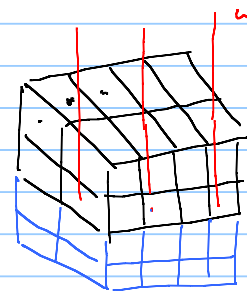
- Production scheduling
- Dry gas equations
- introduction to excel VBA (functions)
- class exercise

Production profiles (field performance) are typically estimated with:

examples of commercial software
- ECLIPSE
- CMG
- Intersect
- Nexus
- MRST
- OPM
- SENSOR

- Reservoir simulator.

well
- target rate q_T
- minimum bottom hole pressure →



try to produce target rate, if not, change to minimum bottomhole pressure

in FD, a workflow that is typically used by oil companies to compute realistic production profiles is:

Reservoir engineering
- 3D reservoir model

q_{Target} rates (t) ~ $q(t)$

$P_{wfmin}(t)$ $P_{wf}(t)$

Production and facilities engineering

production simulator (steady-state)
check at each point in time is

$q(t)$, $P_{wf}(t)$ } feasible?

↳ is it enough to reach separator?

example of commercial software
- Pipesim
- Prosper, gap
- Olga
- pipesoft
- ReO

if not, try to make it feasible

flag years in which it is not possible to produce the rates

send feedback to

At early FD, there is usually no information on wells, gathering network or facilities, thus they are typically neglected

- Reservoir simulator "coupled" with a well + gathering network simulator in a IAM software
  - ↳ integrated asset management

examples of software
- Resolve
- Avocet
- Pipe-it (now Tieto)

- $\underbrace{\text{material balance}}_{\text{single tank}}$ + $\underbrace{\text{Inflow performance relationship}}$

