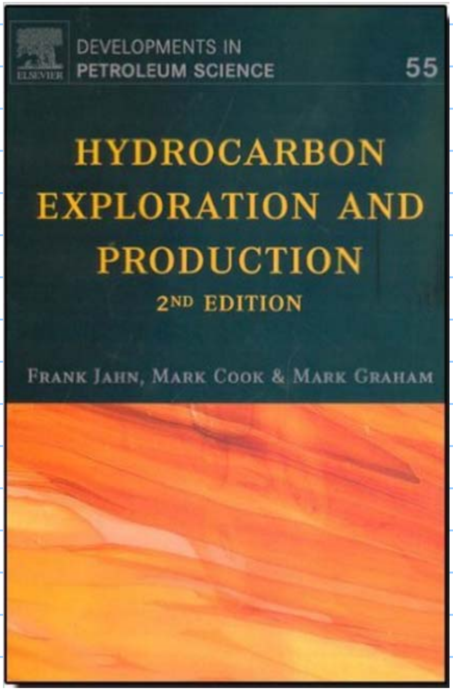
ME683 - Field development and operations . Prof. Milan Stanko (NTNU)

- 3.12.2018 - 07.12.2018 09:00 → 14:00
- excel exercises
- Evaluation: Prof. Liberato Haule
  - 10% delivery of exercises
  - 2x15% mini quiz (2018, 2019)
  - 60% final exam (2019)
- Reference material:



DEVELOPMENTS IN PETROLEUM SCIENCE 55

HYDROCARBON EXPLORATION AND PRODUCTION

2ND EDITION

FRANK JAHN, MARK COOK & MARK GRAHAM

Frank Jahn, Mark Cook, Mark Graham

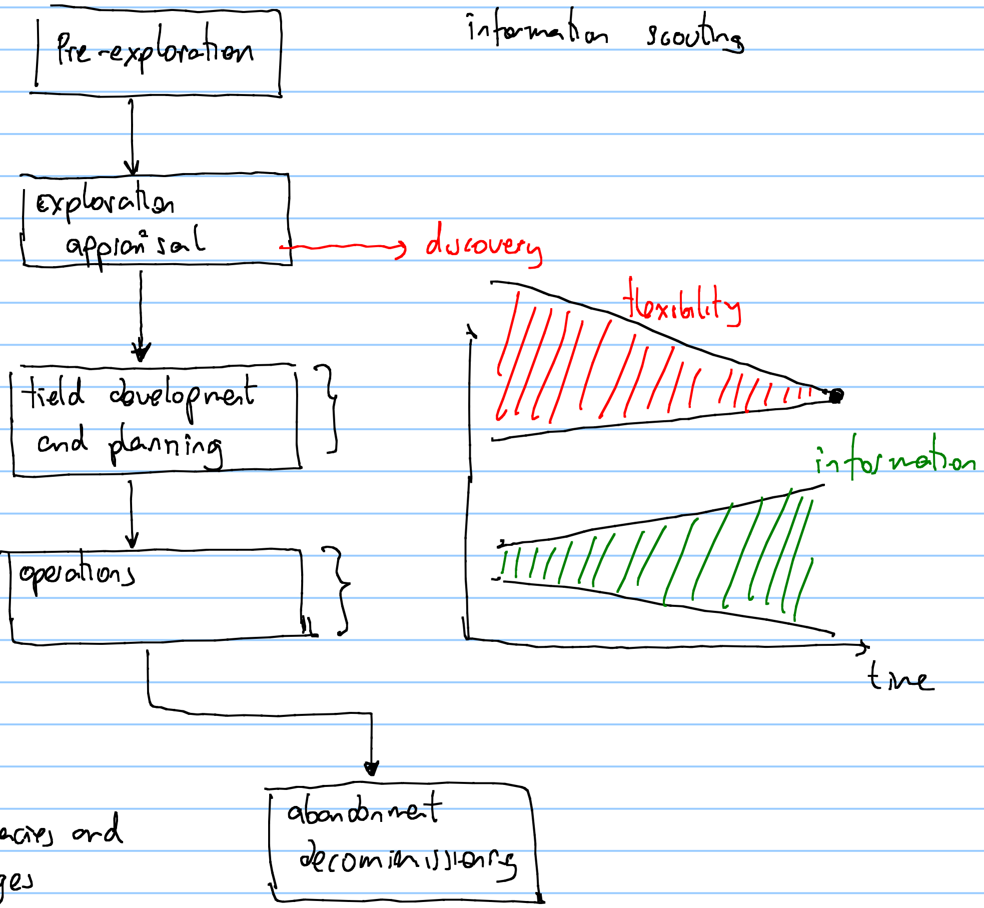
- material from previous courses: http://www.ipt.ntnu.no/~stanko/files/Courses/ME683

http://www.ipt.ntnu.no/~stanko/files/Courses/TPG4230

Milan's youtube channel → "playlist" → TPG4230 Field development and operations (2017)

https://www.youtube.com/channel/UCWMfsCe1NQMgx4UZWrVvFg

Life cycle of an oil /gas offshore field



- produce efficiently
- increase uptime

Nr operational days in year

- trouble shooting
- deal with defficiencies and exploit advantages

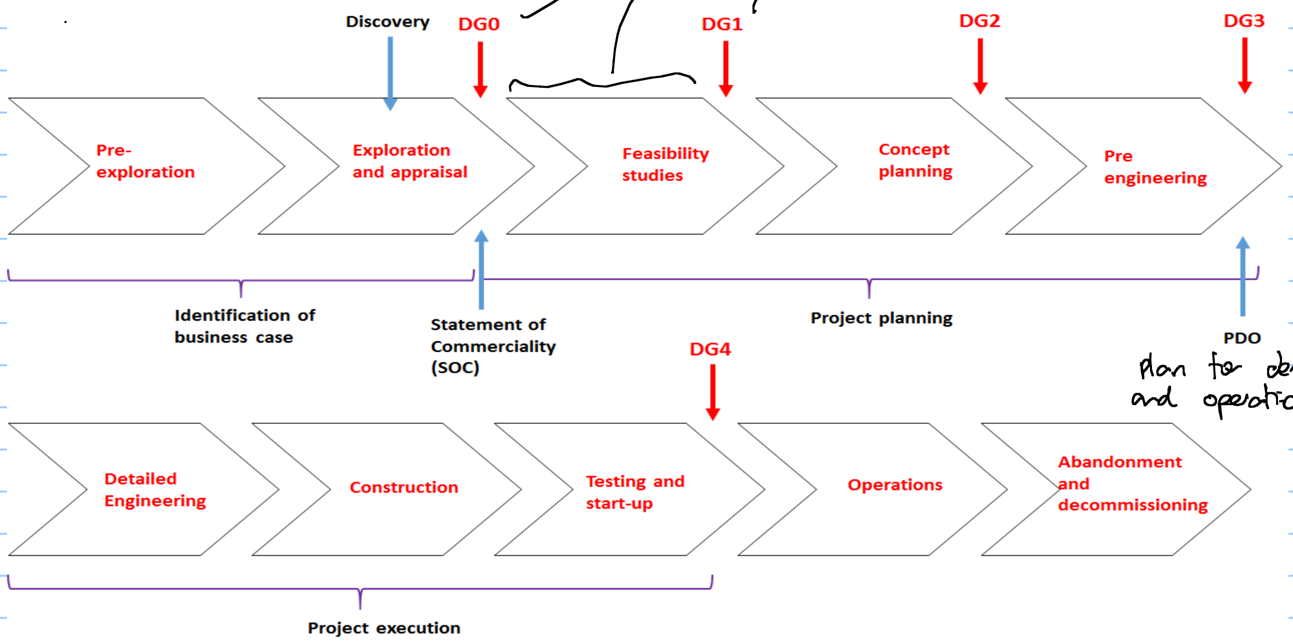
IOR improved oil recovery

field development workflow:

DG Decision gate → economics of field → profitability

find at least 1 way to develop the field

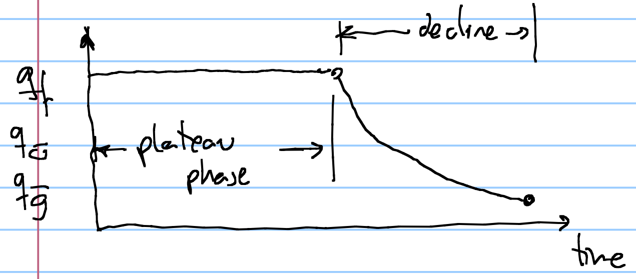
select one and proceed further



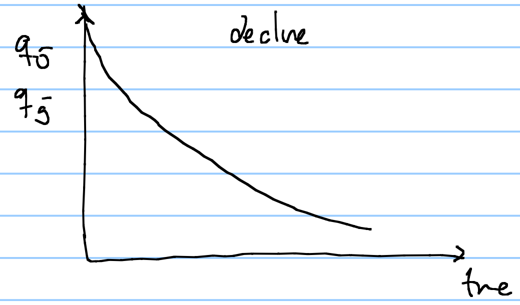
Plan for development and operations

- Production scheduling : defining how much oil/gas will be produced with time from field

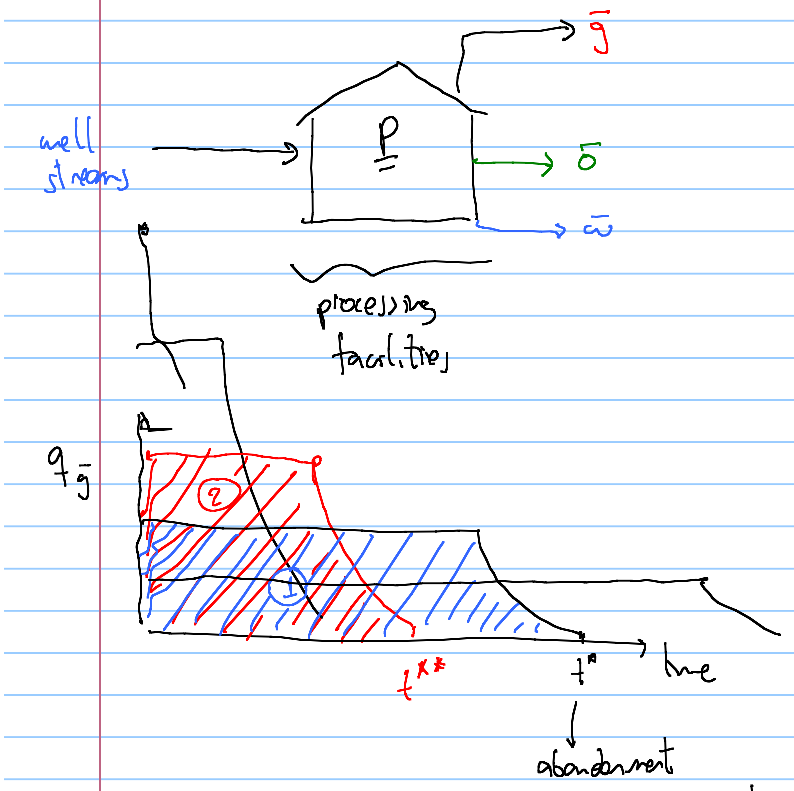
Production mode A (plateau)



Production mode B (potential)



$\bar o$ at standard conditions



cumulative production

$$G_p = \int_0^{t^*} q_{\bar g}\, dt$$

according to SPE

Society of Petroleum engineers

initial oil in place (OOIP) — N oil surface volume

G gas

Q oil/gas

at abandonment $G_p \to G_{pu}$

} ultimate

Mode A

- typically used for new standalone developments
- for medium-large recoverable size $\begin{pmatrix} M \\ G \end{pmatrix}$
- find a balance between revenue $\left(q_{\bar{g}} \cdot P_{\bar{g}} \right)$ and cost !

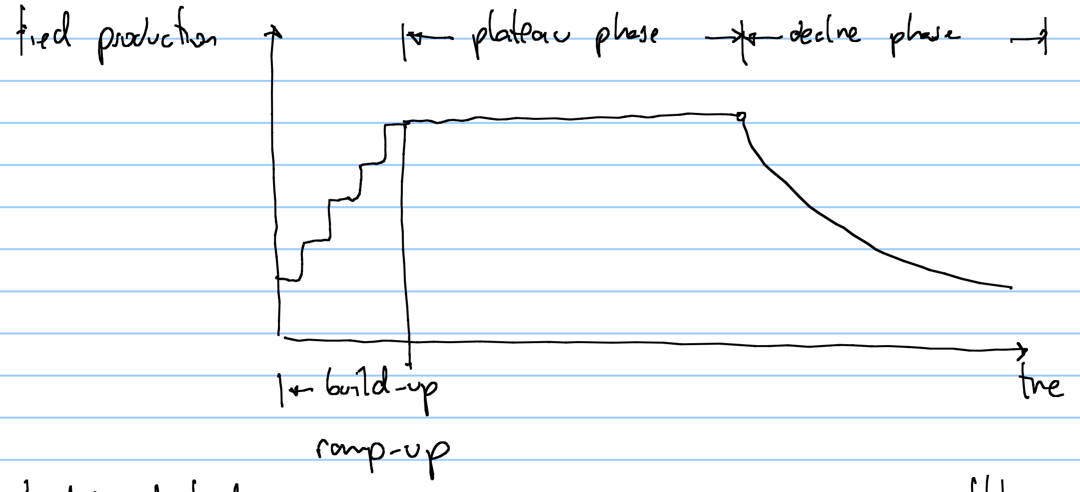
if ↑ $q_{\bar{g}}$ → more revenues (early revenue)

↑ $q_{\bar{g}}$ → more expensive facilities

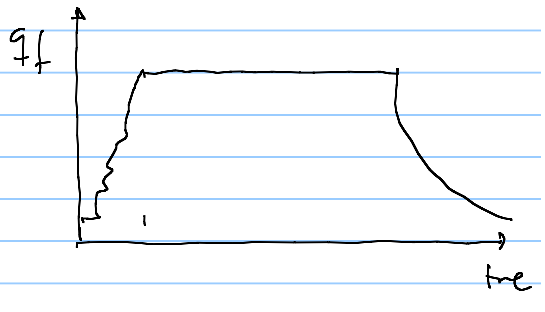
- contracts
  - for oil it is sold on market
  - for gas it is typical to have contract
    - amount →
    - period of time

Mode B

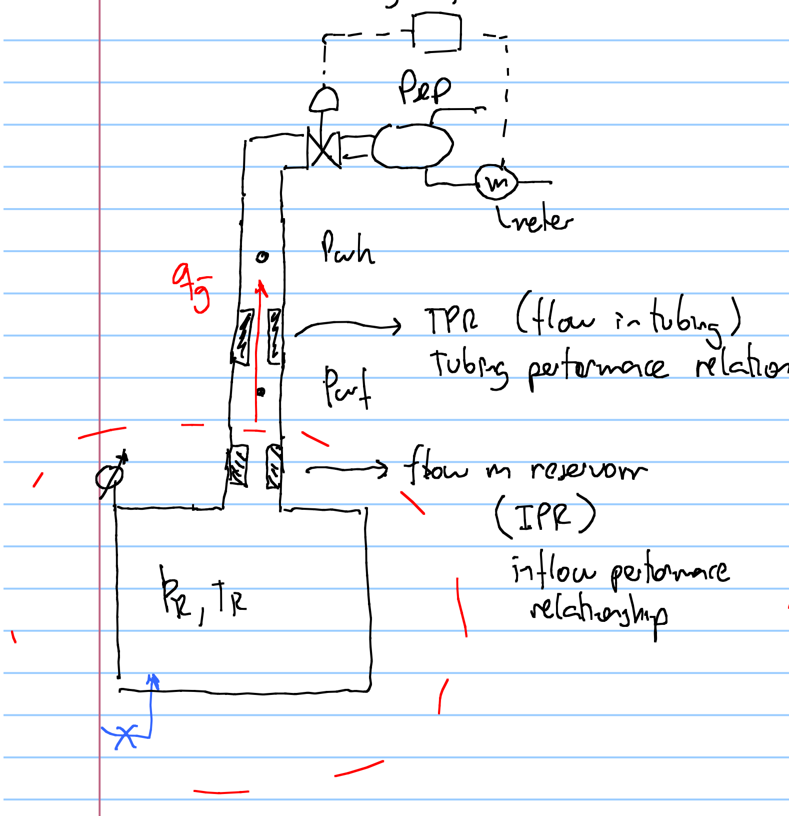
- typically used for small-medium (marginal) size reservoirs that have an existing facility close by with spare capacity
- to produce as much as possible as quick as possible

