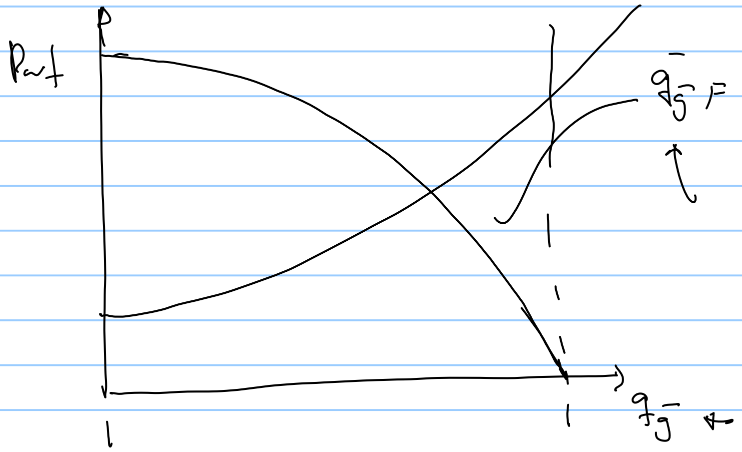
Day 3

http://folk.ntnu.no/stanko/Courses/POFE_UEM/2017/

- IPR - TPR equilibrium downhole

→ tubing equation $p_2^2 = \frac{p_1^2}{e^s} - \frac{q_g^2}{C_T^2}$ check

$q_g = C_R (p_R^2 - p_{wf}^2)^n$



Single_dry_gas_well_flow_equilibrium.xls - Compatibility Mode - Excel

Eva No 3			
p_R, Res pressure	304	bara	
C_R	104	Sm3/d/bar^2n	
n, exponent	0.9		
C_t, tubing	4.25E+04	$Sm^3/d/bar$	
s, elevation	0.155		
C_{fl}, flowline	1.25E+05	4.00E+04	$Sm^3/d/bar$
p_{sep}	40	bara	

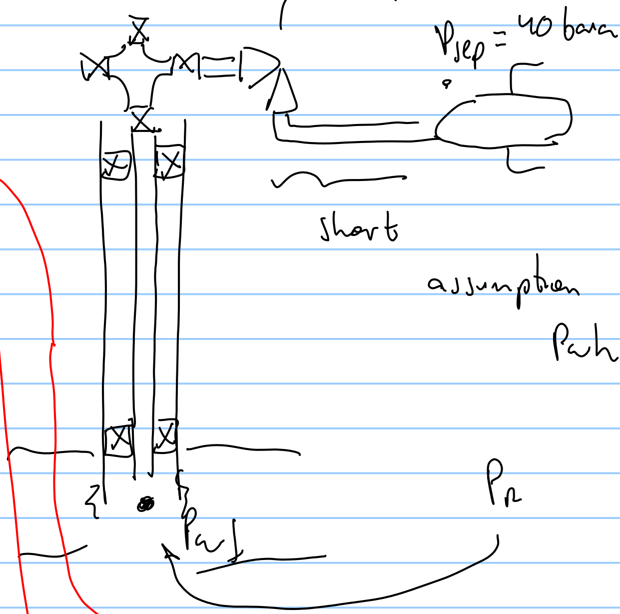
fully open

$p_{sep} = 40$ bara

short

assumption

$p_{wh} = const = p_{sep}$



available — independent variable

p_{wf} (bara)	IPR q_g $[Sm^3/d]$	TPR p_{wf} (bara) — required
p_R	$q_g = C_R (p_R^2 - p_{wf}^2)^n$	$p_1 = e^{s/2} \left(p_2^2 + \frac{q_g^2}{C_T^2} \right)^{0.5}$
$p_2 = p_R - 20$ bar		
$p_3 = p_2 - 20$		
$p_4 = p_3 - 20$		
0		

$p_2^2 = \frac{p_1^2}{e^s} - \frac{q_g^2}{C_T^2}$

to freeze cells in excel [F4]

