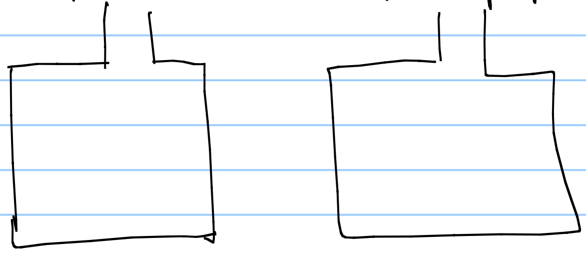
How do we predict reservoir performance

RF
q_o, q_g, q_w vs time
P_{wf} flowing bottomhole pressures
for each well

- material balance

tank approach with uniform properties
- P
- T
- S_o, S_w, S_g
- K
- ϕ



n_{g_i} $n_{g_{i+1}}$

$$n_{g_{i+1}} - n_{g_i} = \Delta n$$

- Reservoir simulator

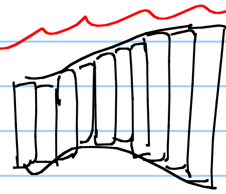
domain reservoir $\xrightarrow{\text{discretize}}$ Grid

FDM

$\vdash \Delta x \rightarrow$

P_i P_{i+1}

$$\frac{\partial p}{\partial x} = \frac{P_{i+1} - P_i}{\Delta x}$$



Set of differential equations
- flow in porous media
- fluid behavior

$\xrightarrow{\text{numerical approximation}}$ Finite difference method FDM

Set of algebraic equations $\xrightarrow{\text{applied}}$ Grid

System of algebraic equations

initial conditions

$P, S_o,$

boundary conditions

customized set of algebraic equations

$$[A] \cdot \{\vec{X}\} = \vec{B}$$

iterative scheme for solving it in time

results

q, P, S_o, S_w, S_o

Advantages: • more realistic, can capture the heterogeneities of the field

(–) take longer computation time

(–) Requires large input ~ in early phase we need to extrapolate or assume *water:*

$$\nabla \circ \left[\frac{[k]k_{rw}}{\mu_w B_w}(\nabla p_w - \gamma_w \nabla d)\right] + Q_w = \frac{\partial}{\partial t}\left(\phi \frac{S_w}{B_w}\right)$$

oil:

$$\nabla \circ \left[\frac{[k]k_{ro}}{\mu_o B_o}(\nabla p_o - \gamma_o \nabla d)\right] + Q_o = \frac{\partial}{\partial t}\left(\phi \frac{S_o}{B_o}\right)$$

gas:

