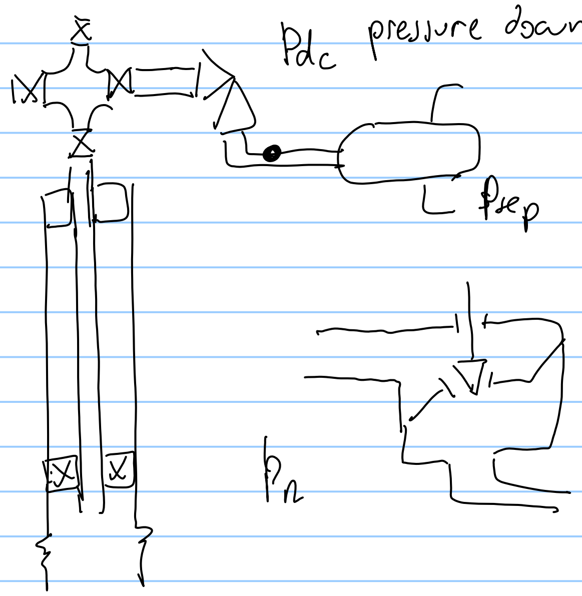
→ wellhead
- • choke design
- • well test

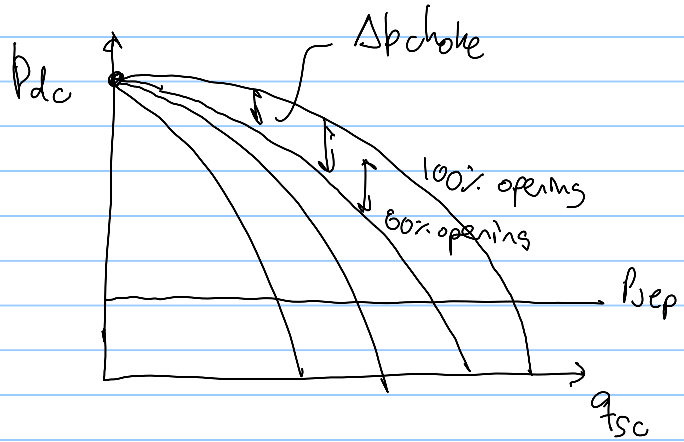


$\rho_o + \rho_g$

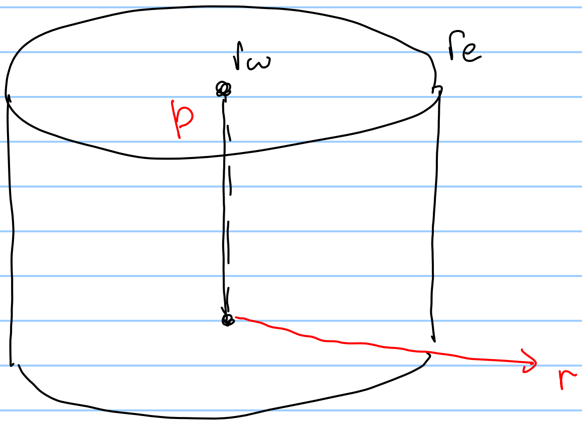
Δp

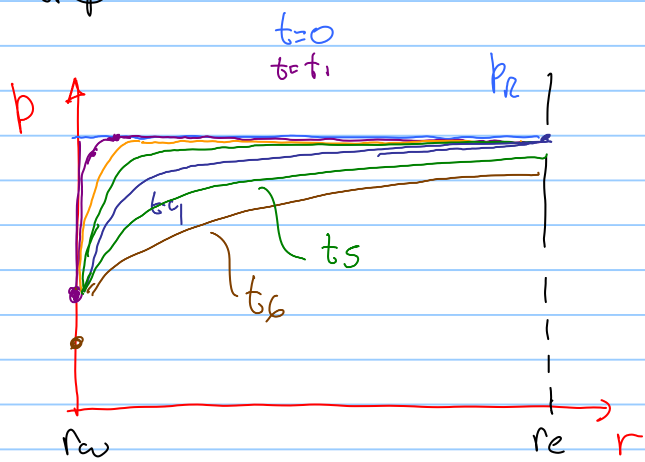
Flow equilibrium including the choke





• IPR Inflow performance relationship





$t_0 \rightarrow t_4$ transient, infinite acting

t_4 forward → pseudo steady state (PSS)

