NTNU | Norwegian University of Science and Technology

TPG4230 – Field development and operations

Spring Semester 2022

Information

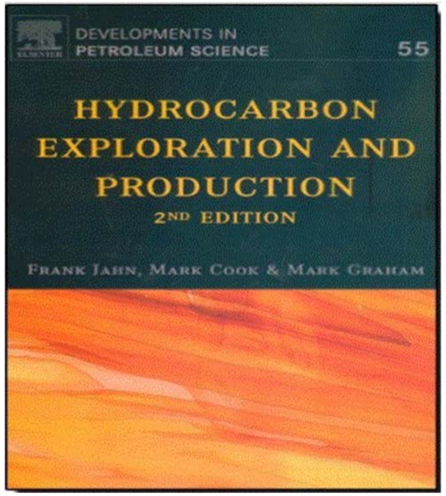
- Lecturer: Assoc. Prof. Milan Stanko (Production Tech) (milan.stanko@ntnu.no). Office 510.
- Teaching assistant: TBD
- Lecture schedule (Zoom or P11)
  - Tuesdays, 09:15-12:00 (theory and exercises)
  - Fridays, 14:15-16:00 (theory and exercises)
- Course description

Information

- Lectures until 26 April (breaking for Easter)
- Consultation time: preferably after class. Try to make an email appointment.
- Reference group – **any volunteers?**
  - Anonymous comment box
- **Use Blackboard to navigate the course**
  - Use the forum for Q&A
  - Join a group before delivering the exercise (even if one person only!!)

Reference material

- Compendium
- Recommended
- Supplementary
- Hydrocarbon exploration and production (Jahn, Cook and Graham)



Evaluation

- 60% exam (digital home exam in Inspera 9-June, 9:00-12:00, all material allowed).
  - Previous years exams
  - Examples 2018, 2020, 2021
  - Make it nice, easy to understand and follow. When provided, use the Excel template

Evaluation

- 40% - assignments
  - All assignments must be delivered to get access to the exam, and at least get 20/40 (pass)
  - Home exercises (delivered in Inspera). Deadline probably in April. Individual delivery. Working in groups is allowed.
    - (Most likely) non-graded partial deliveries in BB to check progress and give feedback → group delivery allowed
  - Codes of approval of **all** online quizes. (X/40)
  - **Let me know early if there is a deadline conflict with other courses**
  - **Work on the assignments during the semester!**

Teaching

- Digital, until further notice
- Flipped classroom
  - Participants watch by themselves pre-recorded videos (ca 45 min) (on Youtube)
  - Live classes every week/2 weeks
    - Discussing further theory, exercises, tutorials on software, Q&A, advanced topics
    - In person or via Zoom, depending on the situation
    - Classes will be streamed via Zoom, when possible, and the recording will be shared on Blackboard

Teaching

- Watching pre-recorded videos (on Youtube):
  - Watch at higher playback speed (1.5x -2x, Milan speaks slow) 😅
  - At certain time stamps (**or at the end of the video**), the videos have embedded links to: other relevant videos, material and quizzes. Example link1 link2
  - It is recommended to go through the complete video and click on the links along the way
  - It helps if you make your own annotations while watching (with pen and paper or on the pdf)

Quizzes

- Supposed to help you remember better
- Embedded on videos link2
- When a quiz is completed, a completion code will be shown at the bottom of the quiz – **collect and save the code, this is a proof of completion**
  - Codes of completion will be submitted together with the home assignments in Inspera in an Excel sheet
  - Codes are individual and non-transferrable
  - Take the quiz using your computer
  - We have ways to detect if you generate codes for others, **don’t do it!, both codes will be invalidated**

Quizzes

- No solution key will be given
- Known bugs
  - When there is a multiple-choice question, if you want to clear your selection, you have to refresh the page ↻
  - In some browsers one must scroll down sometimes to see the rest of the quiz and the result code
  - Be patient, give it time to load and process information

Course progress overview – Excel file

Tools

- Excel (VBA)
- Python (Jupyter Notebook) –using Google Colab
- Hysys (Aspentech, run on ntnu farm) or DWSIM
- IPM (Petex) or Pipesim (SLB) – maybe?

Questions?

Notes for youtube video nr. 1

Field development and operations

offshore oil and gas production (from fields in Norway)

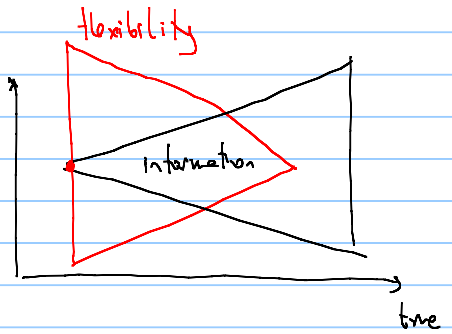
Field development: maximize economic value of HC explotation project for shareholders, subjected to technical constraints (eng., petroleum engineering) HSE constraints

operations: define KPI's

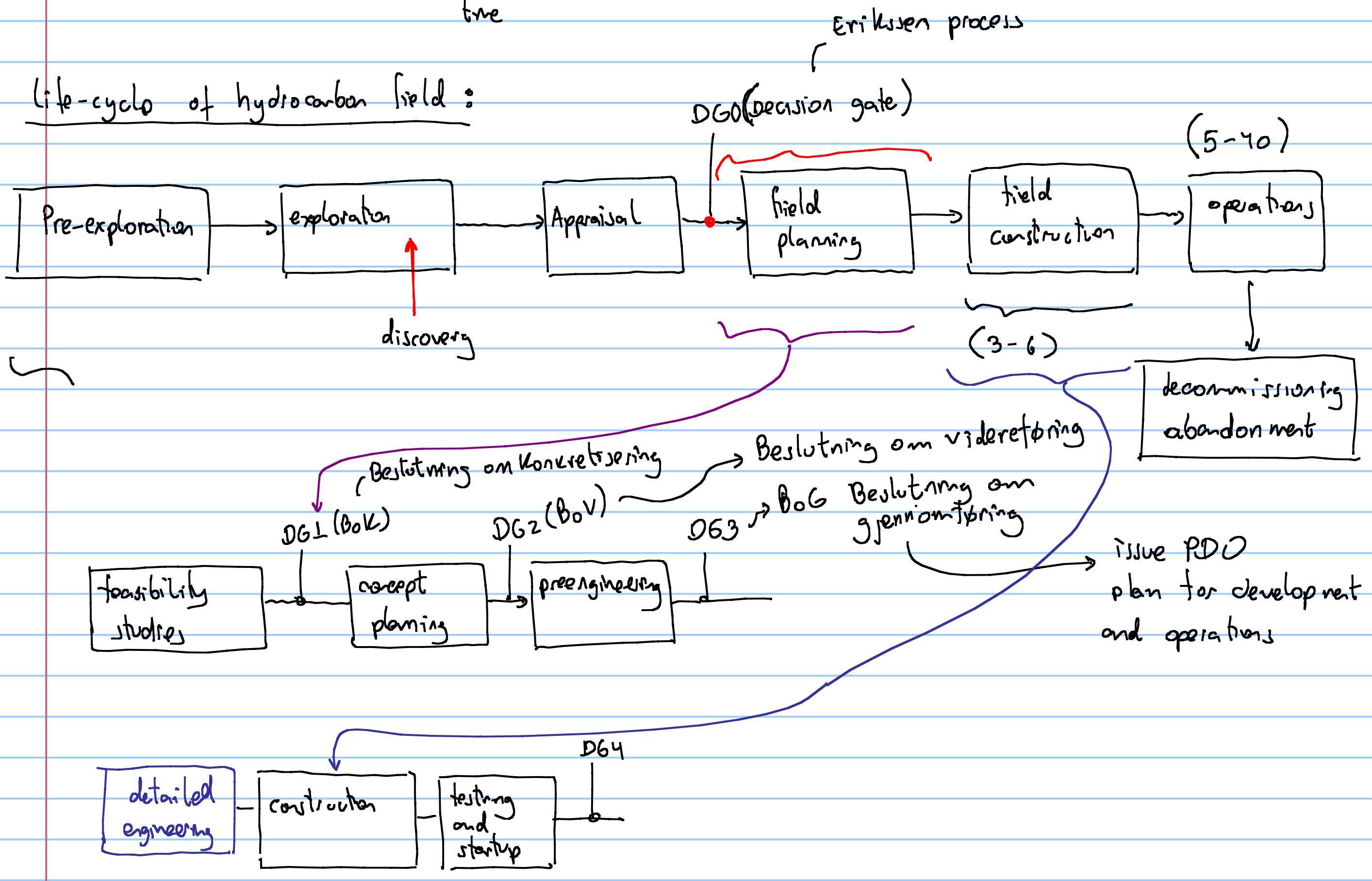
- stuck with an existing system
- reduce the impact of system defficiencies
- exploit the advantages
- optimize/"effectivize" production

Decide on main features of field

- define KPI's for project (Key performance indicator)
- collect information $
- define alternatives
- analyze data, evidence (modeling)
- choose an alternative



Life-cycle of hydrocarbon field :



Topics to cover in the course:

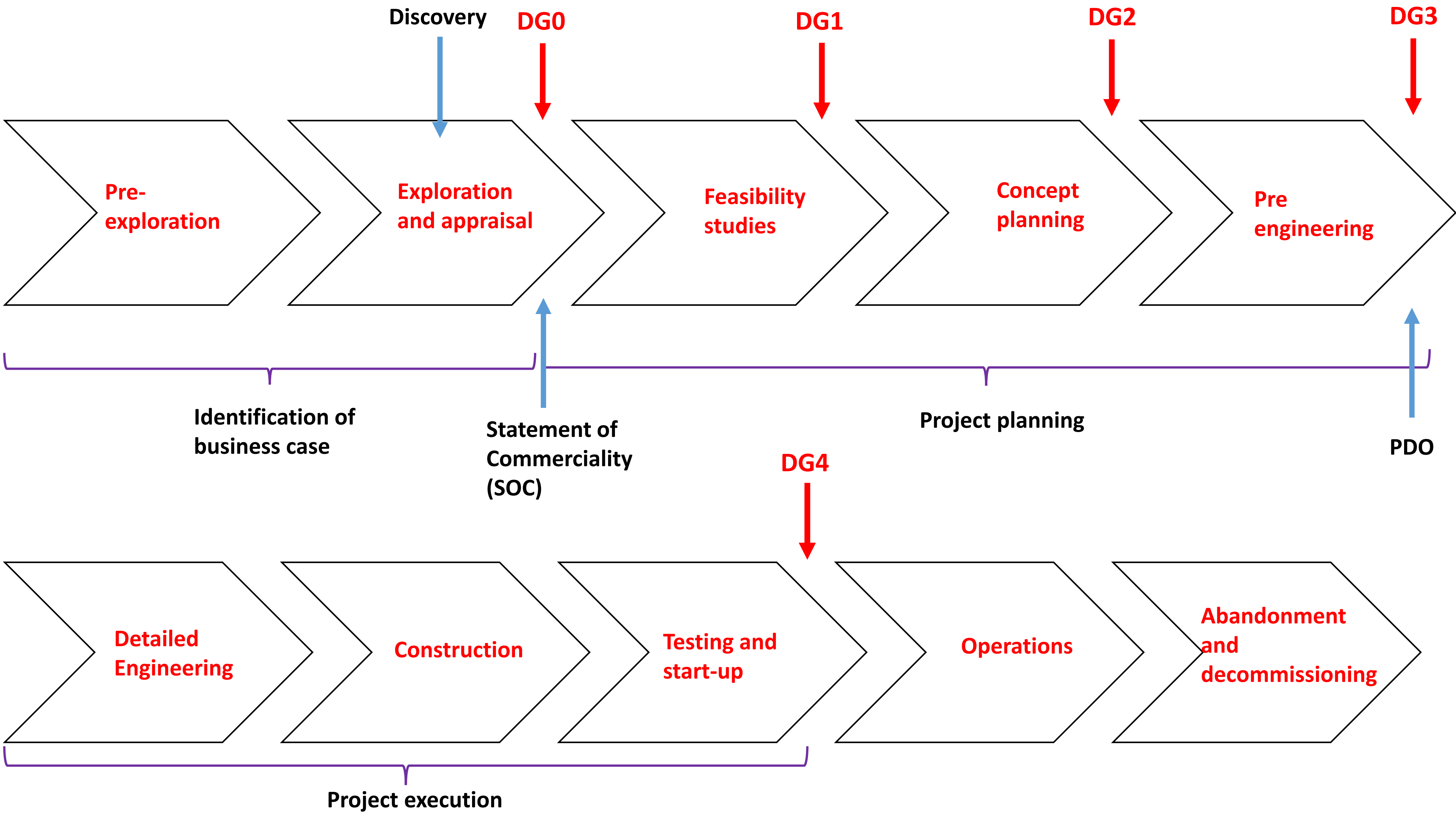
- Overview of FD process, general considerations {
  - Production modes
  - gas vs. oil
  - onshore vs. offshore
  - Production profile stages
- field production performance.
  - production scheduling {
    - Material balance, IPR, TPR, choke, network, downhole network, boosting and AL, } model
    - Coupling with reservoir simulator
    - Plateau height vs. plateau length
  - {
    - production potential
    - Multi-reservoir scheduling
- Value chain model. NPV quantification { q vs t)
- flow assurance issues and considerations in FD
  - {
    - layout of subsea production systems
    - Modeling of wax (or hydrate)

$

- offshore structures, type and selection
- Uncertainty quantification using stochastic analyses and probability trees ← decision making
  - {
    - reserve estimation
    - appraisal

THE FIELD DEVELOPMENT PROCESS

Prof. Milan Stanko (NTNU)



Discovery

DG0

DG1

DG2

DG3

Pre-exploration

Exploration and appraisal

Feasibility studies

Concept planning

Pre engineering

Identification of business case

Statement of Commerciality (SOC)

Project planning

PDO

DG4

Detailed Engineering

Construction

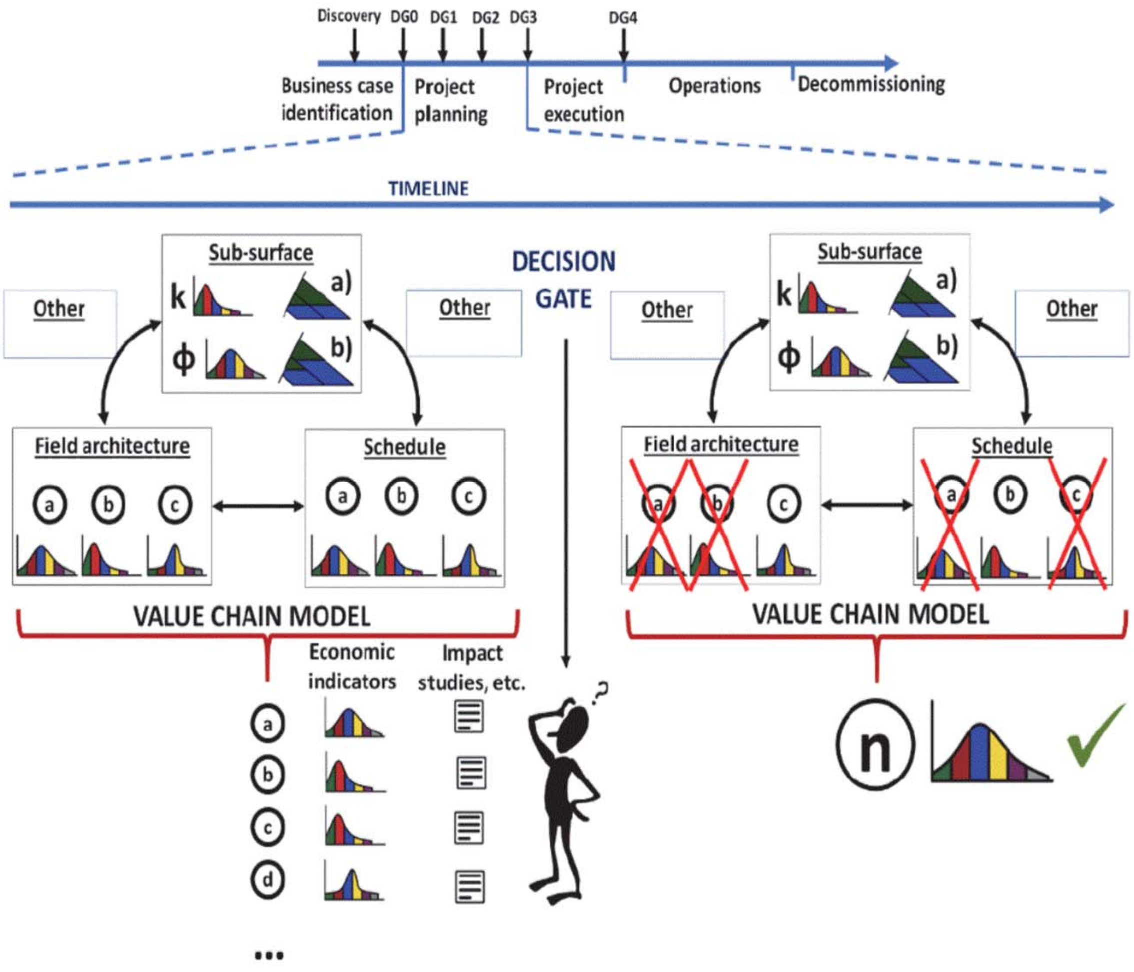
Testing and start-up

Operations

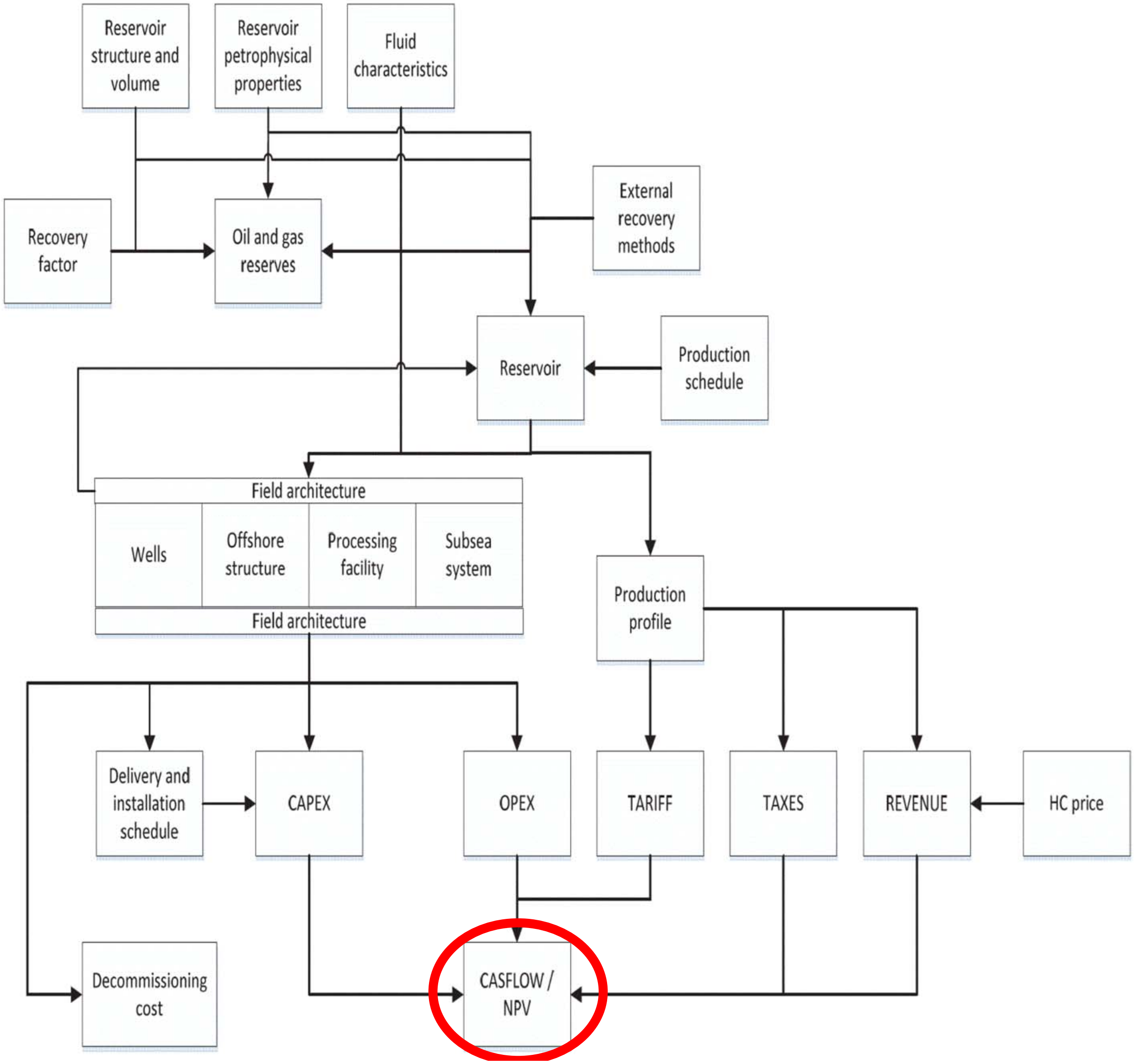
Abandonment and decommissioning

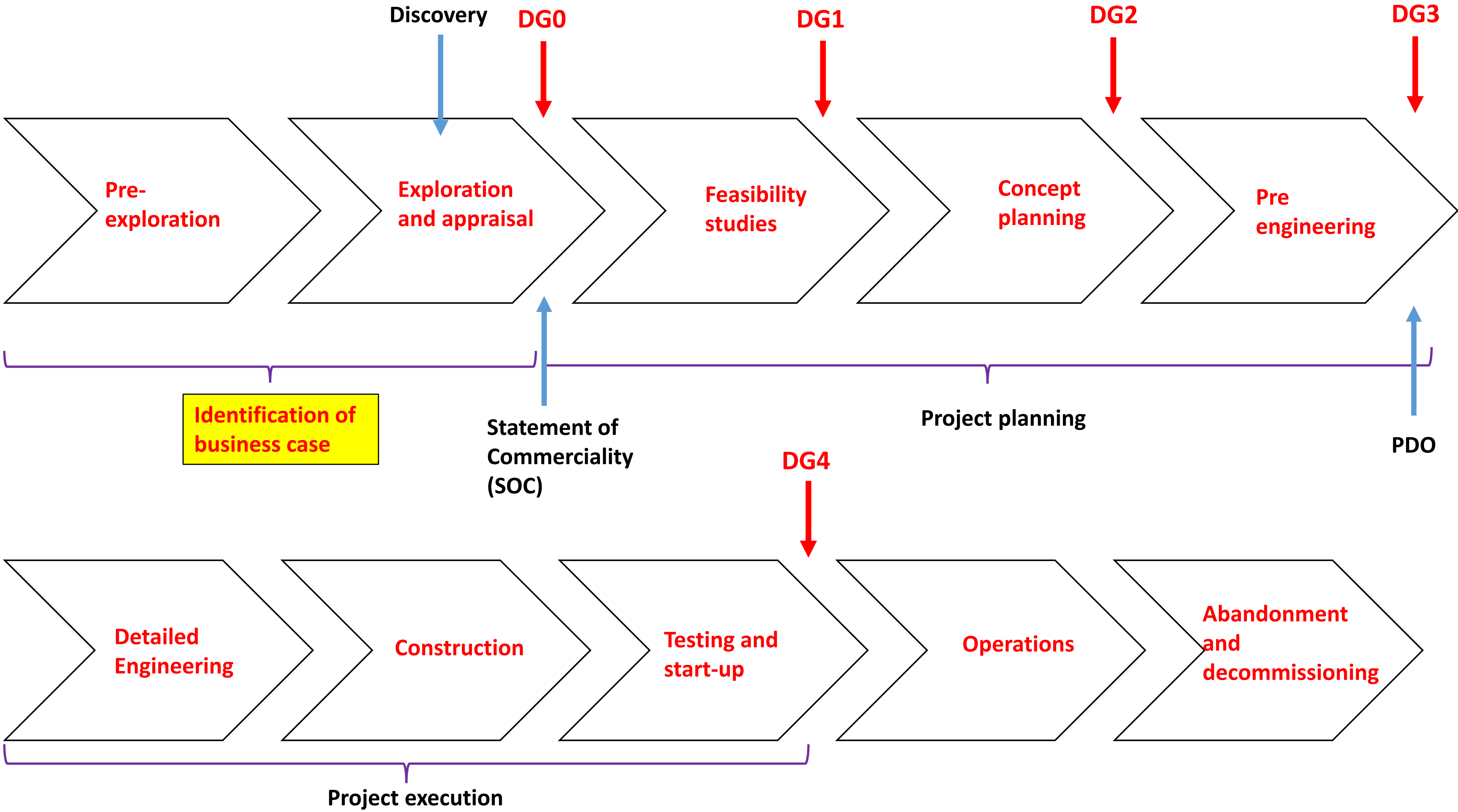
Project execution

During the field development process a model of the value chain is made based on the disciplines involved and populated with information. Initially there are many alternatives and little information. As time progresses and decisions are taken, the model is expanded, there is more information but less flexibility.



Key performance indicators are computed with the value chain model and are used to take decisions in the decision gate process.





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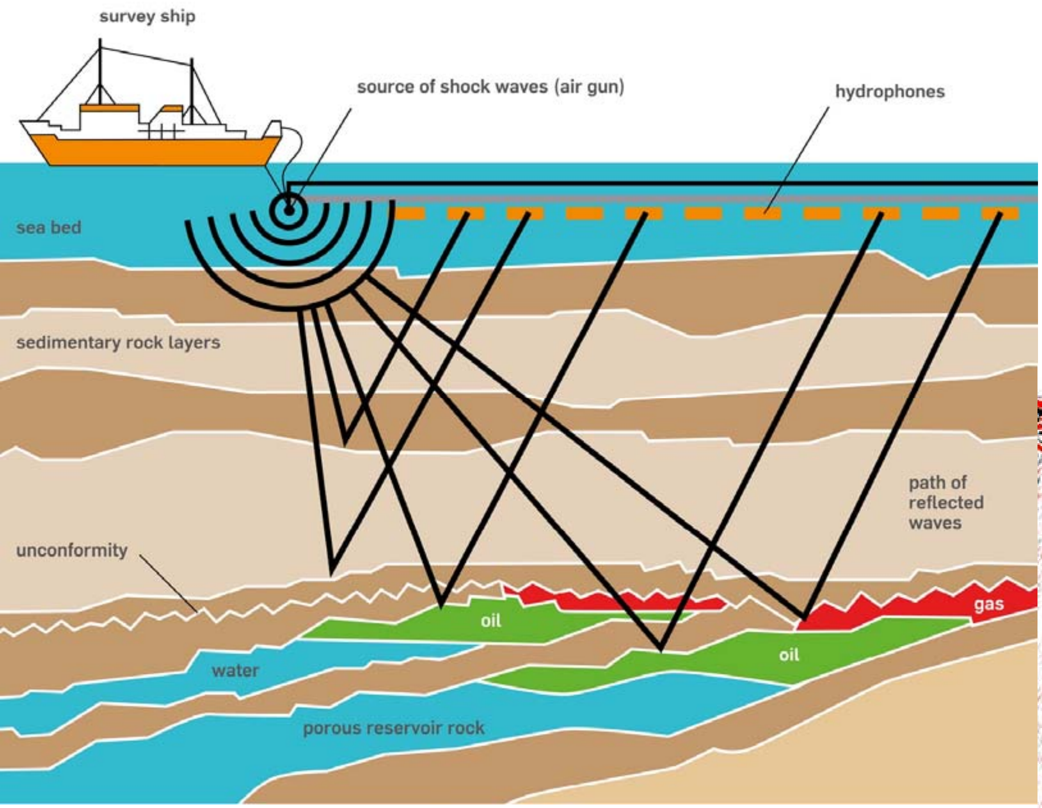
IDENTIFICATION OF BUSINESS CASE

The main goal of this stage is to prove economic potential of the discovery and quantify and reduce the uncertainty in the estimation of reserves.

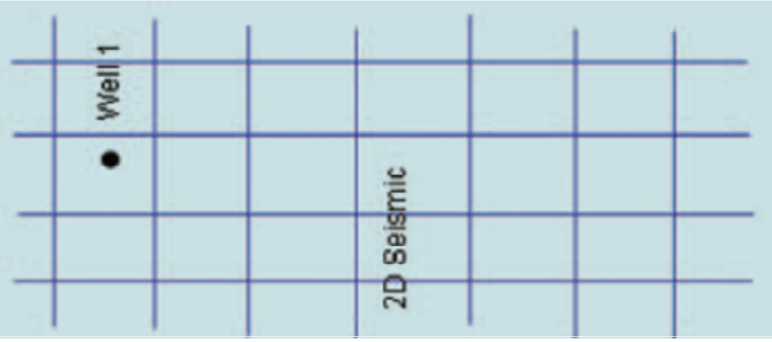
IDENTIFICATION OF BUSINESS CASE - TASKS

- Pre-exploration – scouting: collecting information on areas of interests. Technical, political, geological, geographical, social, environmental considerations are taken into account. E.g. expected size of reserves, political regime, government stability, technical challenges of the area, taxation regime, personnel security, environmental sensitivity, previous experience in the region, etc.
- Getting pre-exploration access – The exploration license (usually non-exclusive). In the NCS only seismic and shallow wells are allowed. This is usually done by specialized companies selling data to oil companies. Area: 500 Km^2
- Identify prospects.