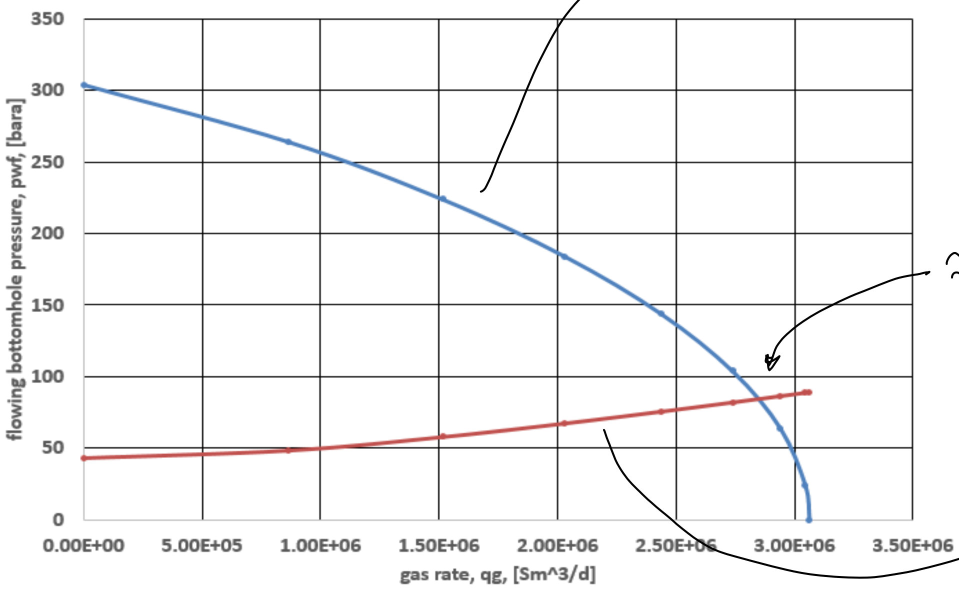
\$E\$4

	IPR	TPR
pwf_avail	qg	pwf_req
[bara]	[sm^3/d]	[bara]
(304)	0	43.2
264	866564	48.5
224	1514206	57.9
184	2031769	67.4
144	2437202	75.6
104	2738763	82.0
64	2940942	86.4
24	3046225	88.7
0	3063415	89.1