$t_0 \to t_4$ t_{pss} time to pseudo steady state

C_f, C_R, μ, K {

tight formation $\downarrow K \sim t_{pss}$ is in order of months years

normal formation $\uparrow K \sim t_{pss}$ hours days

if t_{pss} is short { then I use IPR for PSS } * for this course

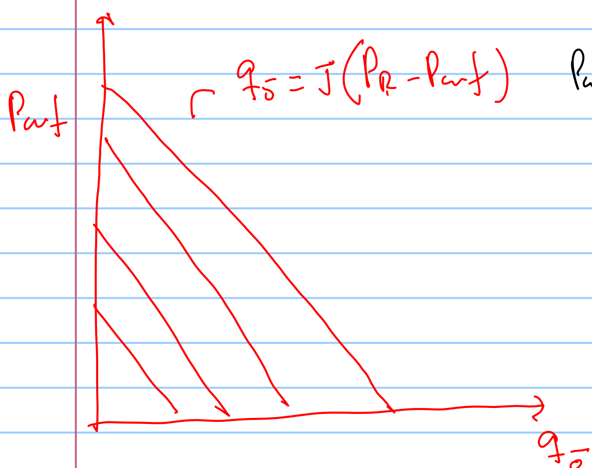
If t_{pss} is long { then use IPR for transient regime

$IPR = f(t)$

PSS IPRs

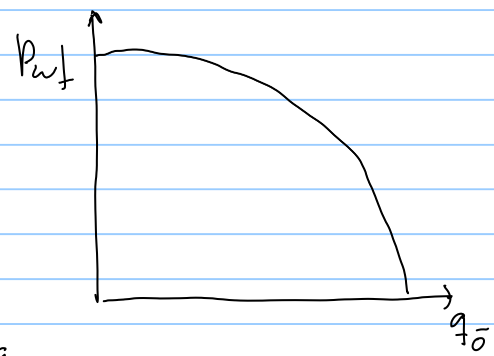
single phase oil

$q_o = J(P_R - P_{wf})$



GAS

Saturated oil (mixture oil + gas)



Vogel

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

$$\frac{q_o}{q_{o\,max}} = 1 - 0.2\frac{P_{wf}}{P_R} + 0.8\frac{P_{wf}^2}{P_R^2}$$

$0.5 \le n \le 1$

turbulent Darcy

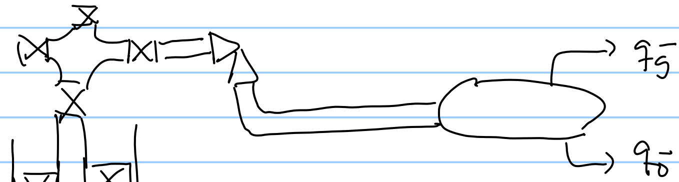
for low pressure $p \le 100$ bara

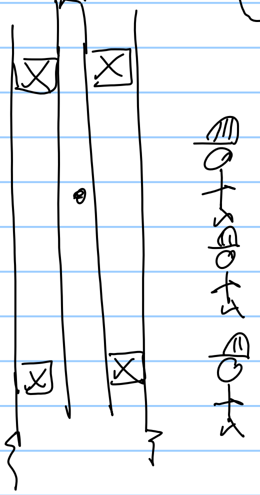
$$m(p) = 2\int_0^p \frac{p}{\mu z}\,dp$$

for medium → high pressure

$$q_g = C\left[m(P_R) - m(P_{wf})\right]^n$$

for the whole pressure range!





mechanical eng.

chemical eng.

petroleum eng.

kg/s mass flow $\quad n = \frac{m}{MW}$

kmol/s molar flow

Sm³/d standard conditions rate

scf/d

stb/d

Δp friction $\approx v$

v, q m³/d

• Case: dry gas

Ideal gas law $\underbrace{pV = nRT}$

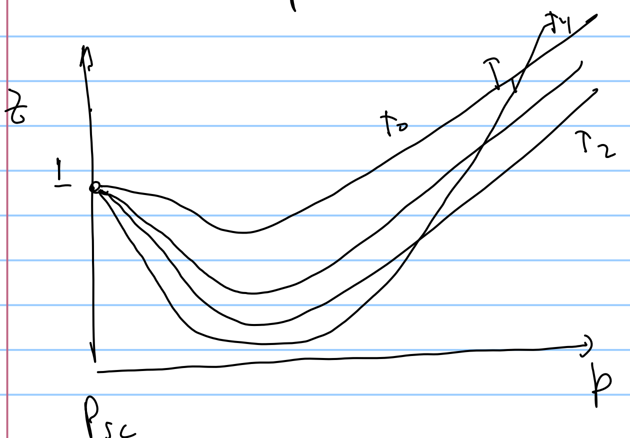
0.7 → 2

Boyle → Hooke

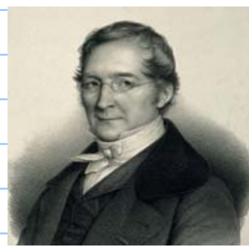
Charles

insert a correcting factor in the ideal gas eq.