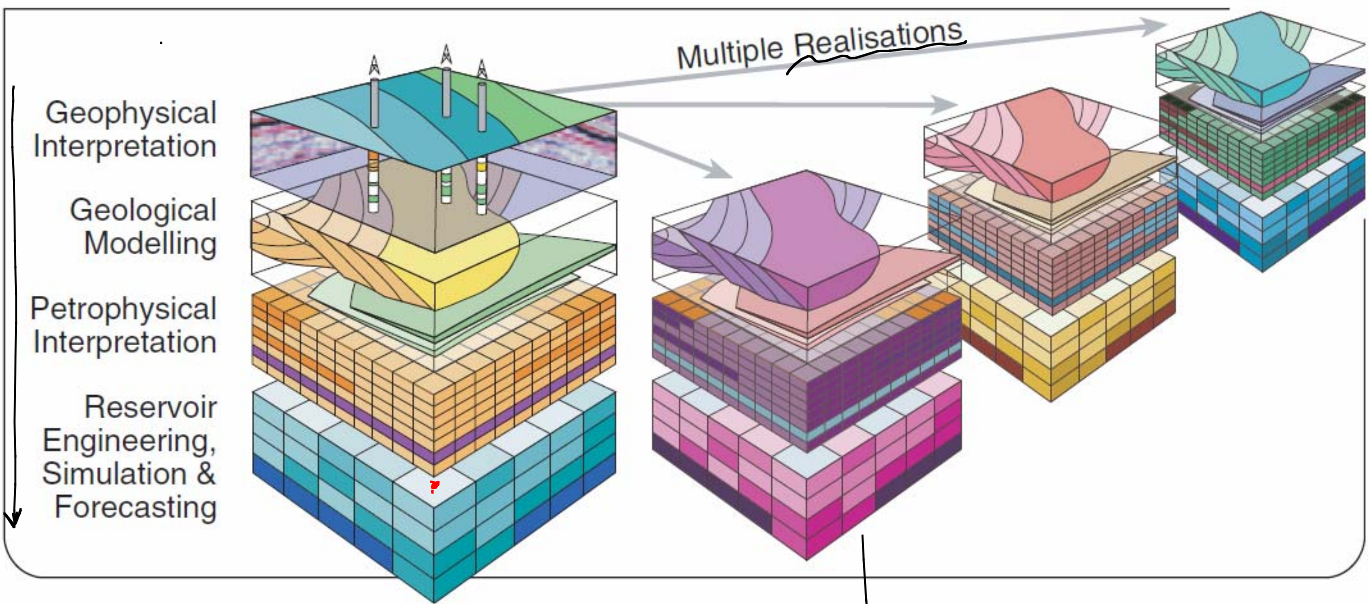
$$\nabla \circ \left[\frac{[k]k_{rg}}{\mu_g B_g}(\nabla p_g - \gamma_g \nabla d)\right] + \nabla \circ \left[\frac{[k]k_{ro}}{\mu_o B_o} R_s (\nabla p_o - \gamma_o \nabla d)\right] + Q_g = \frac{\partial}{\partial t}\left(\phi \frac{S_g}{B_g} + \phi \frac{S_o R_s}{B_o}\right)$$

water:

$$\Delta_y T_{wy} \Delta_y \Psi_w = \left(\frac{k_y k_{rw}}{\mu_w B_w \Delta y}\right)_{j+1/2} \Delta x_i \Delta z_k (\Psi_{w,j+1} - \Psi_{w,j}) - \left(\frac{k_y k_{rw}}{\mu_w B_w \Delta y}\right)_{j-1/2} \Delta x_i \Delta z_k (\Psi_{w,j} - \Psi_{w,j-1})$$

- there is a high uncertainty in the subsurface

workflow to create res model.



TRR $q_o(t)$
RF

- there are 3 ways to address uncertainty in the creation of the subsurface model

  - Define a base case ~ the most likely realization
    run sensitivity analysis on that case.

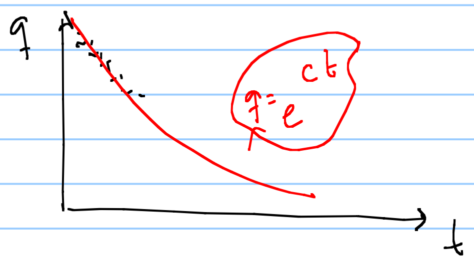
- define a limited number of cases (4-5) – assign a probability to each case. $$
  ask expert

  ↳ run sensitivity analysis on each one of the realizations

- built a stochastic model and compute the most likely outcome using Monte-Carlo, latin Hypercube sampling.

  ↳ very computationally expensive process due to the high number of cells and variables per cell.

- decline curve analysis (DCA) { material balance equation + IPR equation + empirical information