Pwf_aval − Pwf_req

304 − 43.2

$f_1(q_g)$



$\approx 2.8\ E6\ Sm^3/d$

$f_2(q_g)$

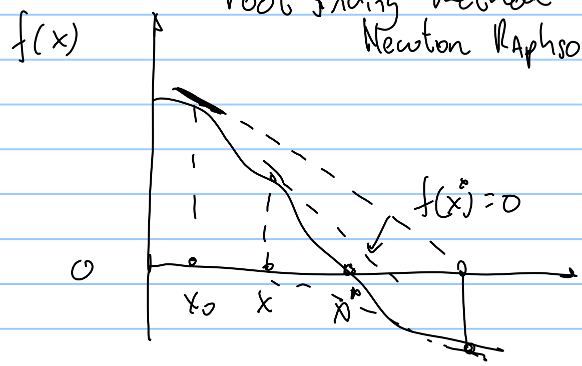
find $q_{g\,eq}^*$ that makes

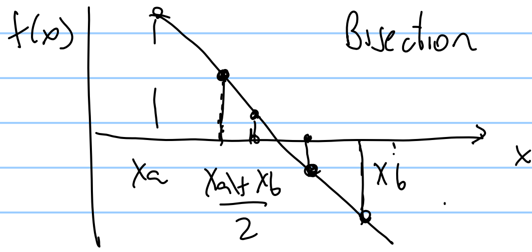
$f_1(q_g^*) = f_2(q_g^*)$

$f_3(q_g) = f_1(q_g) - f_2(q_g)$

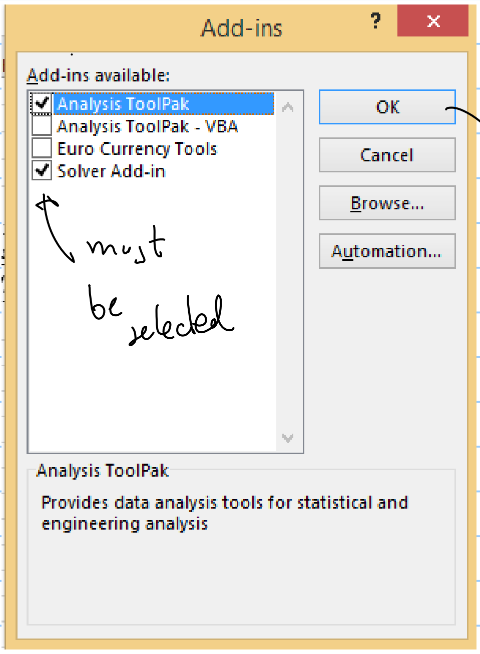
root finding method

Newton Raphson



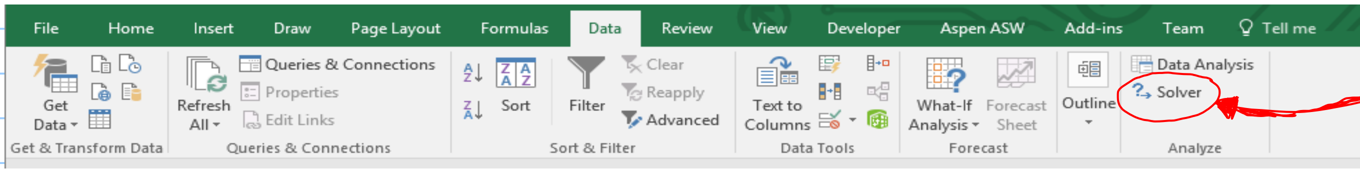


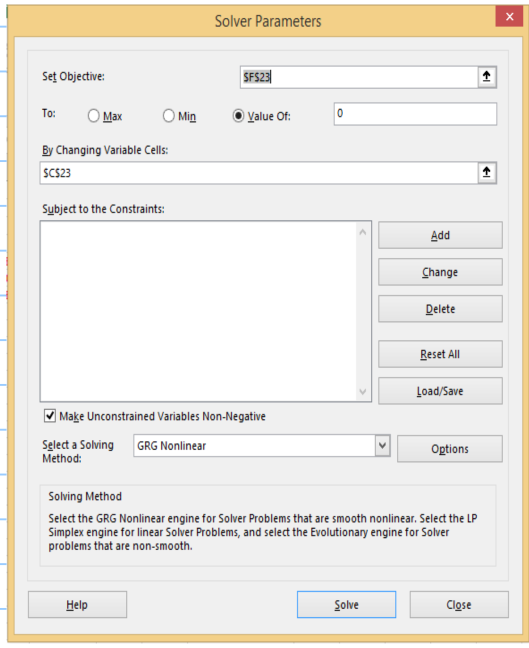
activate the solver in excel options, Add-in, go...



click "ok"