$$pV = ZnRT$$ ✓



Gay Lussac

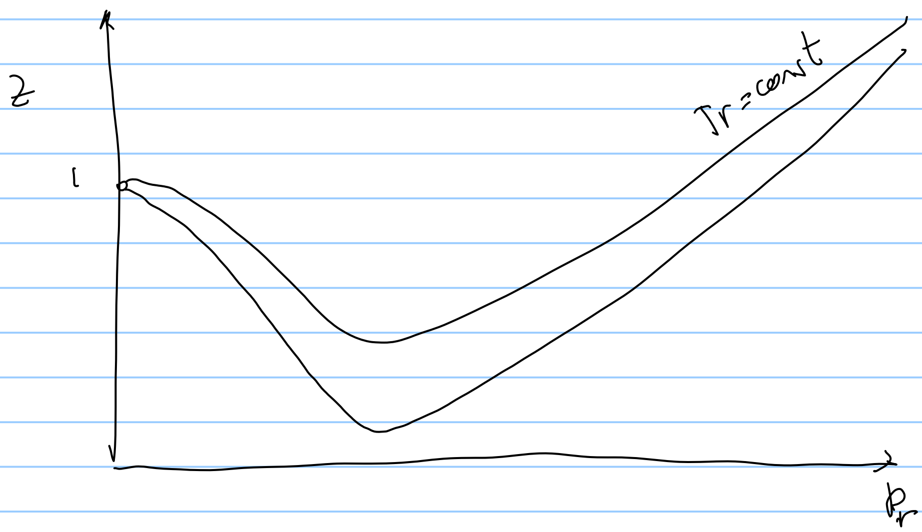


Avogadro

Van der Waals corresponding states principles

pseudo-reduced pressure $p_r = \frac{p}{p_c}$ — psia

pseudo reduced T $T_r = \frac{T}{T_c}$ use absolute units only ! K, °R !



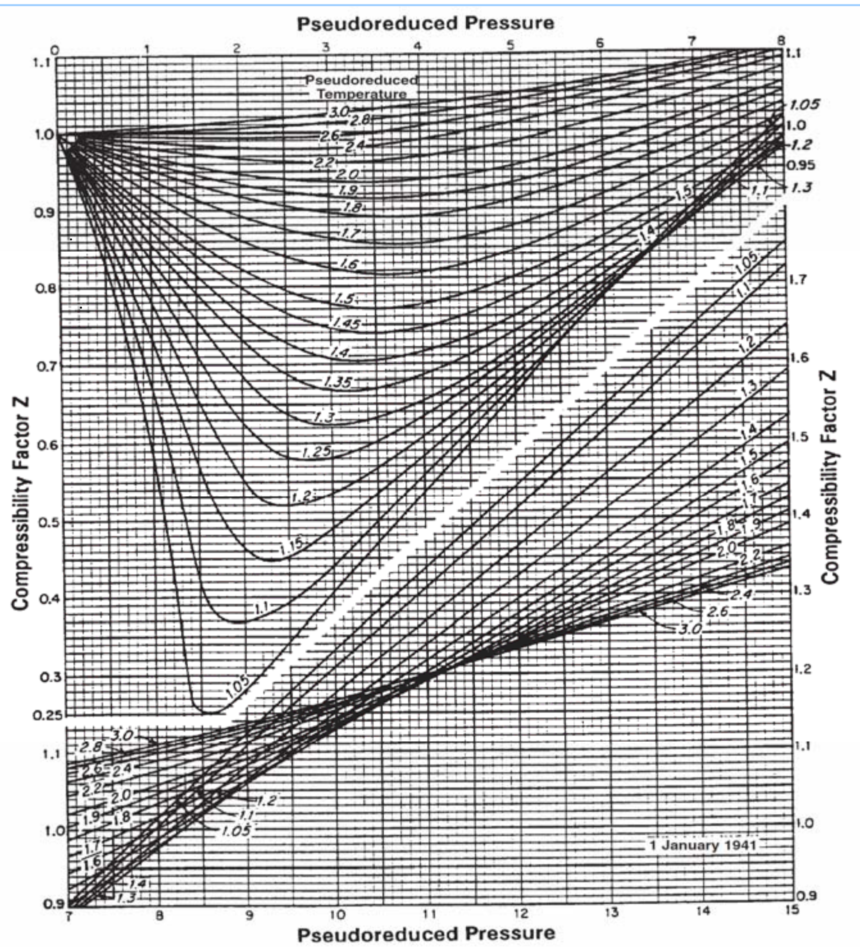


Fig. 3.6—Standing-Katz[4] Z-factor chart.