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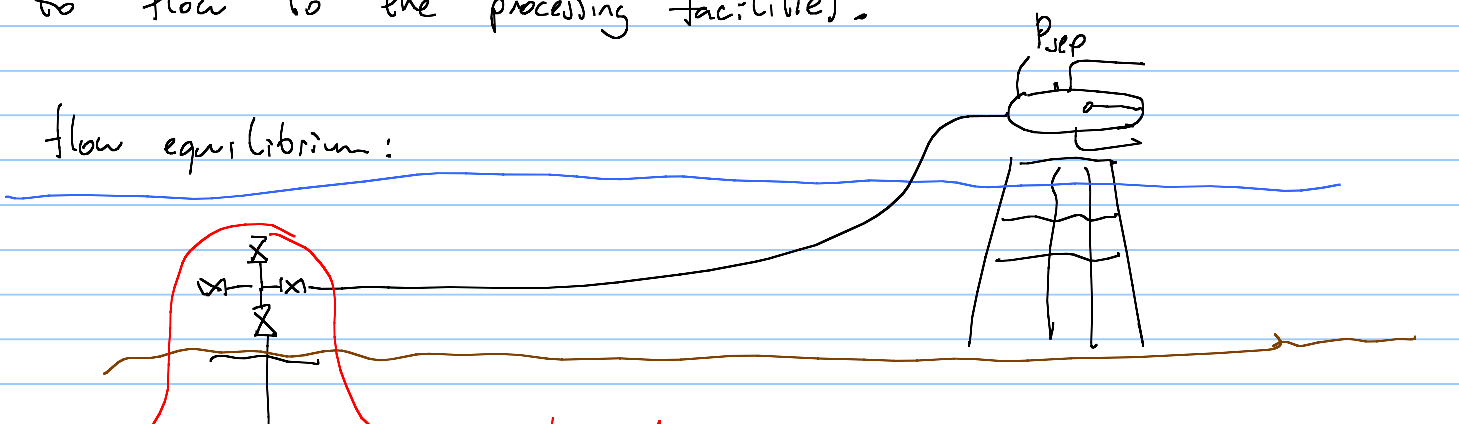
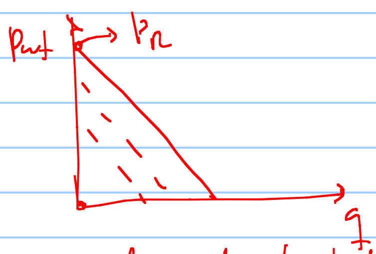
How to capture properly the pressure required at the bottom hole to flow to the processing facilities?

flow equilibrium:

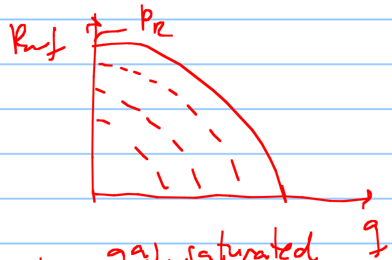


two boundaries: reservoir pressure
separator pressure.

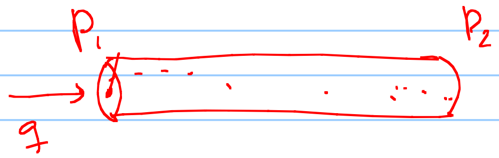
IPR



liquid, undersaturated oil

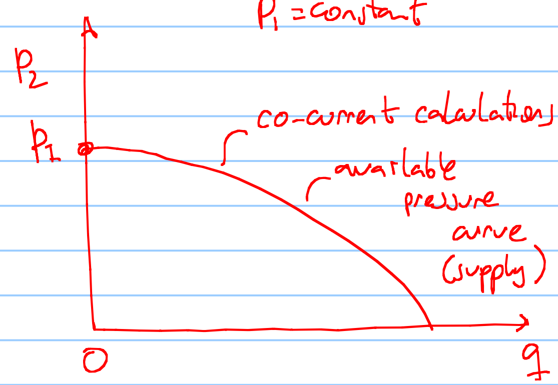


gas, saturated oil.