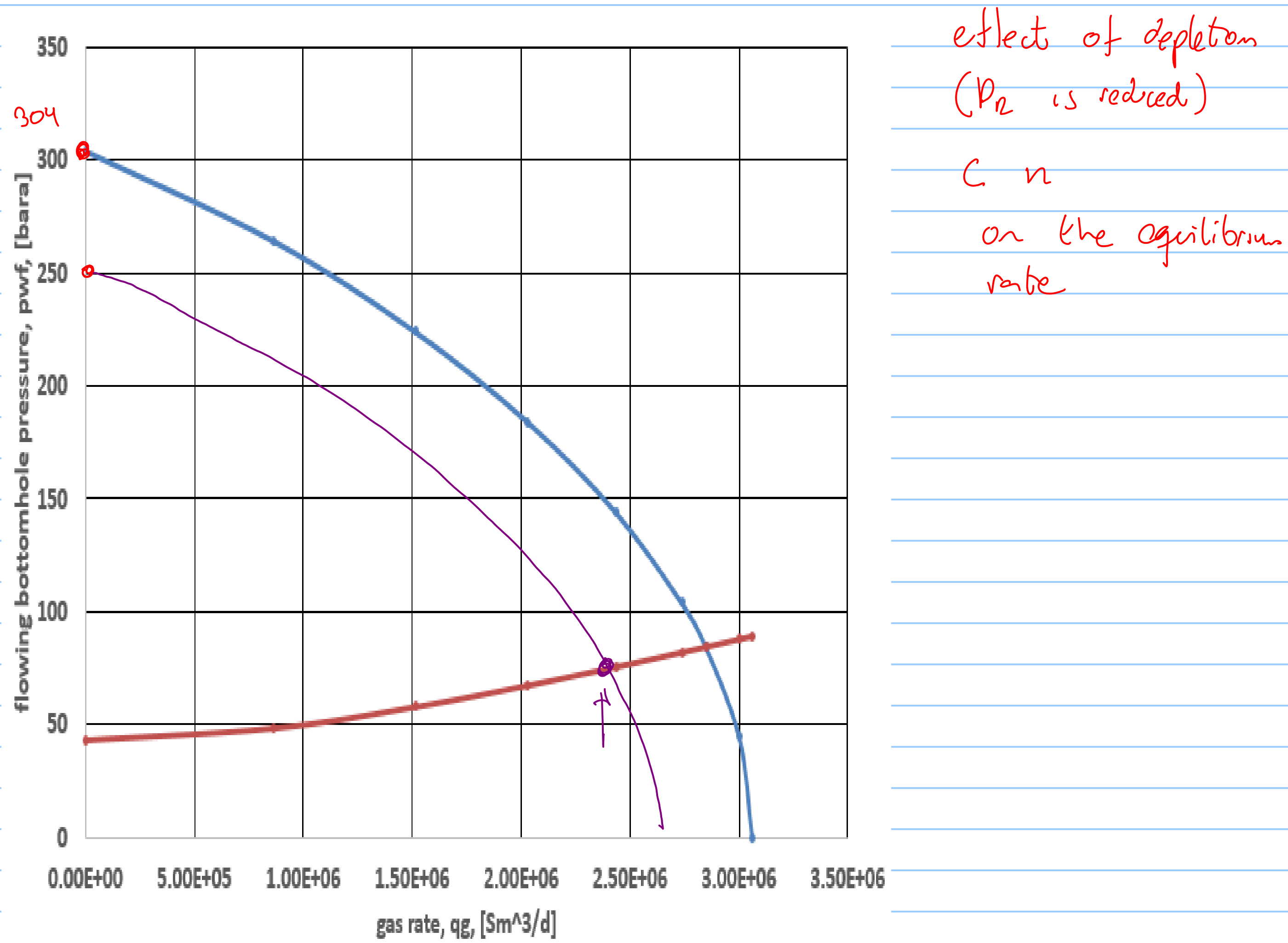
must be selected

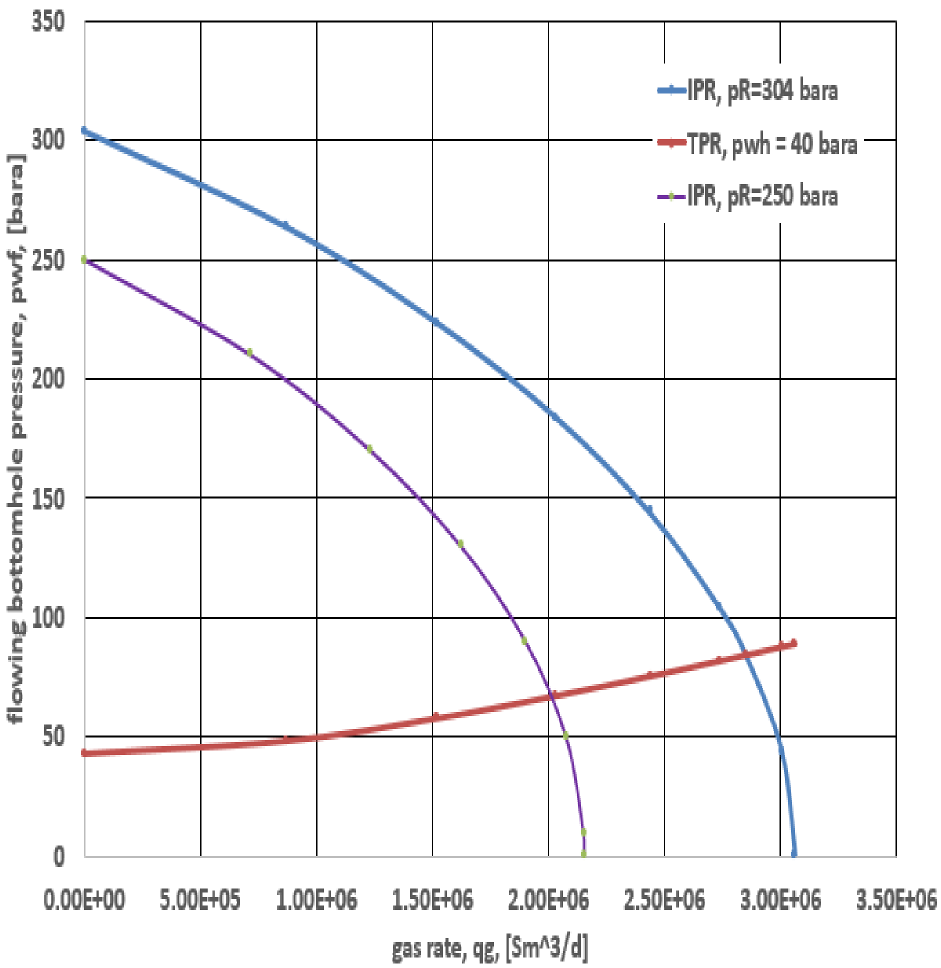




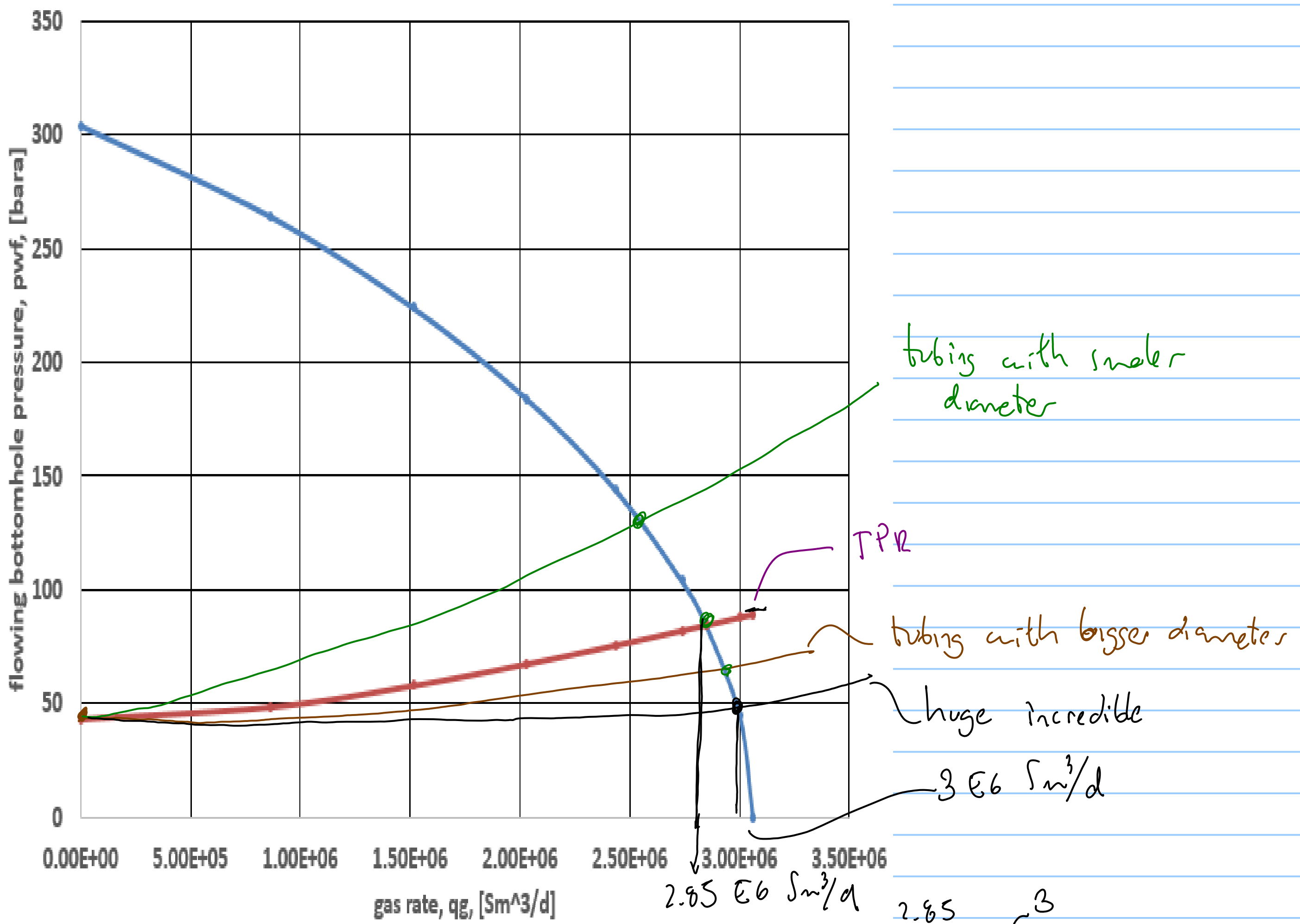
	IPR	TPR	
pwf_avail	qg	pwf_req	pwf_avail_pwf_requ
[bara]	[sm^3/d]	[bara]	[bara]
304	0	43.2	260.8
264	866564	48.5	215.5
224	1514206	57.9	166.1
184	2031769	67.4	116.6
144	2437202	75.6	68.4
104	2738763	82.0	22.0
84.4	2850168	84.4	0.0
44.4	3004597	87.8	-43.4
0	3063415	89.1	-89.1

← solution ✓


effect of depletion
(p_R is reduced)
C n
on the equilibrium rate
304
flowing bottomhole pressure, pwf, [bara]
gas rate, qg, [Sm^3/d]
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06


IPR, pR=304 bara
TPR, pwh = 40 bara
IPR, pR=250 bara
flowing bottomhole pressure, pwf, [bara]
gas rate, qg, [Sm^3/d]