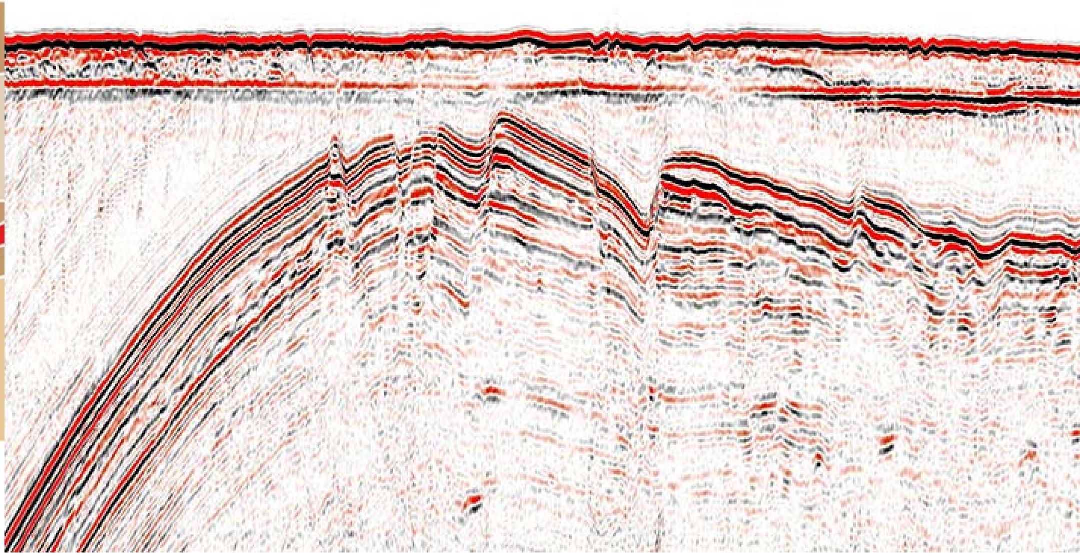
IDENTIFICATION OF BUSINESS CASE - TASKS



Ref: https://krisenergy.com/company/about-oil-and-gas/exploration/

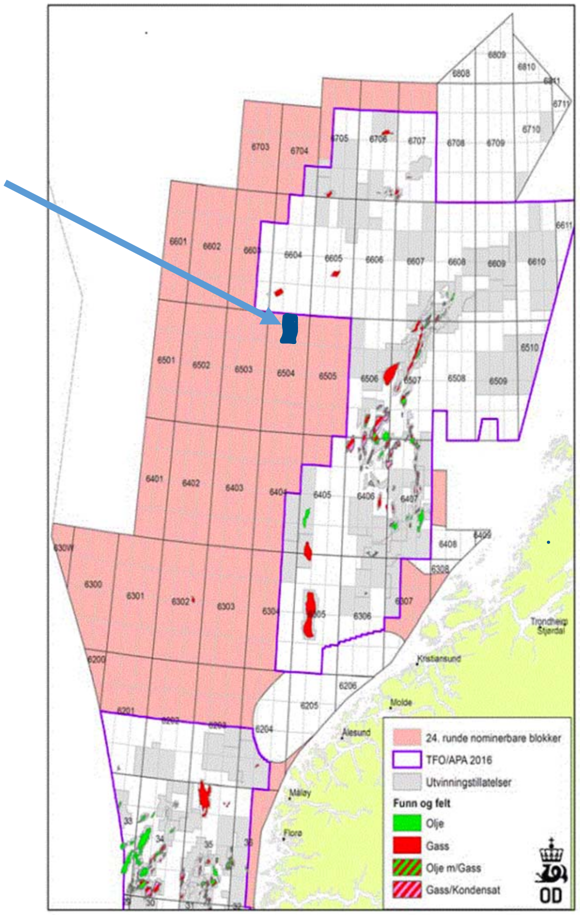


Seismic exploration



IDENTIFICATION OF BUSINESS CASE - TASKS

Ca 500 km^2



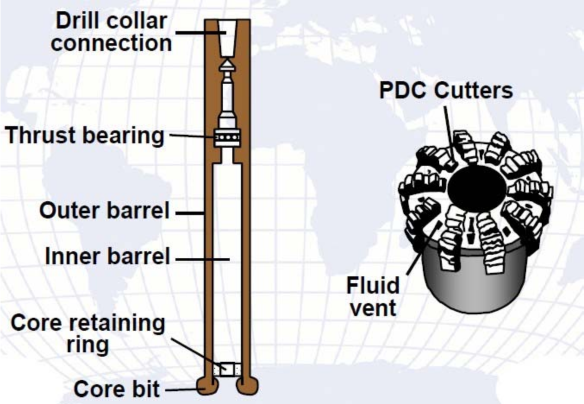
Ref: NPD

- Apply and obtain exclusive production license (6 years, possible to extend for 30 years). In the NCS: Licensing rounds (frontier areas) or Awards in predefined areas (APA). The current fees (if inactive) are 34 000 NOK/km^2 for the first year, 68 000 NOK/km^2 for the second year and 137 000 NOK/km^2 per year thereafter.

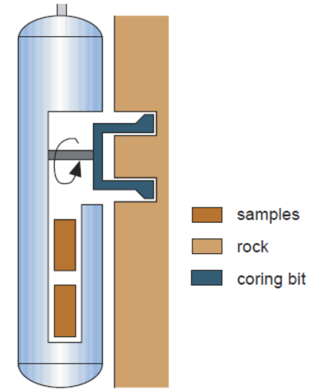
IDENTIFICATION OF BUSINESS CASE - TASKS

- Exploration. Perform geological studies, geophysical surveys, seismic, exploration drilling (Well cores, wall cores, cuttings samples, fluid samples, wireline logs, productivity test).

- Discovery!



Ref: https://www.spec2000.net/09-coremethods.htm



Ref: Hydrocarbon exploration and production, Jahn et al.

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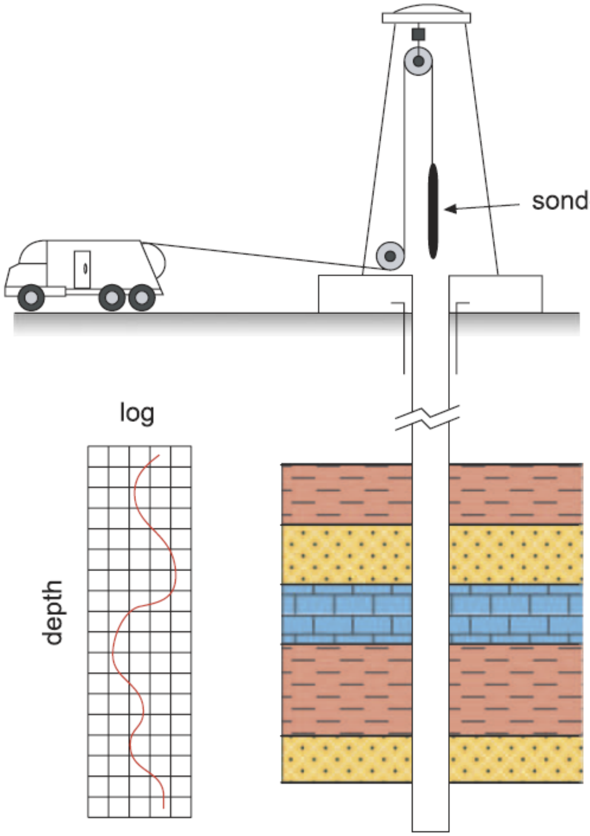

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IDENTIFICATION OF BUSINESS CASE - TASKS

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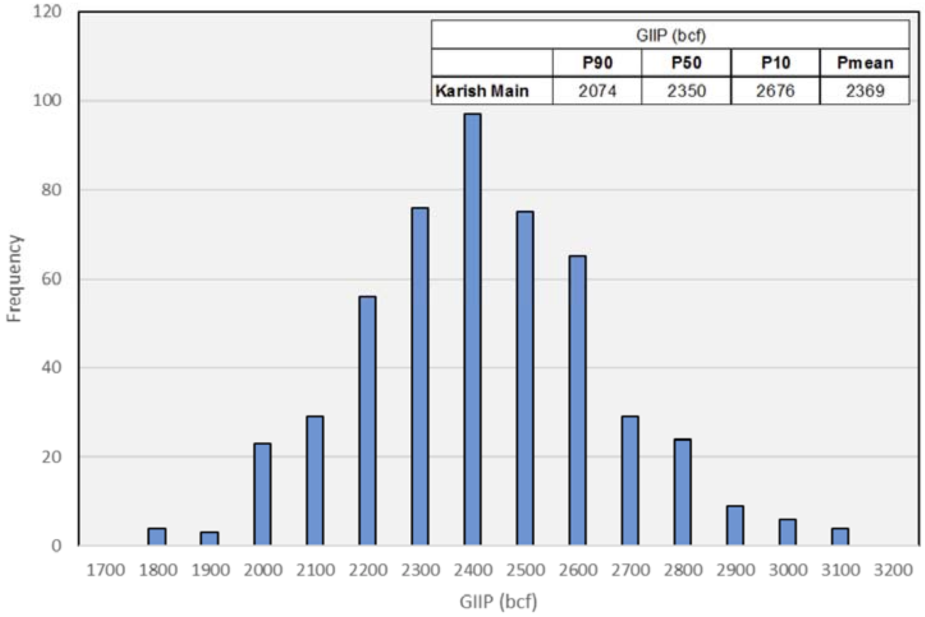
- Discovery!

https://www.youtube.com/watch?v=Qd7F8T0IVXU

IDENTIFICATION OF BUSINESS CASE - TASKS

- Assessment of the discovery and the associated uncertainty. Risk management:
  - **Probabilistic reserve estimation.** Identify and assess additional segments.



	GIIP (bcf)			
	P90	**P50**	**P10**	**Pmean**
Karish Main	2074	2350	2676	2369

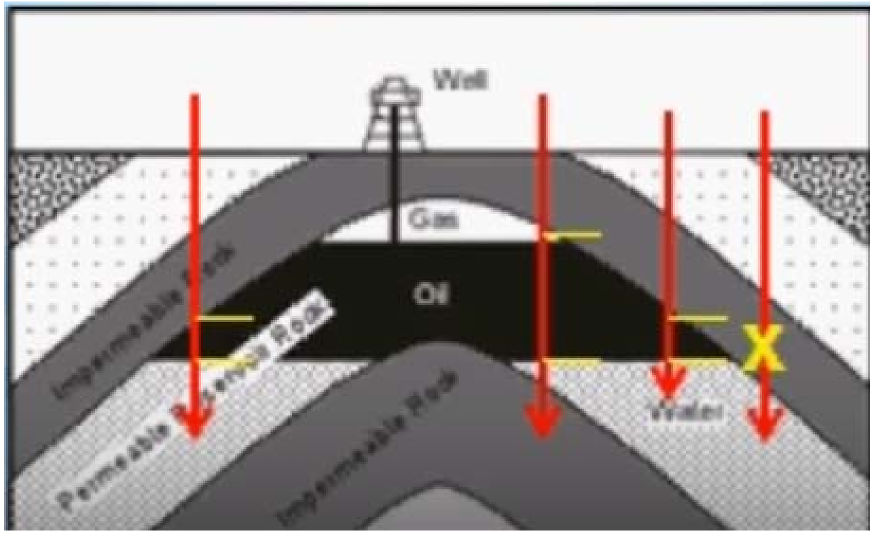
Ref: PDO Karish and Tanin. Energean

IDENTIFICATION OF BUSINESS CASE - TASKS

- Assessment of the discovery and the associated uncertainty. Risk management:
  - **Probabilistic reserve estimation.** Identify and assess additional segments.
  - Perform **simplified economic valuation** of the resources.
  - Field **appraisal** to reduce uncertainty: more exploration wells and seismic to determine for example: fault communication, reservoir extent, aquifer behavior, location of water oil contact or gas oil contact.

IDENTIFICATION OF BUSINESS CASE - TASKS

- Appraisal

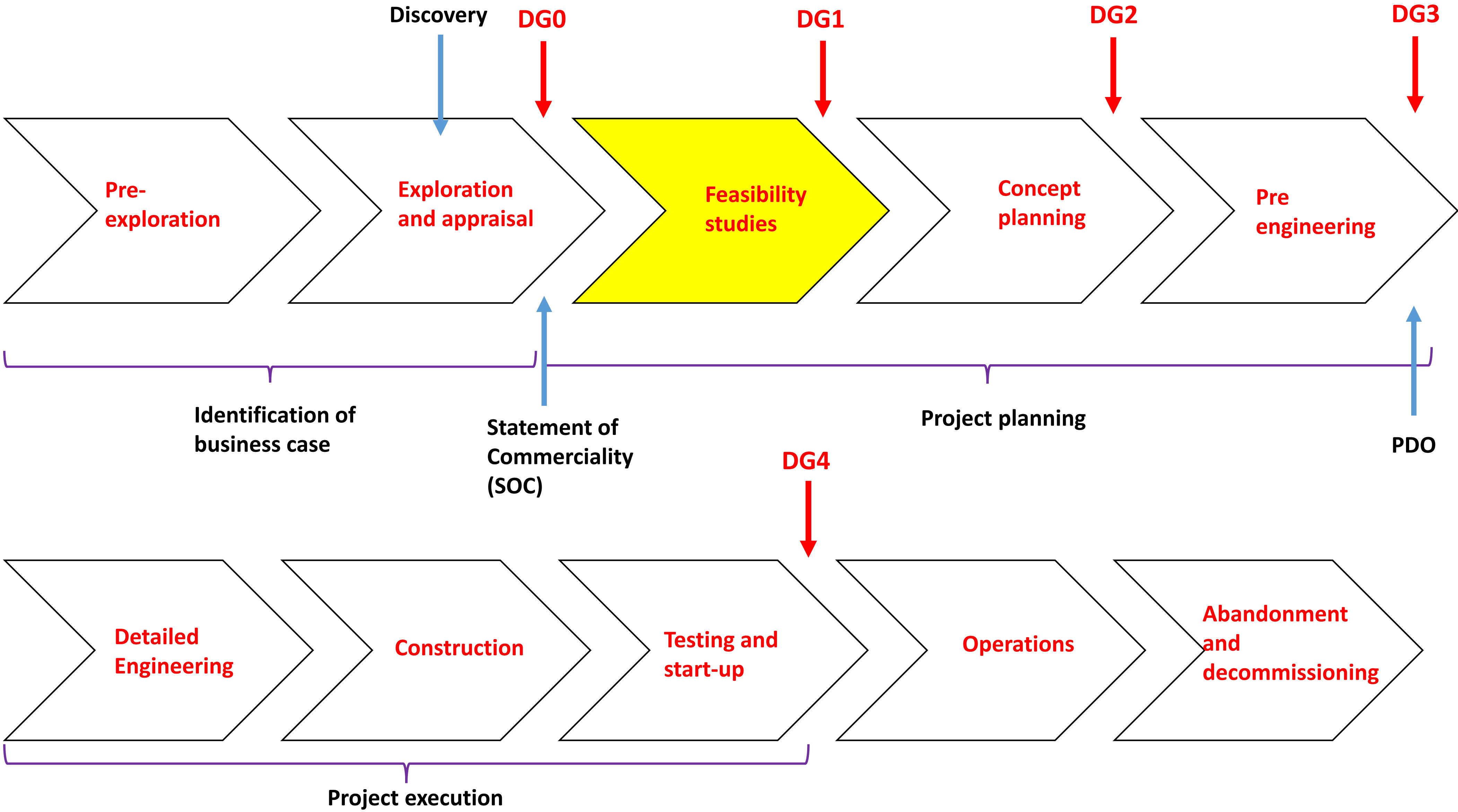


Ref: https://www.youtube.com/watch?v=-e9jjnsquGI

IDENTIFICATION OF BUSINESS CASE - TASKS

DG0:

- Issue a SOC (Statement of Commerciality) and proceed with development.
- Continue with more appraisal
- Sell the discovery.
- Do nothing (wait)
- Relinquish to the government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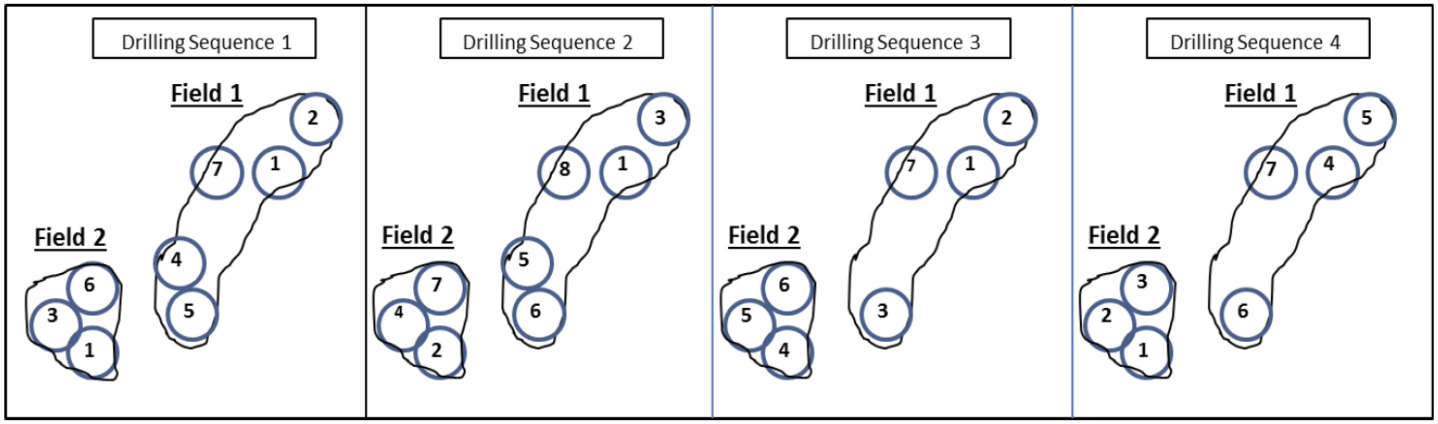
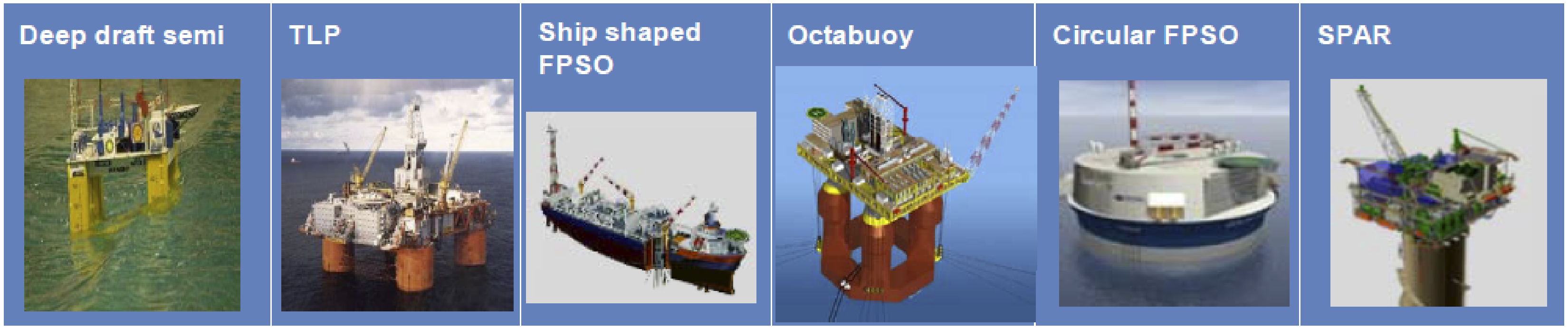
FEASIBILITY STUDIES - TASKS

OBJECTIVE: Justify further development of the project, finding one or more concepts that are technically, commercially and organizationally feasible

- Define objectives of the development in line with the corporate strategy.
- Establish feasible development scenarios.
- Create a project timeline and a workplan.

FEASIBILITY STUDIES - TASKS

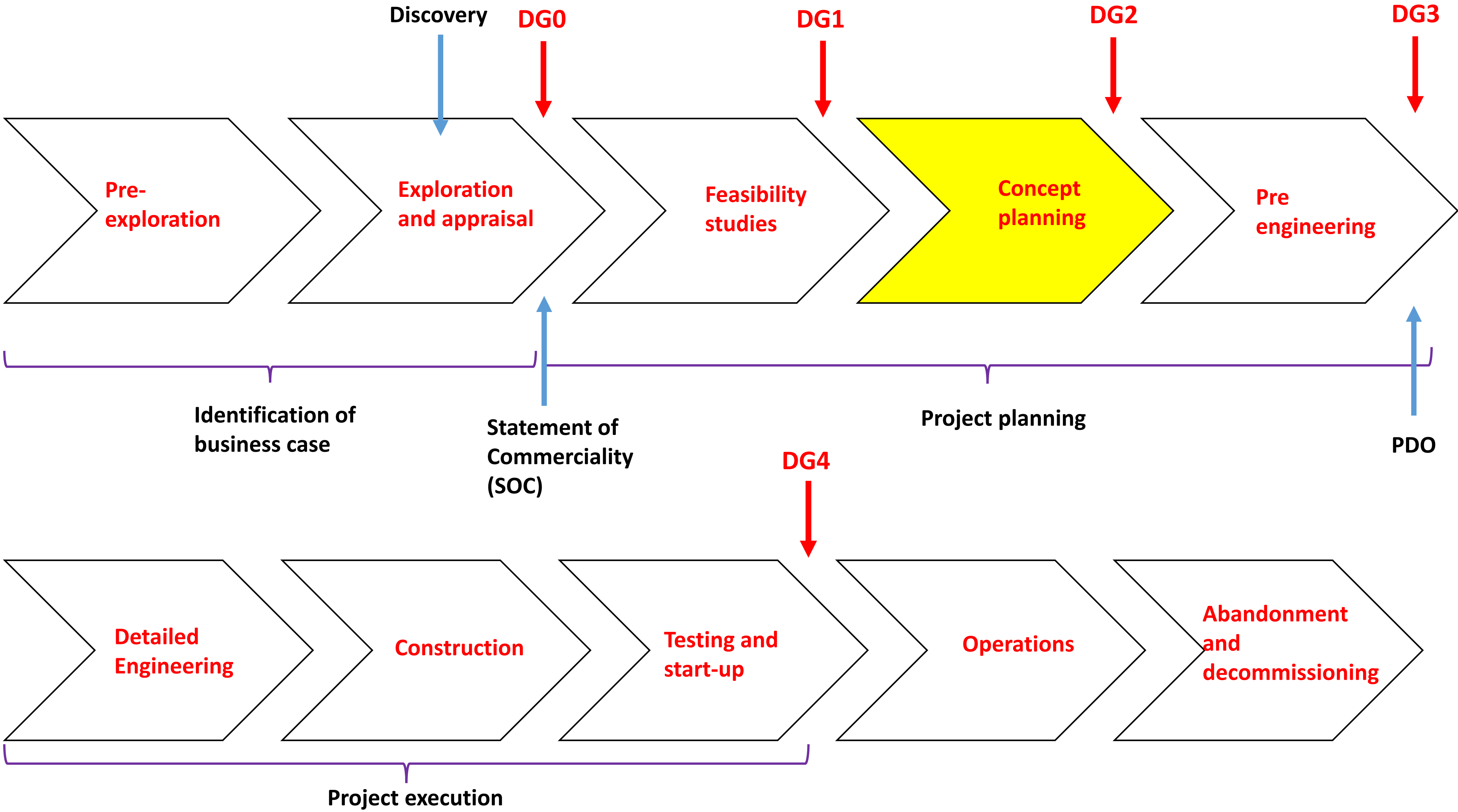




Ref: UTC 2017, Strategies, methods and tools for development of subsea fields, Skogvang and Løken.

FEASIBILITY STUDIES - TASKS

- Identify possible technology gaps and blockers.
- Identify the needs for new technology.
- Identify added value opportunities.
- Cost evaluation for all options (at this stage, cost figures are ±40% uncertain)



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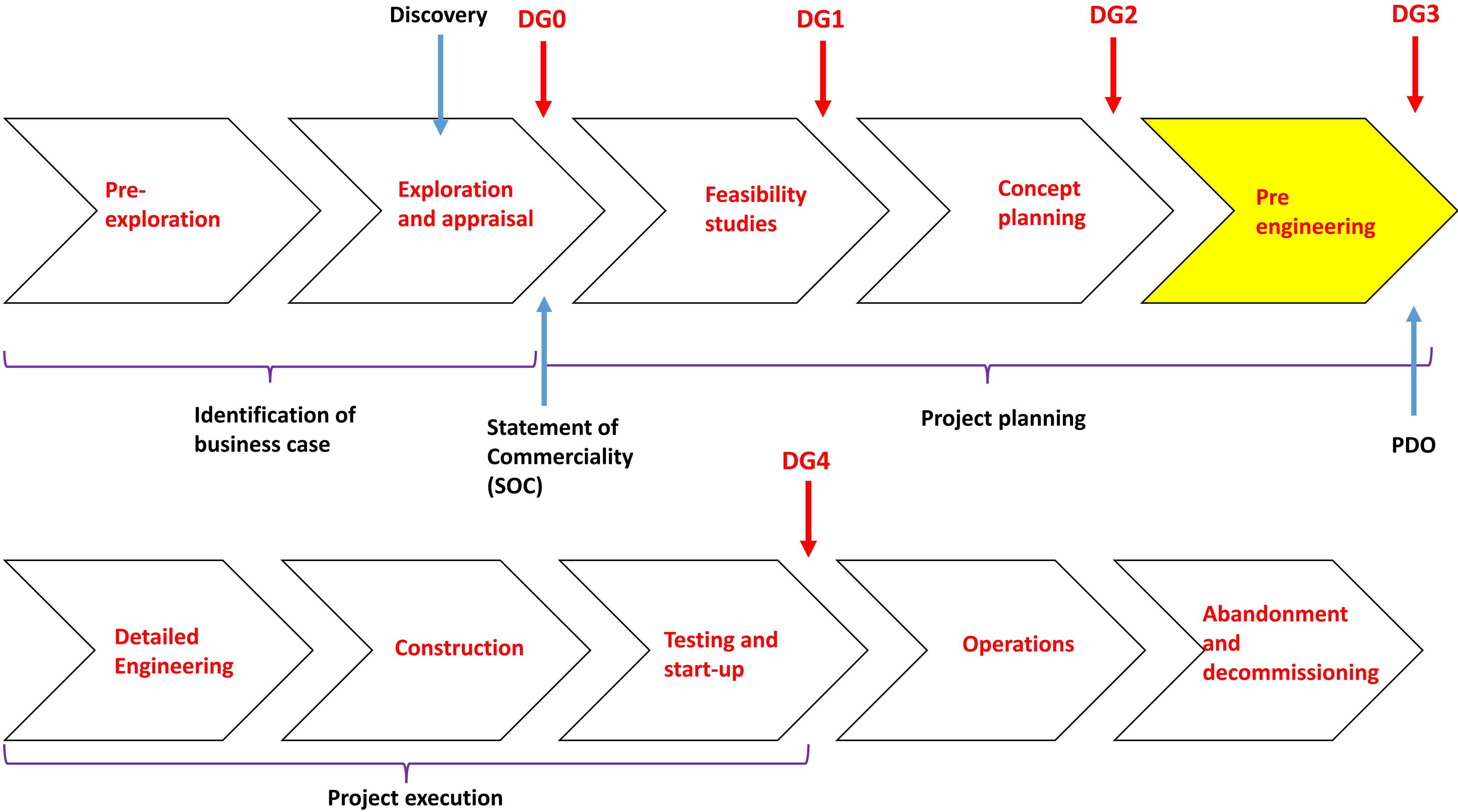
CONCEPT PLANNING - TASKS

OBJECTIVE: Identify development concepts, rank them and select and document a viable concept (Base Case Scenario).

- Evaluate and compare alternatives for development and screen out non-viable options.
- Elaborate a Project Execution Plan (PEP) which describes the project and management system.
- Define the commercial aspects, legislation, agreements, licensing, financing, marketing and supply, taxes.

CONCEPT PLANNING - TASKS

- Create and refine a static and a dynamic model of reservoir. **Define the depletion and production strategy.**
- Define an HSE program
- **Flow assurance evaluation.** Identification of challenges related with fluid properties, multiphase handling and driving pressure.
- Drilling and well planning
- Pre-design of facilities
- Planning of operations, start-up and maintenance
- Cost and manpower estimates of the best viable concept.



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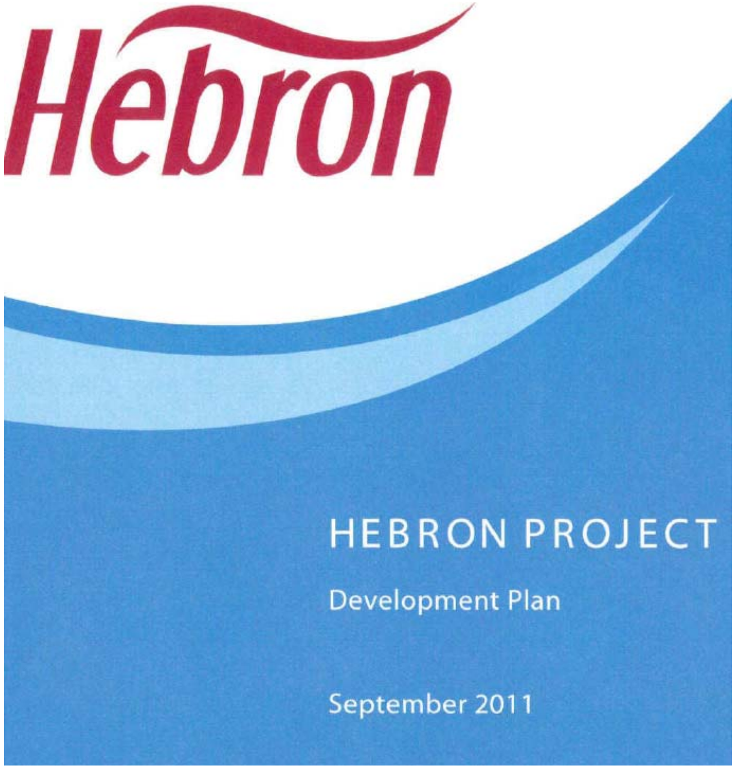
PRE-ENGINEERING - TASKS

OBJECTIVE: Further mature, define and document the development solution based on the selected concept.

- Selection of the final technical solution. Decide and define all remaining critical technical alternatives.
- Execute Front End Engineering Design (FEED) Studies: determine technical requirements (arranged in packages) for the project based on the final solution chosen. Estimate cost of each package.
- Plan and prepare the execution phase.