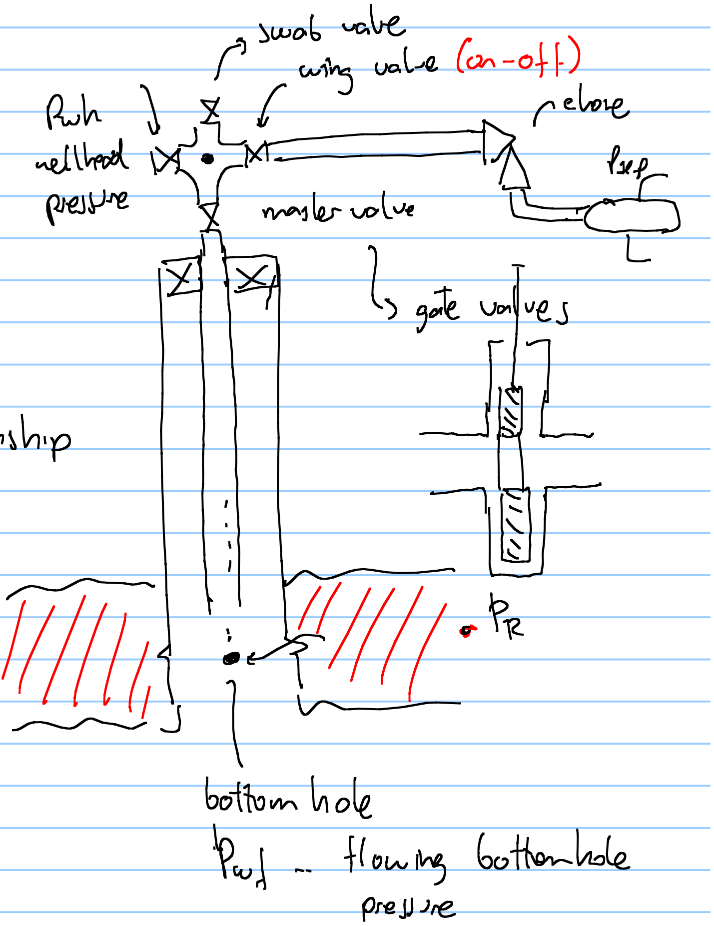



land-based field


offshore fields

Mechanical analog of a field



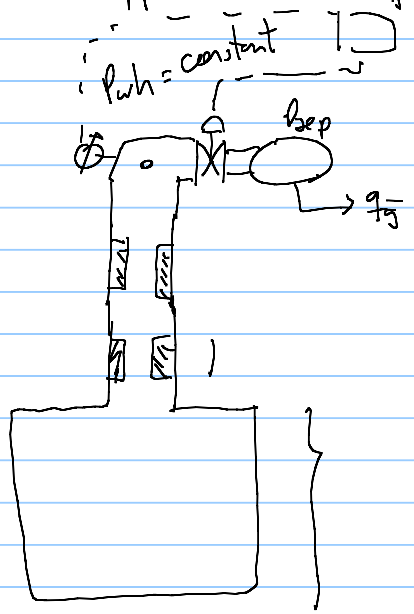


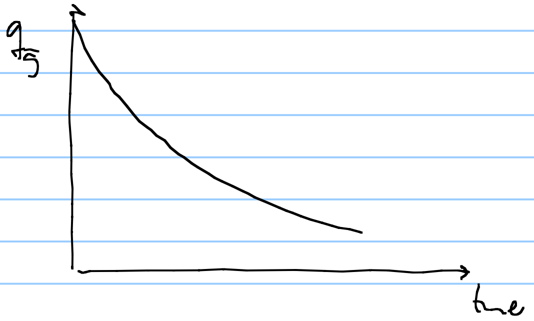
$q_g = f(\underbrace{P_R, P_{sep}}, \text{choke opening})$

with time $\underbrace{P_R - P_{sep}}$ goes down ↓

if $P_R - P_{sep}$ is high q_g ↑, therefore, i need to close!

what happens in case of node B (potential)





Rule of thumb to decide on plateau height (first estimate)

for oil fields 10% yearly outtake of TRR (total recoverable reserves)

$$q_{plateau} = \frac{0.1 \cdot N_{pu}}{\underbrace{N_{days}/year}_{uptime}} = \qquad N_{pu}$$

$$\frac{N_{day}}{365}$$

Goliat oil field $N_{pu} = 180\ E6\ stb$

$q_{plateau}$?

$$q_{plateau} = \frac{0.1 \cdot 180\,E6\ stb}{328.5} \approx 55000\ stb/d$$

90% uptime = $N_{day} = 0.9 \cdot 365 = 328.5$

for gas field

annual oftake 2-5% of TRR

$$q_{\bar{g}\_plateau} = \frac{G_{pu} \cdot (0.02 - 0.05)}{N_{day}/year}$$

↳ operational

for Block 2 offshore Tanzania

$G = 311\ E9\ Sm^3$

$RF = 0.7$ $\qquad G_{pu} = 217.7\ E9\ Sm^3$

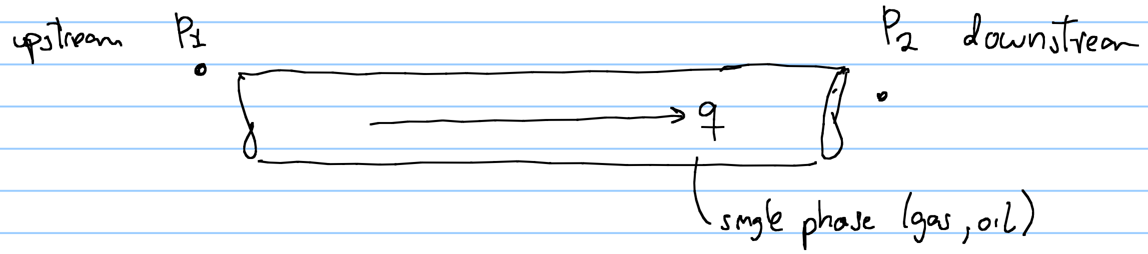
recovery factor $\quad RF = \frac{G_{pu}}{G}$

$$q_{\bar{g}\,plateau} = \frac{217.7\ E9 \cdot (0.025)}{328.5}$$

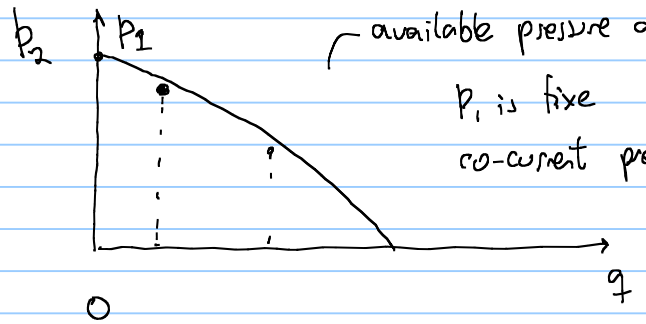
$$q_{\bar{g}\,plateau} = 16.6\ E6\ Sm^3/d$$

flow equilibrium (Nodal analysis, inflow-outflow analysis)

- Horizontal pipe



- keep p_1 fixed, change q, what happens with p_2?