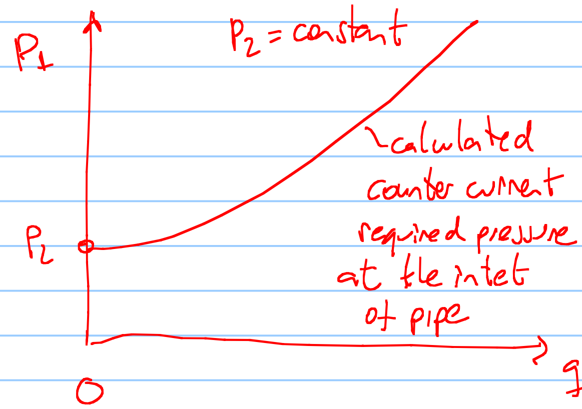
$$\Delta p = \Delta p\Big|_{\text{friction}} + \cancel{\Delta p}\Big|_{\text{gravity}}^{\,0}$$

$f(q)$



① Available pressure at the exit of the pipe

provide p_1, q ⇝ calculate p_2



② Required pressure at the inlet of the pipe

provide p_2, q ⇝ calculate p_1

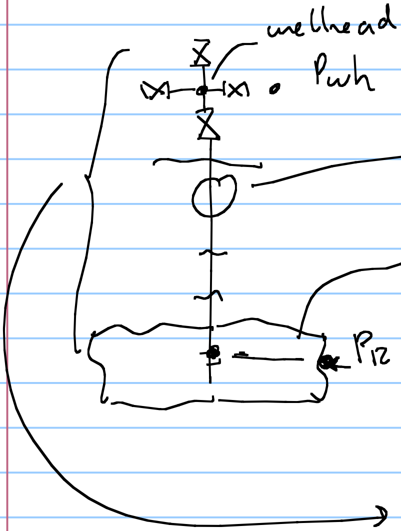
$$p_1 - p_2 = \Delta p$$

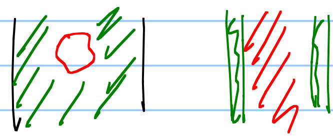
$$p_1 = p_2 + \Delta p$$

③ Calculate rate

provide p_1, p_2 ⇝ calculate q

I can use available and required pressure curves to characterize complex parts of the production system



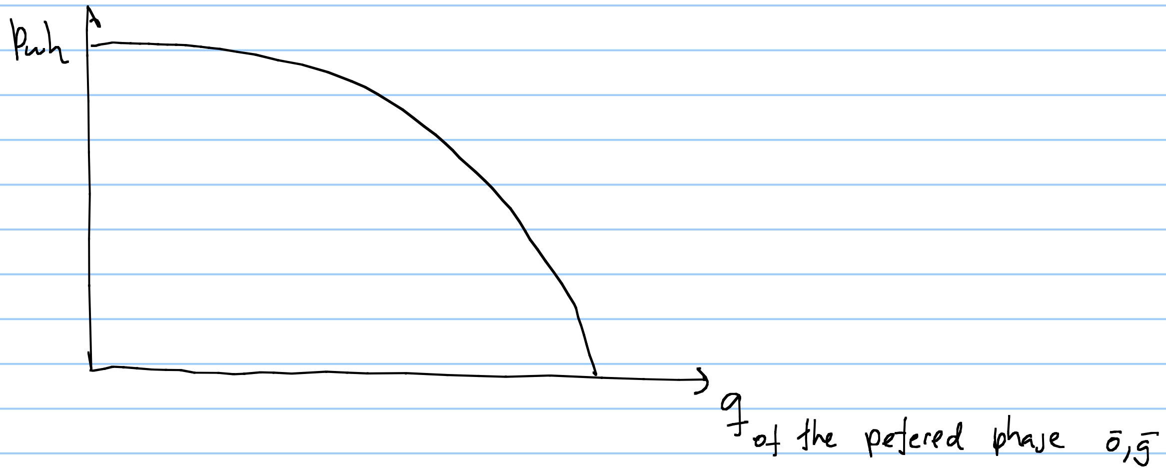


flow in porous media
fluid behavior

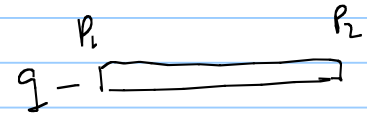
flow in conduits
- pressure drop model $\begin{cases}\text{single}\\ \text{multiphase}\end{cases}$