PRE-ENGINEERING - TASKS

- Prepare for submission of the application to the authorities.
- Perform the Environmental impact assessment.
- Establish the basis for awarding contracts.
- Issue:
  - Plan for development and operations
  - Plan for installation and operations of facilities for transport and utilization of petroleum (PIO)
  - Impact assessment report



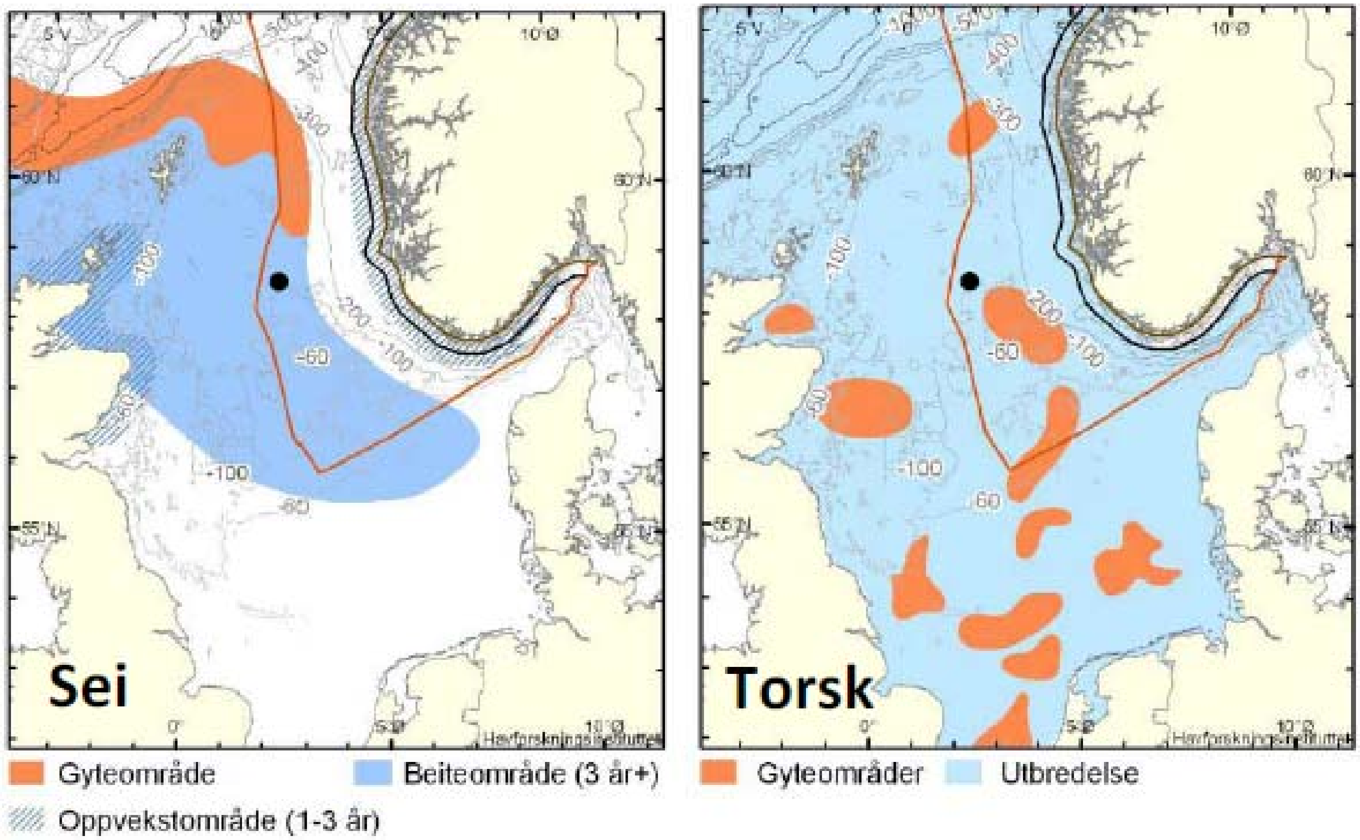
Hebron

HEBRON PROJECT

Development Plan

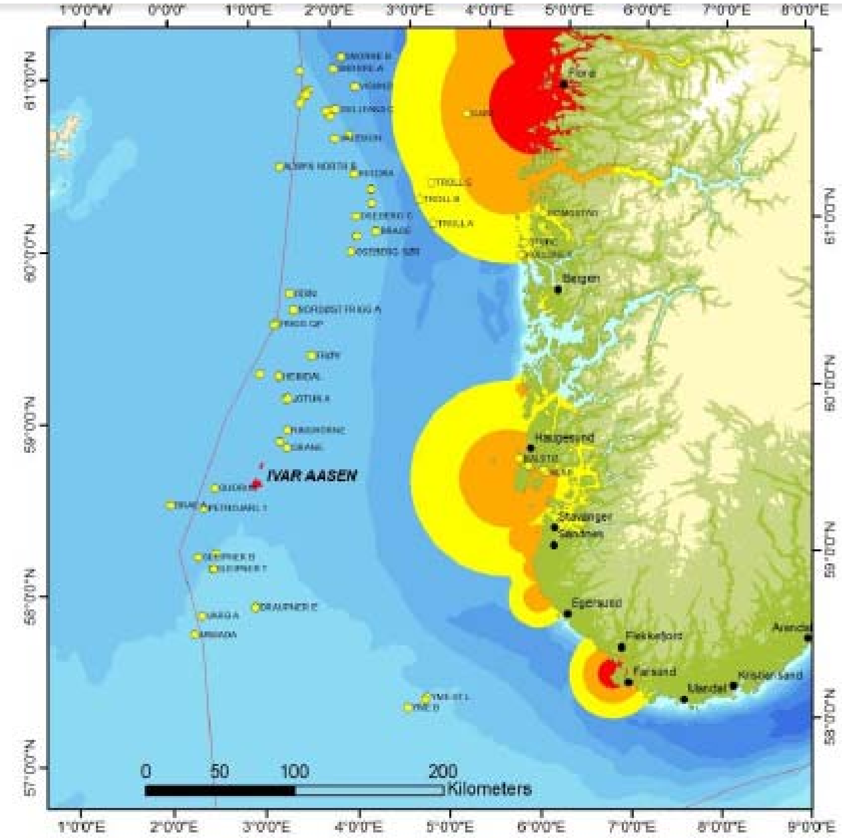
September 2011

PRE-ENGINEERING - TASKS



Ref: PDO Ivar Aasen. Det Norske

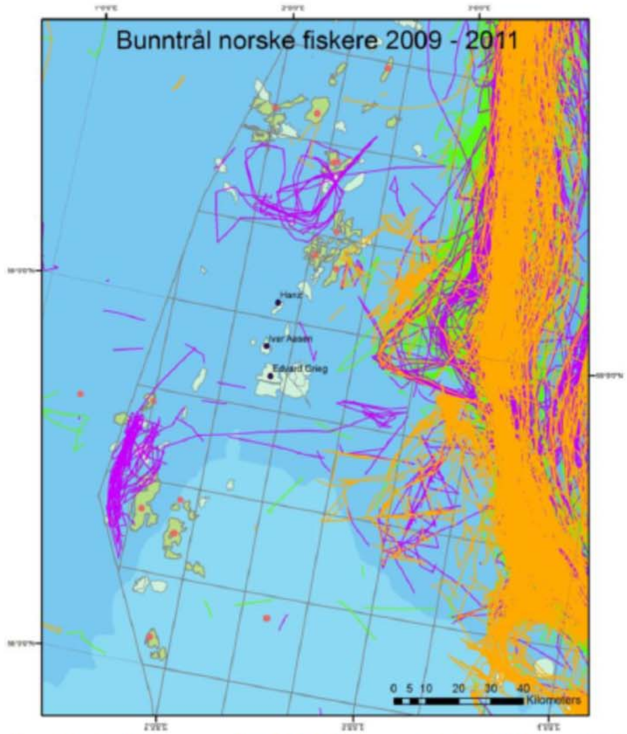
PRE-ENGINEERING - TASKS



Figur 18. Svært viktige (rød), viktige (oransje) og nokså viktige (gule) leveområder for sjøfugl langs kysten av Nordsjøen i hekketiden. Kartet markerer buffersoner rundt de viktige hekkelokalitetene (NINA)

Ref: PDO Ivar Aasen. Det Norske

PRE-ENGINEERING - TASKS



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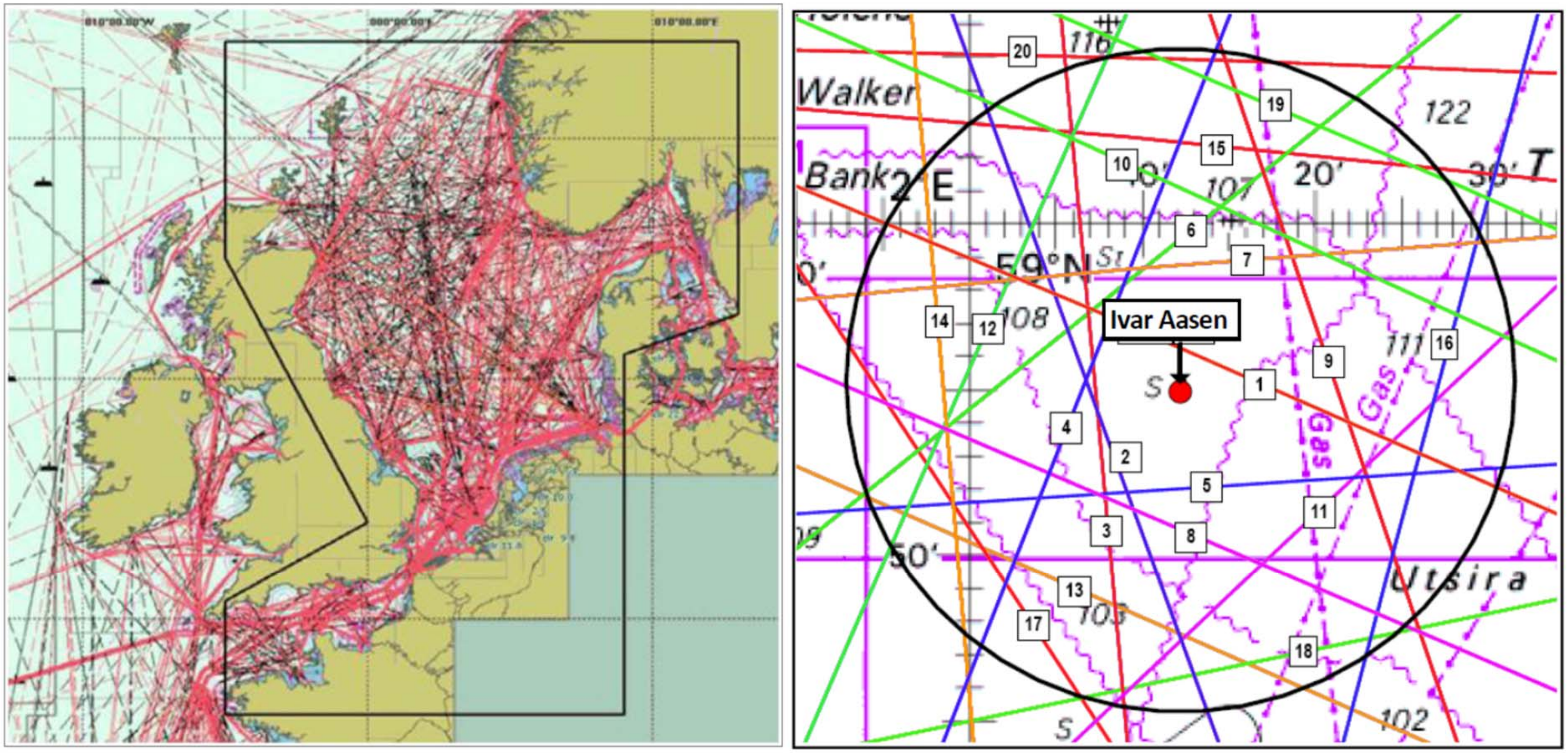
Figur 23. Registrert norsk fiskeriaktivitet med bunntrål i området omkring Aasen i 2009 (grønn), 2010 (fiolett) og 2011 (oransje). Figur utarbeidet på grunnlag av data fra Fiskeridirektoratets satellittsporing av større fiskefartøyer

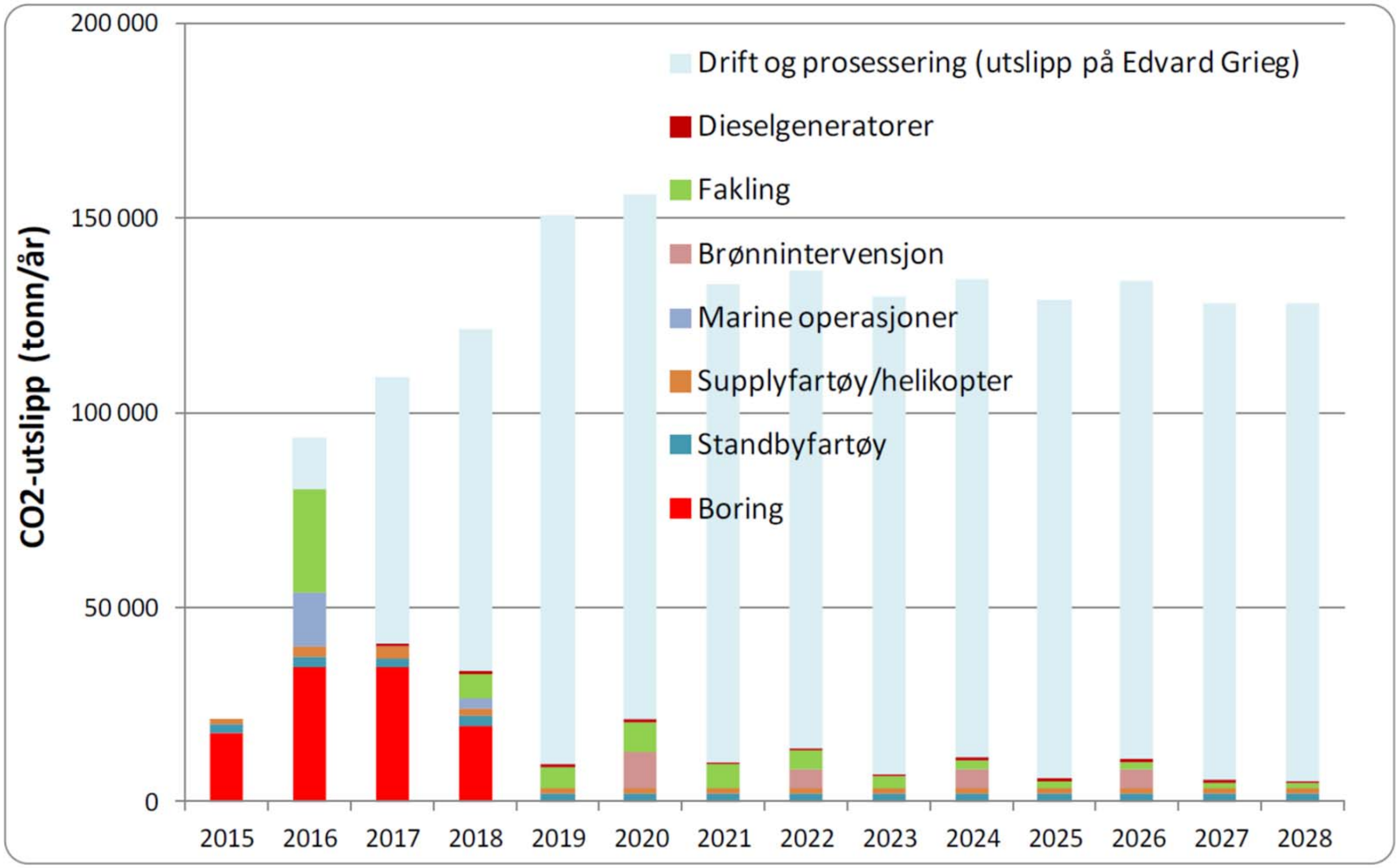
PRE-ENGINEERING - TASKS



Figur 24. Trafikkompleksitet i Nordsjøen (venstre) og skipsleder for handels- og offshorefartøy innenfor en radius på 10 nautiske mil fra Aasen (høyre)

Ref: PDO Ivar Aasen. Det Norske

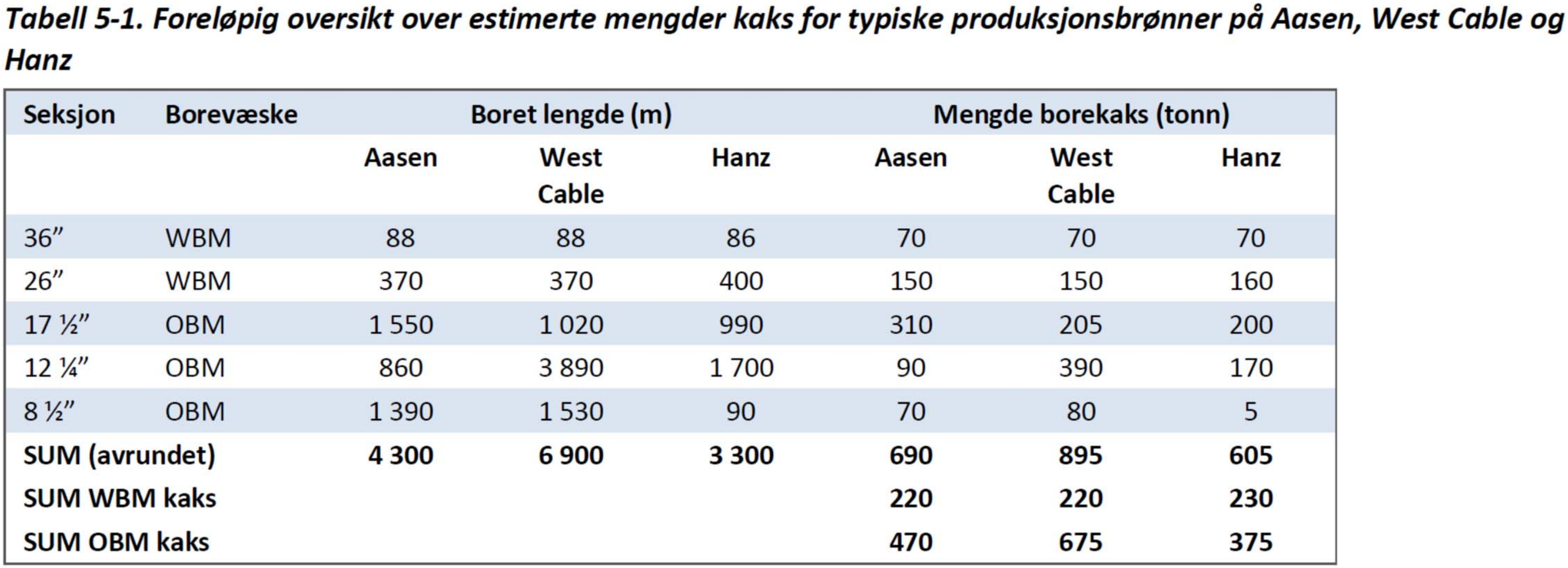
PRE-ENGINEERING - TASKS



Figur 25. Samlede utslipp av CO_2 fra Aasenfeltet i perioden 2015 – 2028

Ref: PDO Ivar Aasen. Det Norske

PRE-ENGINEERING - TASKS

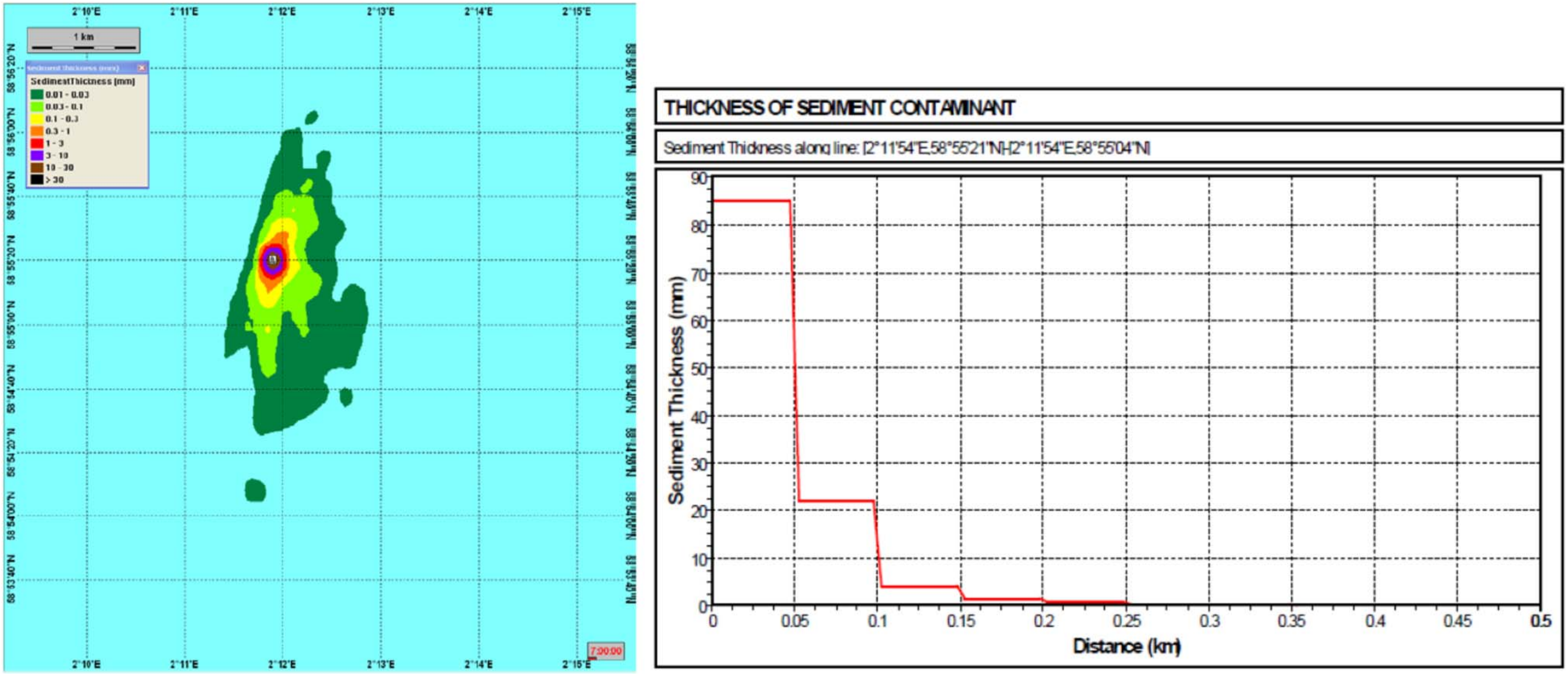


Tabell 5-1. Foreløpig oversikt over estimerte mengder kaks for typiske produksjonsbrønner på Aasen, West Cable og Hanz

Seksjon	**Borevæske**	**Boret lengde (m)**			**Mengde borekaks (tonn)**		
		Aasen	**West Cable**	**Hanz**	**Aasen**	**West Cable**	**Hanz**
36”	WBM	88	88	86	70	70	70
26”	WBM	370	370	400	150	150	160
17 ½”	OBM	1 550	1 020	990	310	205	200
12 ¼”	OBM	860	3 890	1 700	90	390	170
8 ½”	OBM	1 390	1 530	90	70	80	5
SUM (avrundet)		**4 300**	**6 900**	**3 300**	**690**	**895**	**605**
SUM WBM kaks					**220**	**220**	**230**
SUM OBM kaks					**470**	**675**	**375**

Ref: PDO Ivar Aasen. Det Norske

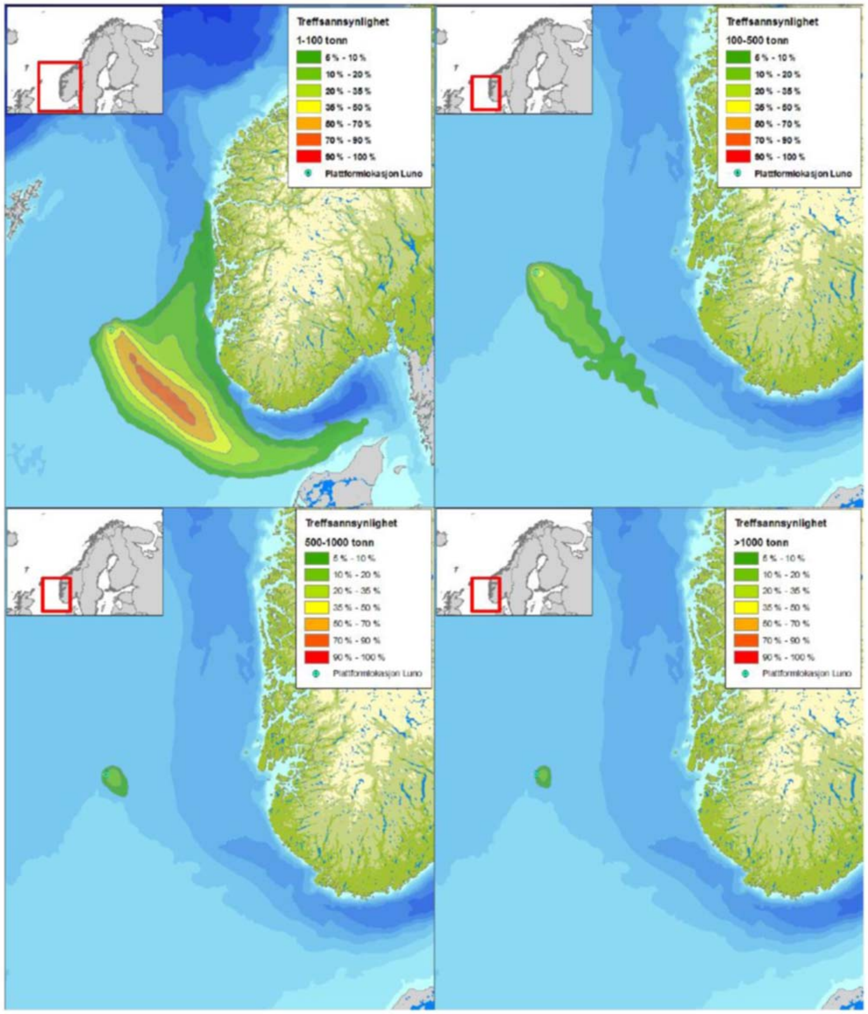
PRE-ENGINEERING - TASKS



Figur 29. Sedimentering ved utslipp av vannbasert kaks ved havbunnen (sommersituasjon)

Ref: PDO Ivar Aasen. Det Norske

PRE-ENGINEERING - TASKS

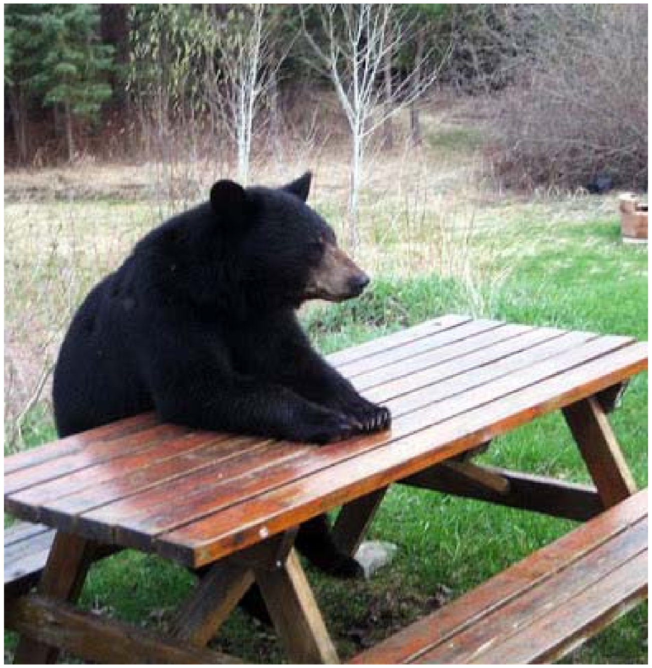


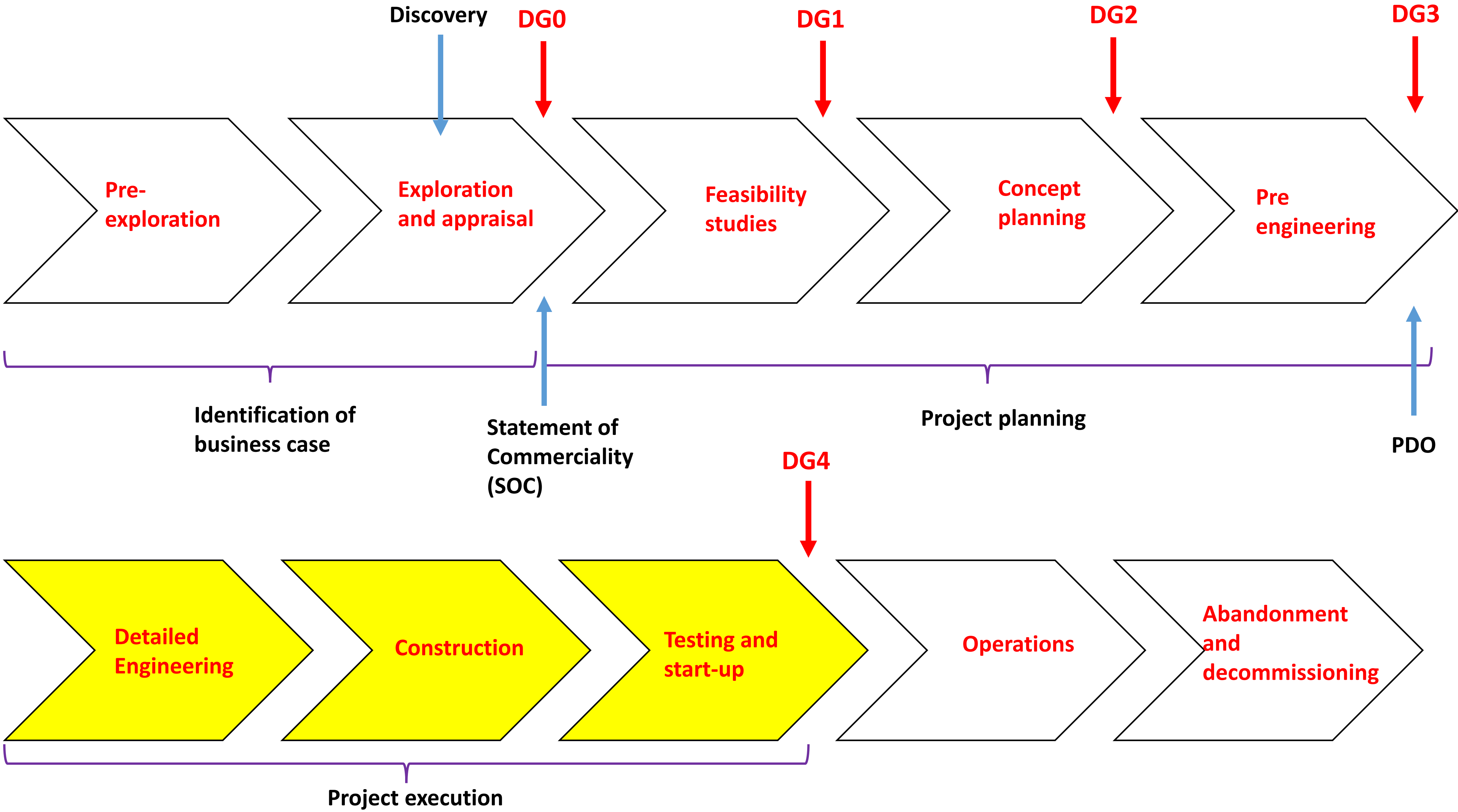
Figur 37. Sannsynligheten for treff av ulike mengdekategorier av olje i 10 × 10 km ruter gitt en sjøbunnsutblåsning fra Aasen/Grieg (helårsstatistikk). Influensområdet er basert på alle utslippsrater og varigheter og deres individuelle sannsynligheter. Merk at det markerte området ikke viser omfanget av et enkelt oljeutslipp, men er det området som berøres i mer enn 5 % av enkeltsimuleringene av oljens drift og spredning (Lundin 2011).