changing tubing size (ID).



relative difference = $\dfrac{(-q_{g\,orig} + q_{g\,new})}{q_{g\,original}} \times 100$ (2.85, 3; $q_{g\,original} \approx 2.85$)

5% increase in the rate of well.

Our well is NOT tubing-restricted

$$p_2^2 = \frac{p_1^2}{e^S} - \frac{q_g^2}{C_T^2}$$

$$C_T = \frac{\pi}{4}\left(\frac{R}{M_{air}}\right)^{0.5}\frac{T_{sc}}{p_{sc}}\left[\frac{\phi^5}{\gamma_g \cdot f \cdot \bar{z}\,\bar{T}\,L}\right]^{0.5}\left[\frac{S\,e^S}{e^S-1}\right]^{0.5}$$

an increase in ϕ → increase C_T

by increasing C_T we can assess what would be the effect of a bigger or smaller diameter if only diameter changes then

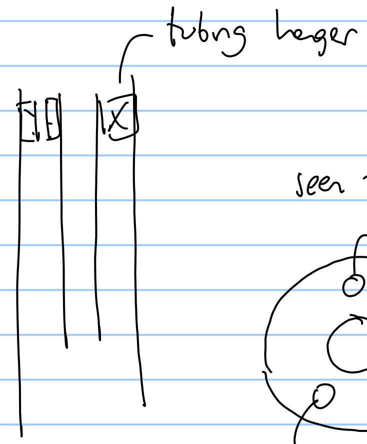
$$C_{T_1} = f(\Phi_1)$$
$$C_{T_2} = f(\Phi_2)$$