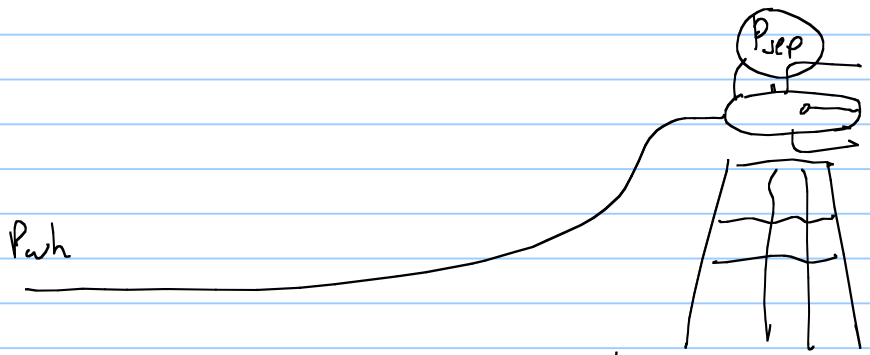
$$\Delta p = \Delta p\Big|_{\text{friction}} + \Delta p\Big|_{\text{gravity}}$$

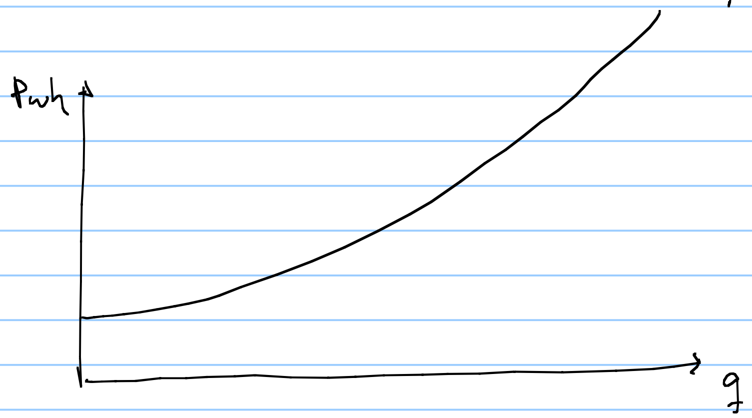
- temperature drop model
- fluid model ~ fluid properties change with pressure and temperature



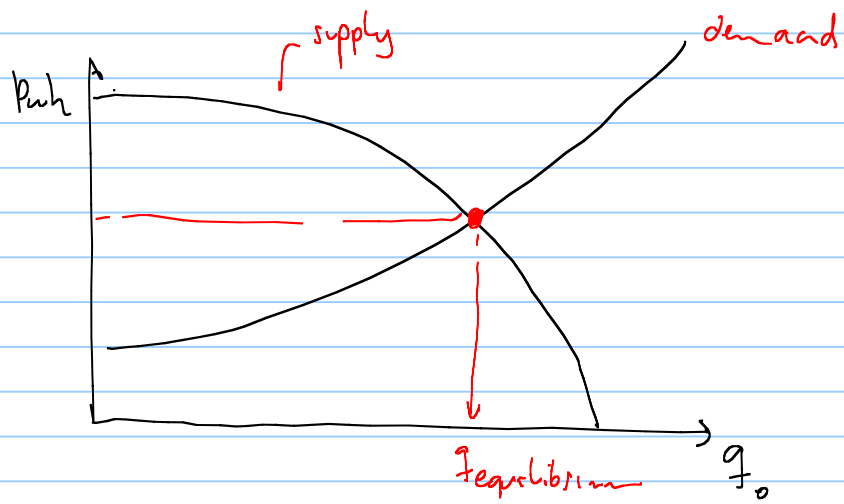
looking at the rest of the system







the only feasible operating rate is the intersection of both curves



one example with dry gas

IPR = $q_{\bar{g}} = C\left(P_R^2 - P_{wf}^2\right)^n$

tubing =

Tubing flow Equation-Dry gas

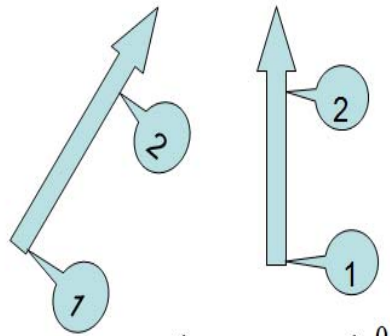
remember pressure drop depends on the velocity. $\frac{q_{local}}{A}$

but we need equations in term of surface rates. so we need a conversion factor between local rate and surface rates B_g