$p_r = 12$

$T_r = 1.4$

Production gas is usually a mixture of several gases (components)

			y_i ~ mole fraction
C_1	N_2	C_1	0.80
C_2	CO_2	C_2	0.10
C_3	H_2S	C_3	0.03
C_4			
C_5			
C_7+			

Σ 1

components

$$MW_{mix} = \sum_{i=1}^{N} y_i MW_i$$

Specific gravity of gas

$$\gamma_g = \frac{MW_{mix}}{MW_{air}} \quad MW_{air} \rightarrow 28.97$$

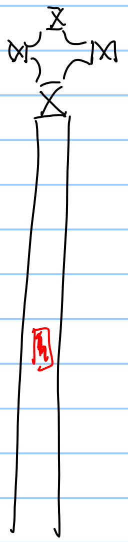
$$P_{c_{mix}} = \sum_{i=1}^{N} y_i P_{ci}$$

$$T_{c_{mix}} = \sum_{i=1}^{N} y_i T_{ci}$$

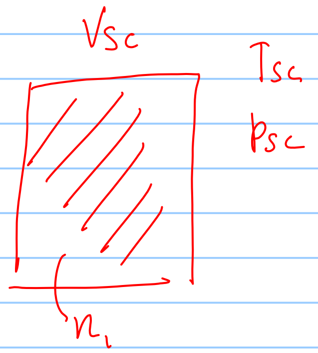
correlation Sutton

$$P_{c_{mix}} = f(\gamma_g)$$

$$T_{c_{mix}} = f(\gamma_g)$$



n_1, p_1, T_1



$$pV = nRTz \quad \text{in S.C} \quad z \simeq 1$$

$$P_{sc} V_{sc} = n R T_{sc}$$

$$R = 8314.3 \ \frac{J}{Kmol\,K}$$

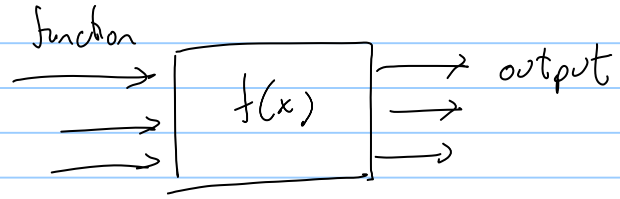
$$V_{sc} = n \cdot \frac{R T_{sc}}{P_{sc}}$$

$$V_{sc} = n \ 23.67 \ \frac{Sm^3}{Kmol}$$

$$\hookrightarrow n \cdot 379.7 \ \frac{Scf}{lb\,mol}$$

Excel VBA   access the VBA module $\boxed{alt} + \boxed{F11}$

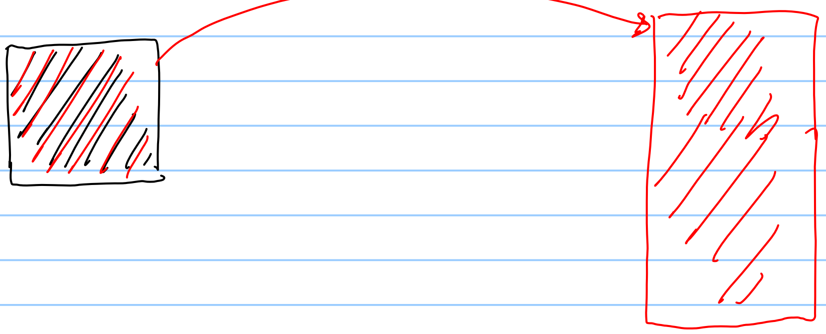
function



options → trust center → trust center options → macro settings
↳ enable all.

at any point in the production system

V @ p, T V_{sc} @ p_{sc}, T_{sc}



no liquid is condensed

gas volume factor $B_{g_d} = \dfrac{V @ p, T}{V_{sc}} = \dfrac{\dfrac{n z R T}{p}}{\dfrac{n\, 1 \cdot R\, T_{sc}}{p_{sc}}} = \dfrac{z\ T}{p}\left(\dfrac{p_{sc}}{T_{sc}}\right)$ ✓ (dry)