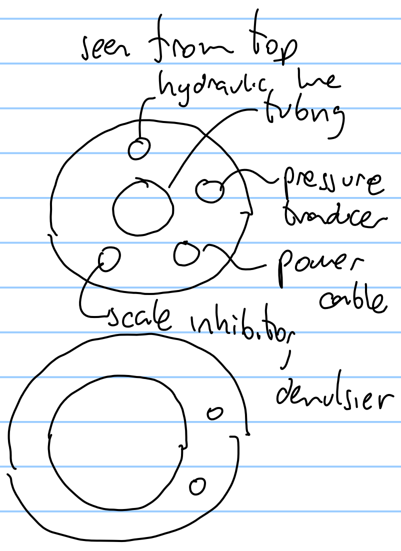
$$\frac{C_{T_1}}{C_{T_2}} = \left(\frac{\Phi_1^5}{\Phi_2^5}\right)^{0.5} = \frac{\Phi_1^{2.5}}{\Phi_2^{2.5}}$$

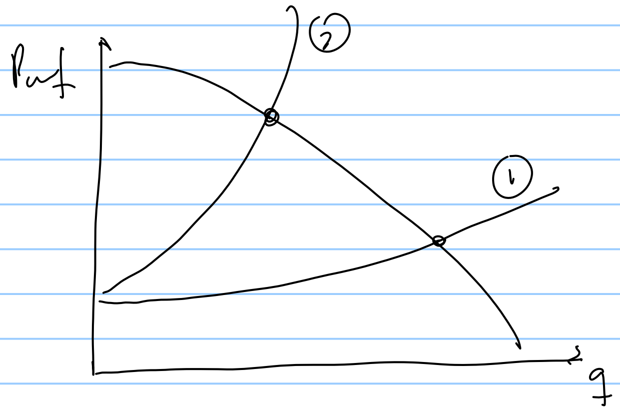
$$C_{T_2} = C_{T_1}\frac{\Phi_2^{2.5}}{(\Phi_1)^{2.5}}$$

tubing sizing.

- ID of production casing
- size and amounts of holes on the tubing hanger
- reduce Δp tubing and increase production





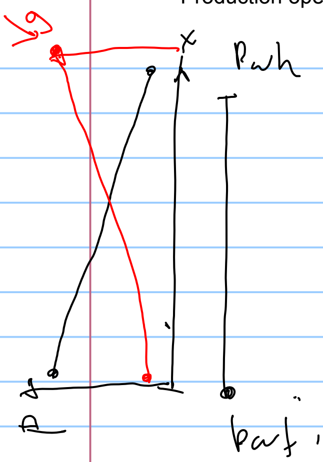


① is better than nr 2

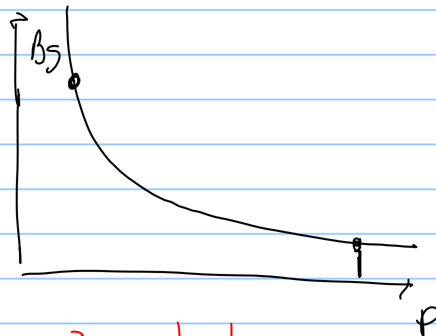
- Erosion $V_{gas} \le V_{erosional}$ velocity → API 14 E

$$\text{Limit } V_{erosional} = \frac{C}{\sqrt{\rho_m}} \qquad C: 100, 120$$

$V_{erosional}$ [ft/s], ρ_m [lb/ft³]



$$V_{gas} = \frac{q_g @ p,T}{A} = \frac{q_{\bar{g}} \cdot B_g(p,T)}{A}$$

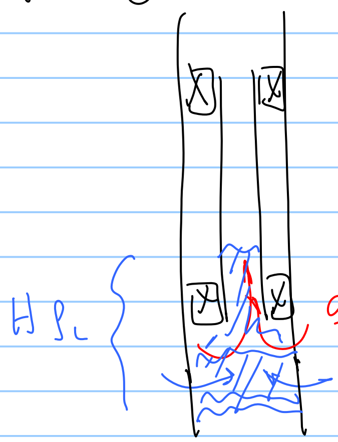


if wellhead $V_g \geq V_{erosional}$ velocity ⇒ I might have erosion in tubing

- avoid liquid loading $v_g \leq V_{erosional}$ velocity

  $V_{gas} \geq V_{Turner}$

- if producing with liquid then



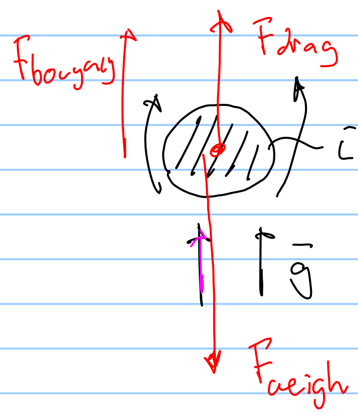
$q_{\bar{g}}$ ↑ such it can carry $q_{\tilde{l}}$

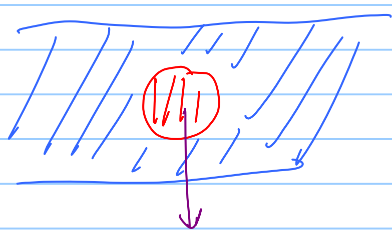
$q_{\bar{l}}$ = condensate water

liquid accumulation in wellbore

↳ liquid loading

Force balance on a droplet





$$F_{drag} = F_{weigh}$$

$$(\rho_l - \rho_g)\, g \cdot V_d$$

$$\frac{1}{2} C_D \rho_g \cdot V_g^2 A_d = (\rho_l - \rho_{\bar{g}})\, g \cdot \frac{\pi \phi^3}{6}$$

