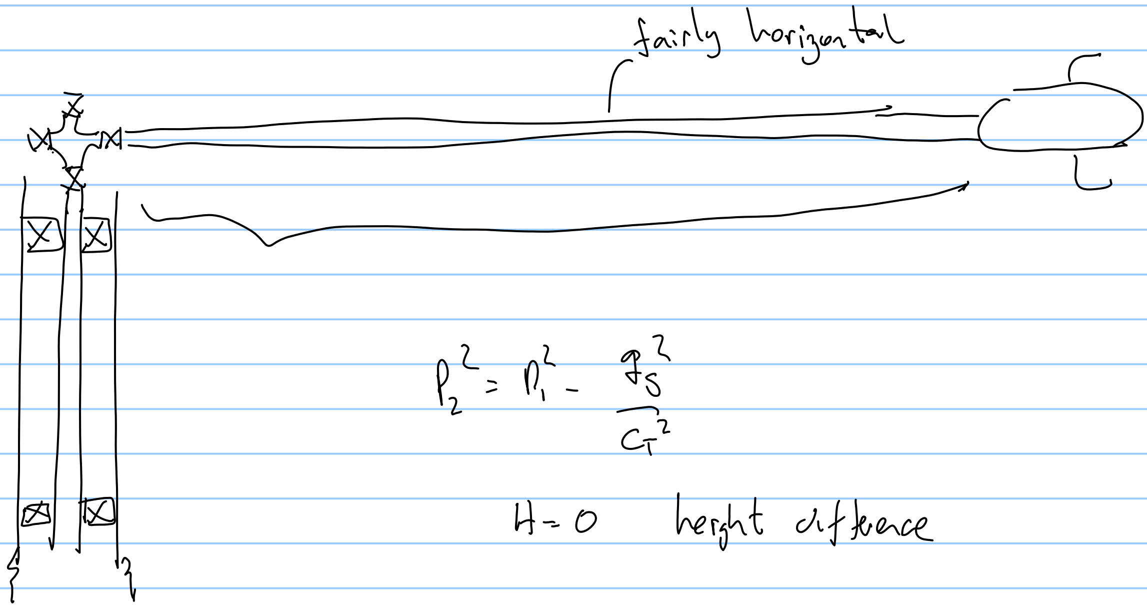
Day 4 :



$$p_2^2 = p_1^2 - \frac{q_s^2}{C_T^2}$$

$H = 0$ height difference

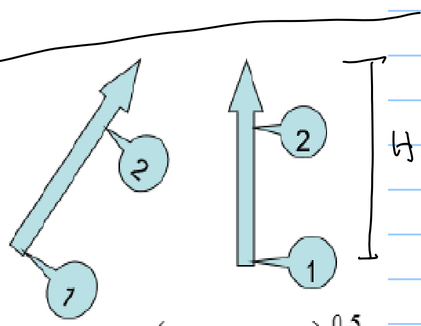
Tubing flow Equation-Dry gas

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

$Z_{av} = f(p_{av}, T_{av})$

$C_T = f(p_{av})$

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



$z_2 - z_1 = H$

z

$H = 0$

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

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

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

if H $S = 0$

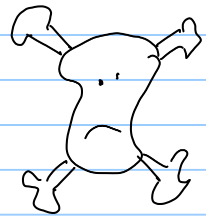
$$p_2^2 = \frac{p_1^2}{e^0} - \frac{q_s^2}{C_T^2}$$

1

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

(S → 0, e^S → 1)

$$\sqrt{p_1^2 - p_2^2} = q_s$$



$$\lim_{s \to 0} \left[\frac{s\, e^{s}}{e^{s} - 1} \right]^{0.5} \quad \frac{0}{0}$$