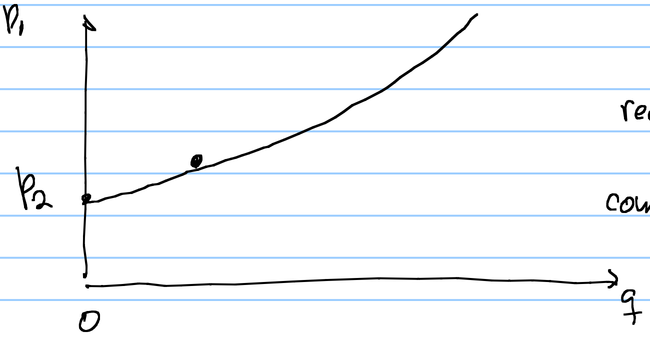


available pressure at pipe outlet

p_1 is fixe

co-curent pressure calculation

- keep p_2 fixed, change q, what happens with p_1

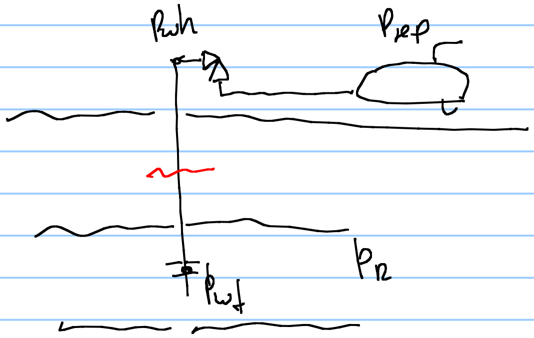


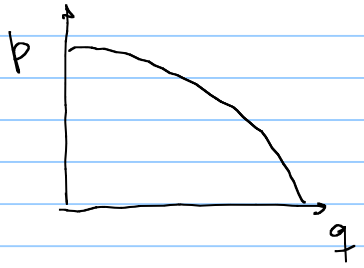
p_2= fixed

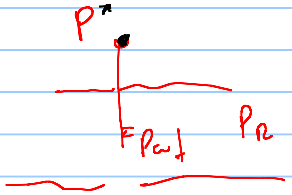
required pressure at pipe inlet

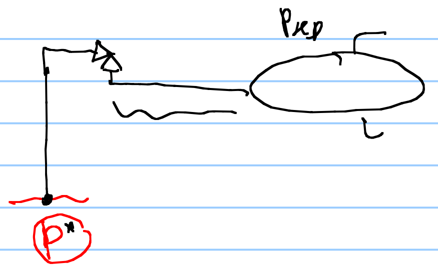
counter-current pressure calculation

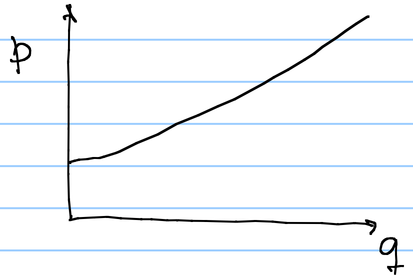
- provide p_1, p_2, calculate q

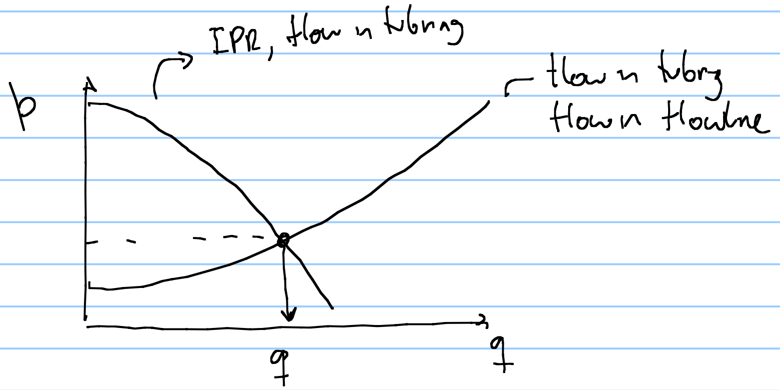




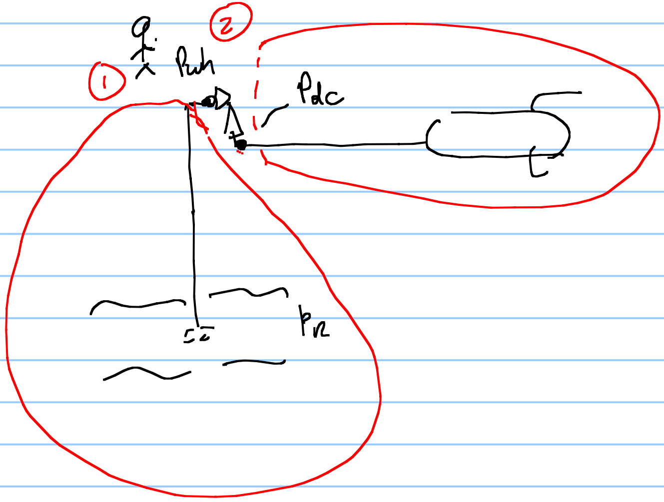


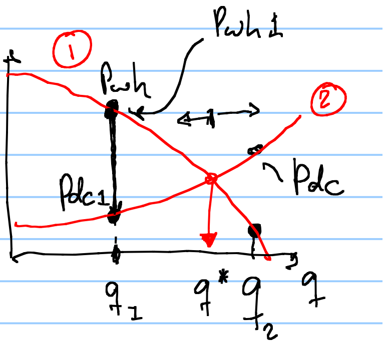


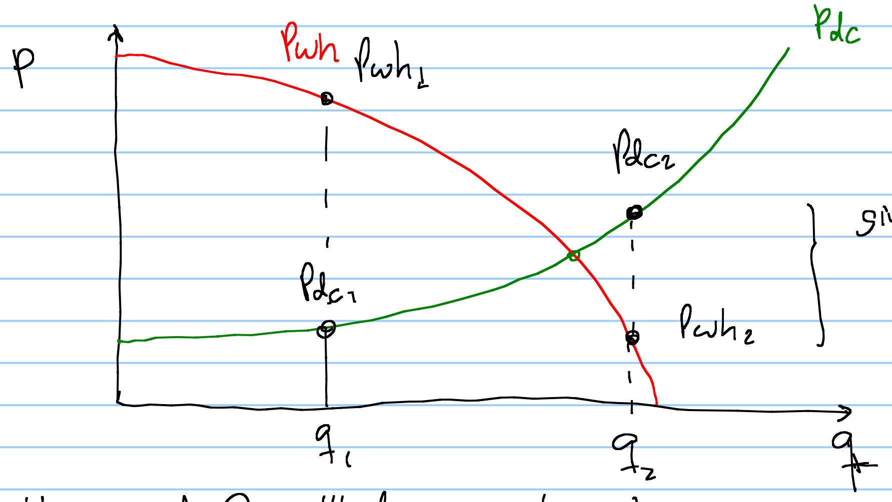




changing equilibrium point @ wellhead





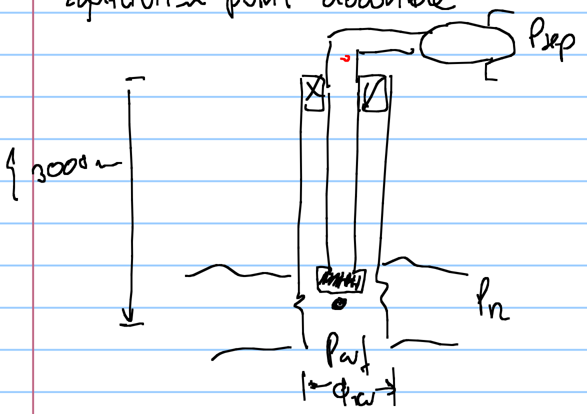


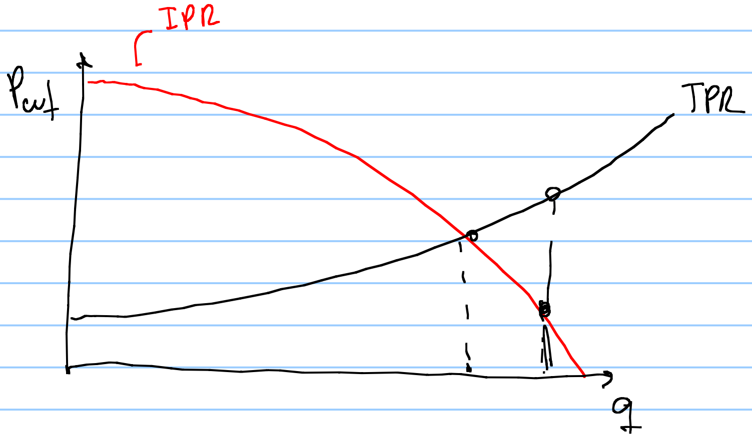
give energy to fluid
(liquid → pump
gas → compressor)

equilibrium point @ wellhead → choke design

↳ topside / surface compression

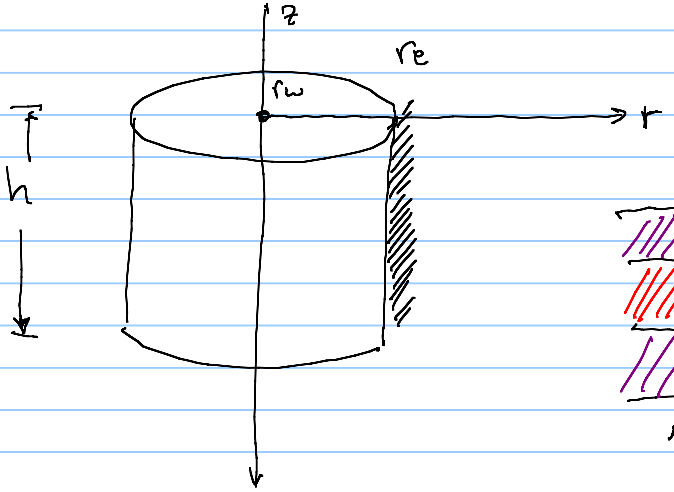
equilibrium point downhole



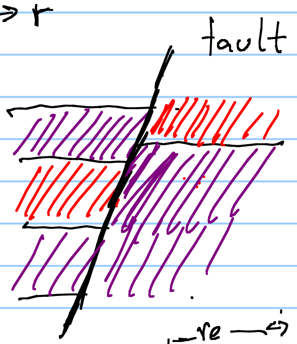


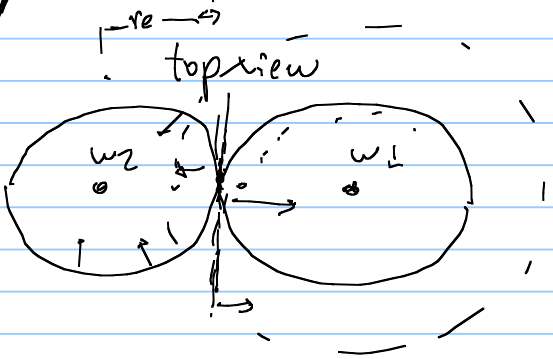
- downhole pump (ESP electric submersible pump)
- downhole choke (not very common)