P_R
S_o vs t
S_g
S_w

$q = f(P_R, P_{wf})$

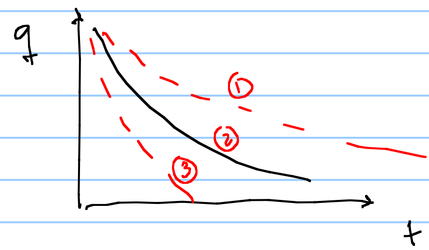
needs assumption on $P_{wf\,min}$

- material balance + well + network model

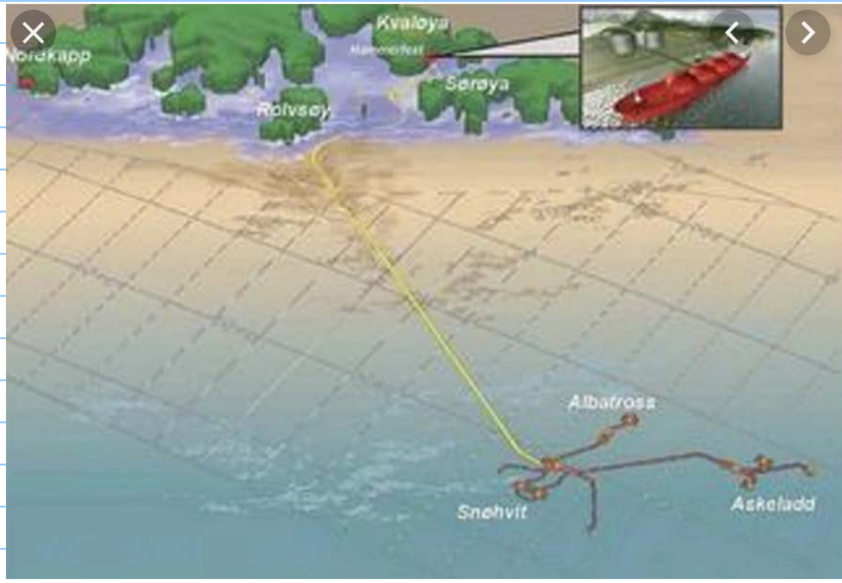
P_R
S_o vs t
S_g
S_w

$q = f(P_R, P_{sep})$

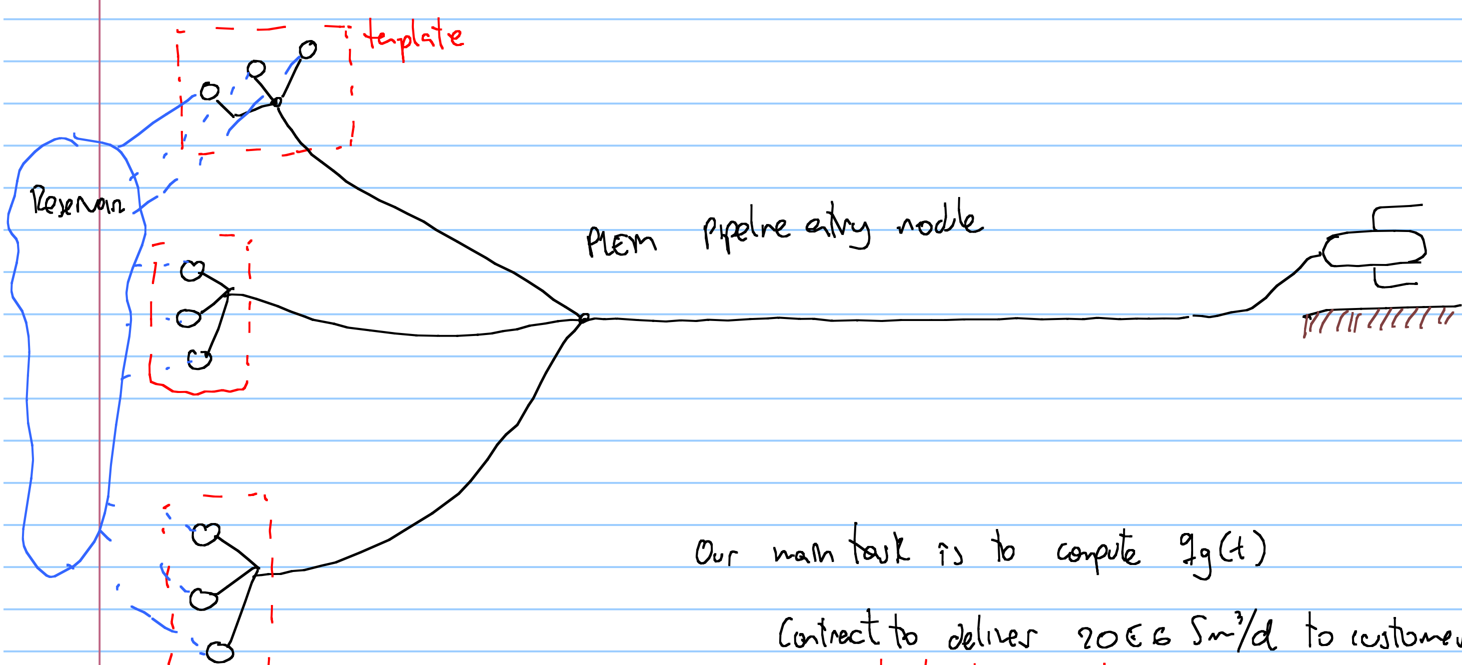
- Decline or type curves { very early FD }