l'Hopital

$$\lim_{s \to 0} \frac{\left(e^{s} + e^{s} \cdot s\right)}{e^{s}} = 1$$

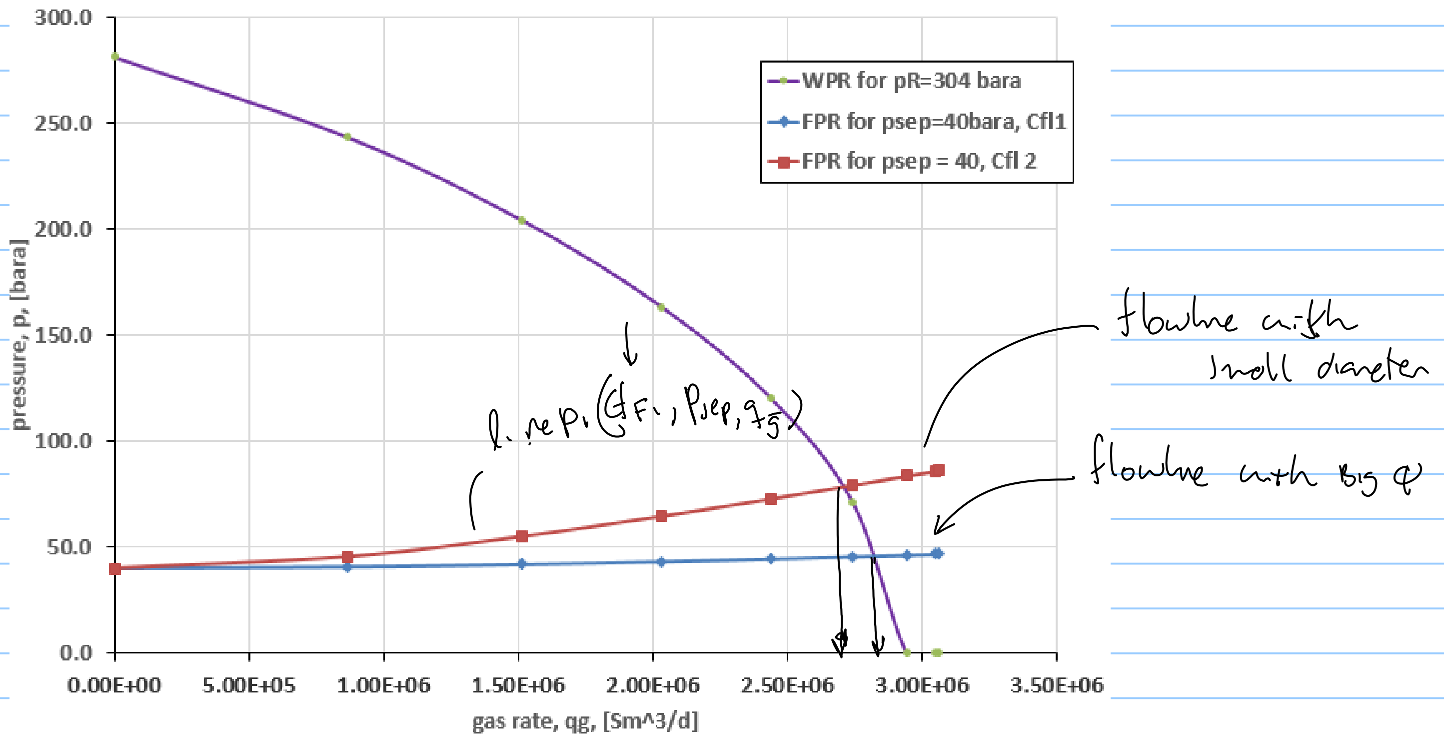
C_f for horizontal flowline is:

$$C_f = \frac{\pi}{4} \left(\frac{R}{M_{air}} \right)^{0.5} \cdot \frac{T_s}{p_{sc}} \left[\frac{D^{5}}{\gamma_g\, f\, \bar{z}\, \bar{T}\, L} \right]^{0.5}$$

→ flowline performance relationship

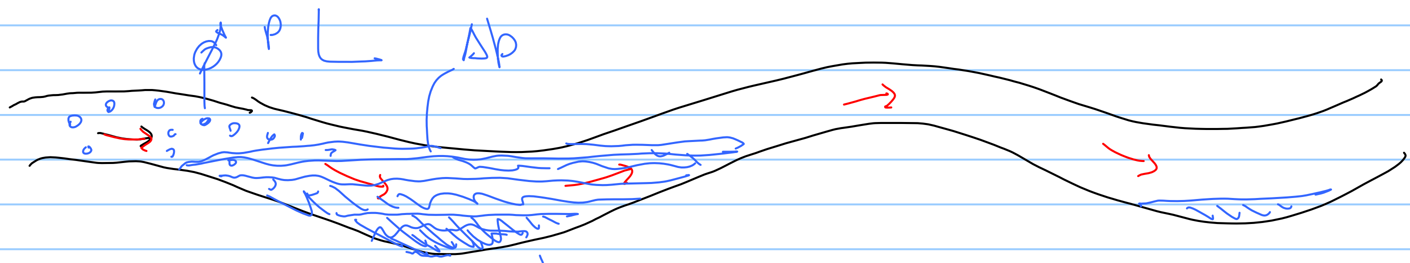
Class exercise   WPR vs FPR

	IPR	TPR			WPR	PPR for Cfl1	PPR for Cfl2
pwf_avail	qg	pwf_req	pwf_avail-pwf_req		pwh_avail	pwh_req	pwh_req
[bara]	[Sm^3/d]	[bara]	[bara]		[bara]	[bara]	[bara]
304	0.00E+00	43.2	260.8		281.3	40.00	40.0
264	8.67E+05	48.5	215.5		243.5	40.60	45.5
224	1.51E+06	57.9	166.1		204.2	41.79	55.1
184	2.03E+06	67.4	116.6		163.4	43.18	64.7
144	2.44E+06	75.6	68.4		120.3	44.50	72.9
104	2.74E+06	82.0	22.0		71.5	45.61	79.3
64	2.94E+06	86.4	-22.4		#VALUE!	46.41	83.7
24	3.05E+06	88.7	-64.7		#VALUE!	46.84	86.0
0	3.06E+06	89.1	-89.1		#VALUE!	46.91	86.4