- flow in formation (Inflow performance relationship)

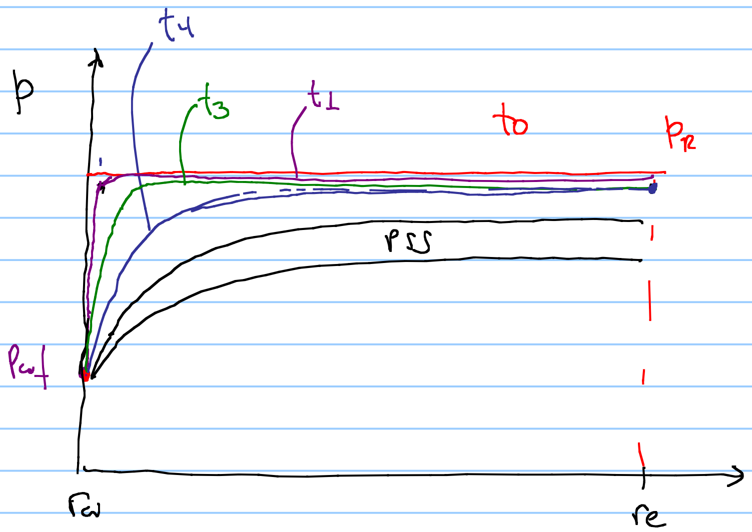


re external reservoir radious
rw wellbore radious





assume initially no production, p_R, t_0



@ t_4, pressure change reaches the boundary r_e

flow regimes in wellbore

$t_0 \rightarrow t_4$

infinite acting (transient)

from ty and forward → steady state (if P_e is kept constant) SS

pseudo steady state (PSS) if P_e changes with time

if no flow at boundary

for wells with medium to high permeability md → 1 darcy

transient is short → hrs → days

$$V = \frac{\textcircled{k}}{\mu A}\left(\frac{\Delta p}{\Delta x}\right)$$

in that case most of production happens at PSS o SS

then we use IPR for PSS, SS

$$IPR = f\left(\overset{\downarrow}{P_R}, P_{wf}, \text{reservoir properties}\right)$$

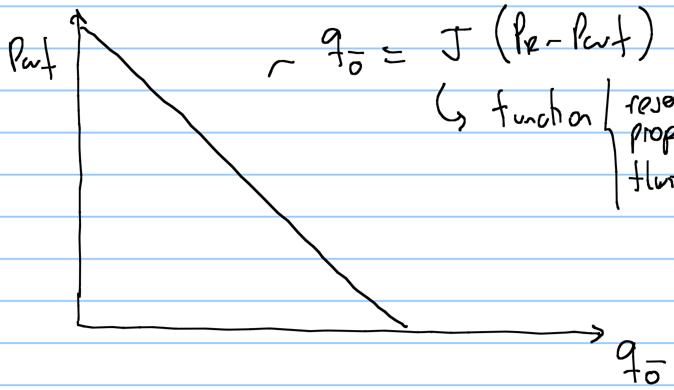
$$IPR \neq \underset{\sim}{f(t)}$$

if significant part of production happen when is transient then

$$IPR = f(t)$$

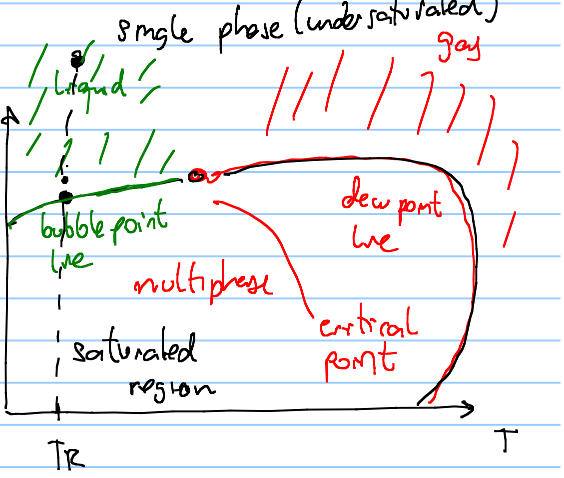
In this course we will assume PSS

IPR equations

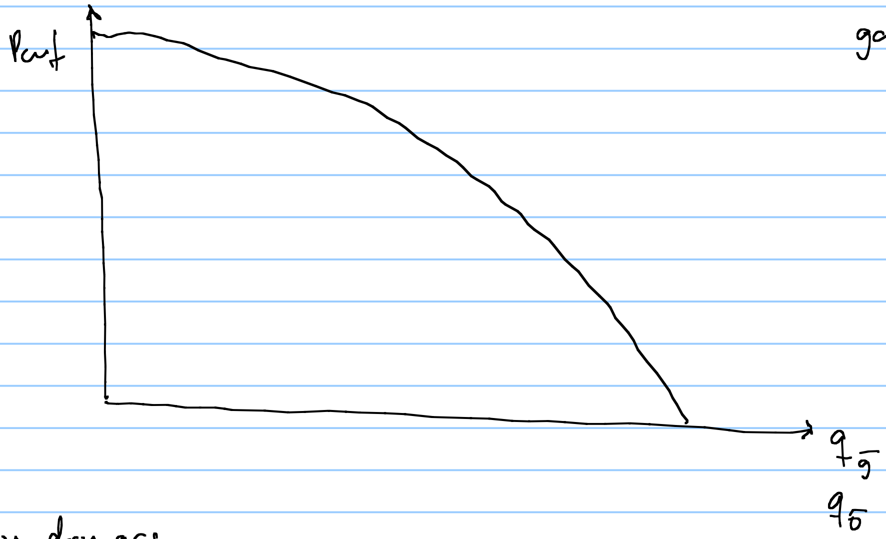


$$q_o = J\left(P_R - P_{wf}\right)$$

↳ function { reservoir properties, fluid properties



only oil (undersaturated oil) $P_{wf} \geq P_b(T_R)$



gas / saturated oil

for dry gas ↳ Back pressure equation

$$q_{\bar{g}} = \underbrace{\overset{\downarrow}{C_R}}_{\text{backpressure coefficient}} \left(p_R^2 - p_{wf}^2\right)^{n}$$

n ← backpressure exponent

empirical equation

$$0.5 \leq n \leq 1$$

0.5 → turbulent flow

1 → Darcy flow (laminar flow)

- for saturated oil $p_{wf} < p_b(T_R)$

Vogel

$$\frac{q_{\bar{o}}}{q_{\bar{o}max}} = 1 - 0.2\,\frac{p_{wf}}{p_R} - \frac{p_{wf}^2}{p_R^2}$$

flow in tubing (A.K.A. the tubing equation for dry gas)