Class exercise: Production scheduling of Snowhite field



Dry gas field



Our main task is to compute $q_g(t)$

Contract to deliver 20E6 Sm³/d to customer

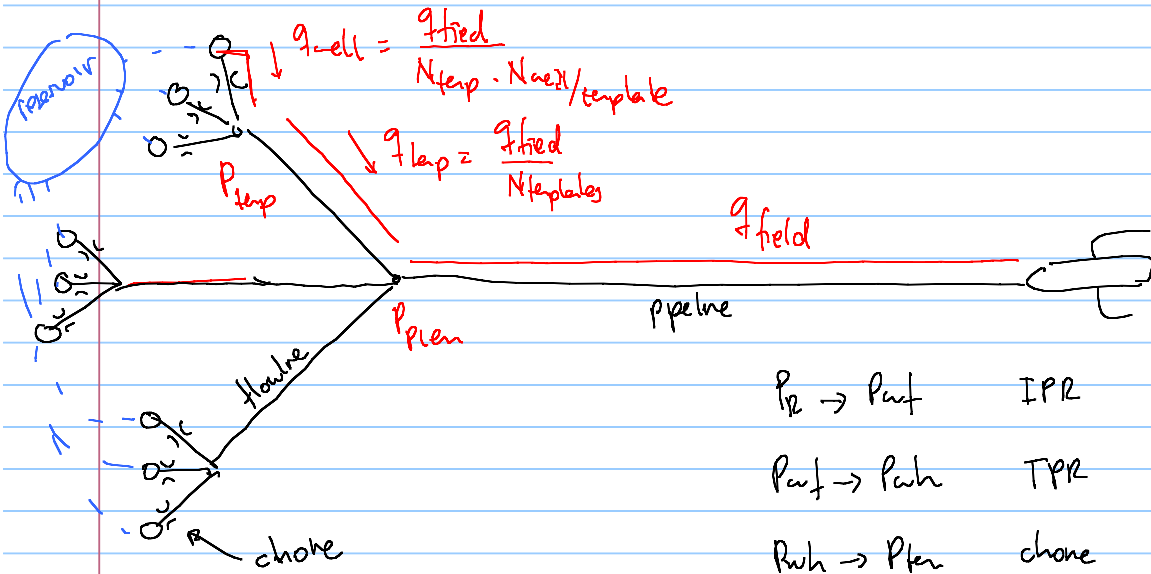
Our task, to compute

- plateau duration and post-plateau production

- Only dry gas, no liquid { no condensate, no water, no production chemicals

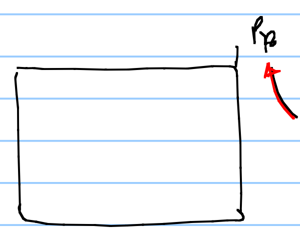
- all wells are identical (same production, same characteristics)

- templates are located symmetrically from the plem



$P_R \to P_{wf}$	IPR	$q_g = f(P_R, P_{wf})$
$P_{wf} \to P_{wh}$	TPR	$q_g = f(P_{wf}, P_{wh})$
$P_{wh} \to P_{tem}$	choke	$q_g = f(P_{wh}, P_{tem}, C_d)$
$P_{temp} \to P_{plem}$	FPR	$q_g = f(P_{tem}, P_{plem})$
$P_{plem} \to P_{sep}$	PPR	$q_g = f(P_{plem}, P_{sep})$

Reservoir model



Dry gas material balance

$$P_R = P_{Ri} \frac{z_R}{z_i}\left(1 - \frac{G_p}{G}\right)$$

G_p: $f(q_g)$, $q_g = f(t)$

$\frac{G_p}{G}$: uncertain value, R_F recovery factor

gas deviation factor

$z\ f(P_r, T_r)$

$T_r = \frac{T_R}{T_c}$, $P_r = \frac{P_R}{P_c}$ → f(gas composition)

MB dry gas equation is implicit

- Given RF, assume P_R
- with P_R compute z_R
- verify that $\varepsilon = P_R - P_{Ri}\frac{z_R}{z_i}\left(1 - R_F\right) = 0 \leq$ Tolerance
- if not,

3.3.2 Z-Factor Correlations. Standing and Katz[4] present a generalized Z-factor chart (**Fig. 3.6**), which has become an industry standard for predicting the volumetric behavior of natural gases. Many empirical equations and EOS's have been fit to the original Standing-Katz chart. For example, Hall and Yarborough[21,22] present an accurate representation of the Standing-Katz chart using a Carnahan-Starling hard-sphere EOS,

$$Z = \alpha p_{pr}/y, \qquad (3.42)$$

Equation approximation to Z chart

where $\alpha = 0.06125t\exp[-1.2(1-t)^2]$, where $t = 1/T_{pr}$.