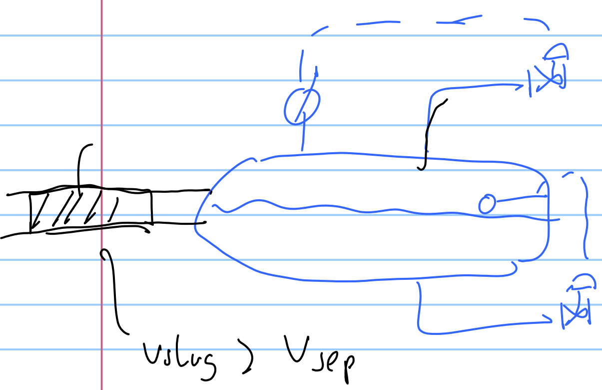


factors that affect the sizing of gas flowlines:

- Cost ↑ Φ ↑ Cost, ↑ USD
- pressure drop ↓ pressure drop ↑ Φ
- liquid transportation



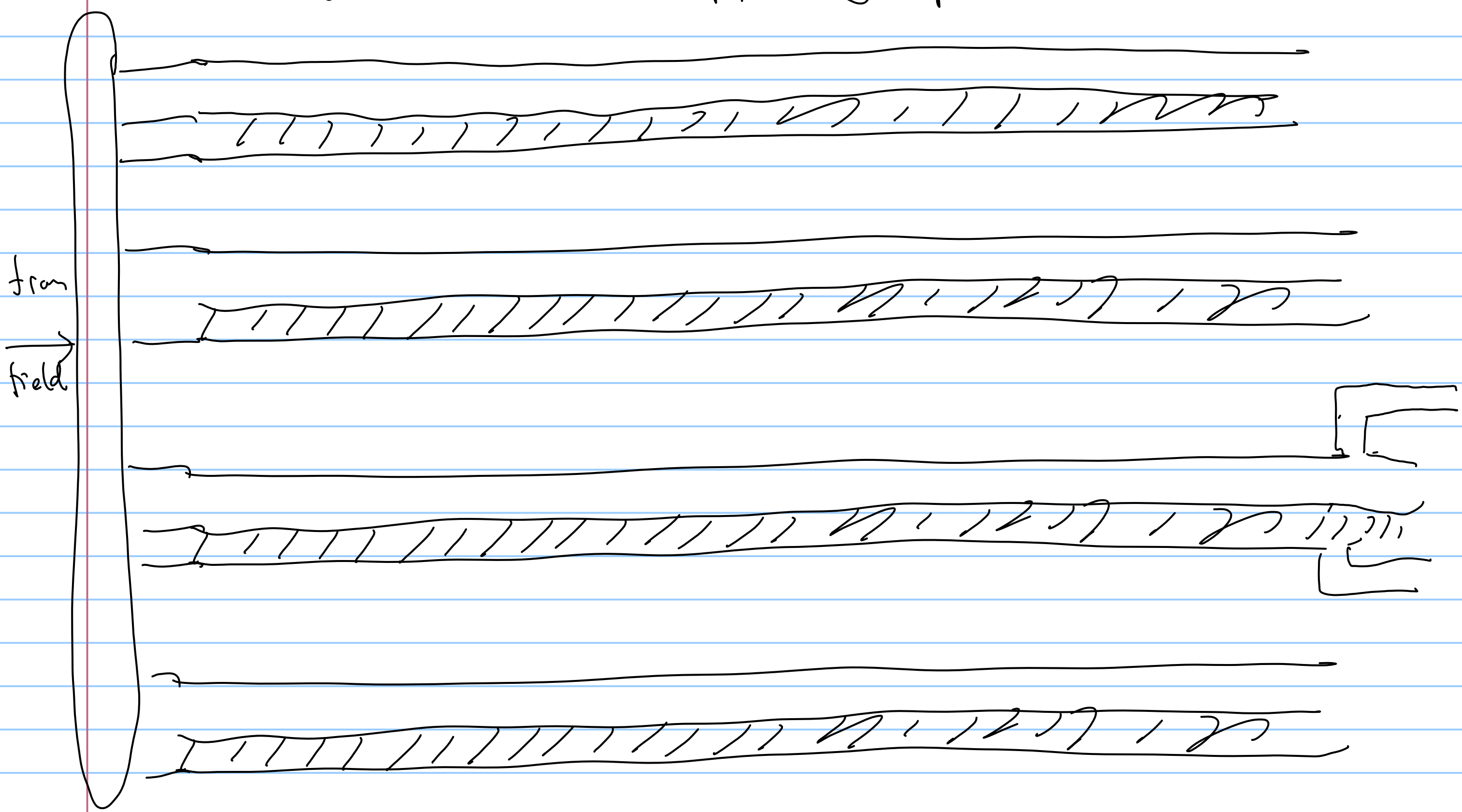
- increased Δp
- pipe blockages
- Corrosion
- Hydrates
- Slugging intermittent production of batches of liquid and gas



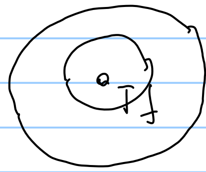
V_{gas} should be high enough to carry liquids and avoid accumulation.