Ref: PDO Ivar Aasen. Det Norske

PRE-ENGINEERING - TASKS

- Wait for the government to study the proposal





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DETAILED ENGINEERING, CONSTRUCTION, TESTING AND STARTUP

OBJECTIVE: Detailed design, procurement of the construction materials, construction, installation and commissioning of the agreed facilities.

Individual contracts

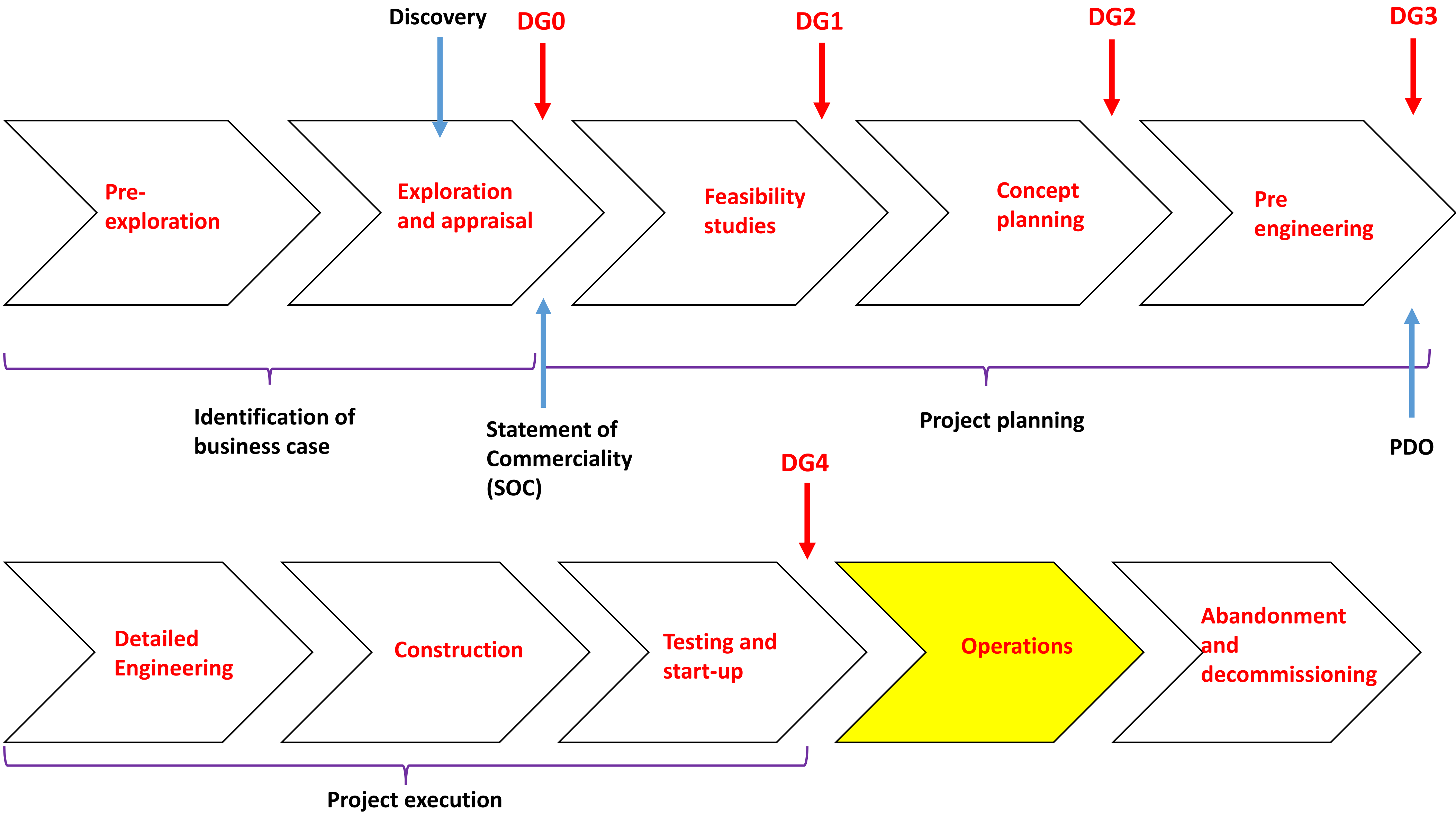
- Detailed engineering
- Bids, contracts
- Construction, fabrication
- Installation
- Commissioning (Cold or Hot)

EPCM (Engineering, procurement, construction, and management contract) with one main contractor.

https://www.youtube.com/watch?v=TzLAfzhqVHc https://www.youtube.com/watch?v=TiWOgTq0YD4

DETAILED ENGINEERING, CONSTRUCTION, TESTING AND STARTUP

- Constructing wells.
- Perform hand over to asset, operations
- Prepare for start-up, operation and maintenance



Discovery

DG0

DG1

DG2

DG3

Pre-exploration

Exploration and appraisal

Feasibility studies

Concept planning

Pre engineering

Identification of business case

Statement of Commerciality (SOC)

Project planning

PDO

DG4

Detailed Engineering

Construction

Testing and start-up

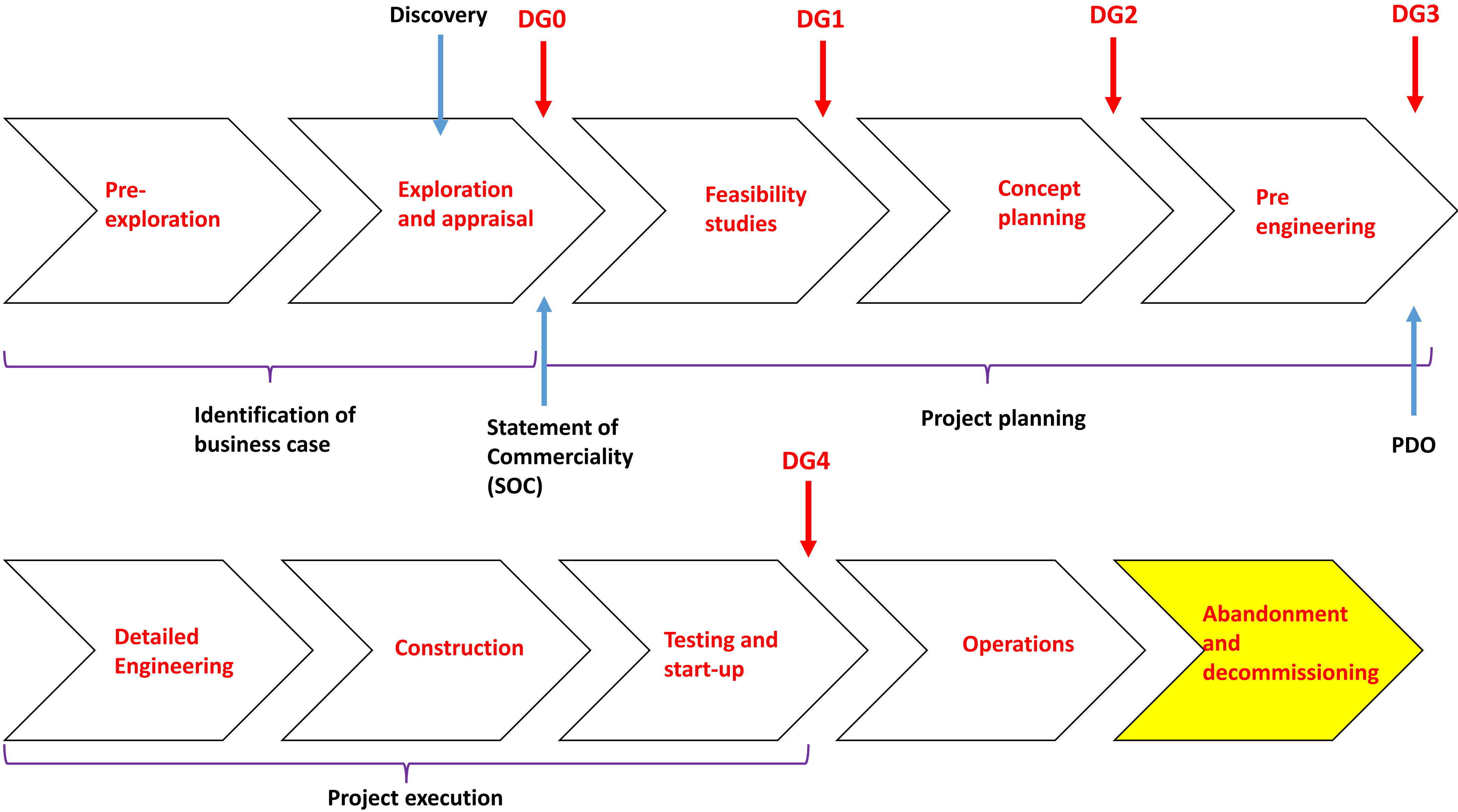
Operations

Abandonment and decommissioning

Project execution

OPERATIONS

- Production startup, Build-up phase, Plateau phase, Decline phase, Tail production, Field shut-down.
- Maintenance.
- Planning Improved Oil recovery methods.
- Allocation and metering.
- De-bottlenecking.
- Troubleshooting.



Discovery

DG0

DG1

DG2

DG3

Pre-exploration

Exploration and appraisal

Feasibility studies

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DG4

Detailed Engineering

Construction

Testing and start-up

Operations

Abandonment and decommissioning

Project execution

DECOMISSIONING AND ABANDONMENT

- Engineering “down and clean”: flushing and cleaning tanks, processing equipment, piping.
- Coordinate with relevant environmental and governmental authorities.
- Well plugging and abandonment (P&A)
- Cut and remove well conductor and casing.
- Remove topside equipment.

DECOMISSIONING AND ABANDONMENT

- Removal of the offshore structure: Lifting operations and transport
- Remove or bury subsea pipelines
- Mark and register leftover installations on marine maps
- Monitoring
- Recovery of material: Scrap (steel) and recycling equipment (Gas turbines, separators, heat exchangers, pumps, processing equipment)
- Disposal of residues

DECOMISSIONING AND ABANDONMENT

https://www.youtube.com/watch?v=SLO9uD5Ub_Y

DECOMISSIONING AND ABANDONMENT

https://www.youtube.com/watch?v=1GA3EIu81rw

Notes for Youtube video nr. 3

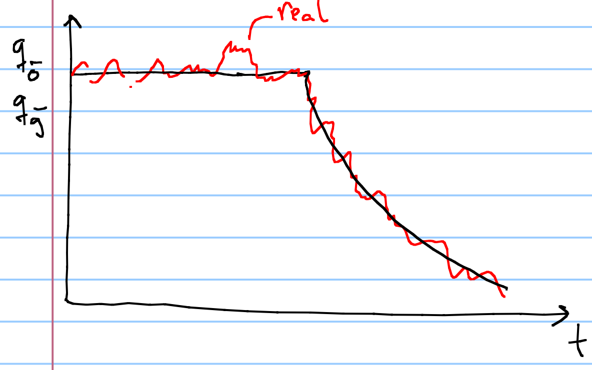
- Field production performance
  - production modes (production scheduling)
  - plateau height vs. plateau length
  - deciding plateau height

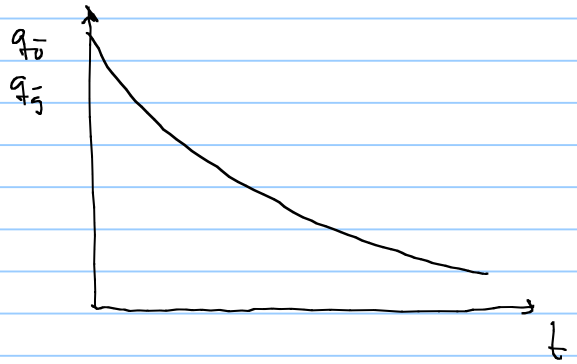
production scheduling: deciding / forecasting rates of oil / gas and associated products (oil, water / gas, water)

during the life of field

two ways to produce a field

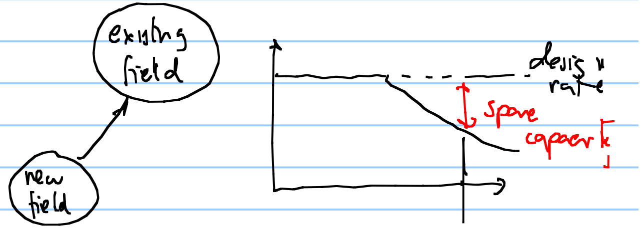
Production mode A "plateau production" | Production mode "B" "decline production"



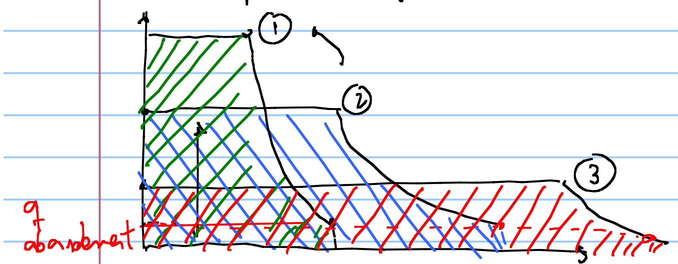


- typically used for gas fields with a contract
- Big-medium reservoir
- standalone development → requires its own facilities, offshore structure etc.

- produce as much as possible as early as possible
- satellite developments to existing fields that use existing infrastructure



in mode "a" there is a relationship between plateau height and duration



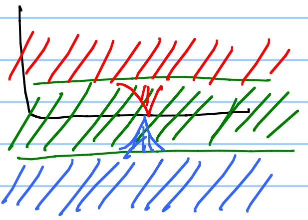
$$N_p = \int_0^t q(t)\,dt$$

↳ cumulative production

until abandonment N_{pu}

🟩 = 🟦 = 🟥

- for gas, plateau height / length is given by contract
- for oil/gas → there is a requirement by authorities to reach certain RF



higher rates can cause high GOR
high WC
sand production

to define plateau rate an economic analysis must be made

higher plateau → higher revenue

cash flow = revenue − expenses

$\Delta Q_{p_i} \cdot P_o^i$ production of oil/gas in year "i"

NPV ⇝ net present value $$NPV = \sum_{i=1}^{N} \frac{CF_i}{(1+c)^i}$$

↑ year

↳ discounting rate (5% → 15%)
0.05 − 0.15

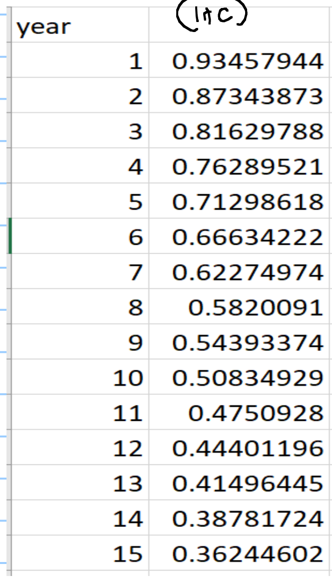
$$\underbrace{NPV}_{} = \overset{(1-5)}{\underbrace{\text{Expenses}}_{}} + \frac{\Delta Q_p^5 \cdot P_o^5 - OPEX^5}{(1+0.07)^5} + \frac{\Delta Q_p^6 \, P_o^6 - OPEX^6}{(1+0.07)^6} + \dots$$

wells
processing facilities
platform

↑ start production

due to discounting, it makes sense to produce as much as possible, as early as possible

$DF = \frac{1}{(1+c)^i}$



year	
1	0.93457944
2	0.87343873
3	0.81629788
4	0.76289521
5	0.71298618
6	0.66634222
7	0.62274974
8	0.5820091
9	0.54393374
10	0.50834929
11	0.4750928
12	0.44401196
13	0.41496445
14	0.38781724
15	0.36244602

if plateau rate is higher → bigger processing facility
→ bigger offshore structure
→ more wells

⇓
"expenses" become very negative

but also revenues become bigger

for HC fields, plateau rate is usually decided by doing an economic evaluation and sensitivity analyses

exceptions { • Blending of crude

Rules of thumb for first iteration on plateau rate

for oil: 10% of N_{pu} per year

ultimate cumulative production (at abandonment)

TRR → total recoverable reserves

Example 180E06 stb → N initial oil in place (OOIP)

$$N_{pu} = \underbrace{R_{Fu}}_{(0.3-0.5)} \cdot N$$

$$N_{pu} = 0.4 \; 180E06 \text{ stb}$$

$$N_{pu} = 72E06 \text{ stb}$$

$$q_{plateau} = \frac{N_{pu} \cdot \boxed{0.1}}{\text{Nr producing day in year}} = \frac{72E06 \cdot 0.1}{0.9 \cdot 365} \simeq 21900 \text{ stb/d}$$

$[Sm^3/d]$

$[stb/d]$

↳ 95% uptime (0.95 . 365)

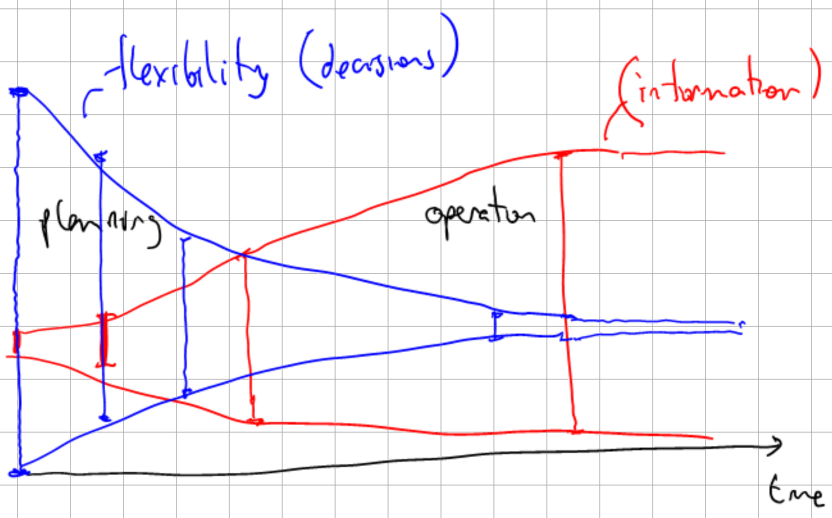
for gas (2-5)% of G_{pu}

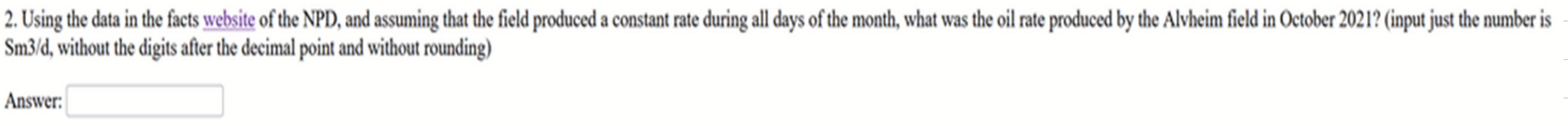
Q is either oil or gas

N is for oil

G is for gas

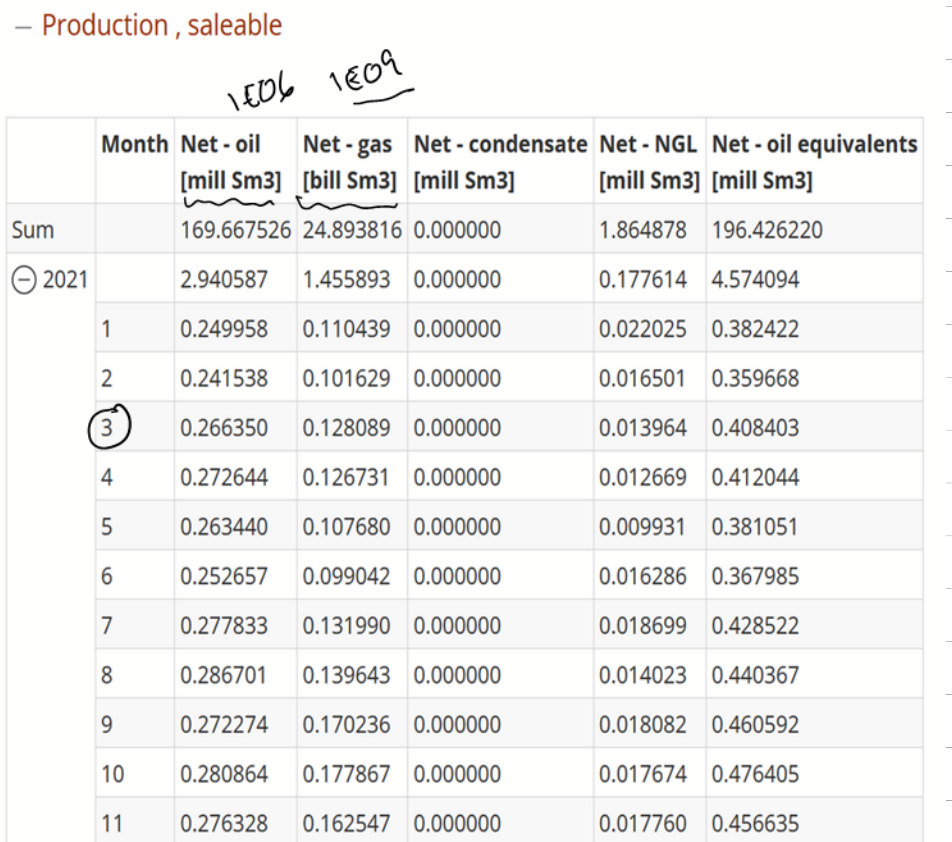
20220121 Online class





2. Using the data in the facts website of the NPD, and assuming that the field produced a constant rate during all days of the month, what was the oil rate produced by the Alvheim field in October 2021? (input just the number is Sm3/d, without the digits after the decimal point and without rounding)

Answer:

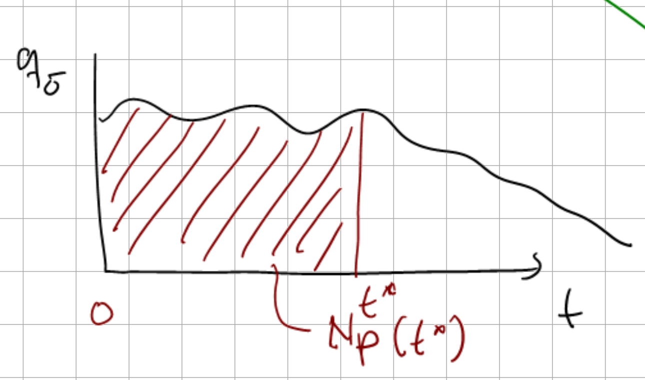


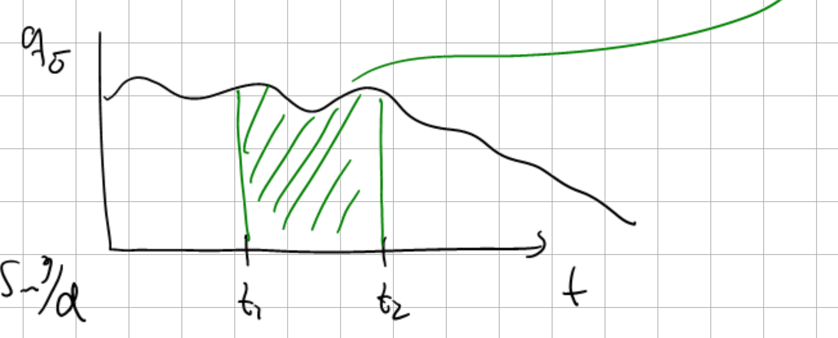
– Production , saleable

1E06 1E09

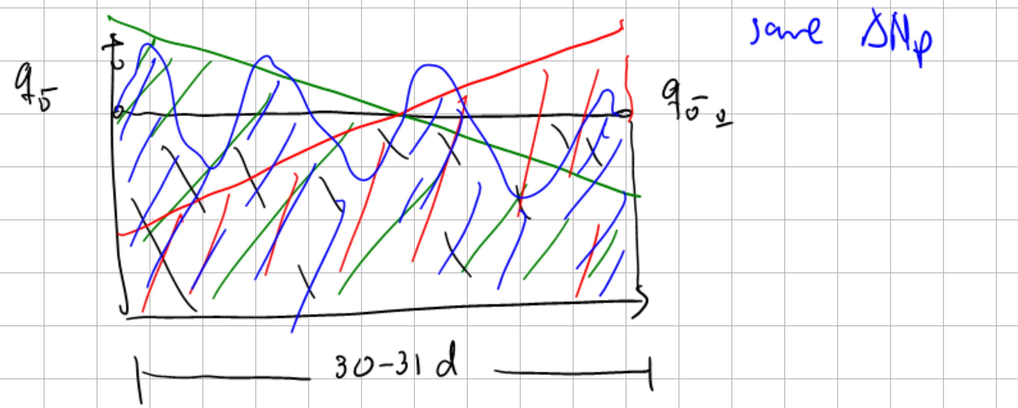
	Month	Net - oil [mill Sm3]	Net - gas [bill Sm3]	Net - condensate [mill Sm3]	Net - NGL [mill Sm3]	Net - oil equivalents [mill Sm3]
Sum		169.667526	24.893816	0.000000	1.864878	196.426220
⊖ 2021		2.940587	1.455893	0.000000	0.177614	4.574094
	1	0.249958	0.110439	0.000000	0.022025	0.382422
	2	0.241538	0.101629	0.000000	0.016501	0.359668
	3	0.266350	0.128089	0.000000	0.013964	0.408403
	4	0.272644	0.126731	0.000000	0.012669	0.412044
	5	0.263440	0.107680	0.000000	0.009931	0.381051
	6	0.252657	0.099042	0.000000	0.016286	0.367985
	7	0.277833	0.131990	0.000000	0.018699	0.428522
	8	0.286701	0.139643	0.000000	0.014023	0.440367
	9	0.272274	0.170236	0.000000	0.018082	0.460592
	10	0.280864	0.177867	0.000000	0.017674	0.476405
	11	0.276328	0.162547	0.000000	0.017760	0.456635

$$\Delta N_p = \int_{t_1}^{t_2} q_{\bar{o}}\, dt$$





$$q_{\bar{o}}^{march} = \frac{\Delta N_p^{march}}{day^{march}} = \frac{0.266350\ E06}{31} = Sm^3/d$$



4. A while ago, Milan made an Excel file that shows the production profile of field in the NCS using data from the npd website. Using the data in the excel sheet, compute a range for the initial gas in place of the Snohvit field using the rule of thumb discussed in class. Assume an uptime of 95%, and ultimate recovery factor of 85%. Select the closest from the list below.