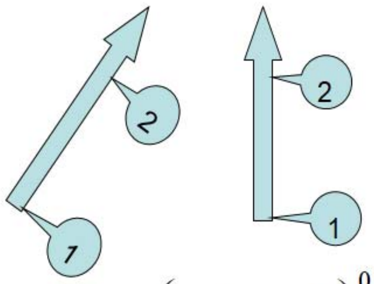
$$p v = R T \qquad R = \frac{R_u}{MW}$$

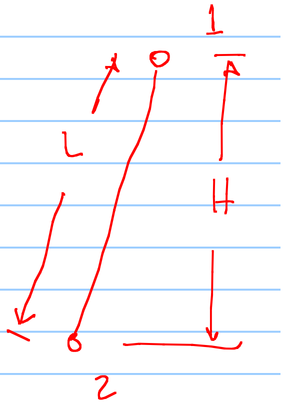
Tubing flow Equation-Dry gas

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

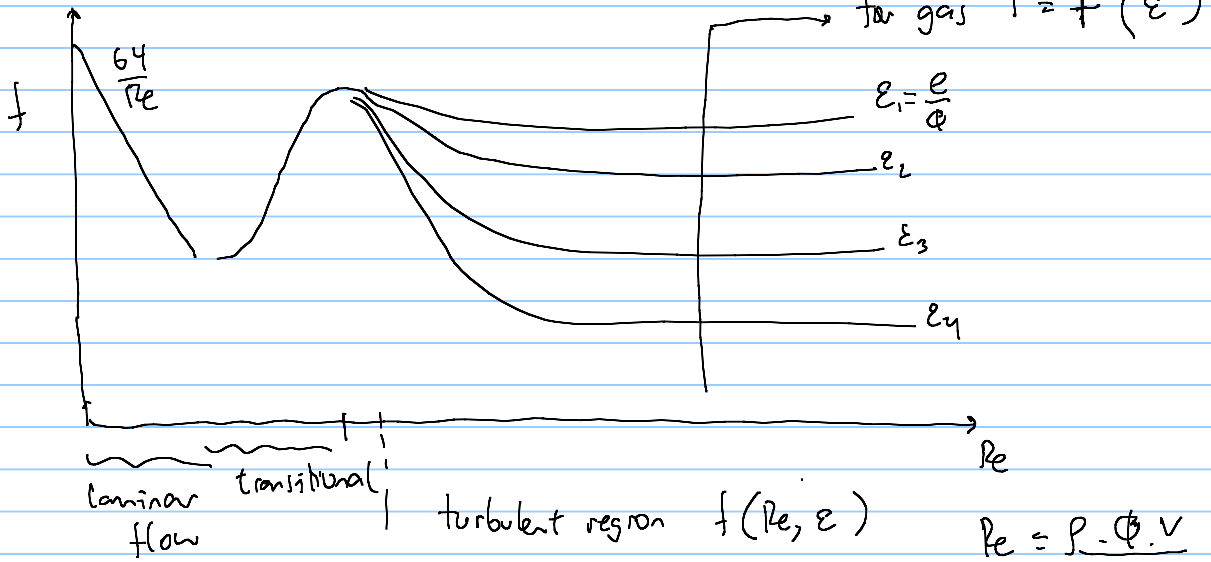
$$\boxed{\frac{s}{2} = \frac{M_g g}{Z_{av} R T_{av}} H = \frac{(28.97)\gamma_g g}{Z_{av} R T_{av}} H}$$

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





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



$Re = \frac{\rho \cdot \Phi \cdot V}{\mu}$

$\underset{\sim}{e}$ depend mainly on Φ

$f = F(\Phi)$

$$f_M = \frac{0.01748}{D^{0.224}\left[|1m|\left|\frac{39.37inch}{1m}\right|\right]^{0.224}} = \frac{0.0077}{D^{0.224}}$$

Smith (1950)

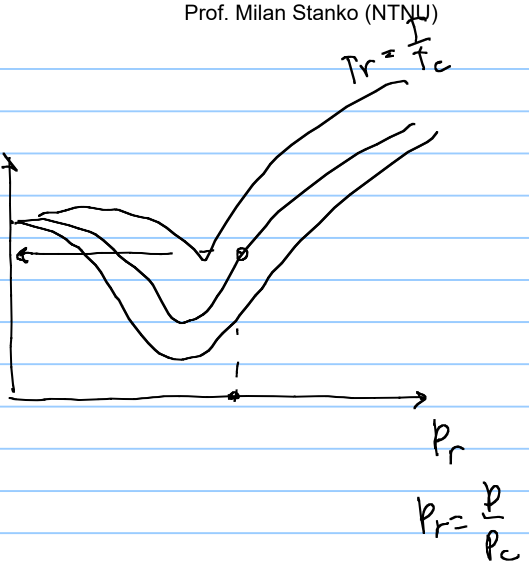
$$\underset{\sim}{q_g} = C_T \cdot \left(\frac{p_1^2}{e^s} - p_2^2\right)^{0.5}$$