- If slugging cannot be avoided
  - Snøhvit ~ subsea gas field 146 km from coast
  - Block-2 Tanzania
  - Coral

Slug catcher a multi pipe long separator

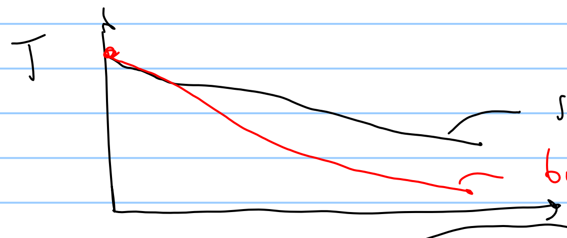


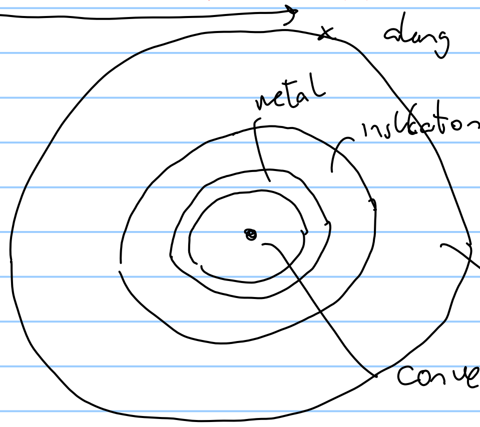
- Cooling of fluid



pipe cross section

Tamb





convection + inner conduction in pipe + conduction in the insulating layer

$$A \cdot U \left(T_{fluid} - T_{amb}\right) = q$$

$A \cdot U$: universal heat transfer coefficient (includes conduction, convection, radiation)

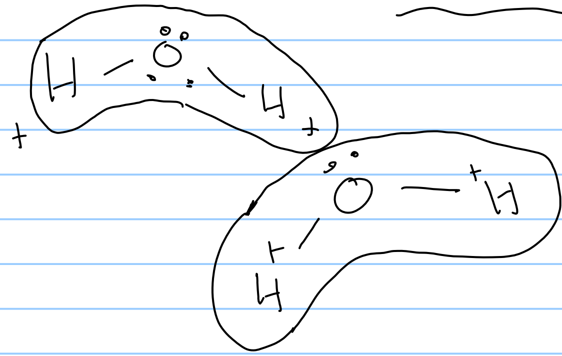
Lower Temperature → more condensation of liquid

Risk forming Hydrates

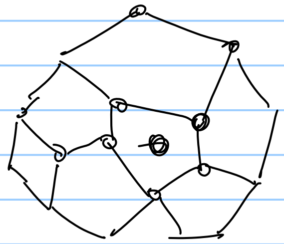
Short comment on Hydrates

at $p = 12$ bara

$T = 4\,°C$



Ice with HC



CH_4 CO_2

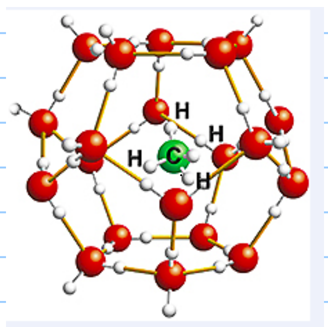
C_2H_6 N_2

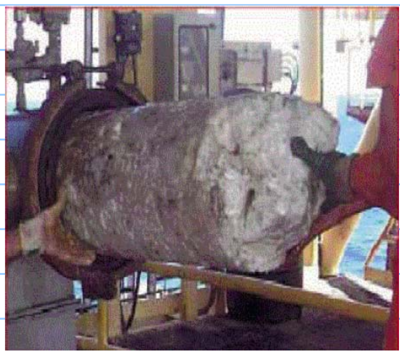
C_3H_8

C_4H_{10}

necessary conditions:

- low T
- liquid water (free water)
- Small HC molecules

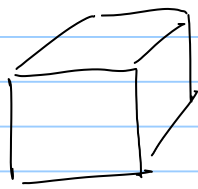




$4\,CH_4\ 23\,H_2O$ ~ $MW = 478\ \frac{kg}{kmol}$

$\rho \simeq 900\ kg/m^3$

1 m^3

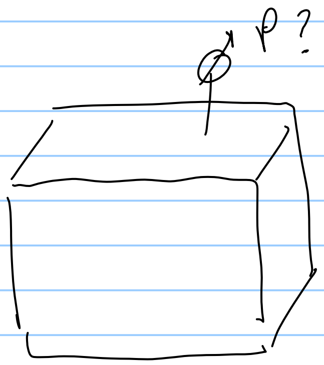


How much methane in a 1 m^3 of Hydrate methane clathrate

$$Mass = \rho \cdot Vol = 900 \cdot 1 = 900\ kg$$

$$n = \frac{900\ kg}{478} = 1.88\ kmol\ Hydrate$$

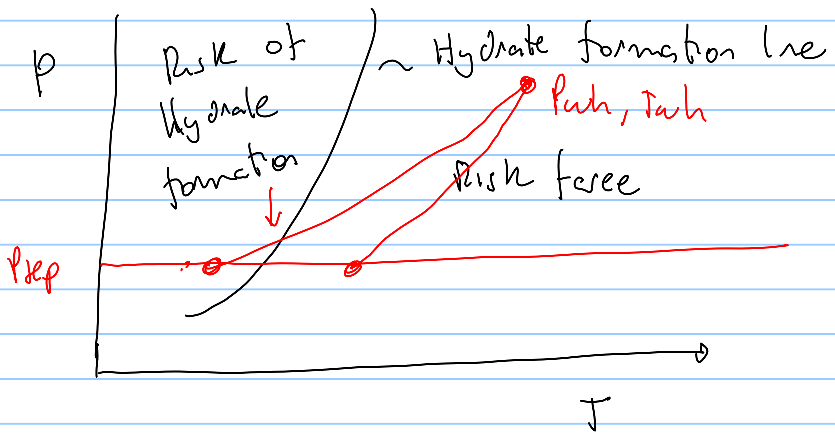
$$n_{CH_4} = 7.53\ kmoles$$

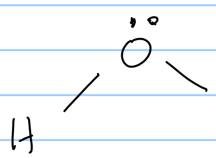


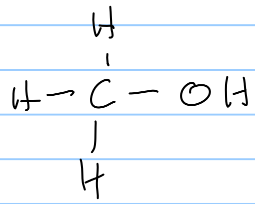
$$V_{sc} = n \cdot 23.67$$

$$V_{sc} = 178\ Sm^3\ of\ CH_4$$

$$p = \frac{7.53 \cdot R\ T_{sc}}{1\ m^3} \simeq 180\ bara$$

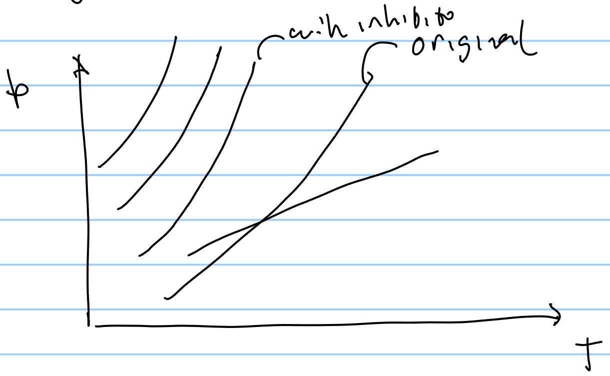