○ 1.6 E11 - 4.1 E11 Sm3
○ 6.2 E11 - 8.5 E11 Sm3
○ 0.8 E11 - 1 E11 Sm3

for Oseberg East $q_{\bar{o}\,\text{plateau}} = 10000\ Sm^3/d$

$$q_{\bar{o}\,\text{plateau}} = \frac{N_{pu} \cdot \overset{a_1}{f}}{N_{\text{day year}}}$$

0.4

365

$$10.000 = \frac{N \cdot R_{fu} \cdot 0.1}{0.95 \cdot 365}$$

$$N = \frac{10\,000 \cdot 0.95 \cdot 365}{0.1 \cdot 0.4}$$

$N = 8.67\ E7\ Sm^3$

Real N (from NPD website)

$N = 73.87\ E06\ Sm^3$

$$\varepsilon = \frac{74 - 87}{74} \times 100 = 17\%$$

"production year"

project year

(5) (5)

$$\text{NPV} = \sum_{i=1}^{n} \frac{CF_i}{(1+c)^i} \simeq \text{expenses}\ \begin{cases}\text{platform} \\ \text{drilling} \\ \text{pipes}\end{cases} + \frac{\Delta N_p^1 \cdot P_o^1 - OPEX^1}{(1+c)^5}$$

$f(q_{\bar{o},\text{plateau}}, N_{well})$

t

– 0

end of year → 1

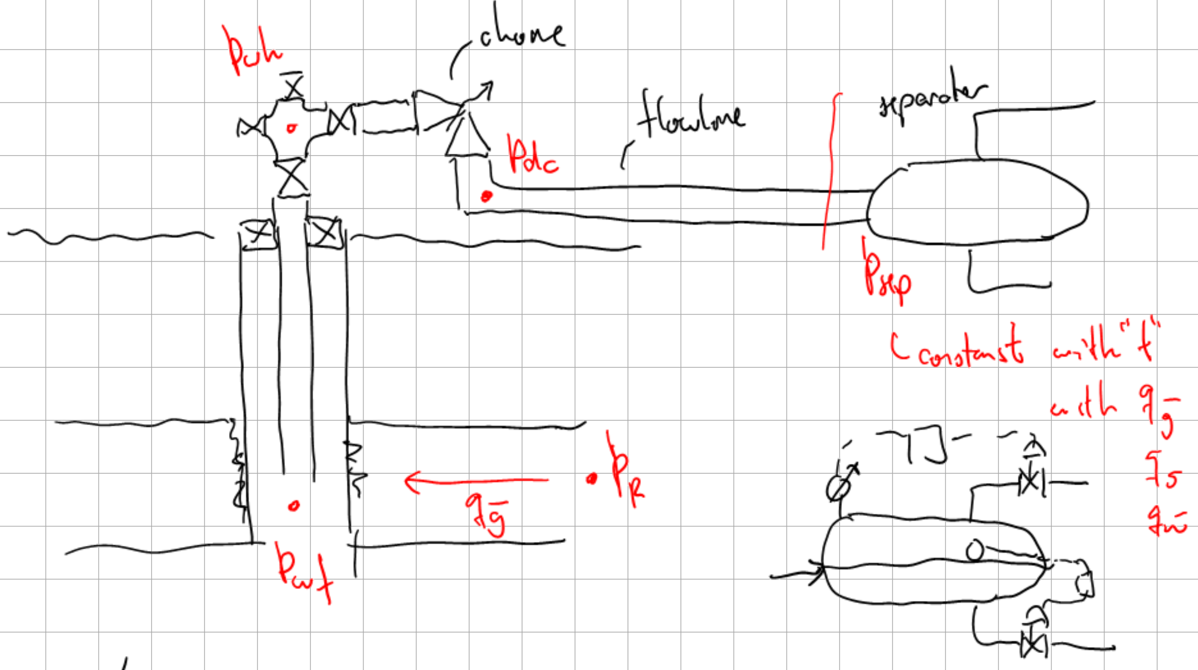
2

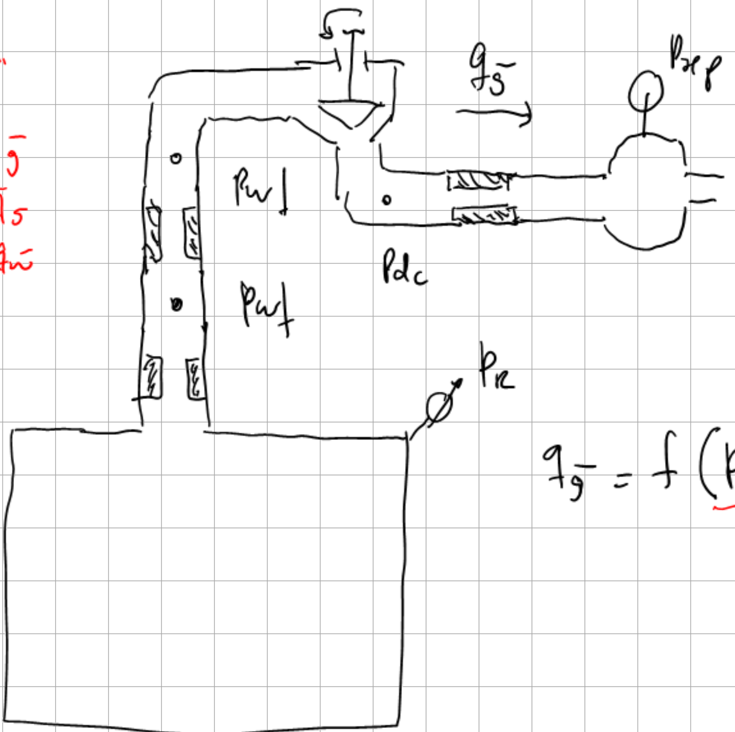
Intro to Excel VBA, functions and subs

There were no notes for this video

Live lecture 20220128

Understand production performance of the production system → $q_{\bar{o}}$ (standard conditions), $q_{\bar{g}}$, $q_{\bar{w}}$ vs t — profiles





$$q_{\bar{g}} = f(\underbrace{p_R}, \underbrace{p_{sep}}, \underbrace{C_o})$$

goes down with time

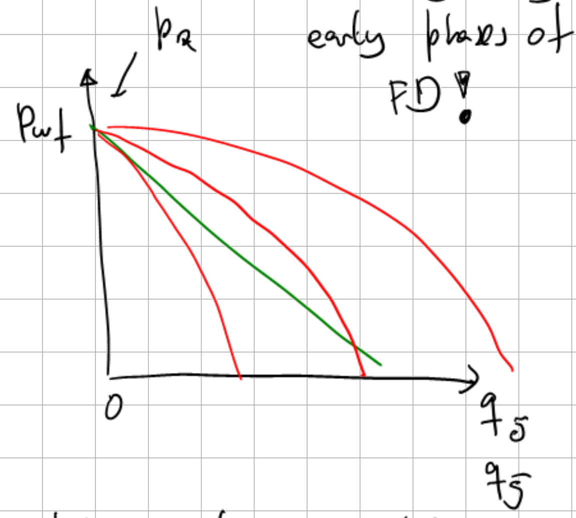
choke opening

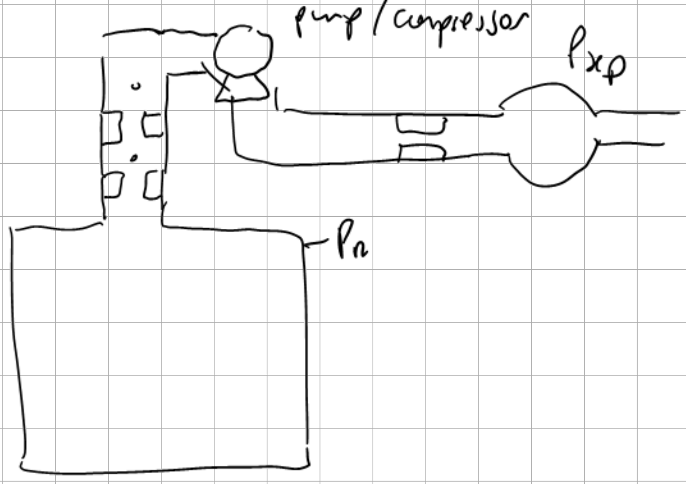
Dry gas / undersaturated oil

- $p_R \rightarrow p_{wf}$ IPR equation $\underbrace{\text{inflow performance relationship}}$

$q_{\bar{o}} = f_1(p_R, p_{wf})$
$q_{\bar{g}}$

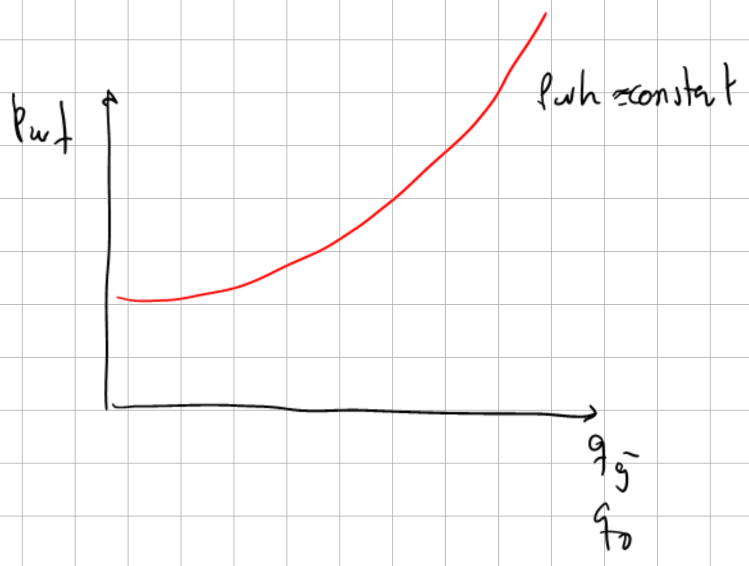
Big uncertainty during early phases of FD!





- $p_{wf} \rightarrow p_{wh}$ TPR equation tubing performance relationship

$q_{\bar{g}}$ $f_2(p_{wf}, p_{wh})$, GOR, WC
$q_{\bar{o}}$



- $p_{wh} \rightarrow p_{dc}$ CPR choke performance relationship

$$\underbrace{\begin{matrix} q_{\bar{g}} \\ q_{\bar{o}} \end{matrix} - f_3(p_{wh}, p_{dc}, C_o)}$$

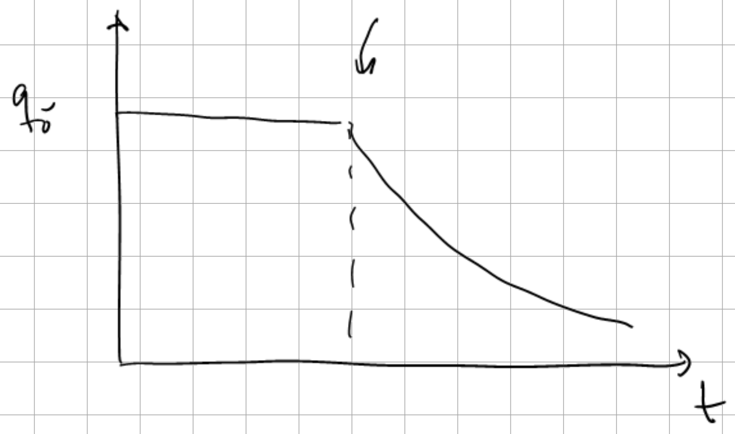
- is often non-predictive
- non-linear →

- $p_{dc} \rightarrow p_{sep}$ PPR / FPR flowline performance relationship
  pipeline

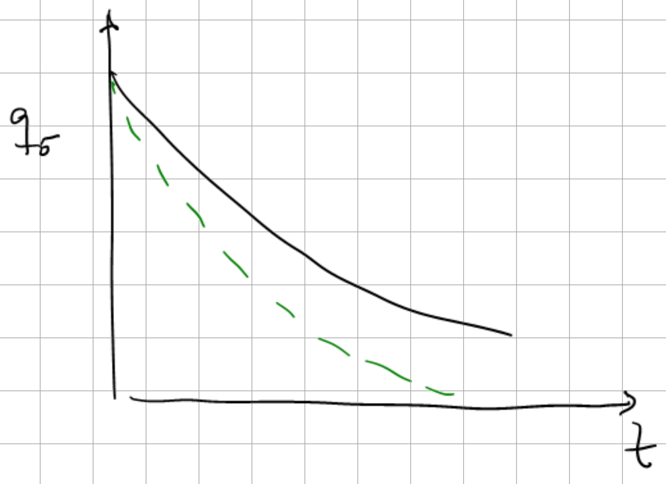
$q_{\bar{g}}$ $f_4(p_{dc}, p_{sep})$
$q_{\bar{o}}$

why plateau ends?

MODE A



MODE B



- Not enough energy (p_R) to produce the desired rate ($q_{o,p}$ $q_{g,p}$) against Psep

→ ◦ fix $q_{g,p}$

◦ Compute P_{wf} (IPR)

◦ Compute P_{wh} (TPR)

◦ Compute ΔP_{comp}

◦ Compute P_{sep}^{calc} (FPR)

◦ compare if $P_{sep}^{calc} > P_{sep}^{system}$ ⟶ $q_{g,p}$ is feasible choking is needed

↓

$P_{sep}^{calc} < P_{sep}^{system}$

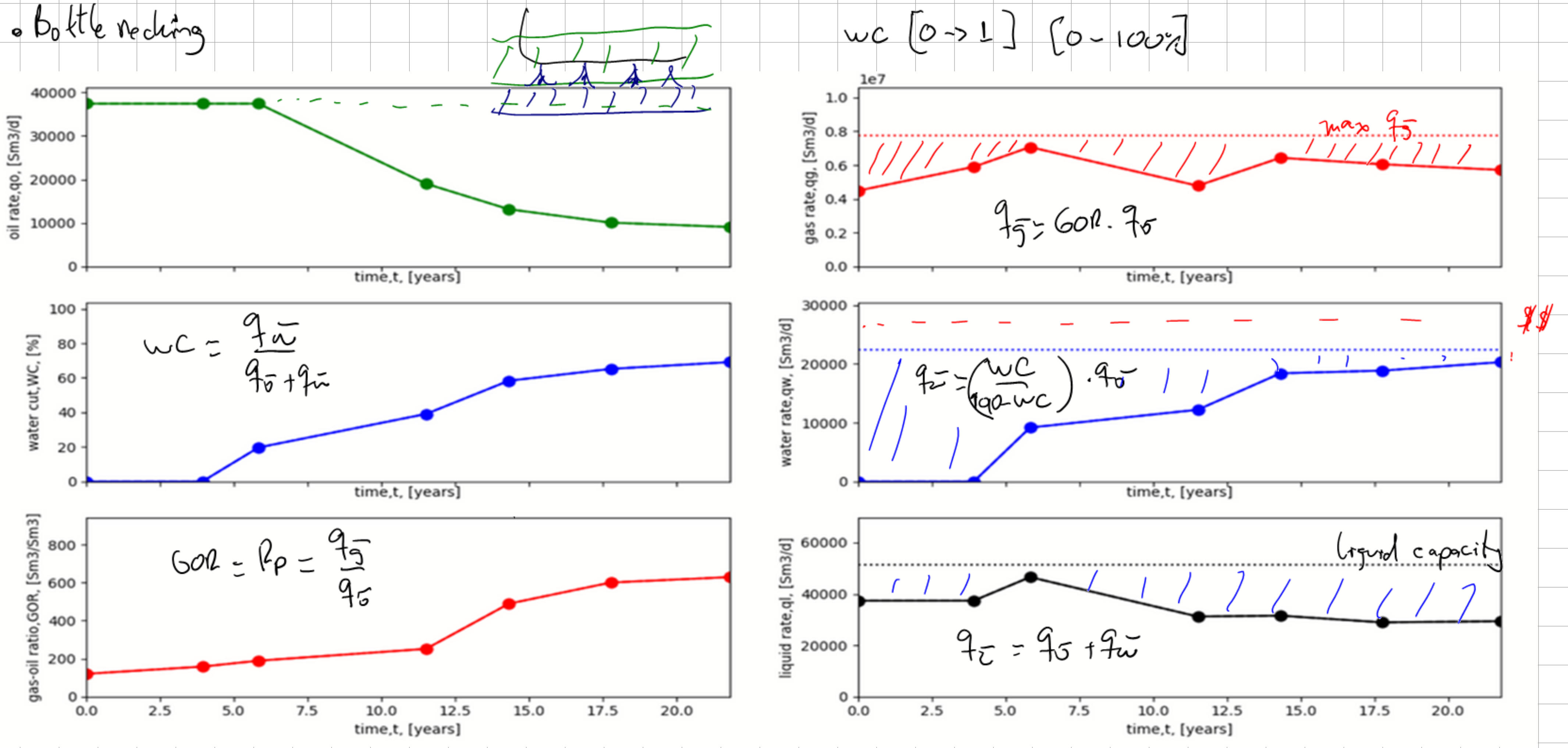
↓

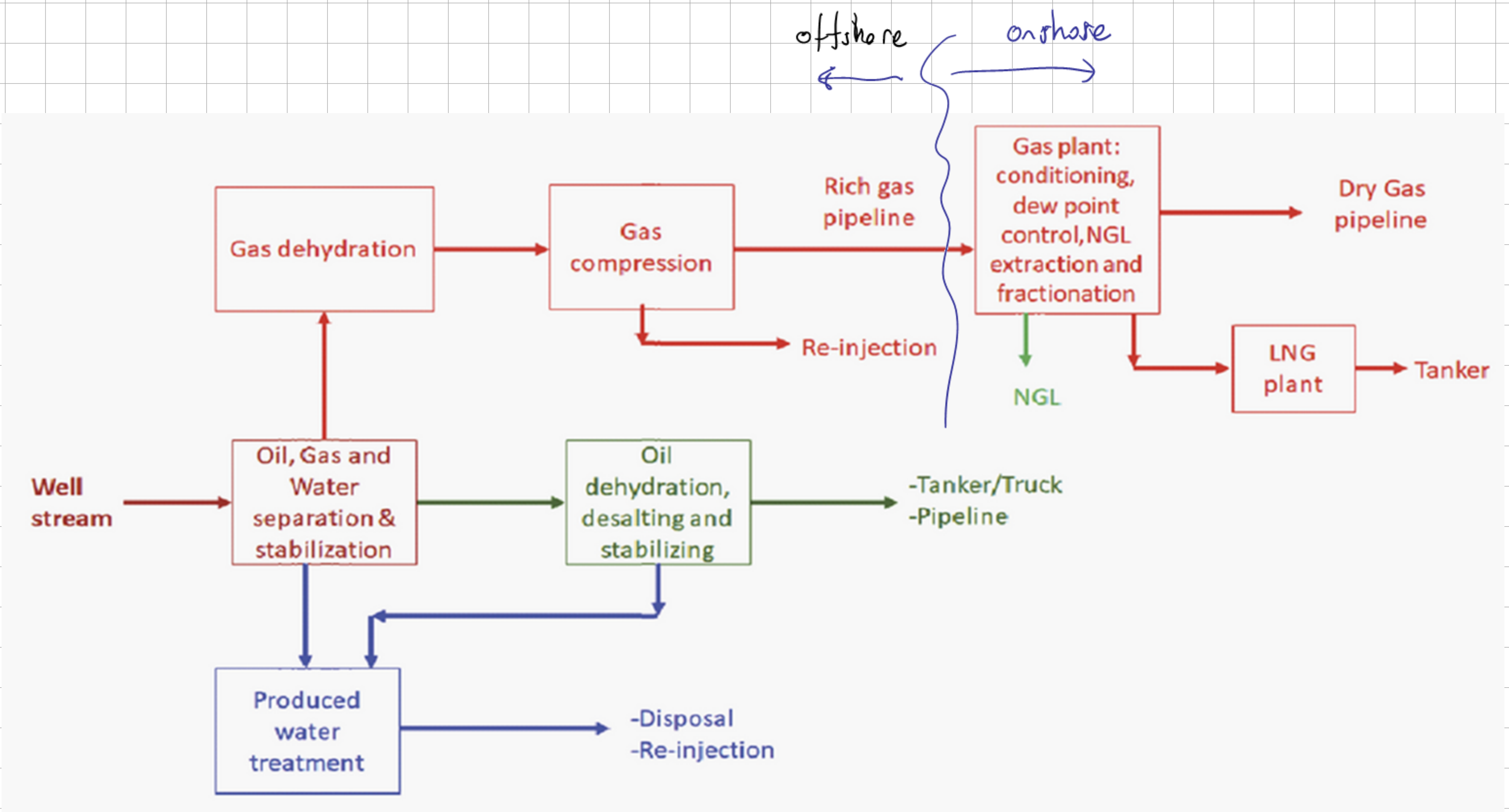
$q_{g,p}$ is not feasible

we will perform this analysis in the course using flow equilibrium (nodal analysis)

◦ bottle necking

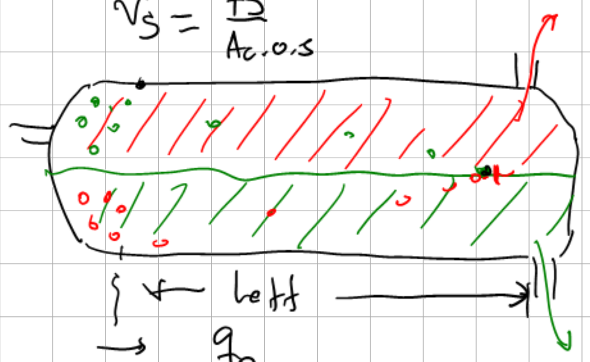
wc [0 -> 1] [0 - 100%]



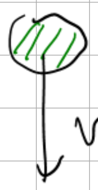


Horizontal gravity seperator

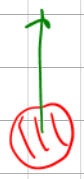
$v_g = \frac{q_g}{A_c \cdot 0.5}$



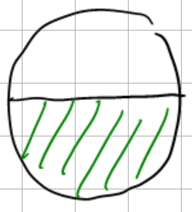
$\vec{v}_o = \frac{q_o}{A_c \cdot 0.5}$



$v_{s,o}$ setting velocity of oil



$v_{r,B}$ rising velocity of gas bubble



$\frac{V_g}{q_g} < 30s$

$$\overbrace{t_{r,g} = \frac{\frac{\Phi}{2}}{v_{s,o}}}^{\text{residence time}} \approx \frac{V_g}{q_g}$$

30s - 60s

↳ local rate at P_{sep}

$t_{r,g} = \frac{L_{eff}}{v_g} = \frac{V_g}{q_g}$

$t_{r,o} = \frac{\Phi/2}{v_{r,g}}$ $\frac{V_o}{q_o}$

$t_{r,o} = \frac{L_{eff}}{v_o} = \frac{V_o}{q_o}$ 30-120 s

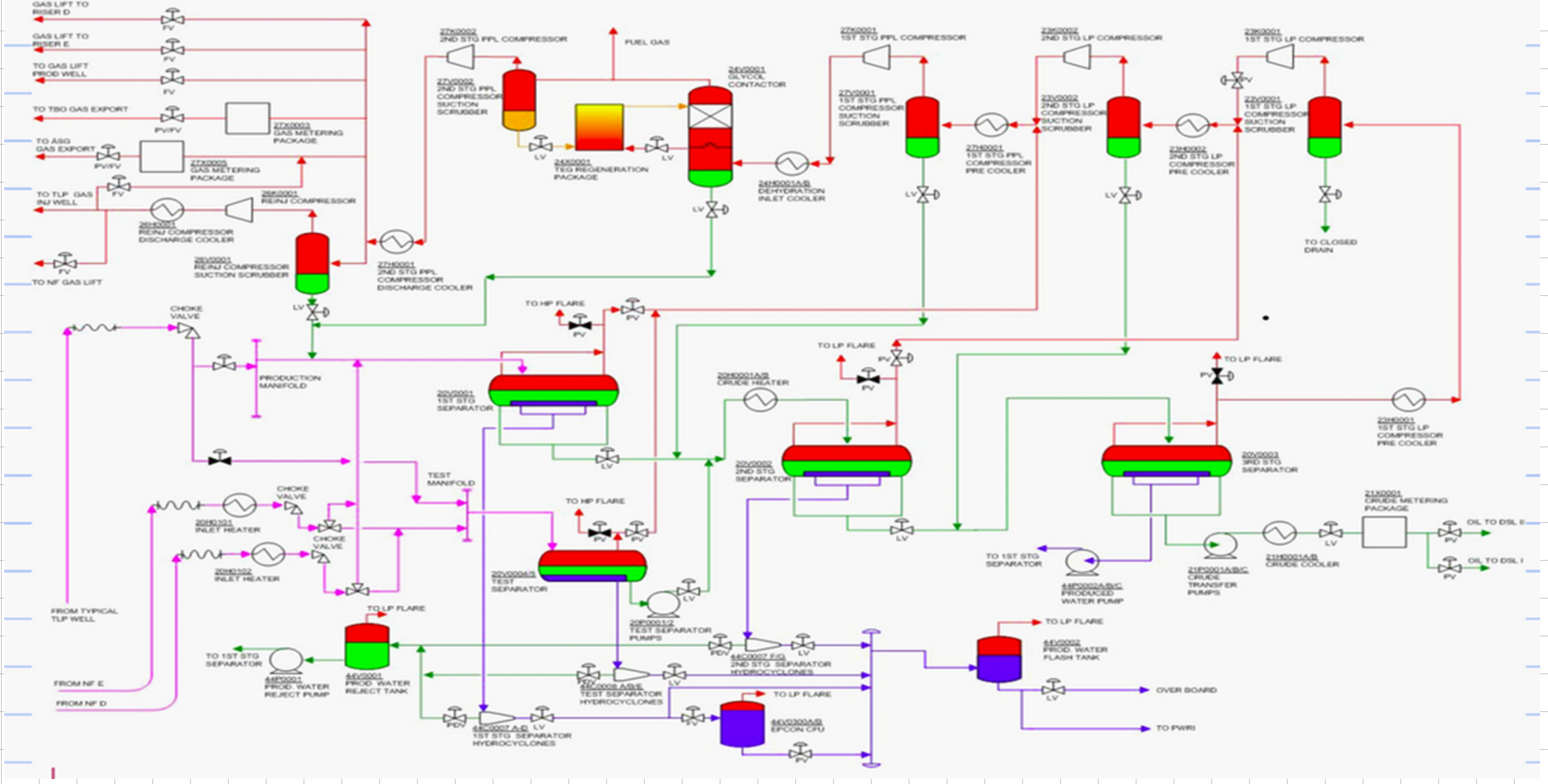
$q_o \to q_{\bar{o}}$

$q_{\bar{o}} \to q_o$ (BO properties)

$q_o = \underline{B_o} \, q_{\bar{o}}$

$q_g = \underline{B_g} \left(GOR - R_s \right) q_{\bar{o}}$

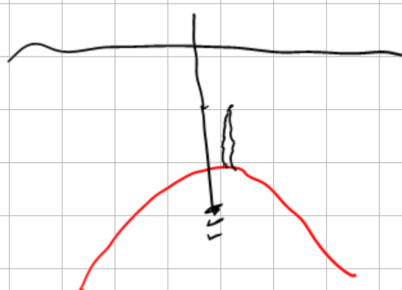
$q_g = B_g \left(q_{\bar{g}} - R_s q_{\bar{o}} \right)$



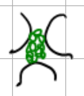
Bottlenecking can occur due to:

- separation capacity (residence times) → high gas rates
  high water rates
  → low $\left\{ \begin{array}{l} V_{s,o} \\ V_{s,b} \end{array} \right\}$ foaming
  emulsion

- rotating equipment: compressors
  pumps
  Heat exchanger

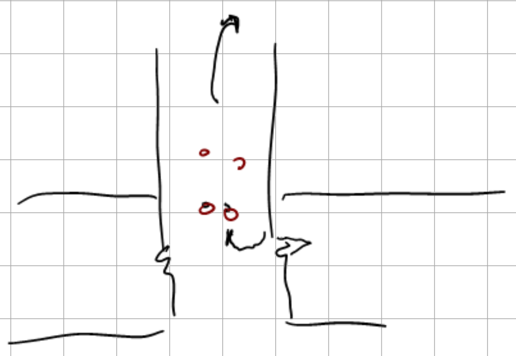


- water disposal → injectors → plugging of injectors
  gas



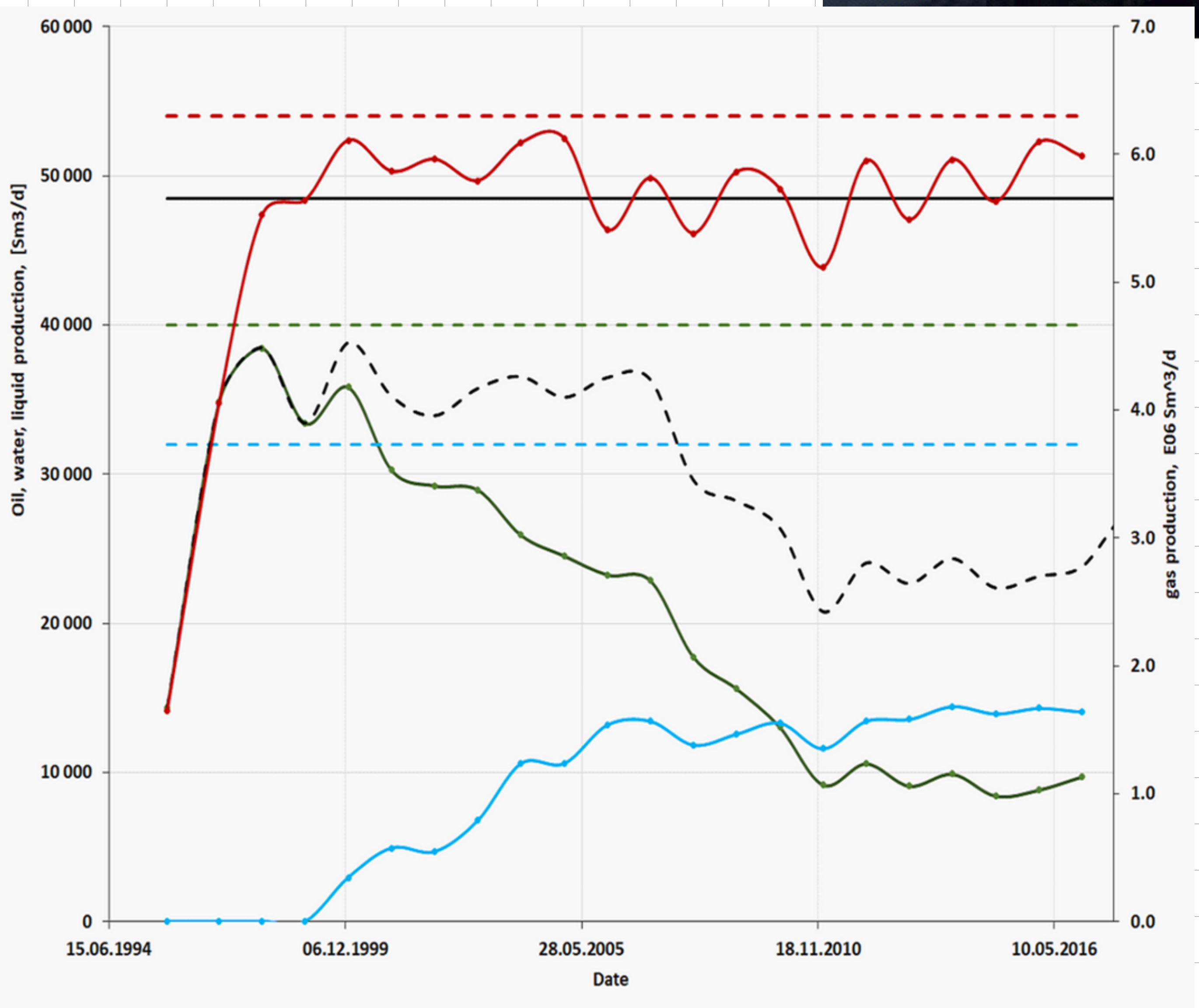
fracking of injectors

- excessive sand production → reduce the rate



An example

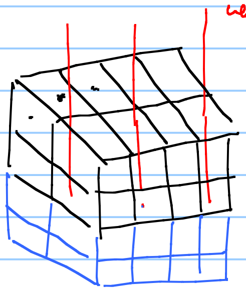

Heidrun
Trondheim
Norway
Bergen
Oslo
Stavanger
United Kingdom
Denmark


60 000
50 000
40 000
30 000
20 000
10 000
0
Oil, water, liquid production, [Sm3/d]
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
gas production, E06 Sm^3/d
15.06.1994
06.12.1999
28.05.2005
18.11.2010
10.05.2016
Date

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 bottom-hole 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)

$P_{wf\,min}(t)$ $P_{wf}(t)$

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)