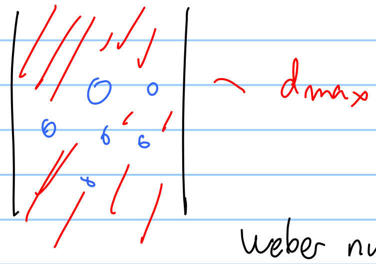
$$A_d = \frac{\pi \phi^2}{4}$$

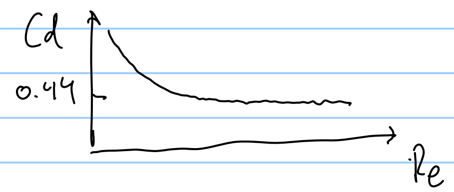
$\rho_L \approx cont$ $PV = ZnRT$

$$V = \sqrt{\frac{\Phi g (\rho_L - \rho_g)}{C_d \rho_g} \frac{4}{3}} \quad (1)$$

Hinze

C_d in the turbulent region is 0.44





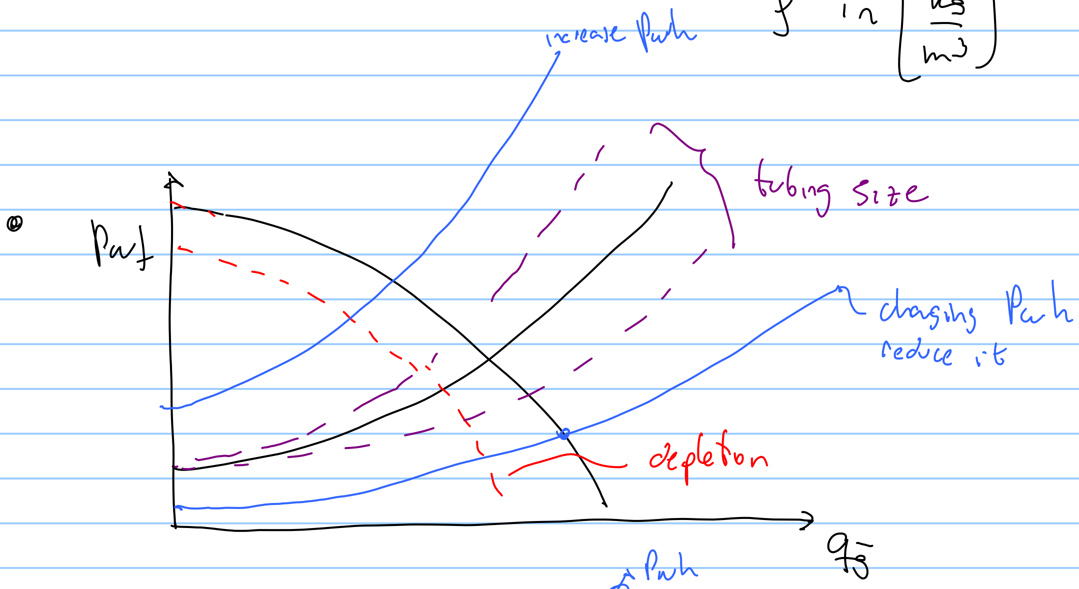
Weber number $= \frac{(\rho_g u_g^2 \Phi)}{\sigma}$

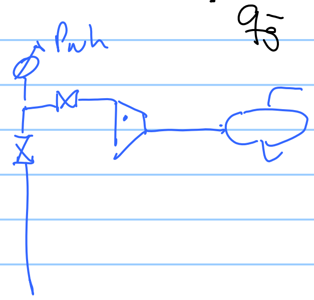
when $N_w = 30$ that gives you Φ_{max}

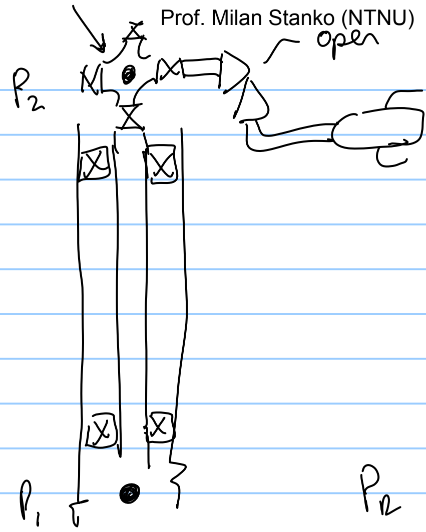
$$\frac{u_g^2 \rho_g \Phi_{max}}{\sigma} = 30 \quad (2)$$ substitute eq (2) in (1)