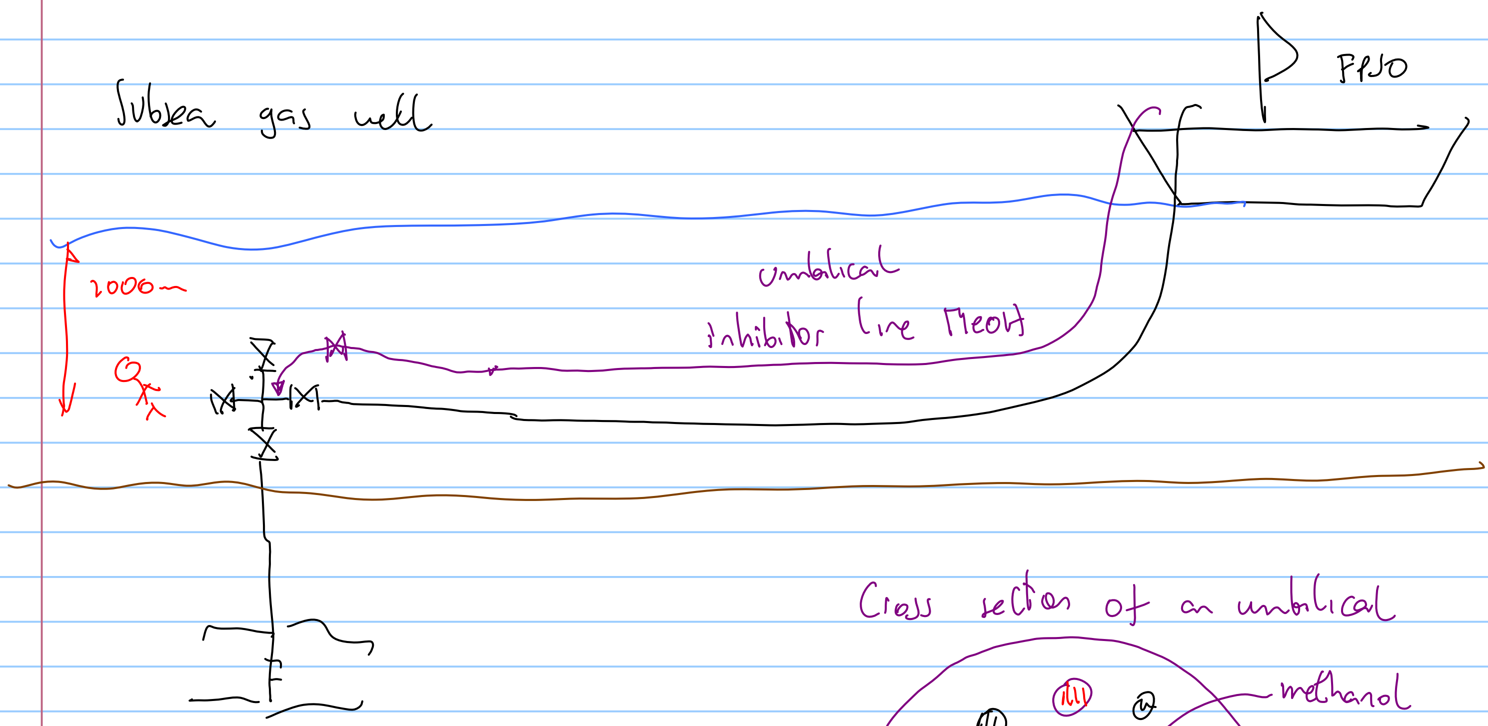


methanol
TEG
MEG

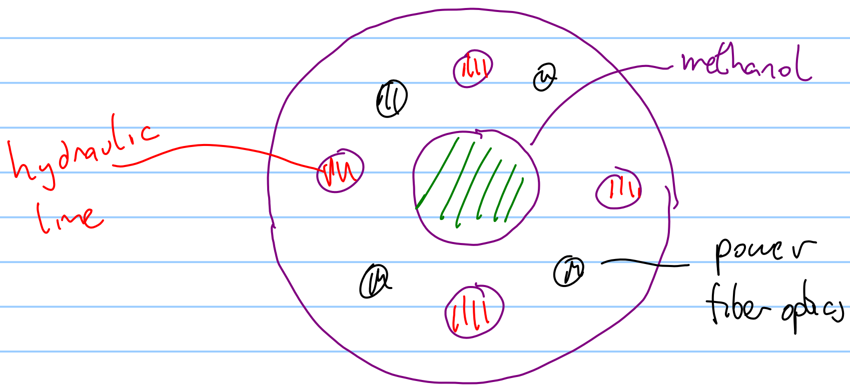
Using hydrate inhibitors to change the hydrate formation line



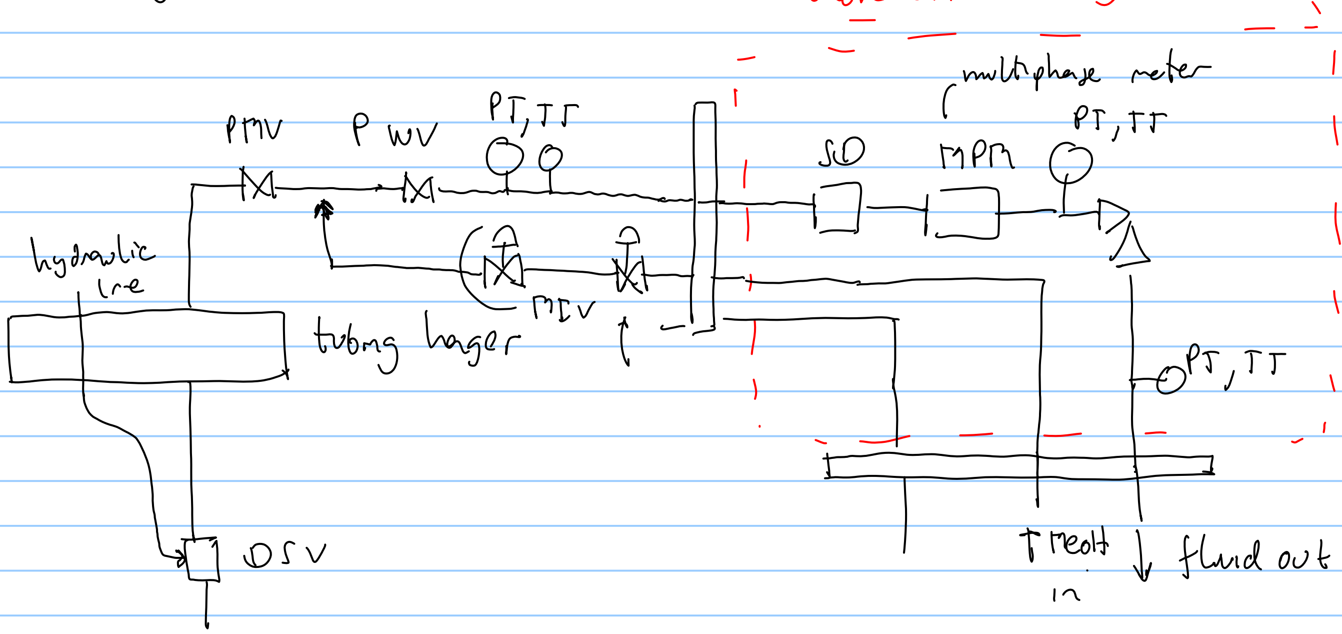
Subsea gas well



Cross section of an umbilical



flow diagram of a subsea well



SD .. Sand detection

PWV production wing valve

PMV ... production master valve

PT pressure transducer

TT temperature transducer

MIV .. Methanol injection valve

- Better estimation of C_T

when using P_R and P_{in} to estimate P_{av}, $\frac{304+40}{2}$

I obtain $C_T = 42500 \ Sm^3/d/bara$

$S = 0.153$

the equilibrium P_{wf} is actually 84.378 bara way different than $P_R = 304$ bara.