- material balance single tank + Inflow performance relationship

p_R
S_o vs t
S_g
S_w

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

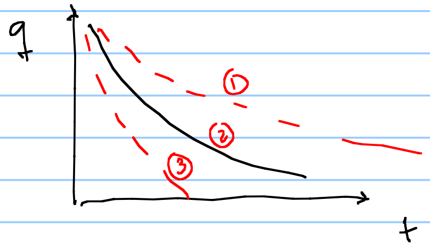
needs assumption on $P_{wf\,min}$

- material balance + well + network model

P_R
S_o vs t
S_g
S_w

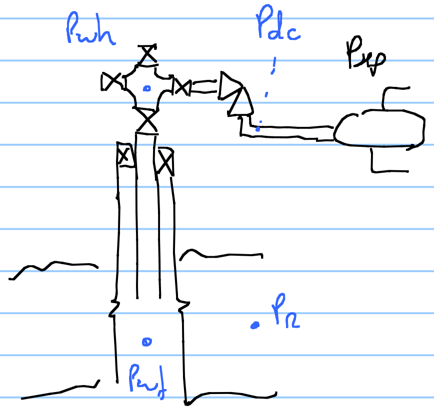
$q = f(P_R, P_{sep})$

- Decline or type curves { very early FD }

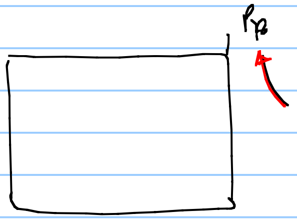


Youtube video: modeling dry gas systems

Simplified dry gas production system



Reservoir model



Dry gas material balance

$$\underbrace{p_R = p_{Ri}\frac{z_R}{z_i}\left(1 - \underbrace{\frac{G_p}{G}}_{R_F}\right)}$$

G_p ← $f(q_g)$, $q_g = f(t)$

G ← uncertain value

R_F recovery factor

z_R ← gas deviation factor

$$z\ f(P_r, T_r) \qquad T_r = \frac{T_R}{T_c}$$

$$P_r = \frac{P_R}{P_c} \rightsquigarrow f(\text{gas composition})$$

T_c → $f(\text{gas composition})$

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,

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

Equation approximation to Z chart

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

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

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

with

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

The derivative ∂Z/∂p used in the definition of c_g is given by

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

to predict Tc, Pc we will use

Sutton correlations

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

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

and

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

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

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

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

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

laminar n ~ 1
turbulent n → 0.5

↑ inflow coefficient { T_R, K, h, s (skin factor)

- pseudo-steady state regime (boundary dominated flow) page 37 of compendium

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

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

elevation coefficient

tubing coefficient (friction losses)

(hydrostatic losses)

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

Page 156, Appendix A of compendium

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

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

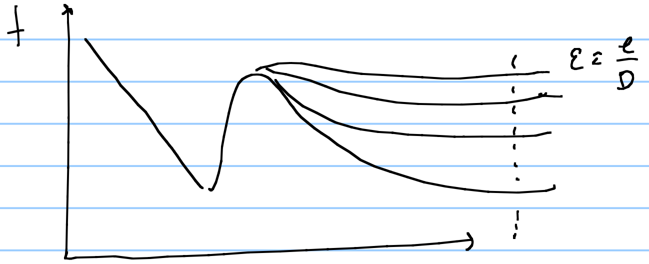
$$S = 2\cdot L\cdot C_a = 2\cdot\frac{M_g}{Z_{av}\cdot R\cdot T_{av}}\cdot L\cdot g\cdot\cos(\alpha)$$

Comments about tubing equation

to compute G_T $T_{av} \rightarrow \frac{T_{wf} + T_{wh}}{2}$ An estimate of T_{wh} is needed

$Z_{av} \sim \frac{Z_{wf} + Z_{wh}}{2}$

f_M friction factor



$$Re = \frac{v \rho D}{\mu}$$

$V = f(q_{local})$ for gas $v \uparrow \uparrow$ ρ is low compared to liquid

$q_{local} \; f(\rho)$

liquid V - $[0.5 - 4]$ m/s

gas V - $[5 - 40]$ m/s

μ_g is $<< \mu_L$

$Re_g >>$

always in fully turbulent regime

$f_M = f(\varepsilon)$ however $e = f(C.D)$ due to manufacturing hoke equation for dry gas: (page 166)

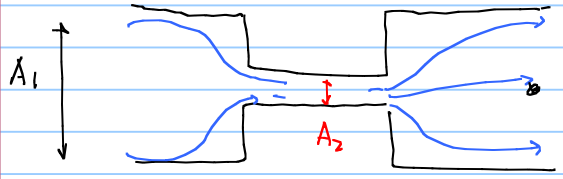
"opening" tuning factor

$$q_{\bar{g}} = \frac{\overset{\text{"opening"}}{p_1 \cdot T_{sc} \cdot A_2} \cdot \overset{\text{tuning factor}}{C_d}}{\underset{P_{sc} = 1.01325 \text{ bara},\ T_{sc} = 15.56\,°C}{p_{sc}}} \cdot \sqrt{2 \cdot \frac{\overset{\frac{R\bar{u}}{MW_g}}{R}}{Z_1 \cdot T_1 \cdot M_w} \cdot \frac{\overset{k = \frac{Cp}{Cv}}{k}}{k-1} \cdot \left(y^{\frac{2}{k}} - y^{\frac{k+1}{k}}\right)}$$

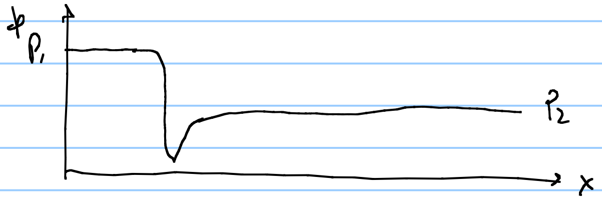
$P_{sc} = 1.01325$ bara

$T_{sc} = 15.56\,°C$

$y = \frac{P_2 \text{ (downstream)}}{P_1 \text{ (upstream)}}$



if $y > y_c \simeq (0.6)$, there is critical flow at the throat



if $y > y_c$ $\quad q_{\bar{g}} = q_{\bar{g}_c} =$

$$q_{\bar{g}} = \frac{p_1 \cdot T_{sc} \cdot A_2 \cdot C_d}{p_{sc}} \cdot \sqrt{2 \cdot \frac{R}{Z_1 \cdot T_1 \cdot M_w} \cdot \frac{k}{k-1} \cdot \left(\underset{y_c}{y}^{\frac{2}{k}} - \underset{y_c}{y}^{\frac{k+1}{k}}\right)}$$

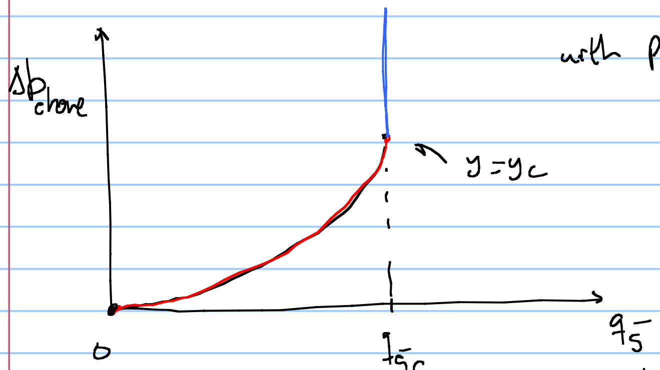
in blue

if $y < y_c$

$$q_{\bar{g}} = \frac{p_1 \cdot T_{sc} \cdot A_2 \cdot C_d}{p_{sc}} \cdot \sqrt{2 \cdot \frac{R}{Z_1 \cdot T_1 \cdot M_w} \cdot \frac{k}{\underset{2}{k-1}} \cdot \left(y^{\frac{2}{k}} - y^{\frac{k+1}{k}}\right)}$$

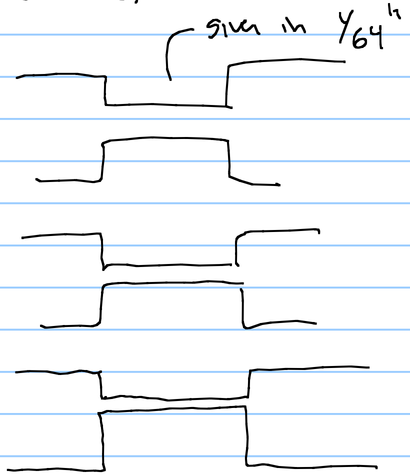
in red

with P_1 = constant

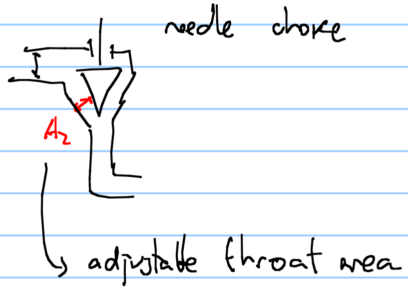


(flow is "choked", critical flow)

in onshore fields, bean choke are often used



offshore often adjustable chokes are used
needle choke



→ Psep flowline → tubing equation can be used for flowline

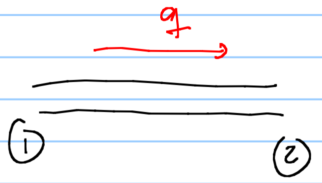
horizontal flowline, the tubing equation simplifies to

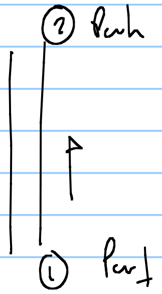
$$q_g = C_{FL}\left(P_{dc}^2 - P_{sep}^2\right)^{0.5}$$

$$S=0 \quad (\text{L'Hopital})$$

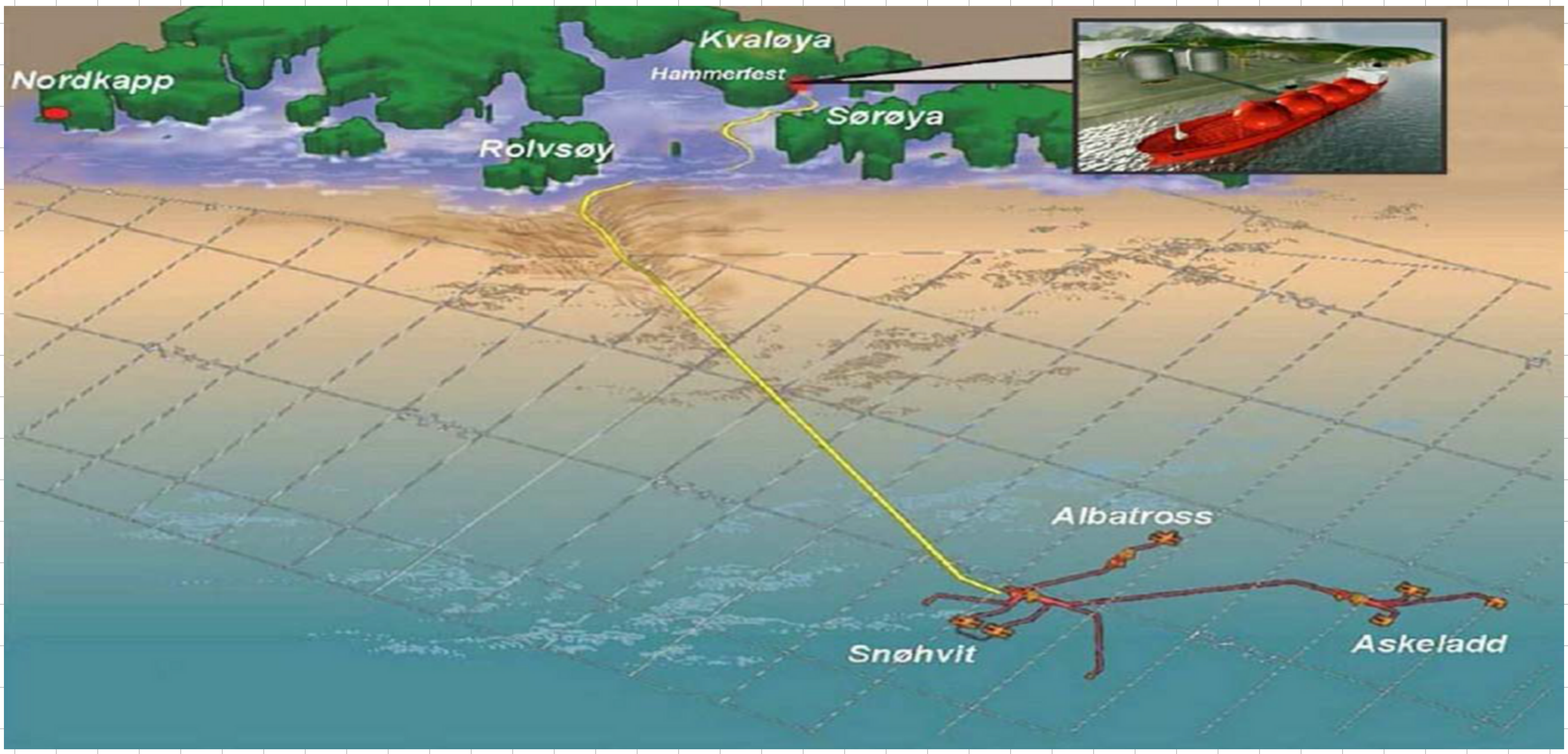
VBA Visual basic for applications

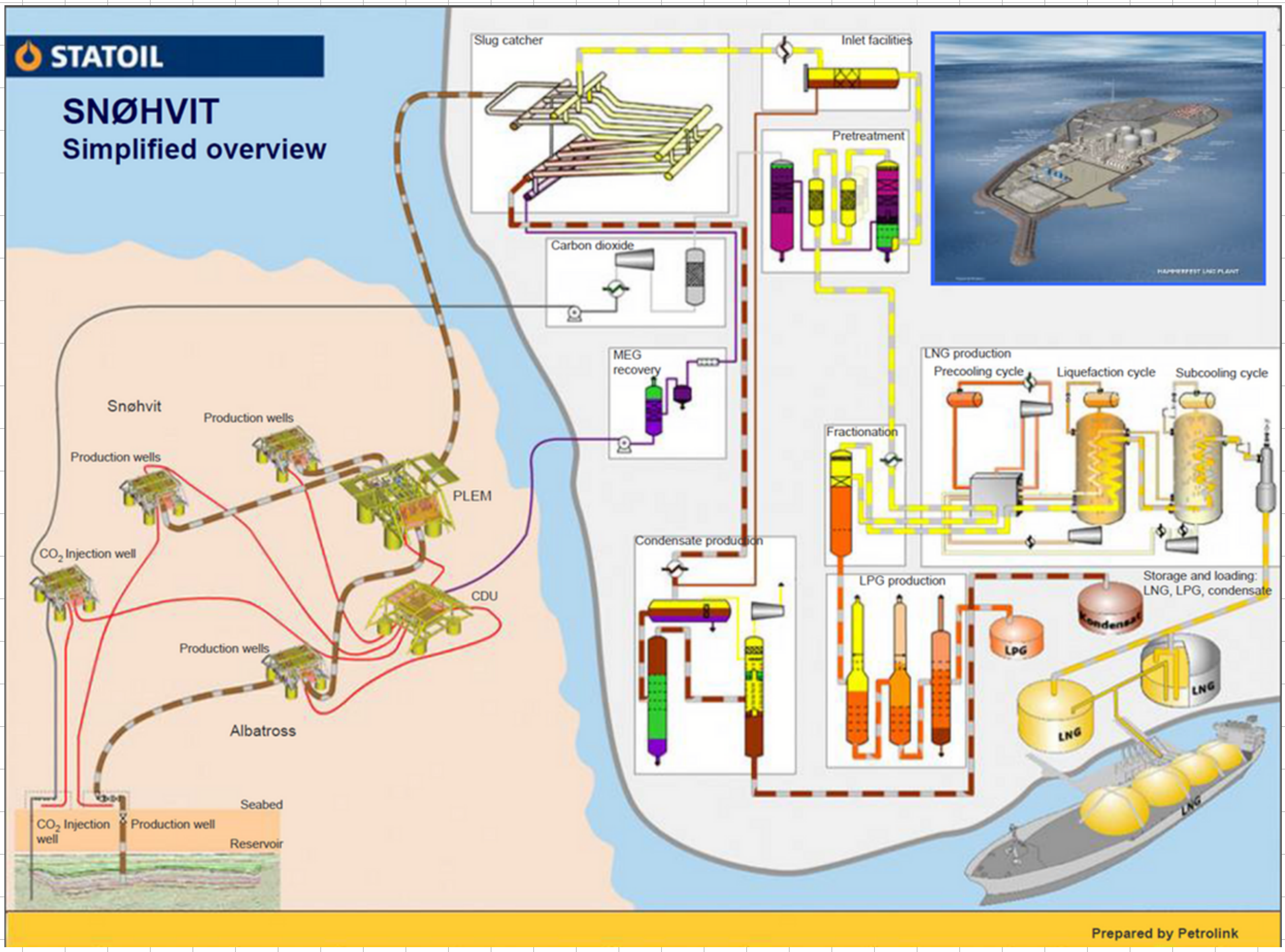
for pipe equations in VBA ① is upstream
② is downstream





live lecture 04.02.2022



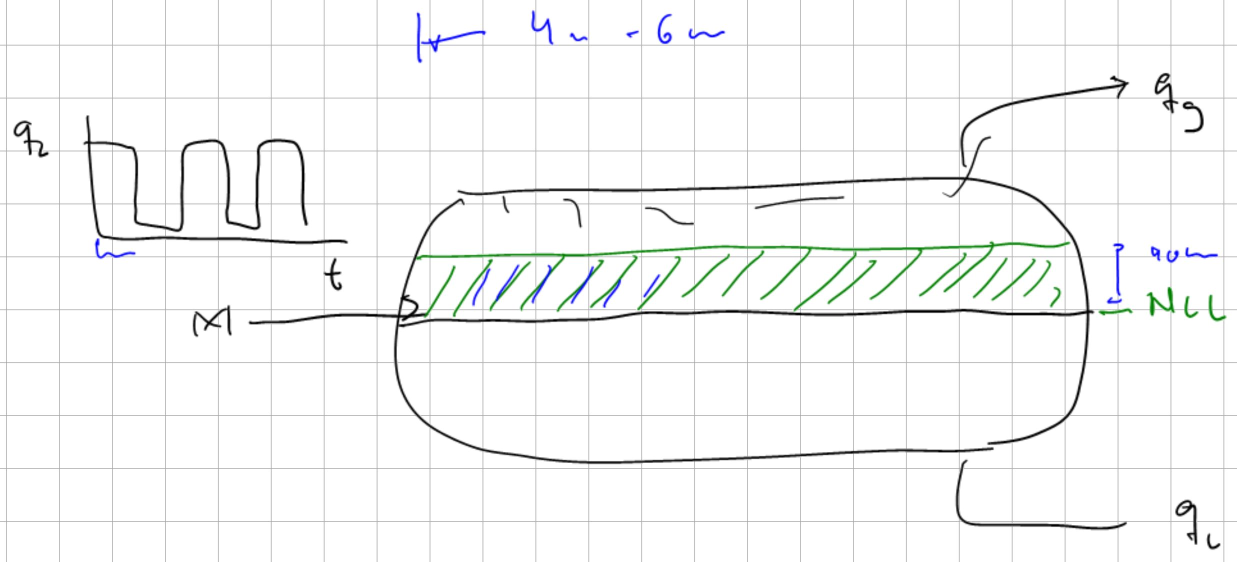


https://www.youtube.com/watch?v=xY4WdJLal_0

https://www.youtube.com/watch?v=LKLW5284adI

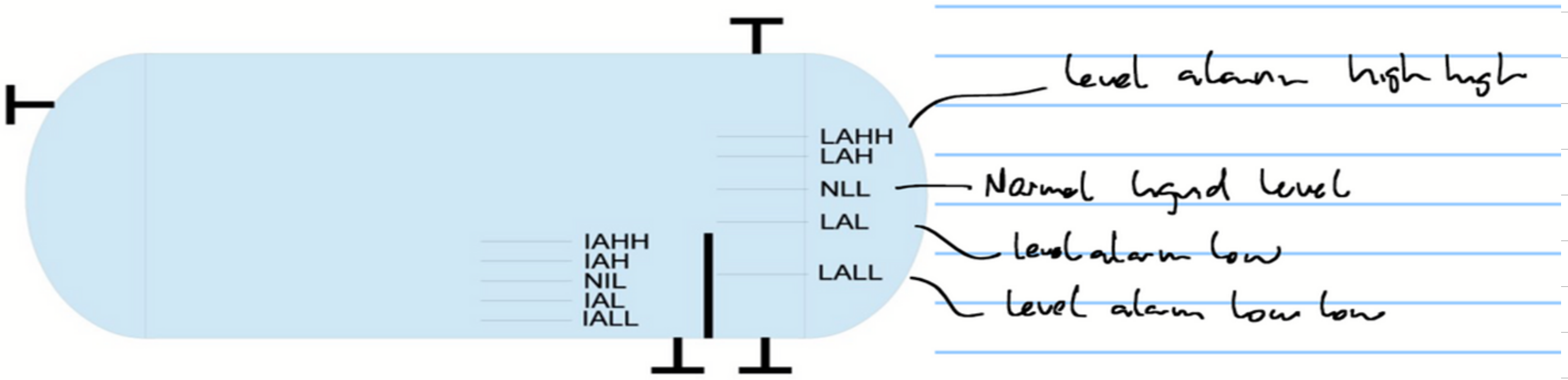
Slugcatcher – link between offshore and onshore systems

Comment about liquid slugs entering a horizontal gravity separator

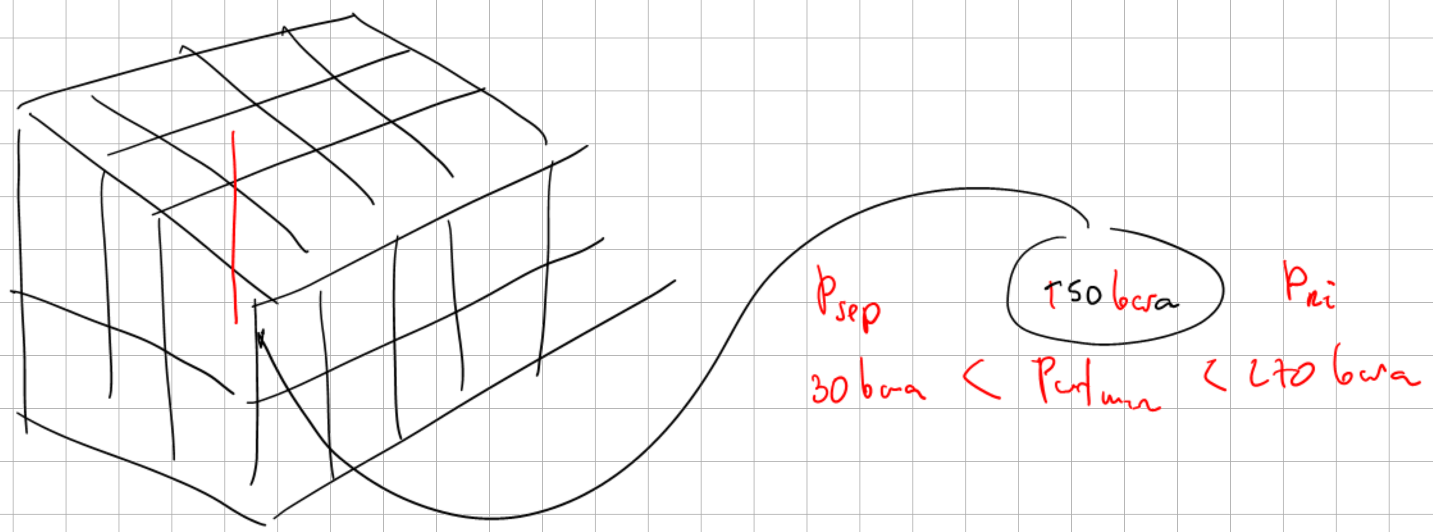


- Highest high alarm
- High level low alarm

$\phi \in (1.5 - 4m)$



How reservoir simulator works

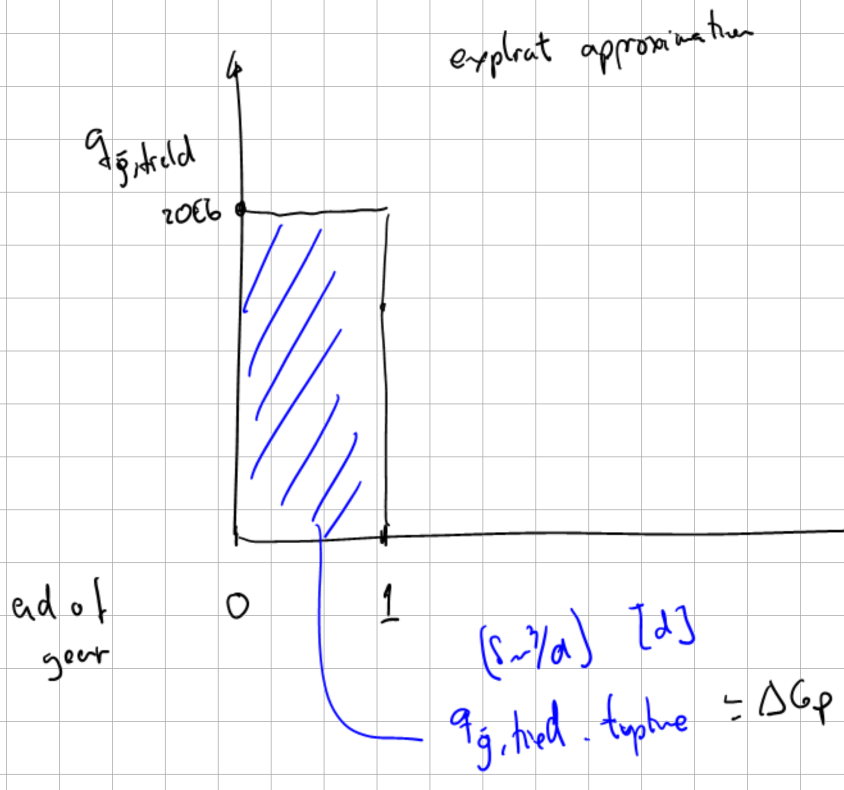


$q_{pot,well} > q_{target,well} \rightsquigarrow$ target rates is fasible

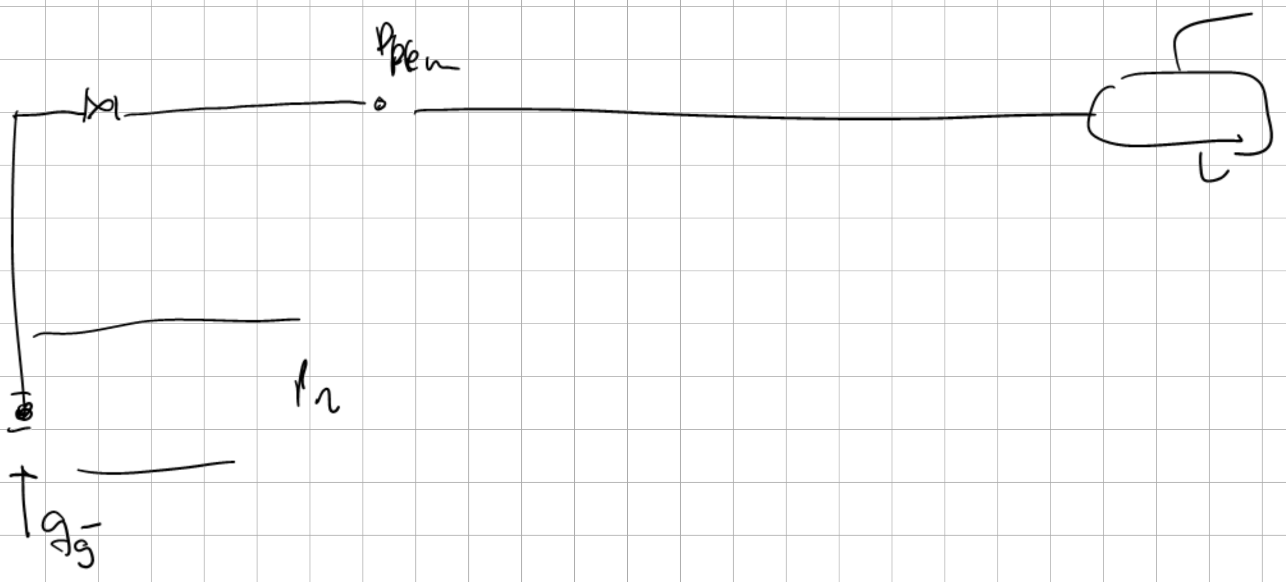
change P_{wf} until $q_{well} = q_{target,well}$

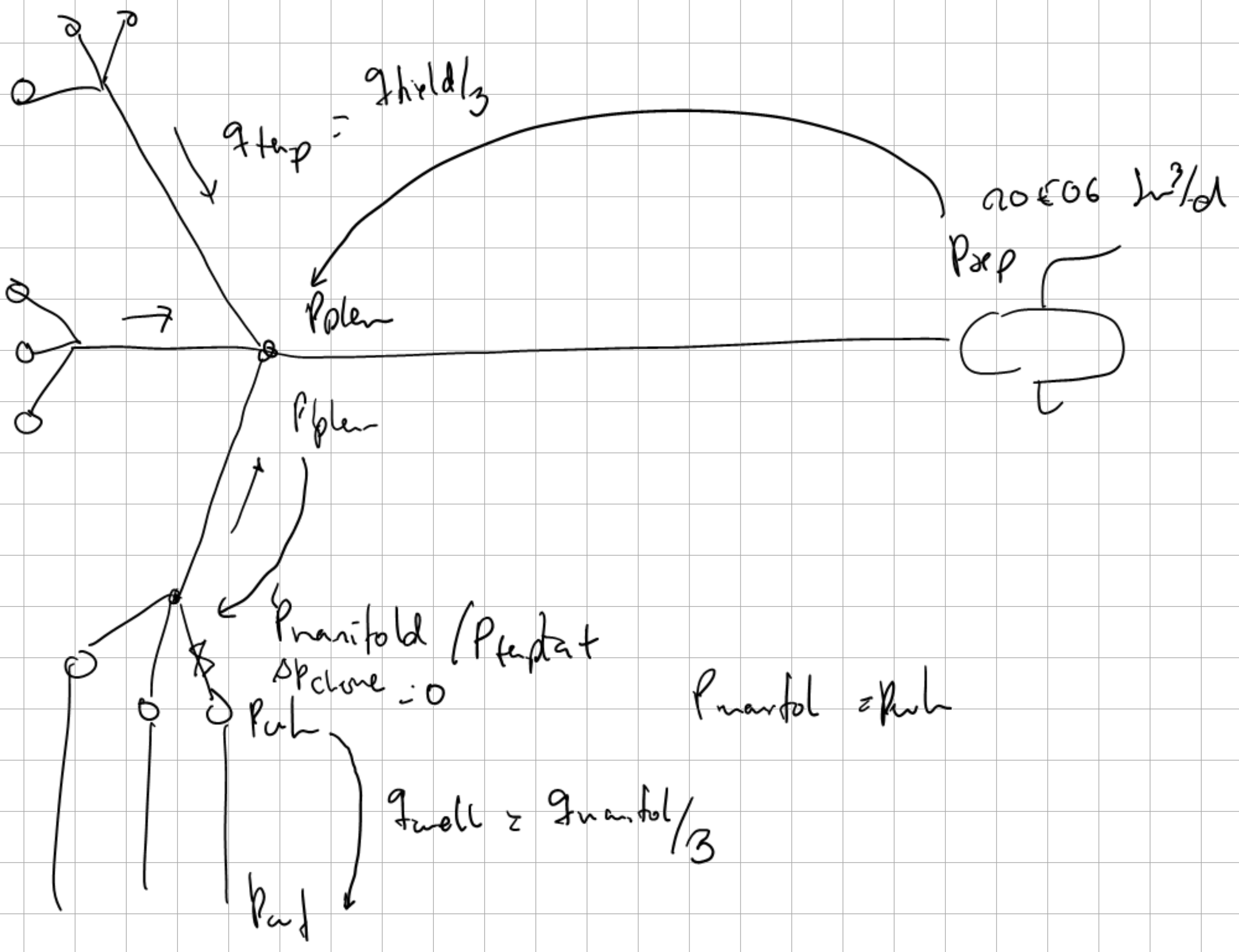
$$q_{well} = C_R\left(P_R^2 - P_{wf}^2\right)^n$$

How to estimate deltaGp?