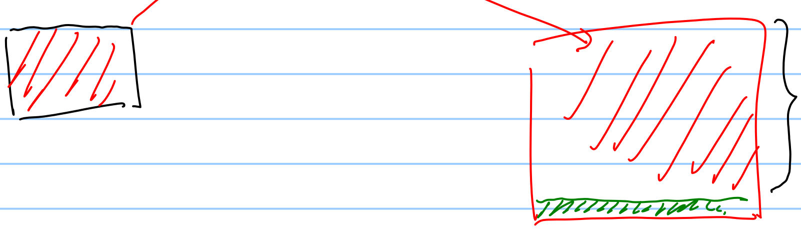
if $T = T_R$
$p = p_R$

gas formation volume factor

if I give you q_g @ sc
find $q_{g@p,T}$

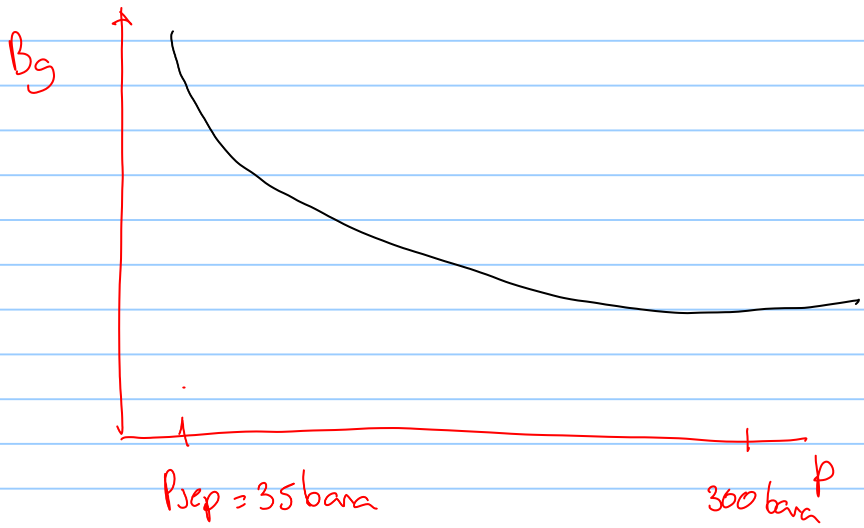
$$\underbrace{q_{g@p,T}} = \underbrace{B_{g@p,T} \cdot q_{sc}}$$

V, p, T



V_{sc}, p_{sc}, t_{sc}

B_{g_w} ← wet



$\gamma_g = 0.55$

$T = 80\,°C$

✱ homework 2:

plot B_g for

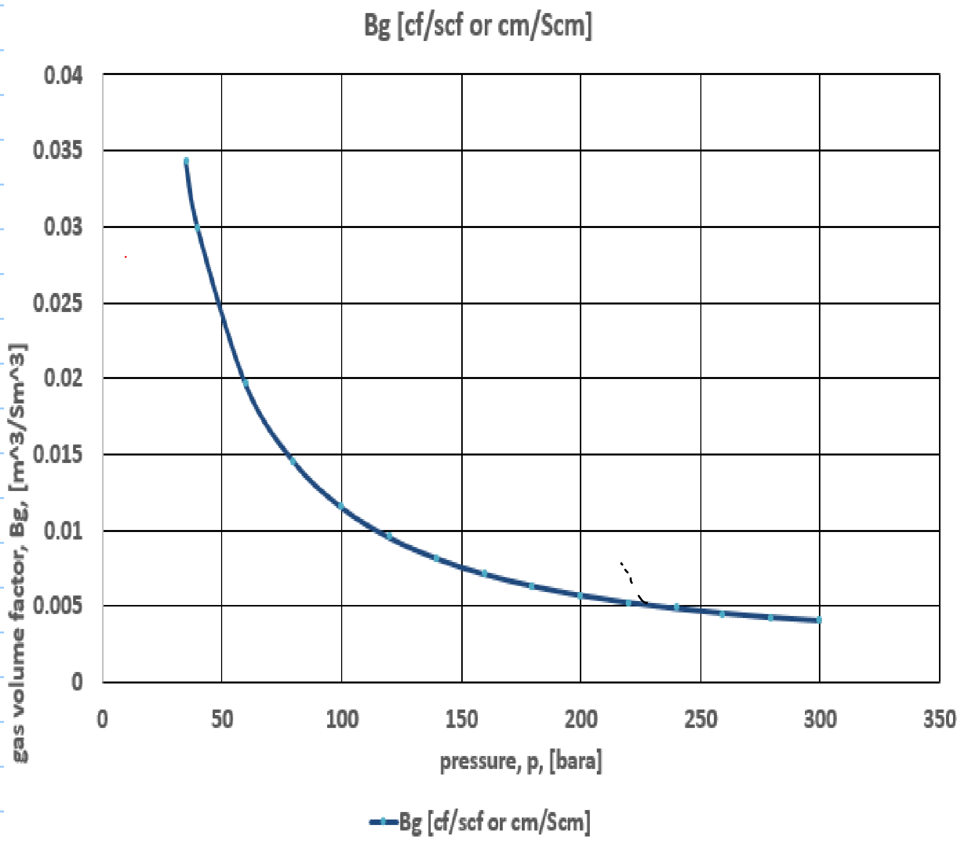
$T = 120\,°C$

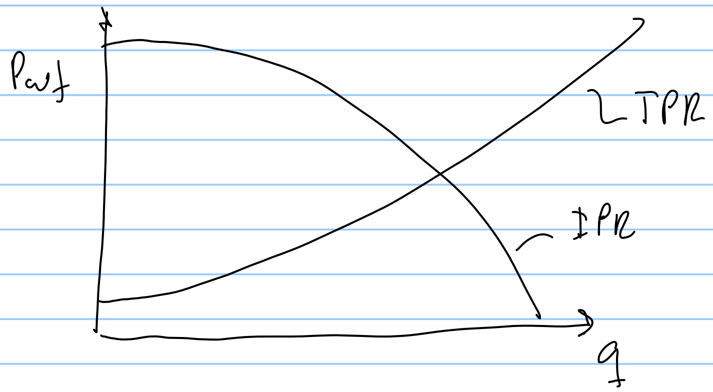
$T = 60\,°C$

$T = 80\,°C$

$p \in [35 \text{ bara} - 300 \text{ bara}]$

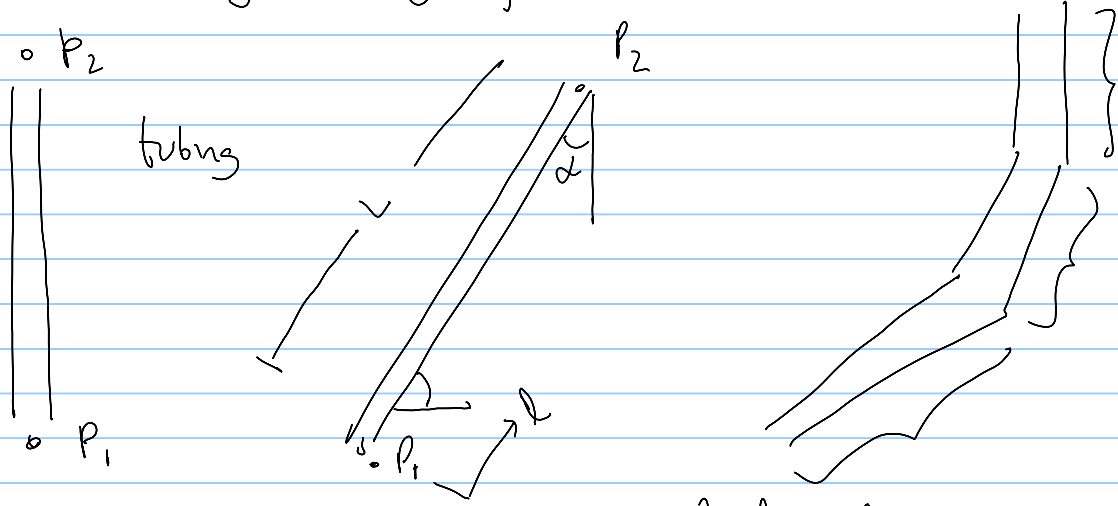
$\gamma_g = 0.55$





also applicable for

Development of Dry gas tubing equation ⇝ flowlines



divide and conquer

$$\frac{dp}{dl} = \underbrace{-\rho \cdot g \cos\alpha}_{\text{hidrostatic}} - f \rho \frac{u^2}{2\underset{\text{ID}}{\Phi}}$$

p changes along tubing

T " " "

$$\rho = f(p, T)$$

$$\rho = \frac{p\, Mw}{zRT}$$

$$\frac{dp}{dl} = -\left(\frac{p\, Mw}{zRT}\right) g \cdot \cos\alpha - f \frac{p\, Mw}{zRT} \frac{u^2}{2\Phi}$$

$$u = \frac{\dot{m}}{\rho \cdot A} \quad \frac{kg/s}{kg/m^3 \cdot m^2} = \frac{m}{s}$$

$$A = \pi \cdot \Phi^2 \cdot 0.25$$

$$u = \frac{\dot{m} \cdot zRT\, 4}{p\, Mw \cdot \pi \Phi^2}$$

$$\frac{dp}{dl} = -\frac{p\, Mw}{zRT} g \cos\alpha - f \frac{\cancel{p\, Mw}}{\cancel{zRT}\, 2\Phi} \frac{\overset{8}{\cancel{16}}\, \dot{m}^2 (zRT)^2}{p^{\cancel{2}} Mw^{\cancel{2}} \pi^2 \Phi^4}$$

$$\frac{dp}{dl} = -\frac{p\, Mw}{zRT} g \cos\alpha - f \frac{\dot{m}^2 zRT\, 8}{\Phi^5 \cdot \pi^2 p\, Mw}$$