The reduced-density parameter, y (the product of a van der Waals covolume and density), is obtained by solving

$$f(y) = 0 = -\alpha p_{pr} + \frac{y + y^2 + y^3 - y^4}{(1-y)^3} - (14.76t - 9.76t^2 + 4.58t^3)y^2 + (90.7t - 242.2t^2 + 42.4t^3)y^{2.18+2.82t}, \qquad (3.43)$$

with

$$\frac{df(y)}{dy} = \frac{1 + 4y + 4y^2 - 4y^3 + y^4}{(1-y)^4} - (29.52t - 19.52t^2 + 9.16t^3)y + (2.18 + 2.82t)(90.7t - 242.2t^2 + 42.4t^3) \times y^{1.18+2.82t}. \qquad (3.44)$$

The derivative $\partial Z/\partial p$ used in the definition of c_g is given by

$$\left(\frac{\partial Z}{\partial p}\right)_T = \frac{\alpha}{p_{pc}}\left[\frac{1}{y} - \frac{\alpha p_{pr}/y^2}{df(y)/dy}\right]. \qquad (3.45)$$

to predict T_c, P_c we will use Sutton correlations

Sutton[7] suggests the following correlations for hydrocarbon gas mixtures.

$$T_{pcHC} = 169.2 + 349.5\gamma_{gHC} - 74.0\gamma_{gHC}^2 \qquad (3.47a)$$

and

$$p_{pcHC} = 756.8 - 131\gamma_{gHC} - 3.6\gamma_{gHC}^2. \qquad (3.47b)$$

$$\gamma_g = \frac{Mw_{gas}}{Mw_{air}\ (28.97)}$$

$$Mw_{gas} = \sum_{i=1}^{N} z_i Mw_i$$

$P_R \rightarrow P_{wf}$ IPR equation low pressure dry gas equation

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

← backpressure exponent
laminar $n \sim 1$
turbulent $n \to 0.5$

inflow coefficient $\{T_R, k, h, s$ (skin factor)

- pseudo-steady state regime (boundary dominated flow) page 97 of compendium

- $P_{wf} \rightarrow P_{wh}$ Dry gas tubing equation

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

tubing coefficient (friction losses)

elevation coefficient (hydrostatic losses)

$q_g = 0 \qquad P_{wf} = P_{wh}\, e^{S/2}$

Page 156, Appendix A of compendium

$$q_{sc} = \left(\frac{\pi}{4}\right)\cdot\left(\frac{R}{M_{air}}\right)^{0.5}\cdot\left(\frac{T_{sc}}{p_{sc}}\right)\cdot\left(\frac{D^5}{f_M\cdot L\cdot\gamma_g\cdot Z_{av}\cdot T_{av}}\right)^{0.5}\cdot\left[\left(p_{wf}^2 - p_t^2\cdot e^S\right)\cdot\left(\frac{S}{e^S-1}\right)\right]^{0.5}$$

$$C_T = \left(\frac{\pi}{4}\right)\cdot\left(\frac{R}{M_{air}}\right)^{0.5}\cdot\left(\frac{T_{sc}}{p_{sc}}\right)\cdot\left(\frac{D^5}{f_M\cdot L\cdot\gamma_g\cdot Z_{av}\cdot T_{av}}\right)^{0.5}\cdot\left(\frac{S\cdot e^S}{e^S-1}\right)^{0.5}$$

$$S = 2\cdot L\cdot C_a = 2\cdot\frac{M_g}{Z_{av}\cdot R\cdot T_{av}}\cdot L\cdot g\cdot\cos(\alpha)$$