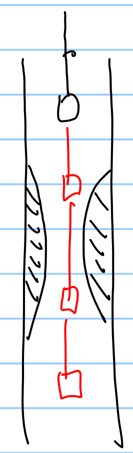
Using this $P_{av} = \frac{84.378+40}{2}$ I obtain $C_T = 41900 \ Sm^3/d/bara$

$S = 0.151$

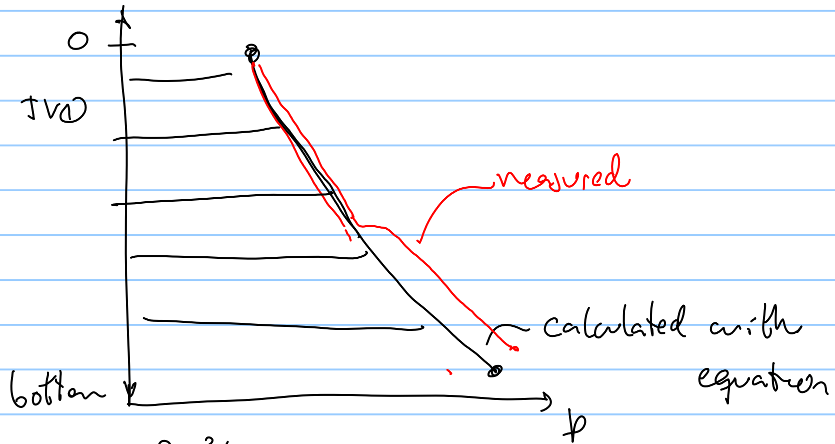
However the equilibrium point is not affected dramatically !

Pressure traverse calculation

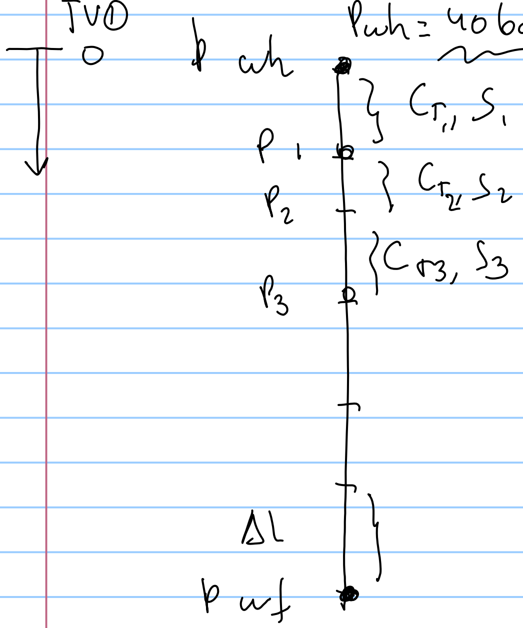
pressure distribution along tubing



example .. traverse calculation can help diagnose a well with scaling.

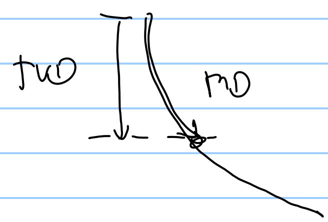


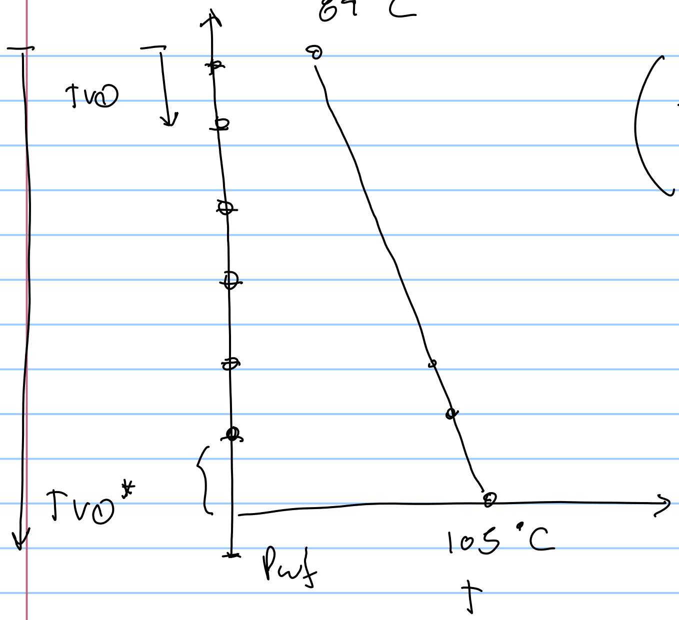
true vertical depth



Calculate p distribution along tubing for equilibrium rate

MD measured depth





$$\left(\frac{105°C - 89}{TVD^* - 0}\right) = \left(\frac{105 - T}{TVD^* - TVD}\right)$$