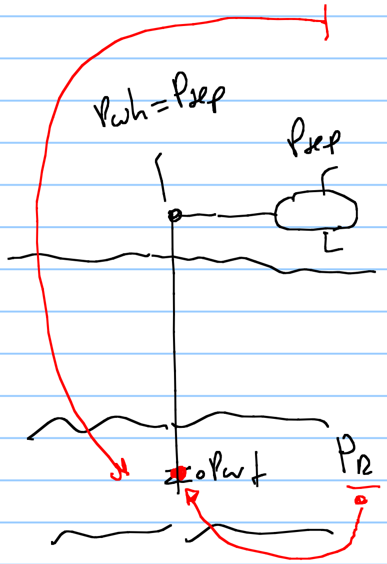
$P_1 = 200$ bara $P_2 = 80$ bara

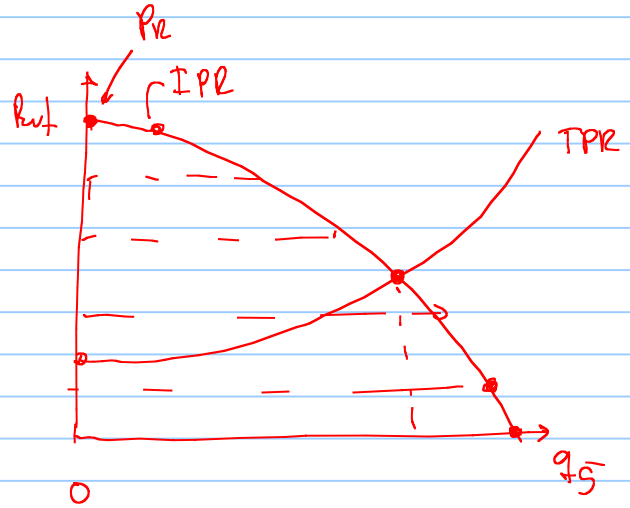
flow equilibrium of single dry gas well

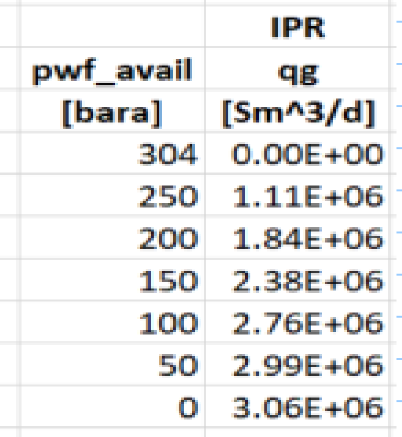
Z

$pV = ZRT$

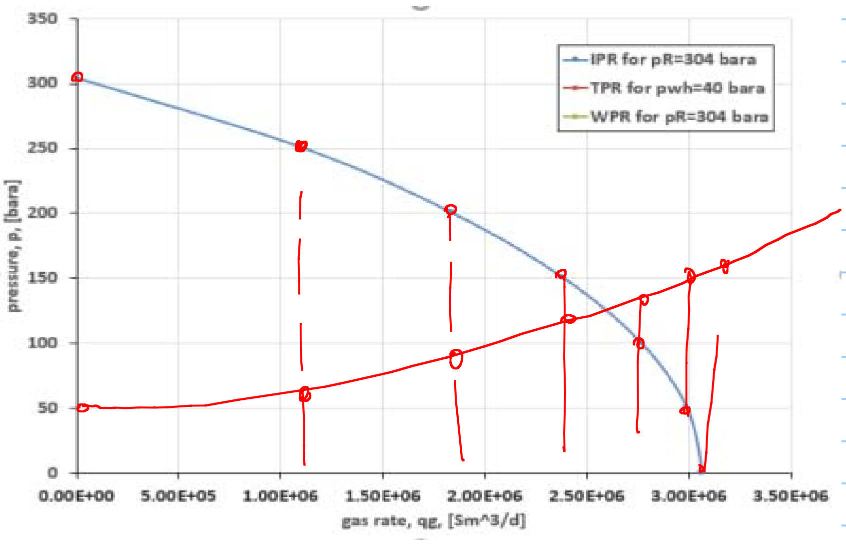






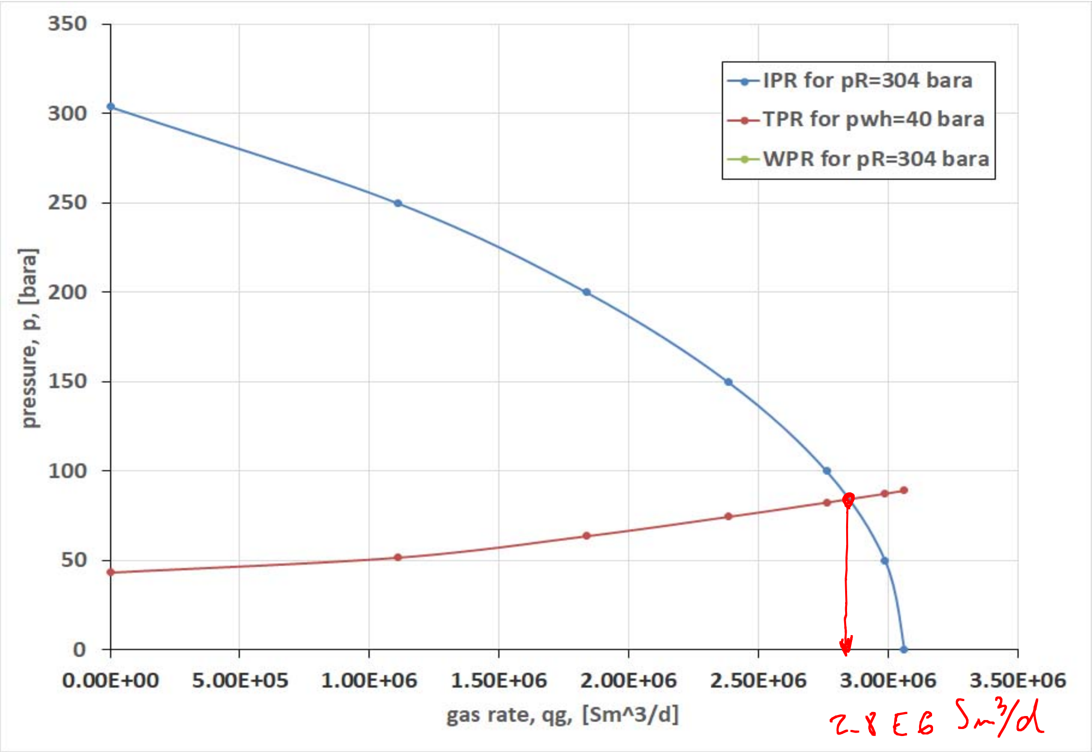


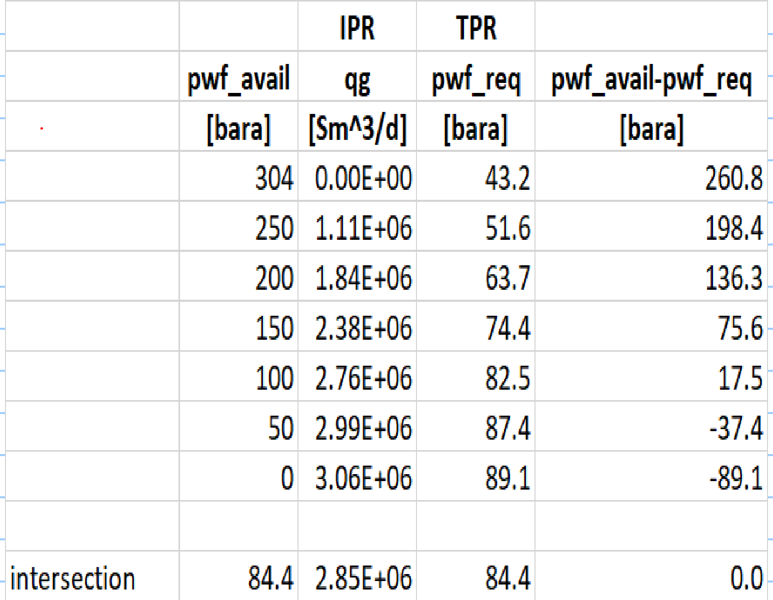
	IPR
pwf_avail	qg
[bara]	[Sm^3/d]
304	0.00E+00
250	1.11E+06
200	1.84E+06
150	2.38E+06
100	2.76E+06
50	2.99E+06
0	3.06E+06



$$\underset{\sim}{q_g} = C_T \cdot \left(\frac{p_1^2}{e^s} - p_2^2\right)^{0.5}$$

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





		IPR	TPR	
	pwf_avail	qg	pwf_req	pwf_avail-pwf_req
	[bara]	[Sm^3/d]	[bara]	[bara]
	304	0.00E+00	43.2	260.8
	250	1.11E+06	51.6	198.4
	200	1.84E+06	63.7	136.3
	150	2.38E+06	74.4	75.6
	100	2.76E+06	82.5	17.5
	50	2.99E+06	87.4	-37.4
	0	3.06E+06	89.1	-89.1
intersection	84.4	2.85E+06	84.4	0.0