$P_{wh} \rightarrow P_{template}$ choke   no need for equation

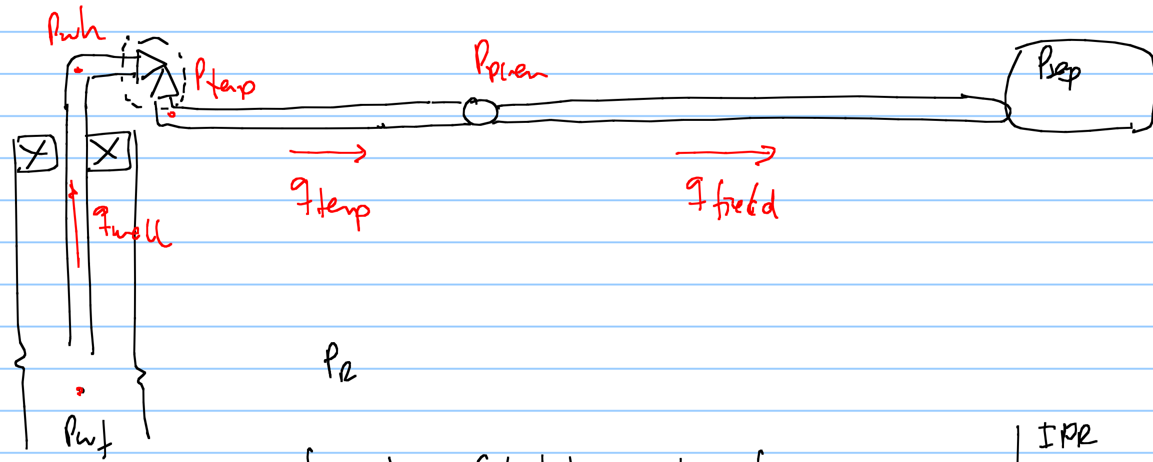
$P_{temp} \rightarrow P_{plem}$ flowline $\rightarrow$ tubing equation can be used for flowline

horizontal flowline, the tubing equation simplifies to

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

$S = 0$ (L'Hopital)

$P_{plem} \rightarrow P_{sep}$ $q_g = C_{PL}\left(P_{plem}^2 - P_{sep}^2\right)^{0.5}$



fix rate. Calculate P_{wh} from reservoir { IPR, TPR

Calculate P_{temp} from sep { PPR, FPR

verify $P_{wh} > P_{temp}$ → rates is feasible

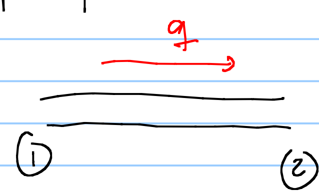
$P_{wh} < P_{temp}$ → rate not feasible, must be reduced

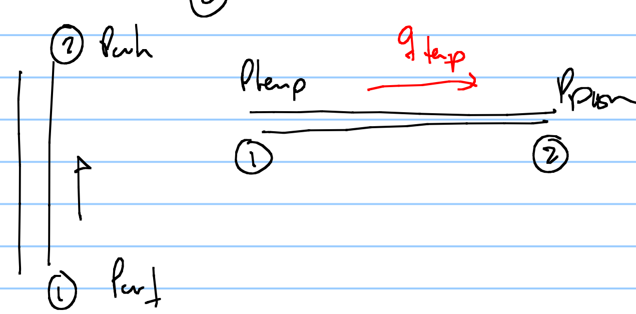
http://www.ipt.ntnu.no/~stanko/files/Courses/TPG4230/2020/Class_files/20200124/