Constant $B = \dfrac{M_w \cdot g \cos\alpha}{z R T}$

$$D = \frac{f\, z^{?} R T^{?}\, 8\, \dot{m}^2}{\Phi^5 \pi^2 M_w}$$

$$\frac{dp}{dl} = -B \cdot p - \frac{D}{p} \qquad - \frac{dp}{Bp + \frac{D}{p}} = dl$$

B and D are constant and equal to

$$B = \frac{M_w\, g \cos\alpha}{\bar{z} R \bar{T}}$$

$$\bar{z} = f(\bar{p}, \bar{T}) \qquad \bar{T} = \frac{T_1 + T_2}{2}$$

$$D = \frac{\bar{f}\, \bar{z} R \bar{T}\, 8\, \dot{m}^2}{\Phi^5 \pi^2 M_w}$$

$$\underbrace{\int_1^2 \frac{dp}{Bp + \frac{D}{p}}} = \int_1^2 -dl$$

$$= -L$$

$$\int_1^2 \frac{p\, dp}{Bp^2 + D}$$

change variable $U = Bp^2 + D$

$dU = 2pB\, dp$

$$\frac{1}{2B} \int_1^2 \frac{dU}{U} = \frac{1}{2B} \ln\left(\frac{U_2}{U_1}\right)$$

return the variable change

$$\frac{1}{2B} \ln\left(\frac{B p_2^2 + D}{B p_1^2 + D}\right) = -L$$

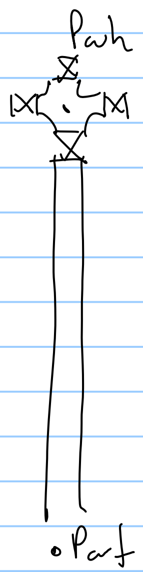
$$\frac{B p_2^2 + D}{B p_1^2 + D} = e^{-L\,2\,B}$$

elevation factor

$$S = 2LB$$

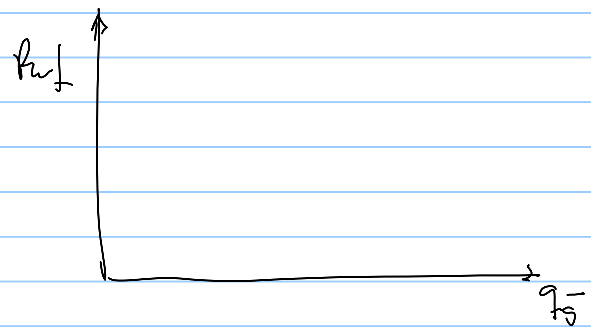
$$\frac{B p_2^2 + D}{B p_1^2 + D} = e^{-S}$$

$$p_1^2 = p_2^2 e^S + \left(\frac{B}{D}\right) e^S - 1$$



$$p_2 = P_{wh}$$

$$p_1 = P_{wf}$$



$$\frac{B}{D} = \frac{\dot{m}^2\, \bar{Z} R \bar{T} \;\; 8 \cdot f \;\; \bar{Z} R \bar{T}}{M_w\, \pi^2 \phi^5 \;\; M_w\, g \cos\alpha}$$

$$\dot{m} = \rho_{sc} \cdot q_{sc}$$

$$\frac{kg}{\cancel{m^3}} \cdot \frac{\cancel{m^3}}{d}$$

$$\frac{B}{D} = \frac{q_{sc}^2 (\bar{Z} R \bar{T})^2\, 8 \cdot f}{\pi^2 \phi^5 \cos\alpha\, R^2 g} \left(\frac{p_{sc}}{T_{sc}}\right)^2$$

$$\rho_{sc} = \frac{p_{sc} \cdot M_w}{\cancel{Z} R\, T_{sc}}$$

1

$$p_1^2 = p_2^2 e^S + q_{sc}^2 \underbrace{\left(\text{constant} \right)}_{\frac{1}{C_T^2}}$$

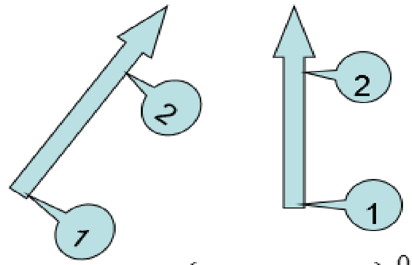
$$p_1^2 = p_2^2 e^S + \frac{q_{sc}^2}{C_T^2}$$