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

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

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



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

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

for dry gas, horizontal line

$$q_{\bar{g}} = C_{FL}\left(p_1^2 - p_2^2\right)^{0.5}$$

let's find mathematically the equilibrium rate

Known
blue

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

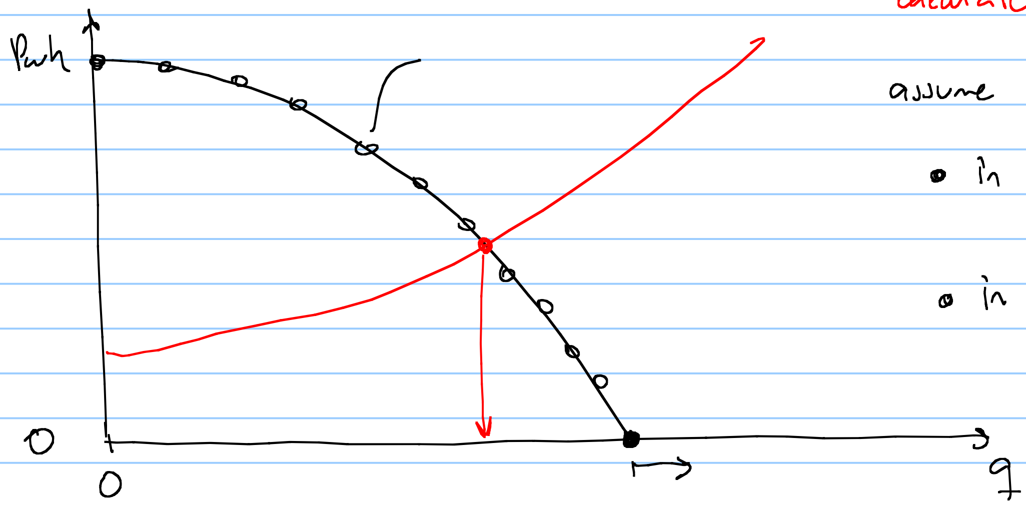
1 eq, 2 unknowns.

$q_{\bar{g}} = C_T\left(\frac{P_{wf}^2}{e^s} - P_{wh}^2\right)^{0.5}$

2equ, 3 unknowns

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

3eq. 3unknowns



calculate available pressure curve

assume q_g $(0 \rightarrow q_g^*)$ in the range

- in IPR eq. calculate P_{wf}
- in tubing equation calculate P_{wh}

repeat for other rates

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

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

calculate the required pressure curve

assume q_g $(0 \rightarrow q_g^*)$

use flowline equation

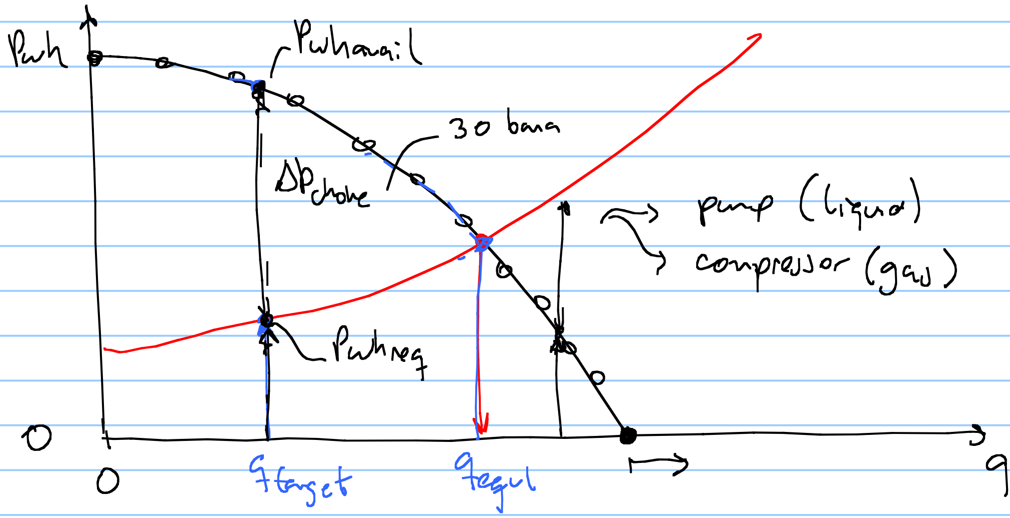
$$q_g = C_{FL} \left(P_{wh}^2 - P_{sep}^2 \right)^{0.5}$$