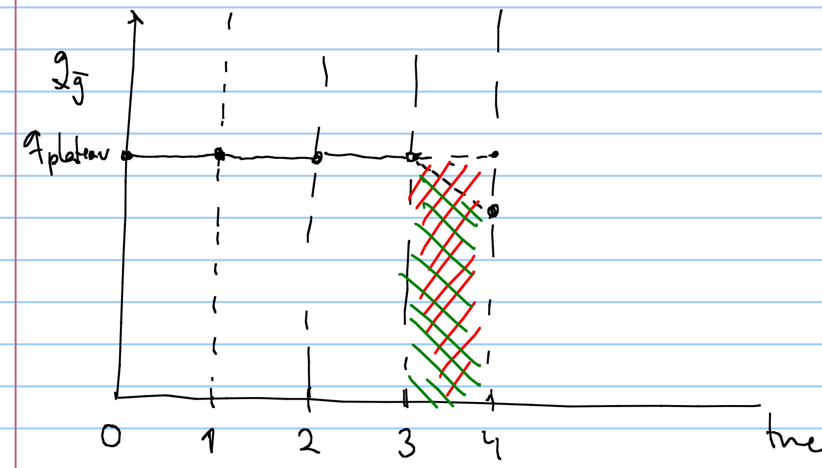
VBA Visual basic for applications

for pipe equations in VBA ① is upstream

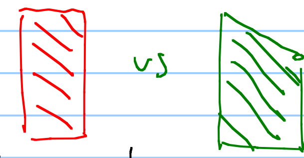
② is downstream







rectangular integration give a poor approximation of Gp when in decline phase



improvement
- use smaller time-step
- use a better integration

$$\Delta G_p^i = \frac{(q^{i-1} + q^i)}{2} \Delta t$$

P_R

$$G_p = \int_0^1 q_{field}\, dt \longrightarrow R_F \longrightarrow P_R$$

Approximation, q^0_{field} is constant between $0 \to 1$

G=IGIP	270E+09	Sm3
Annual production rate	0.027	fraction of IGIP
Production days per year	365	day
T_R	92	oC
Pi, initial Res pressure	276	bara
C, inflow Back pressure coefficient	1000	Sm3/bar^2n
n, backpressure, exponent	1	
Ct, Tubing coefficient (2100 MDx0.15	4.03E+04	Sm3/bar
Elevation coeff, S	0.155	
$C_{FL\ Flowline}$ Template-PLEM (5000x0.	2.83E+05	Sm3/bar
$C_{PL\ Pipeline}$ PLEM-Shore (158600x0.6	2.75E+05	Sm3/bar
Separator (slug catcher) pressure	30	bara
Gas molecular weight (Methane)	16	kg/kmole
Gas specific gravity	0.55	Gas specific gravity
Gas density at Sc	0.67	kg/m^3
Number of templates	3	
Number of wells	9	
Desired plateau	20	years
qfield	20.0E+6	[Sm^3/d]
Field gas rate for abandonment	5.00E+06	[Sm^3/d]

1. Identical wells
i.e same PR CR, n, Ct, S
2. System is symmetric
3. Field Rate = 20 MMSCM
qwell = qg/no.of.wells
PR= ZR* P/Zi * (1-Gp/G)
Pwf = sqrt(Pr^2-qg/C) as n=1
Pwh = sqrt((pwf^2/e^s)-((qg/Ct)^2))
Psep
Pplem
Ptempl

for each well

time	qfield	Gp	Z	PR	qwell	Pwf	Pwh avail	Ptemp req	Pplem req	Psep	qtemp	DeltaPchoke
[years]	[Sm^3/d]	[Sm^3]	[-]	[bara]	[Sm^3/d]	[bara]	[bara]	[bara]	[bara]	[bara]	[Sm^3/d]	[bar]
0	20.0E+6	000.0E+0	0.967291	276.0E+0	2.2E+6	272.0	245.6	82.0	78.6	30.0	6.7E+6	164
1	20.0E+6	7.29E+09	0.962615	269	2.2E+6	264.4	238.4	82.0	78.6	30.0	6.7E+6	156
2	20.0E+6	1.46E+10	0.957442	260	2.2E+6	255.5	230.0	82.0	78.6	30.0	6.7E+6	148
3	20.0E+6	2.19E+10	0.952572	251	2.2E+6	246.6	221.5	82.0	78.6	30.0	6.7E+6	139
4	20.0E+6	2.92E+10	0.948138	242	2.2E+6	237.8	213.1	82.0	78.6	30.0	6.7E+6	131