Tubing flow Equation-Dry gas

$$\boxed{q_{sc}=\left(\frac{\pi}{4}\right)\left(\frac{R}{M_{air}}\right)^{0.5}\left(\frac{T_{SC}}{P_{SC}}\right)\left[\frac{D^5}{\gamma_g f_M Z_{av} T_{av}\, L}\right]^{0.5}\left(\frac{s e^S}{e^S - 1}\right)^{0.5}\left(\frac{p_1^2}{e^S}-p_2^2\right)^{0.5}}$$

$$\boxed{\frac{s}{2}=\frac{M_g g}{Z_{av} R T_{av}} H=\frac{(28.97)\gamma_g g}{Z_{av} R T_{av}} H}$$

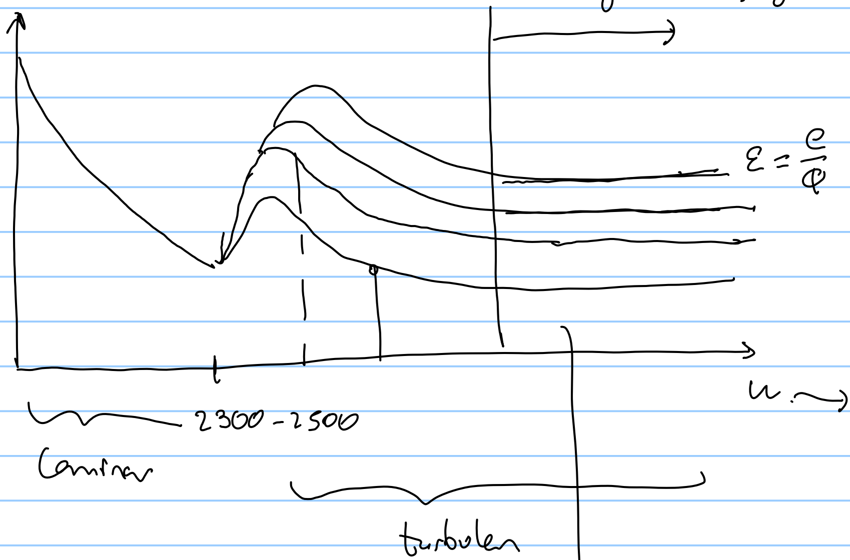
$$q_{gsc}=C_T\left(\frac{p_1^2}{e^s}-p_2^2\right)^{0.5}$$



$$p_{\text{inlet}}=p_1=e^{s/2}\left(p_2^2+\frac{q_g^2}{C_T^2}\right)^{0.5} \qquad p_{wh}=p_2=\left(\frac{p_1^2}{e^s}-\frac{q_g^2}{C_T^2}\right)^{0.5}$$

Reynolds of gas flow

$$f=\frac{\Delta p\, \Phi}{\left(\frac{v^2}{2}\right)L}$$



$u \rightarrow$ $Re = \frac{u \cdot \Phi \cdot \rho}{\mu}$

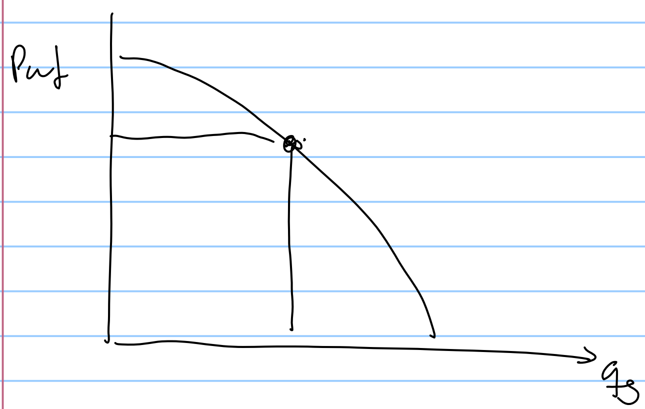
100m

$e = f(\Phi)$

$$f = \frac{0.0777}{\Phi^{0.224}}$$

Φ in mm
inch

IPR



Check tubing constant calculator spreadsheet. Class exercise.

CALCULATION OF TUBING FLOW CONSTANT		
height difference	[m]	3000
Internal Diameter	[m]	0.15
Gas gravity	[-]	0.55
Line length	[m]	3000
Inlet temperature	[K]	378
Outlet temperature	[K]	360
Inlet pressure	[bara]	303
Outlet pressure	[bara]	275
Ave. Temperature	[K]	369
Ave. Pressure	[bara]	289
Ave. Compressibility factor	[-]	0.981
Friction factor	[-]	0.012
Elevation Coeff, S		0.156
Tubing flow constant	[Sm^3/bar]	3.58E+04