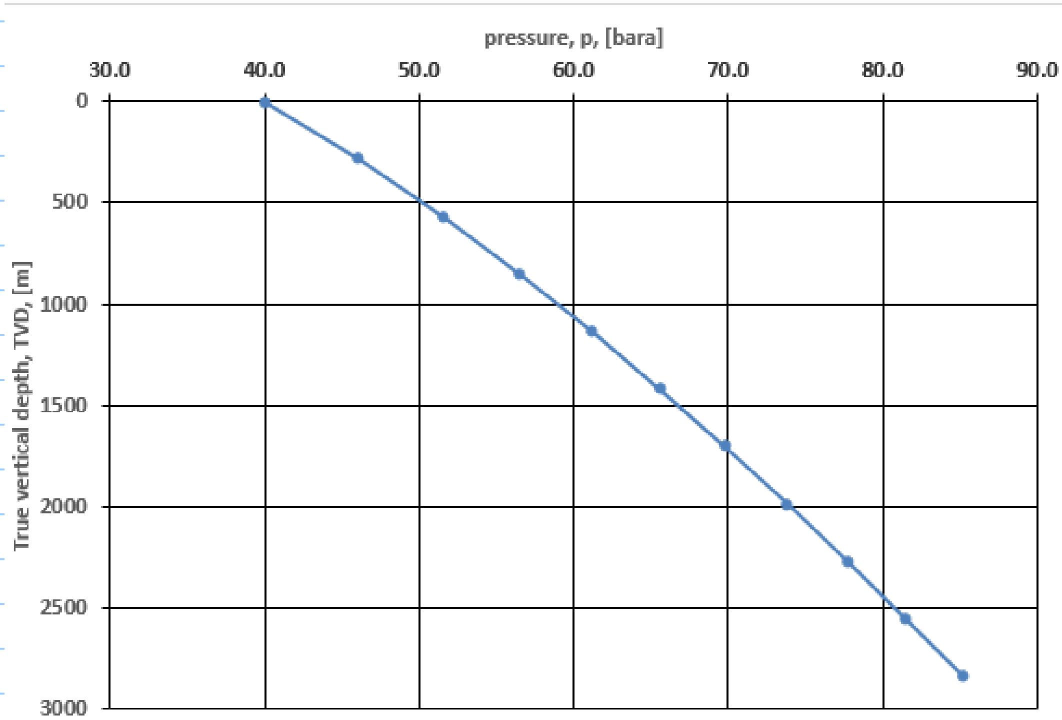
from equilibrium analysis $P_{wf\,eq} = 84.375$ bara

$P_{wh} = 40$ bar

| i assume | Δp = const for every section.

$$\Delta p = \frac{(P_{wf\,eq} - P_{wh})}{N_{section}} = \frac{84.378 - 40}{10}$$

Tubing MD [m]	2837							
Tubing TVD [m]	2837							
Tubing ID [m]	0.157							
Tubing Cross section A [m^2]	0.019							
Wellhead pressure [bara]	40							
Gas gravity	0.55							
Twf [K]	378	104.85						
Twh [K]	360	86.85						
pR [bara]	304			DP	4.4378			
friction factor [-]	0.012							
qg [Sm^3/d]	2.85E+06							
liquid density [kg/m^3]	8.97E+02							
TVD	T	Tav	passumed	Pav	Zav	S	Ct	p
[m]	[K]	[K]	[bara]	[bara]	[-]	[-]	[Sm^3/bar]	[bara]
0	360.0	360.9	40.0	42.2	0.967	0.015	1.3E+05	40.0
284	361.8	362.7	44.4	46.7	0.964	0.015	1.3E+05	46.0
567	363.6	364.5	48.9	51.1	0.962	0.015	1.3E+05	51.5
851	365.4	366.3	53.3	55.5	0.960	0.015	1.3E+05	56.5
1135	367.2	368.1	57.8	60.0	0.959	0.015	1.3E+05	61.1
1418	369.0	369.9	62.2	64.4	0.957	0.015	1.3E+05	65.6
1702	370.8	371.7	66.6	68.8	0.956	0.015	1.3E+05	69.8
1986	372.6	373.5	71.1	73.3	0.955	0.015	1.3E+05	73.8
2269	374.4	375.3	75.5	77.7	0.954	0.015	1.3E+05	77.7
2553	376.2	377.1	79.9	82.2	0.954	0.015	1.3E+05	81.4
2837	378.0		84.4					85.1



- Homework: Solve this exense by yourself at home
  Find p vs TVD for the well studied in class!
  for p_{wh} = 40 bara and q_g = 2.85 E6 Sm^3/d