Turner equation : $V = 5.46 \left[\frac{\sigma^{0.25} (\rho_L - \rho_g)^{0.25}}{\rho_g^{0.5}} \right]$

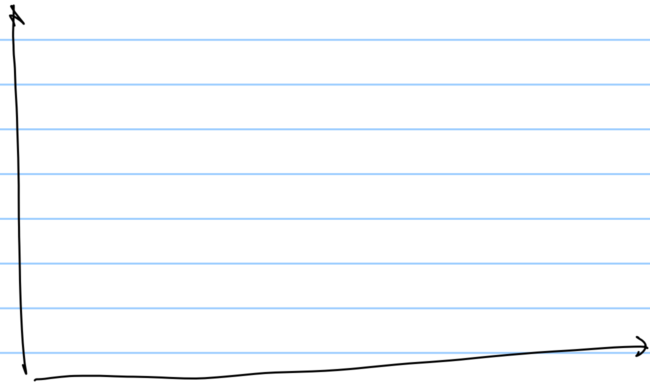
ρ in $\left[\frac{kg}{m^3}\right]$ σ in $\left[\frac{N}{m}\right]$

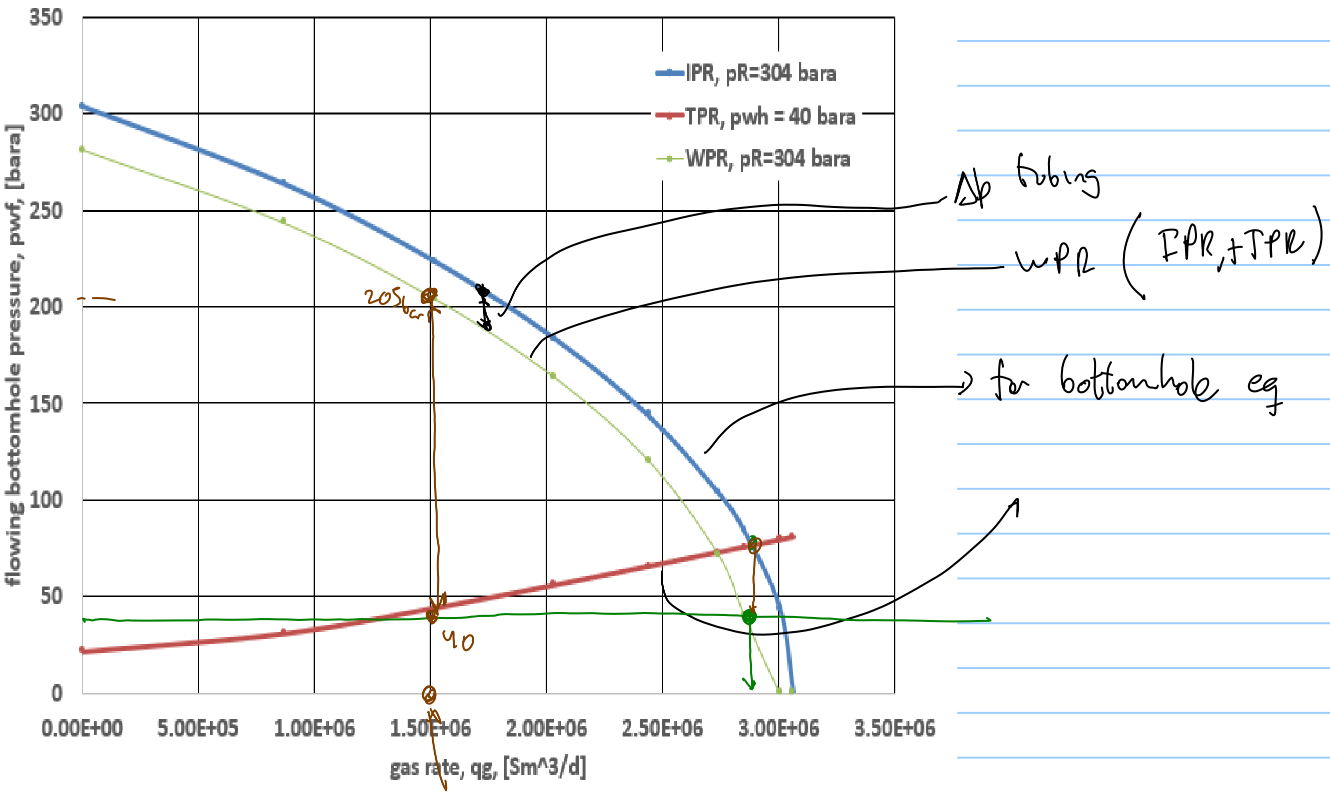






Perform wellhead equilibrium





$\Delta p_{choke} = 205 - 40 = 4.65$ bar

(3) Homework.

Perform flow equilibrium for this class exercise but using the wellhead as the equilibrium point.

- Compute WPR
- WPR − p_{sep}
- find q_g such as $WPR - p_{sep} = 0$
- make plot

find Δp choke such as $q_g = 2.E06$ Sm^3/d