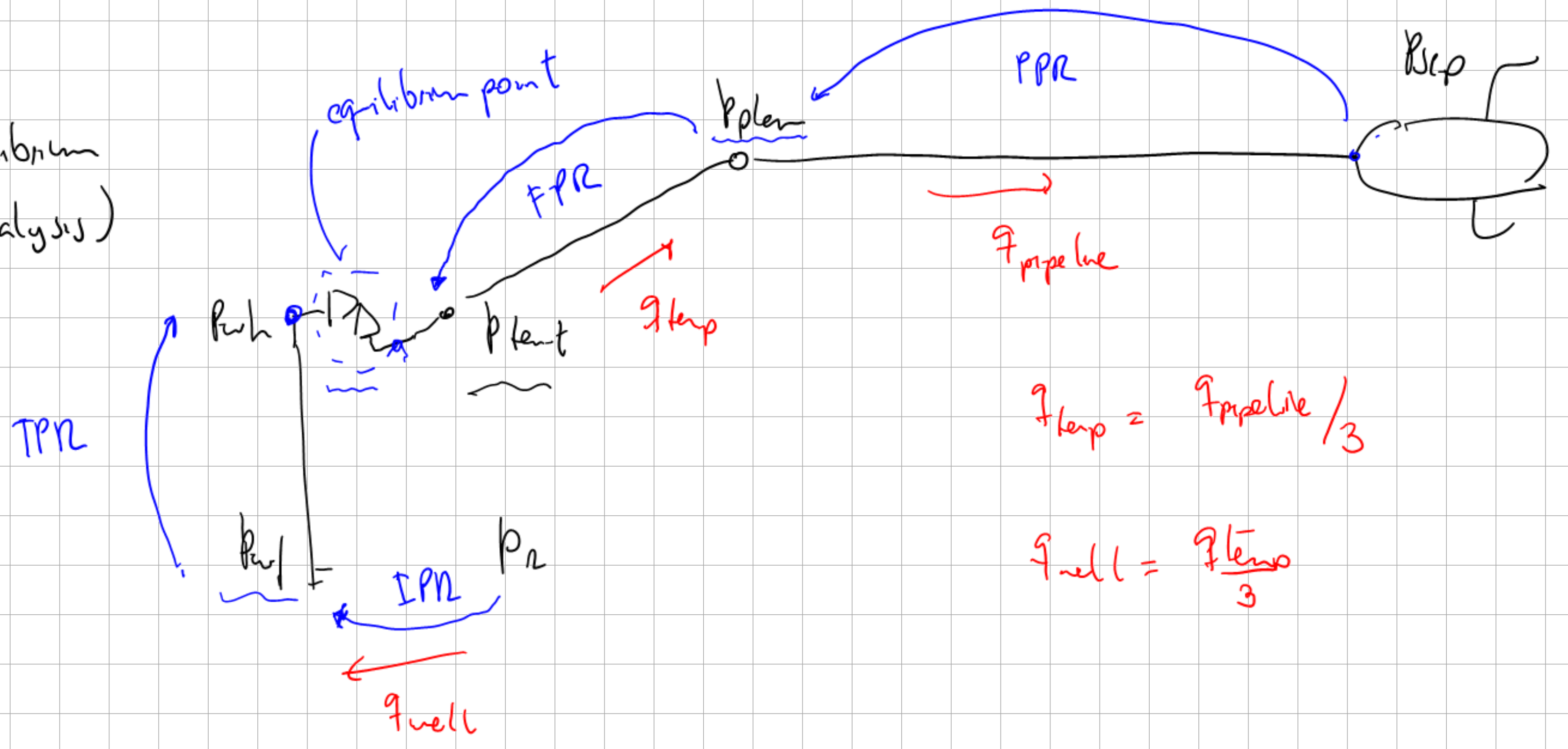
$$G_p^i = G_p^{i-1} + \Delta G_p^i$$





Live lecture 08.02.2022

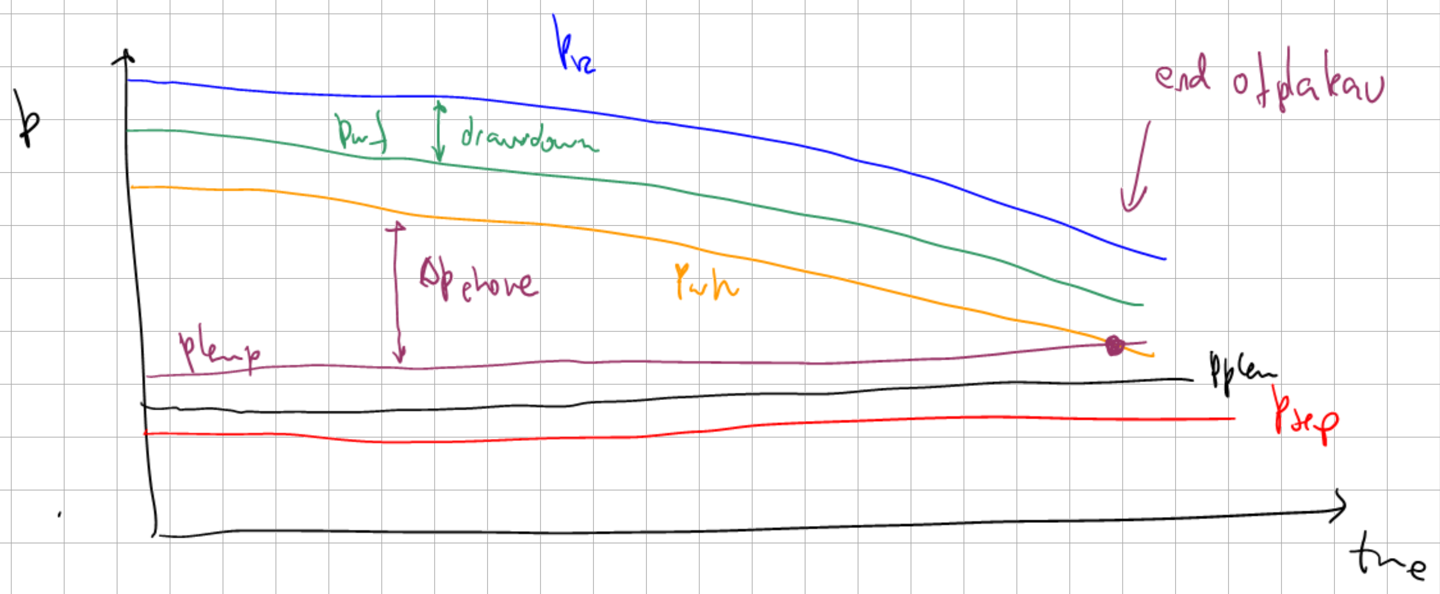
Flow equilibrium
(Nodal analysis)



$q_{temp} = q_{pipeline}/3$

$q_{well} = \frac{q_{temp}}{3}$

$q_{target} = 2.2E06\ Sm^3/d$



$(P_R - P_{wf})$

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

↓ P_R → P_{wf} ↑

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

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

p_p

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

↑ ↑ ↑

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

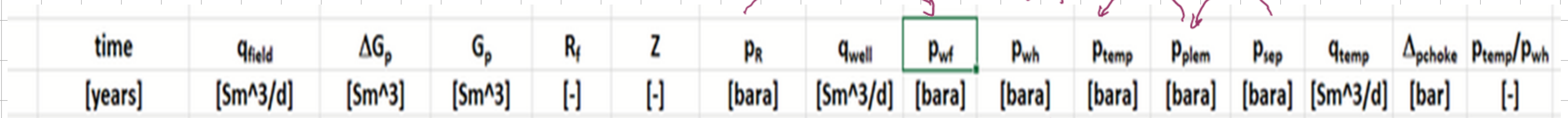
↑ ↑ ↑

$P_i \rightarrow P_2$

? $i \rightarrow$ ②

STOP

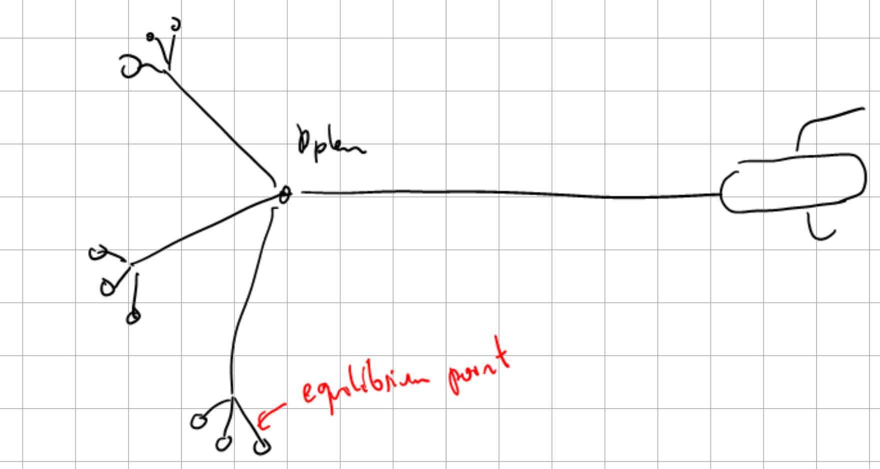
IPR TPR FPR PPR



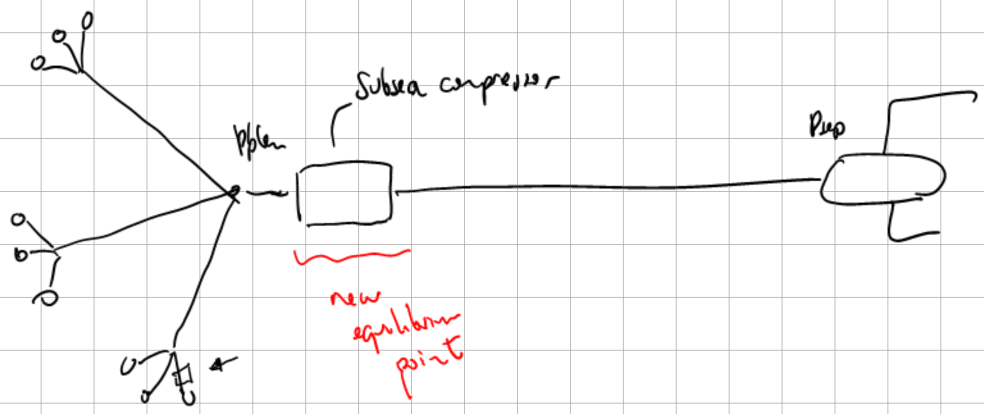
time	q_{field}	ΔG_p	G_p	R_f	Z	p_R	q_{well}	p_{wf}	p_{wh}	p_{temp}	p_{plem}	p_{sep}	q_{temp}	Δ_{pchoke}	p_{temp}/p_{wh}
[years]	[Sm^3/d]	[Sm^3]	[Sm^3]	[-]	[-]	[bara]	[Sm^3/d]	[bara]	[bara]	[bara]	[bara]	[bara]	[Sm^3/d]	[bar]	[-]

$\downarrow$ $P_{wh} - P_{temp}$

During natural plateau



after natural plateau



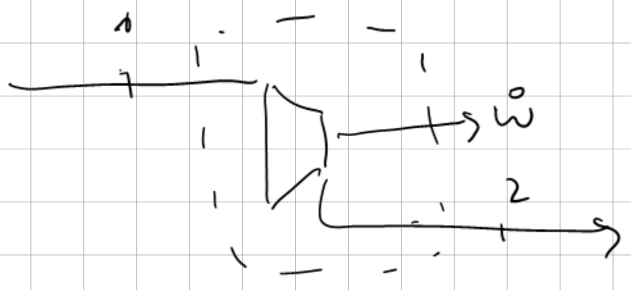
$m^3 \rightarrow kg$

m^3/d

$q_g \; \rho_g = \dot{m}$

How to estimate energy consumption of the compressor

1st law of thermodynamics for open system



enthalpy $u + p.v$

$$\dot{w} = \dot{m}\,(\underbrace{h_1 - h_2})$$

$\rho \, ? = (p, T)$

$p, \rho \rightarrow T$

$\rho, T \rightarrow p$

≈ 70°C

$h_1 = f(p_1, T_1) \rightarrow h_1$

$h_2 = f(p_2, T_2)$

? $T_2 > T_1$

$T_1 \rightarrow T_2$

for gases

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}$$

$\hookrightarrow (\kappa)$

bara

n → polytropic exponent (efficiency of compression process)

$\frac{p_2}{p_1} = r_p$

$n \uparrow$

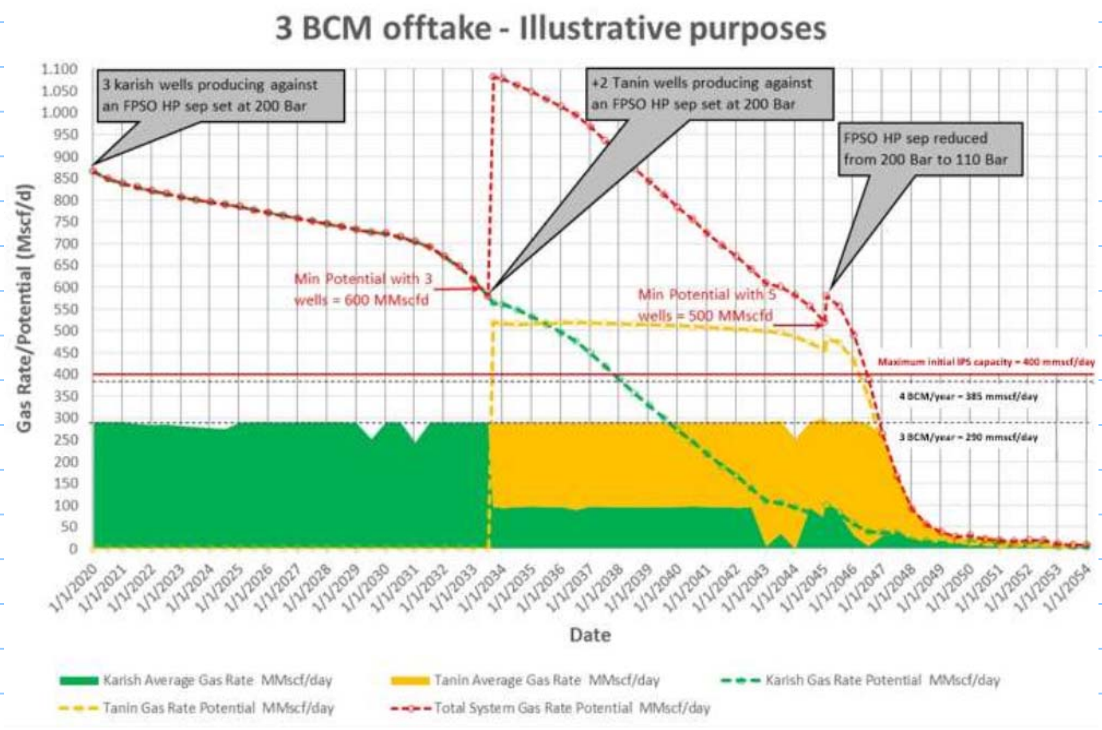
$$T_2 = T_1 \cdot r_p^{\frac{n-1}{n}}$$

$p \downarrow$

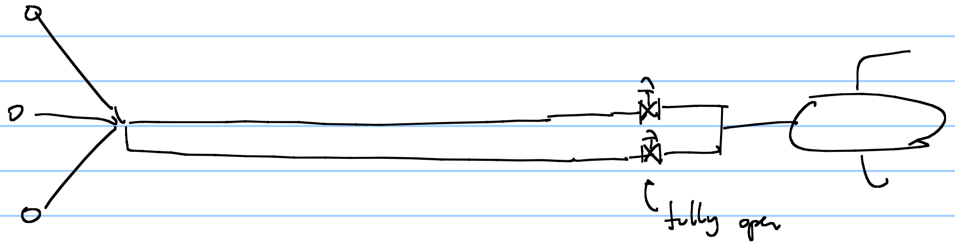
$\dot{m} = \underbrace{\overset{\uparrow}{q_g} \; \overset{\downarrow}{\rho_g}}$

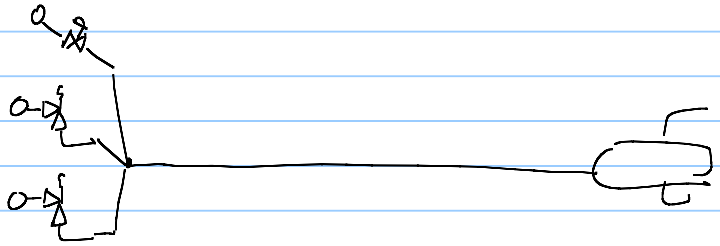
$t_{res} \quad \frac{V_T}{q_g}$

Notes to Youtube video Production potential

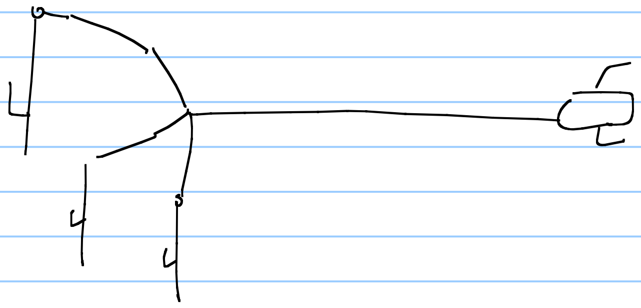


Production potential   maximum rate the production system can deliver at a given time





q_{pp} = fully open choke

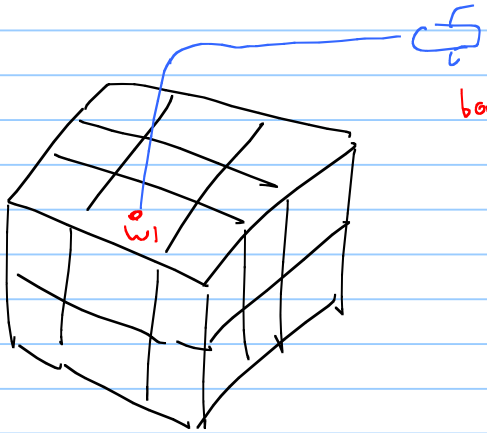


max $q_{\bar{g}}$ by changing $q_{\bar{g}\,inj\,1}$

$q_{\bar{g}\,inj\,2}$

$q_{\bar{g}\,inj\,3}$

Production potential is also used in reservoir simulation

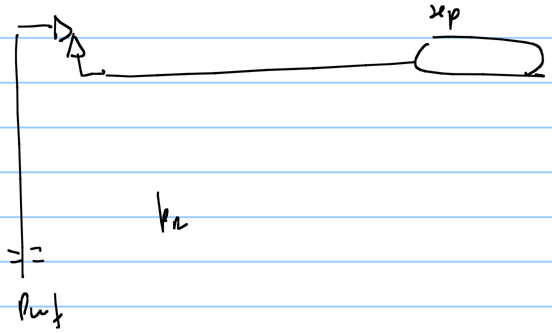


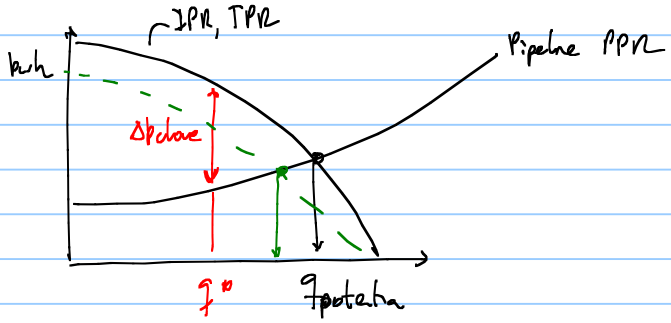
boundary conditions on well 1 → q_{target}

↘ $p_{wf\,min}$

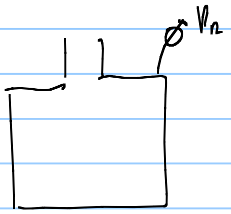
in each time step

- tries $p_{wf\,min}$ → $q_{potential}$
- if $q_{potential} > q_{target}$
  - ↳ q_{target} can be produced
    increase p_{wf} until $q_{well} = q_{target}$
  - ↳ if $q_{pot} < q_{target}$
    - ↳ q_{target} cannot be produced
      $p_{wf} = p_{wf\,min}$
      $q_{well} = q_{potential}$





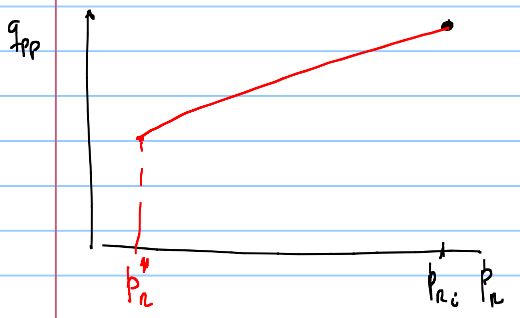
- Production potential is actually a funtion of p_R
  ↳ and p_R is usally a fuction of
  Q_p → G_p (gas)
  ↘ N_p (oil)

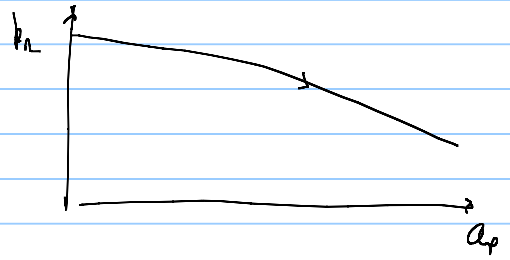


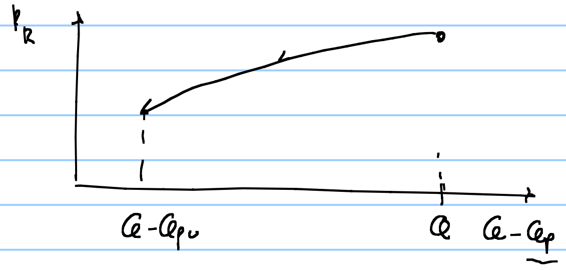
$$P_R = f(Q - Q_p)$$

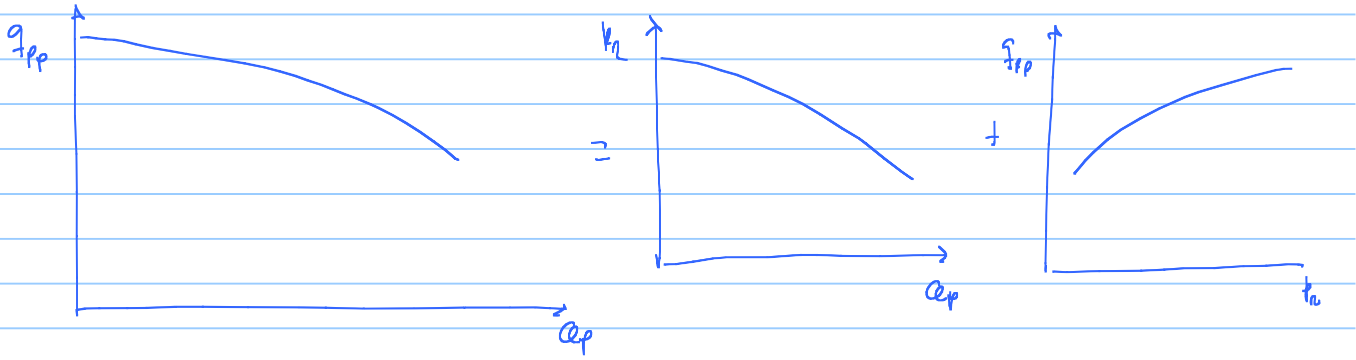
$$P_R(t) = f(Q - Q_p(t))$$

$$P_R = f(Q_p)$$

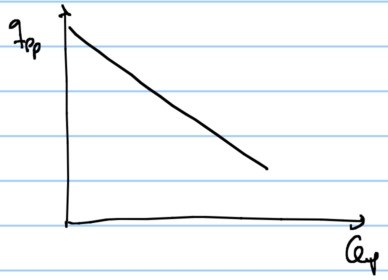




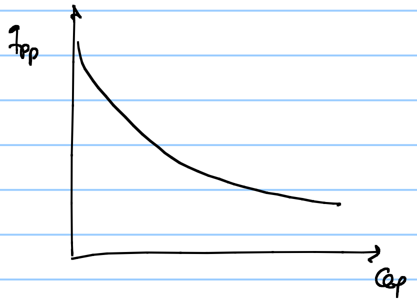




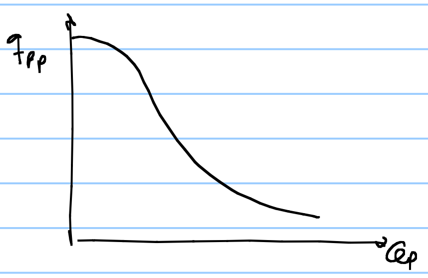
for dry gas and undersaturated oil



for saturated oil

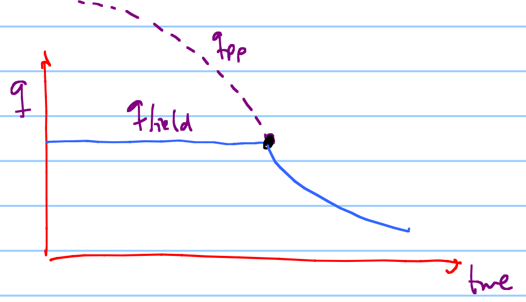


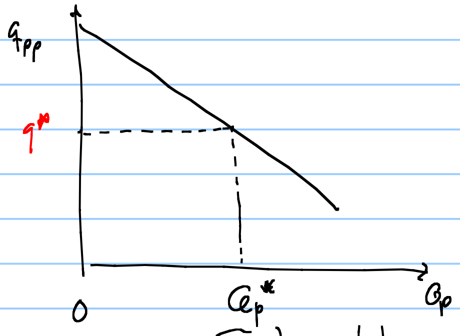
for oil water injection



Production potential curves can be used for

- determine plateau duration
- estimate production profile





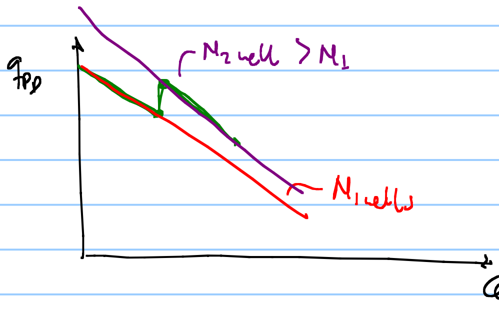
$q_{plateau} = q^*$

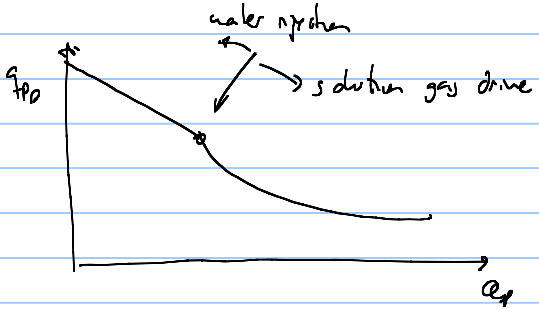
Q_p^* ~ cumulative production at which the end of plateau will occur

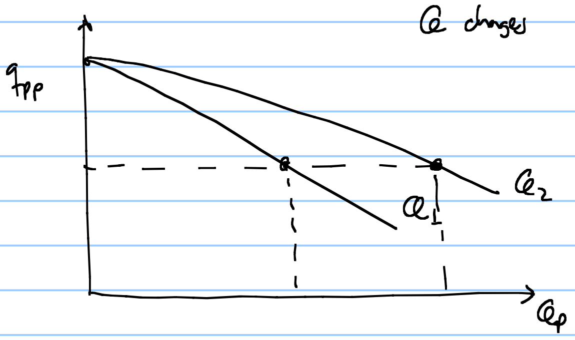
$0 \rightarrow Q_p^*$ has been produced at constant rate q^*

$$t_{plateau} = \frac{Q_p^* \, [Sm^3]}{q^* \, [Sm^3/d] \; t_{uptime}} \longrightarrow \frac{\text{nr. operational days}}{\text{year}}$$

Production potential curve is affected by changes to the production system







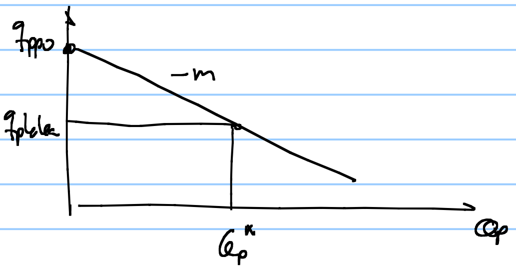
$p_R = f(R_f)$

$\underbrace{R_{f_1}} = \frac{Q_p}{Q_1}$ $\quad R_{f_2} = \underbrace{\frac{Q_p}{Q_2}}$