to get a better approximation of C_T, S assuming $p_{wf} = p_R$

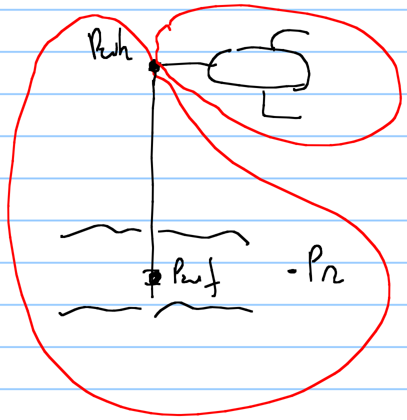
↳ C_T, S

↳ execute flow equilibrium

↓

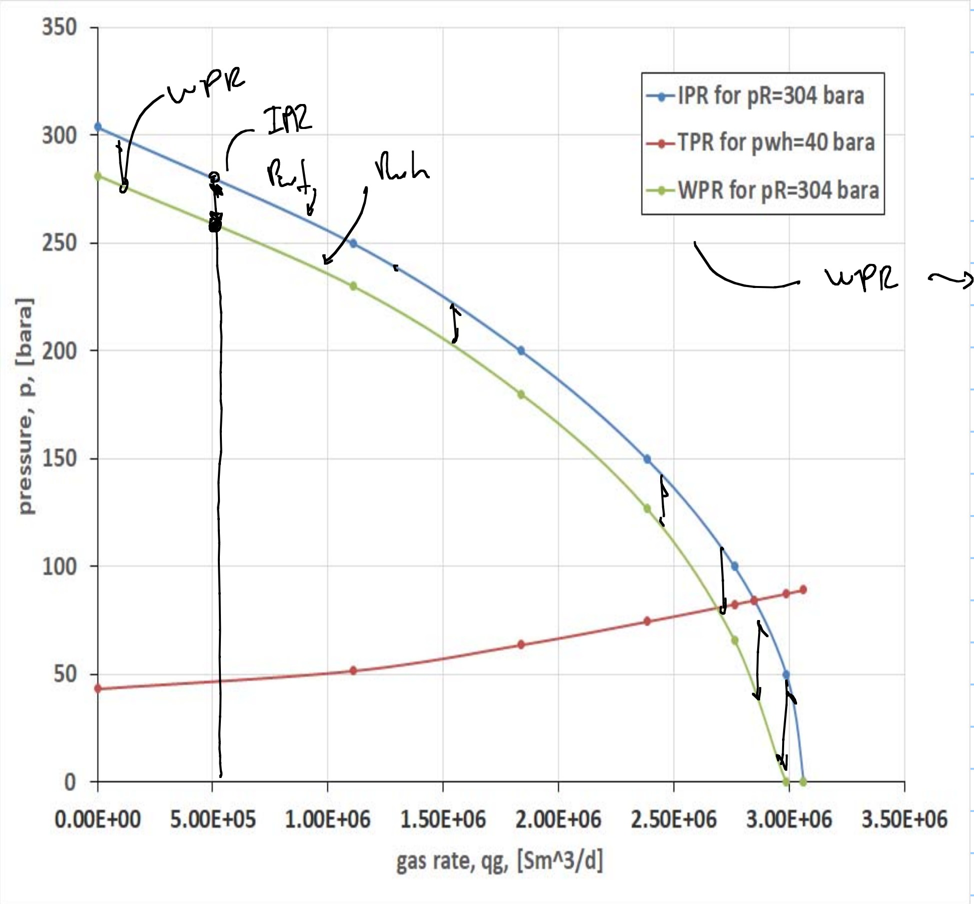
p_{wf}

flow equilibrium at well head

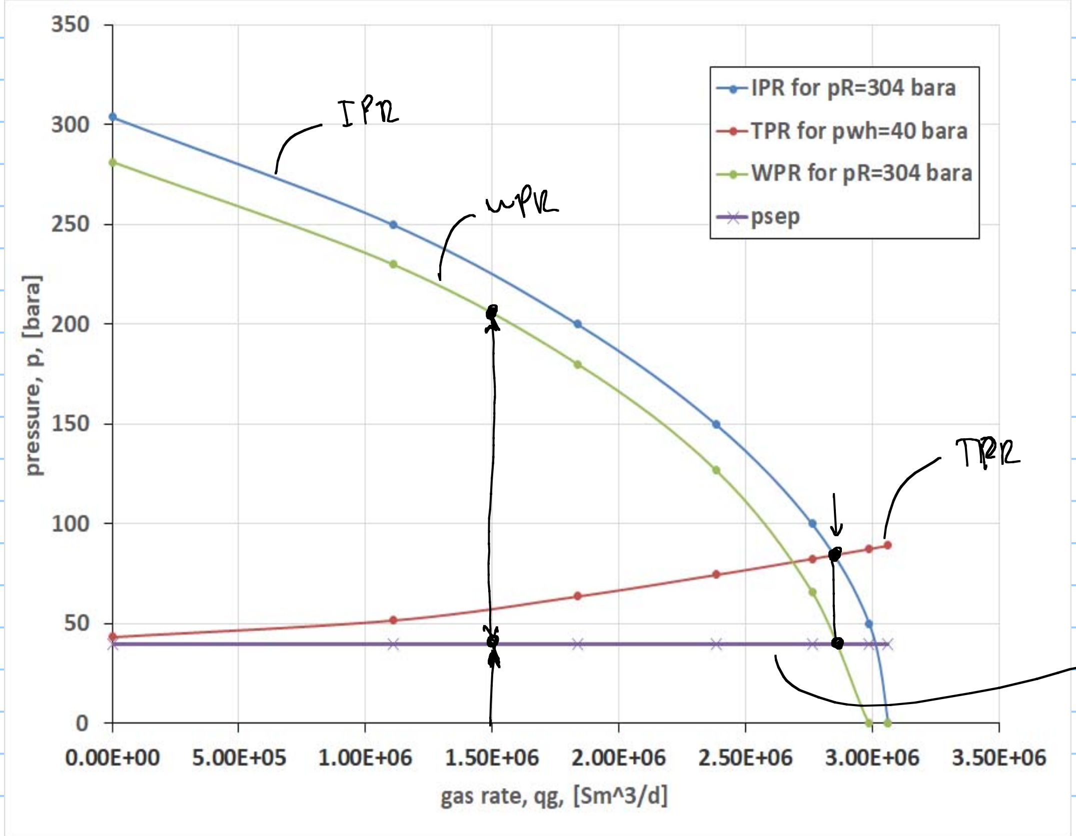


$$q_g = \overset{\checkmark}{C_T}\left(\frac{\overset{\checkmark}{P_{wf}^2}}{e^S} - \overset{?}{P_{wh}^2}\right)^{0.5}$$

$$P_{wh} = \left(\frac{P_{wf}^2}{e^S} - \left(\frac{q_s}{C_T}\right)^2\right)^{0.3}$$



WPR → well head performance relationship

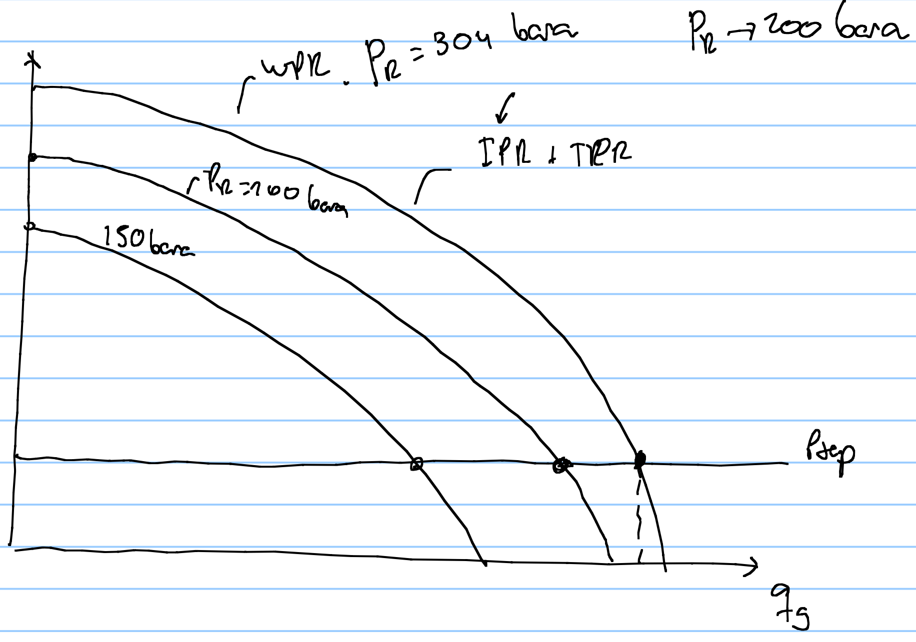


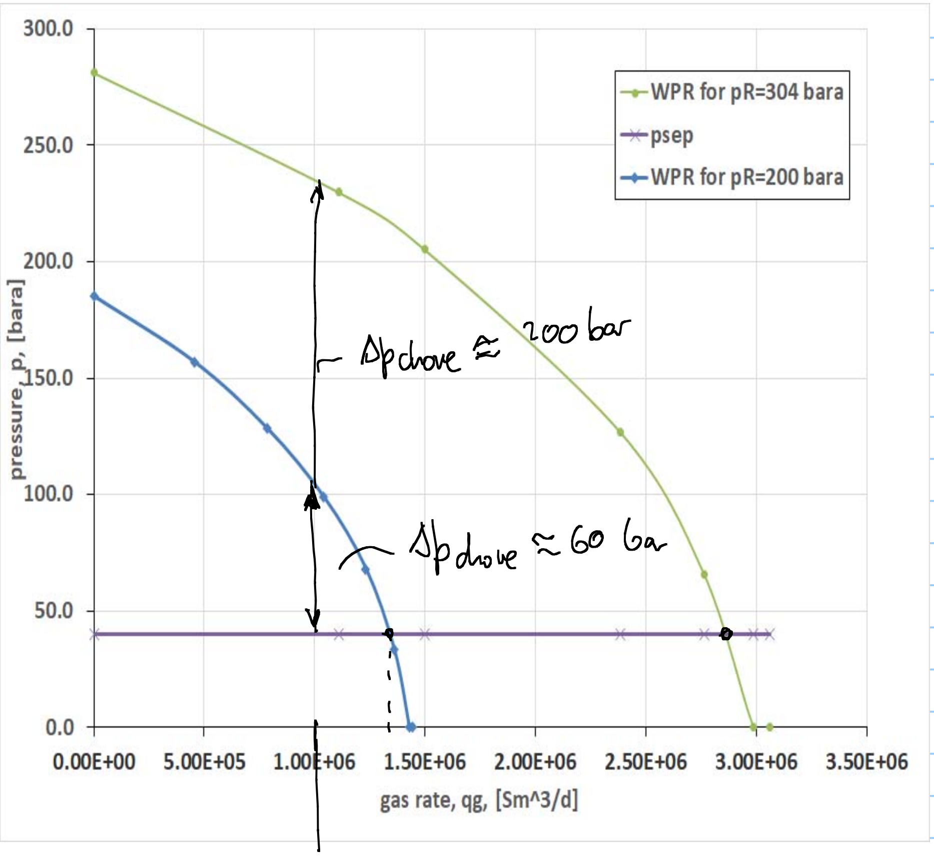
IPR + TPR
downhole equilibrium

Psep + WPR
wellhead equilibrium

to deliver a rate of 1.5 E6 Sm³/d I need to apply choking at wellhead for 165.2 bar Δp

- effect of depletion P_R ↓





1. E6 Sm^3/d

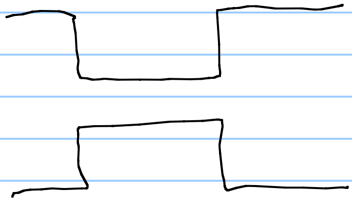
@ $P_R = 304$ bara

$q_g = 2.85$ E6 Sm^3/d

@ $P_R = 200$ bara

$q_g = 1.35$ E6 Sm^3/d

when $P_R = 304$ bara



when $P_R = 200$ bara