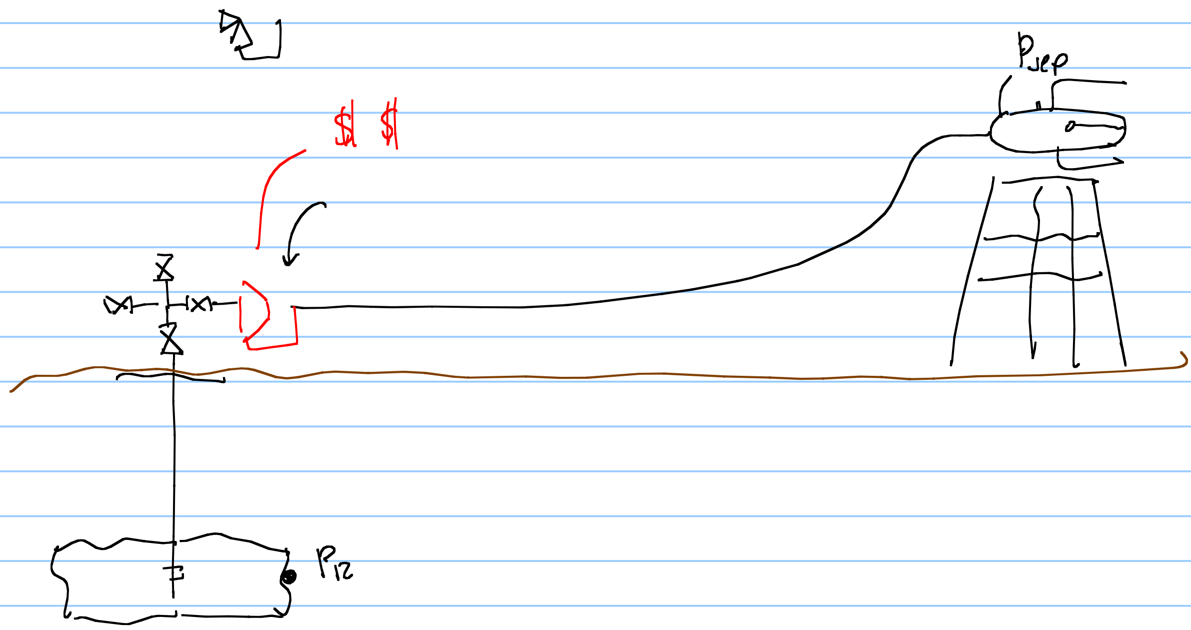
$$P_{wh} = \sqrt{P_{sep}^2 + \left(\frac{q}{C_{FL}} \right)^2}$$

tubing performance relationship

IPR TPR Flowline PR

time	P_R	q_g assume	P_{wf}	$P_{wh\,avail}$	P_{sep}	$P_{wh\,req}$	Error $(P_{wh\,avail} - P_{wh\,req})$
		$0 \rightarrow q_g$					


Pwh
Pwhavail
30 bara
ΔPchoke
pump (liquid)
compressor (gas)
Pwhreq
0
0
qtarget
qequl
q


$ $
Psep
PR