$R_{f_2} < R_{f_1}$

if curve q_{pp} is linear $q_{pp} = -m\, Q_p + q_{pp0}$

derive analitically $q_f(t)$ from q_{pp}



$$q_f(t) \begin{cases} q_{plateau} & \text{for } t \le t_{plateau} = \left(\frac{q_{pp0}}{q_{plateau}} - 1\right)\frac{1}{m} \\ q_{field} = q_{pp} & \text{for } t > t_{plateau} \end{cases}$$

$q_{plateau} = q_{pp} = -m\, Q_p^* + q_{pp0}$

$$Q_p^* = \frac{q_{pp0} - q_{plateau}}{m}$$

$$q_{pp} = -m\left(Q_p^* + \int_{t_{plateau}}^{t} q_{pp}\, dt\right) + q_{pp0}$$

$$t_{plateau} = \frac{Q_p^*}{q_{plateau}} = \left(\frac{q_{pp0}}{q_{plateau}} - 1\right)\frac{1}{m}$$

$$q_{pp} = -m\,\frac{(\cancel{q_{pp0}} - q_{plateau})}{m} - m\int_{t_{plateau}}^{t} q_{pp}\, dt + \cancel{q_{pp0}}$$

$$q_{pp} = q_{plateau} - m\int_{t_{plateau}}^{t} q_{pp}\, dt$$

$\longrightarrow$ a solution to this equation is

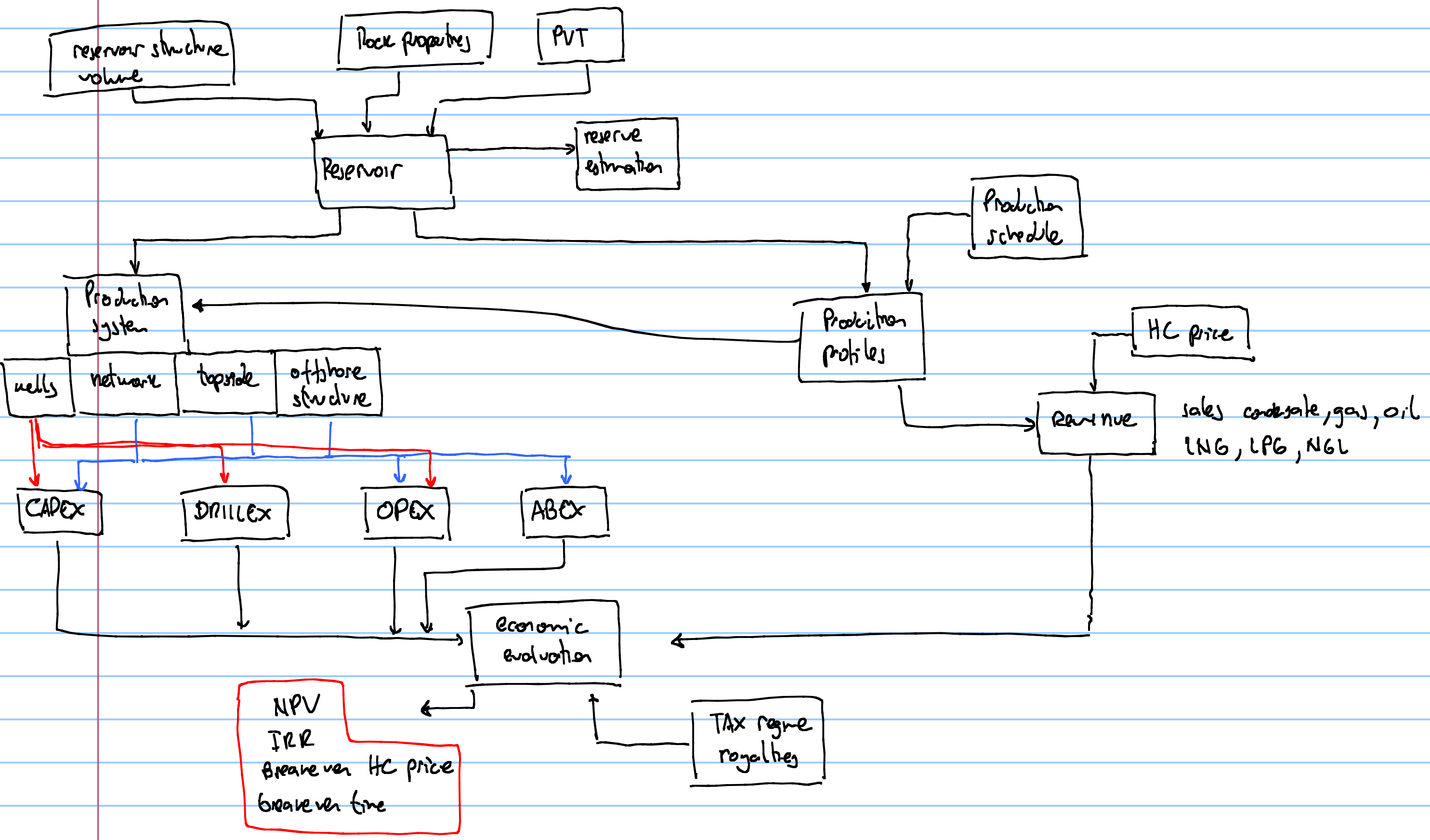
$$q_{pp} = q_{field} = q_{plateau} \cdot e^{-m(t - t_{plateau})}$$

$$q_f(t) \begin{cases} q_{plateau} & \text{if} \quad t \leq t_{plateau} = \left(\frac{q_{pp0}}{q_{plateau}} - 1 \right) \frac{1}{m} \\ q_{plateau}\, e^{-m(t-t_{plateau})} & \text{if} \quad t > plateau \end{cases}$$

$$= e^{\frac{1}{m}(t-t_{plateau})}$$

Notes for Youtube: Net present value and value chain of a petroleum asset

Value chain model



CAPEX:

- engineering studies (salaries, consultants, contractor)
- processing facilities (separators, pumps, compressor, heat exchangers, control system, injection, export, water, oil, gas treatment)
- offshore structure (cost of platform, FPSO, TLP, living quarters, auxiliary equipment, power equipment)
- Subsea system costs (template, flowline, pipeline, risers, umbilicals, control system, metering, boosting)
- export system

DRILLEX

- Drilling rate of vessel
- drilling materials (tubulars, cement, mud, completion, wellhead)
- test during drilling (DST, logging, pressure test, sampling)
- X-mas tree
- drilling tools

OPEX

- Important to estimate abandonment rate.
- workers' salaries
- insurance
- maintenance
- equipment
- well intervention
- Power consumption
- production chemicals { MEG, wax inhibitor, corrosion inhibitor, etc.
- pigging
- transportation and export
- troubleshooting

ABEX

- well plugging
- removal of flowlines, pipelines, offshore structure
- cleaning
- monitoring

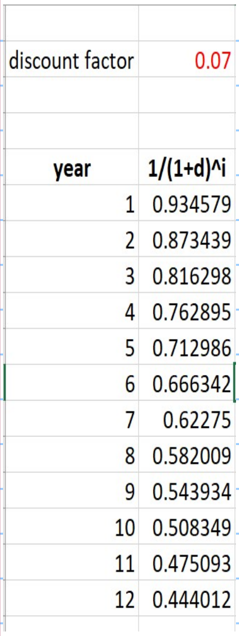
NPV calculations

$$NPV = \sum_{i=1}^{\overset{\text{abandonment}}{N}} \frac{CF_i}{(1+d)^i}$$

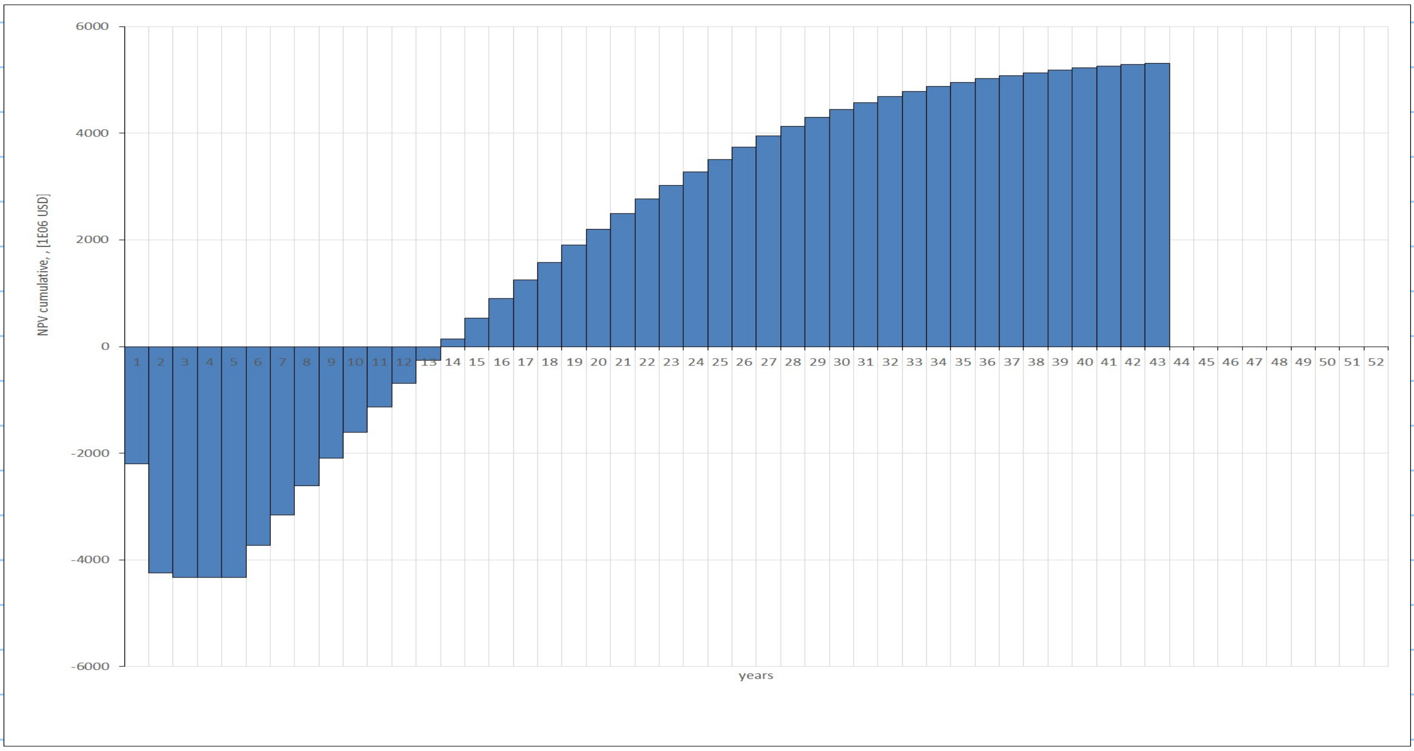
CF_i = revenue − expenditures of year "i"

↳ discount factor $\underbrace{5\% \rightarrow 12\%}$

expenses are executed during early years so $\frac{1}{(1+d)^i}$ is close to "1"

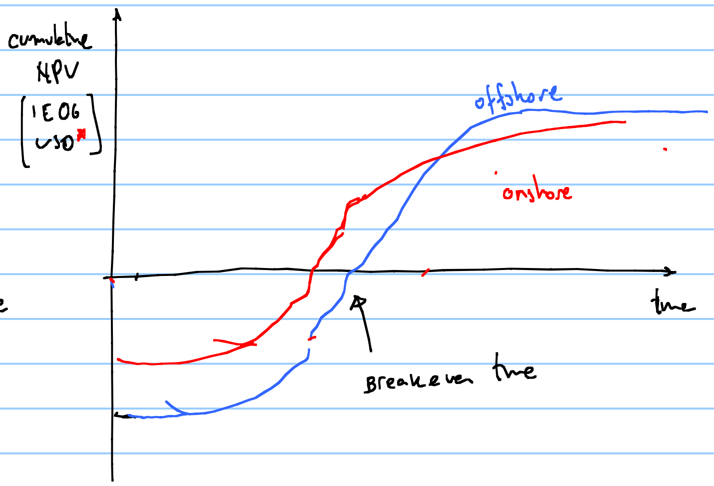


discount factor	0.07
year	1/(1+d)^i
1	0.934579
2	0.873439
3	0.816298
4	0.762895
5	0.712986
6	0.666342
7	0.62275
8	0.582009
9	0.543934
10	0.508349
11	0.475093
12	0.444012



Output to present NPV calculations

*USD of each year



USD of time "0"

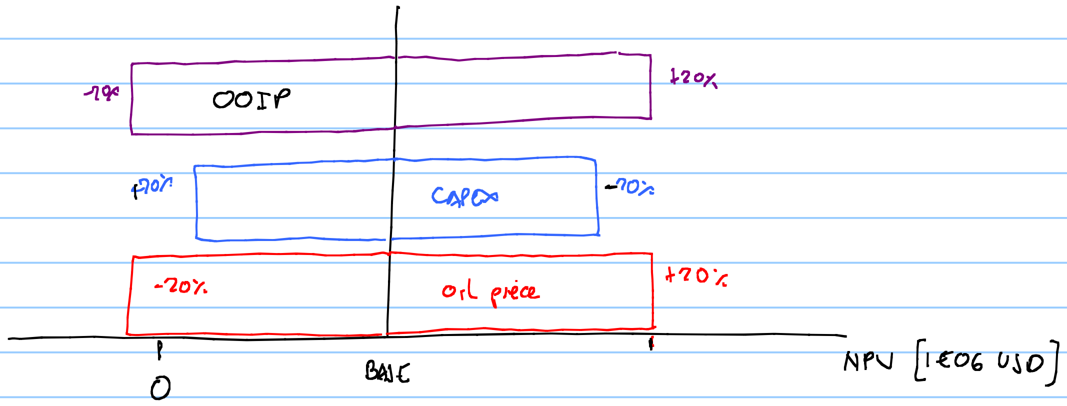
the effect of uncertainty on the project is typically studied using "Ceteris Paribus"
"one at a time"

- oil price uncertainty   OG3   also called sensitivity analysis
- Cost uncertainty (±40% → ±20%)
- N

BASE CASE   NPV =

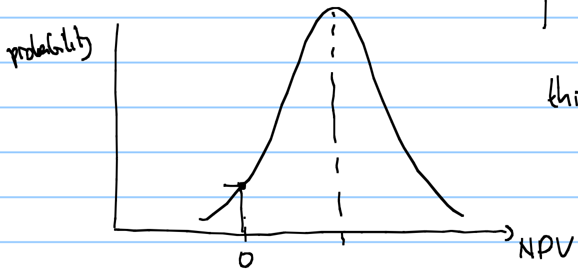
	min	max
Oil price	NPV	NPV
OOIP	NPV	NPV
CAPEX	NPV	NPV

Tornado chart

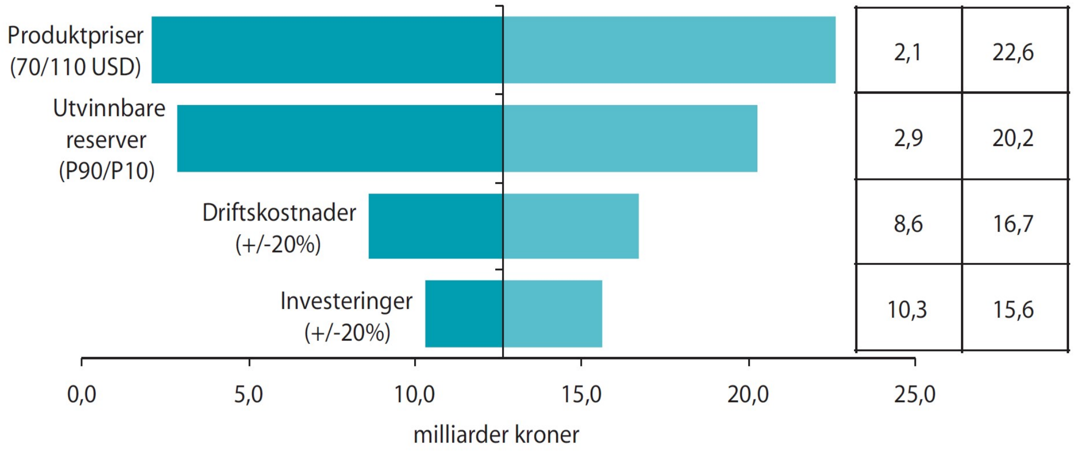


this is NOT a good way to evaluate/quantify uncertainty { we are neglecting other combinations }

a probabilistic evaluation is better!



this requires multiple { 100 500 1010 10000 } evaluations

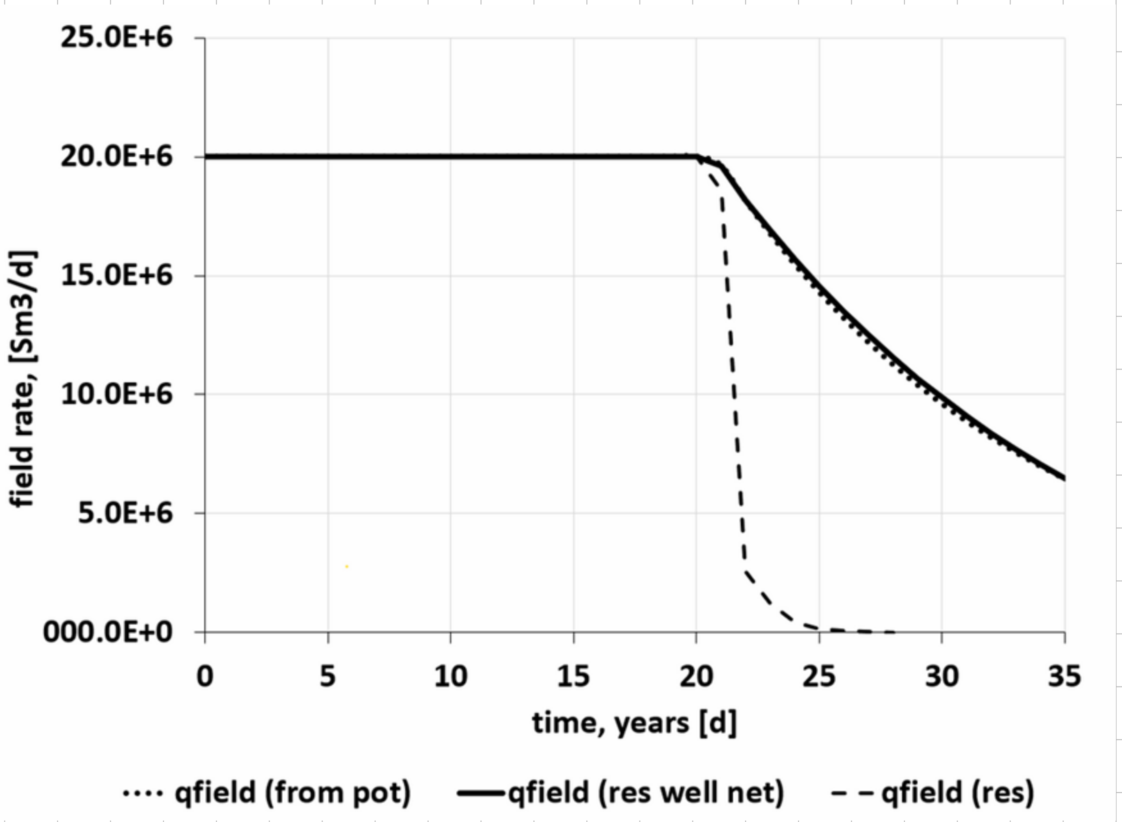


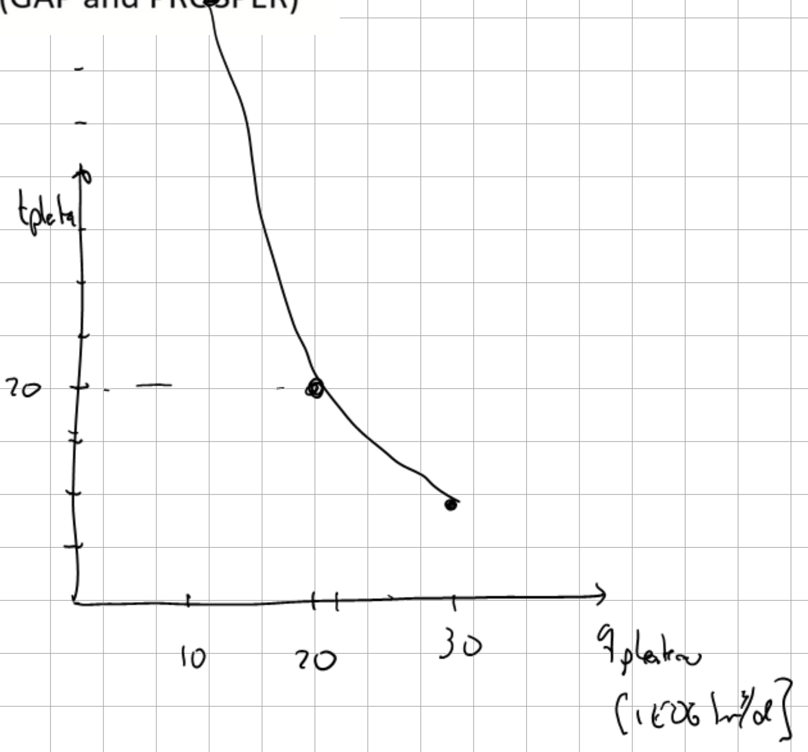
2,1	22,6
2,9	20,2
8,6	16,7
10,3	15,6

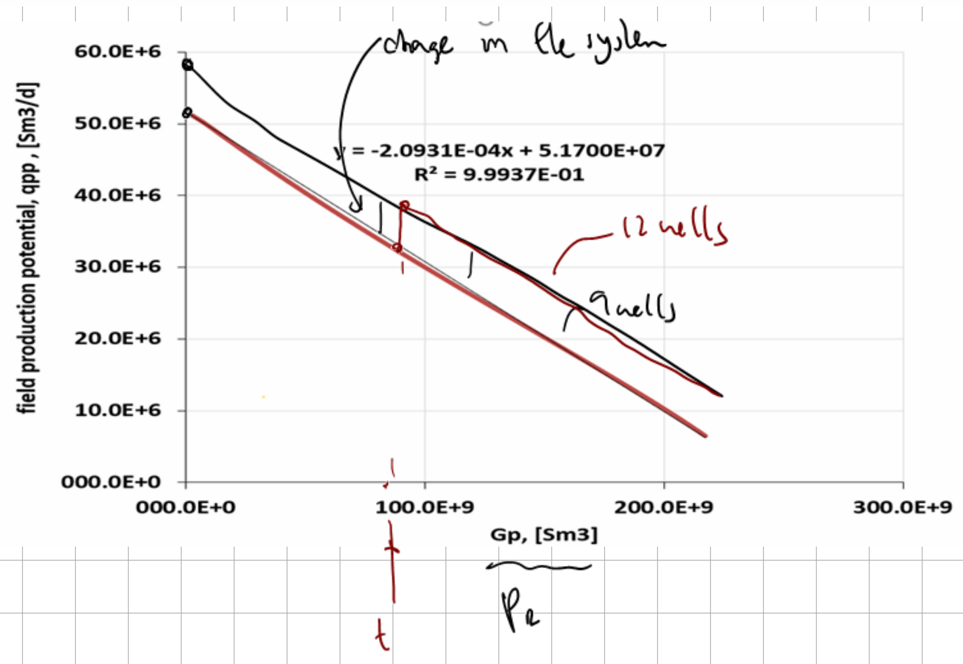
Lecture 18.02.2022

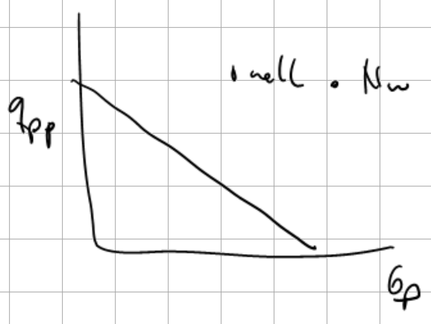
PENSUM:

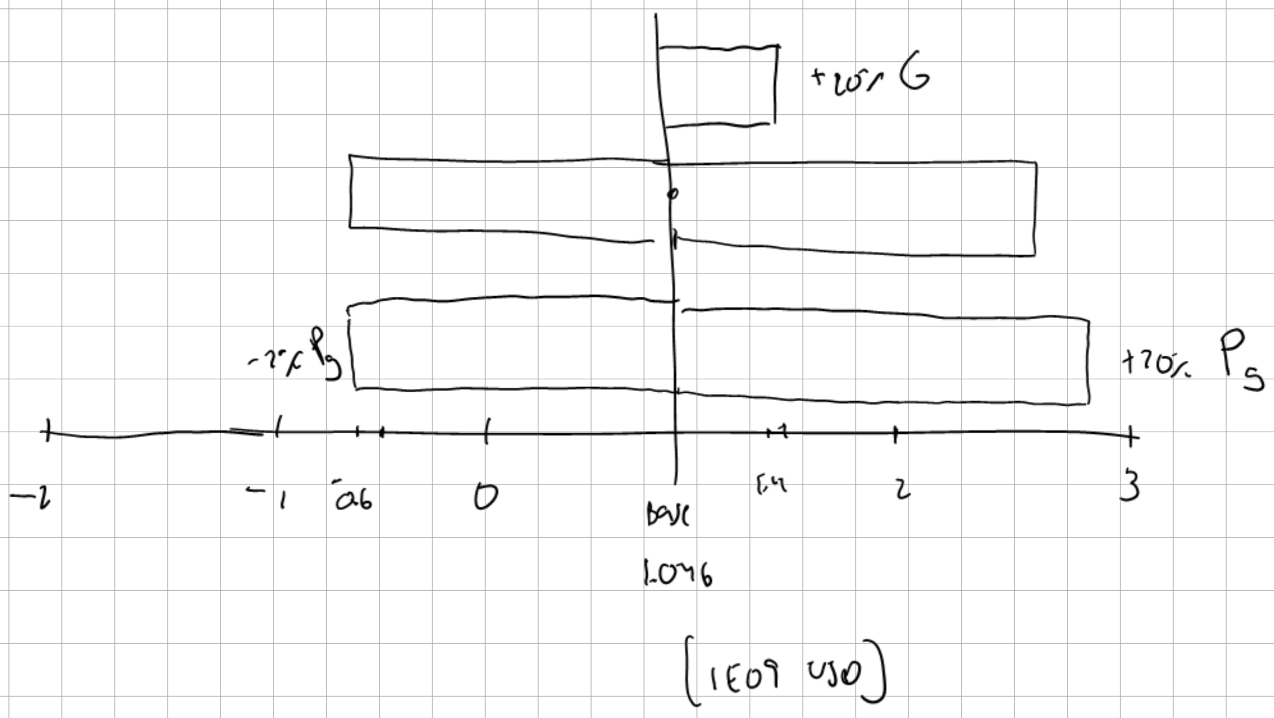
- Field development workflow.
  - Lifecycle of a hydrocarbon field
  - Overview – The field development process
  - Production modes
  - Discounting
  - Relationship between plateau height and length
  - Rule of thumb between plateau height and TRR
  - Bottlenecking and processing capacity (separation capacity)
  - Onshore vs offshore
  - Oil vs gas
- Excel VBA, functions and routines.
- Field production performance
  - Estimation of production profiles
  - Dry gas production system: material balance, IPR, TPR, FPR, choke, flow equilibrium.
  - Dry gas production system: production scheduling
  - Measures to prolong the plateau.
  - Production potential
  - Boosting
  - Dry gas networks.
- Value chain model, cost estimation and NPV calculations
- Dealing with uncertain parameters in FD
  - Probabilistic reserve estimation
    - Monte Carlo
  - Decision and probability tree analysis
- Offshore structures
  - Overview
  - Layout of production systems
  - Marine loads on offshore structures
- Flow assurance considerations
  - General overview
  - Inhibitor subsea system. Disposal.
- Field production performance using commercial software (GAP and PROSPER)



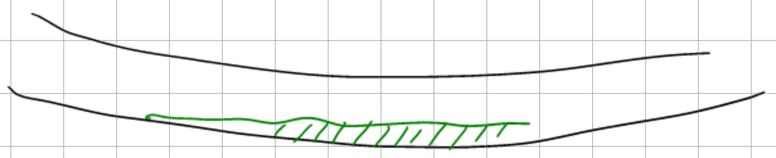


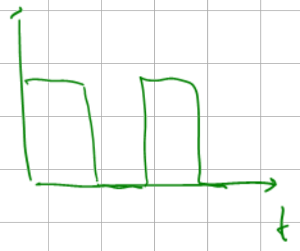


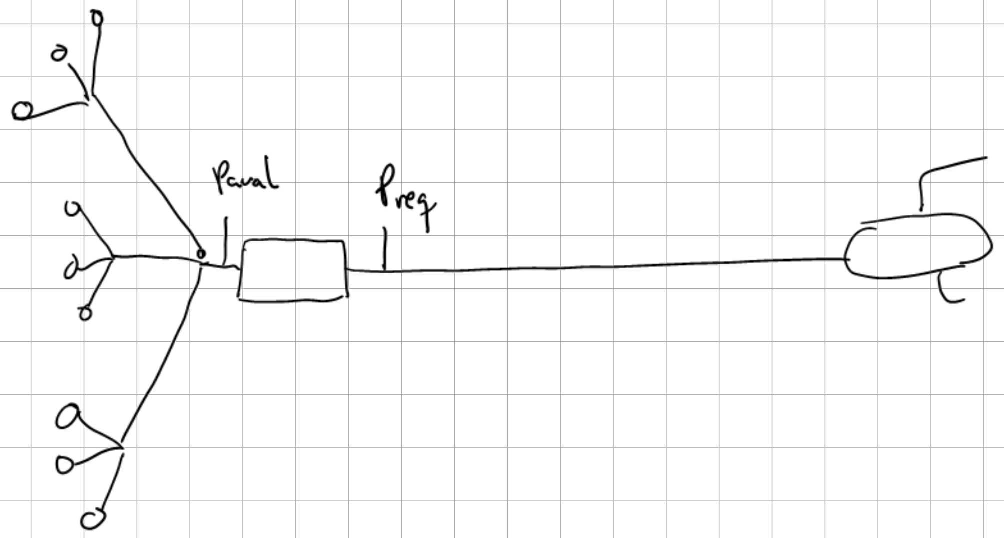



+20% G
-20% Pg
+20% Ps
-2
-1
-0.6
0
1.4
2
3
base
1.046
[1E09 USD]

- Boosting







Aasgard subsea compressor

- Ormen lange
- Snøhvit
- Jahn (Australia)

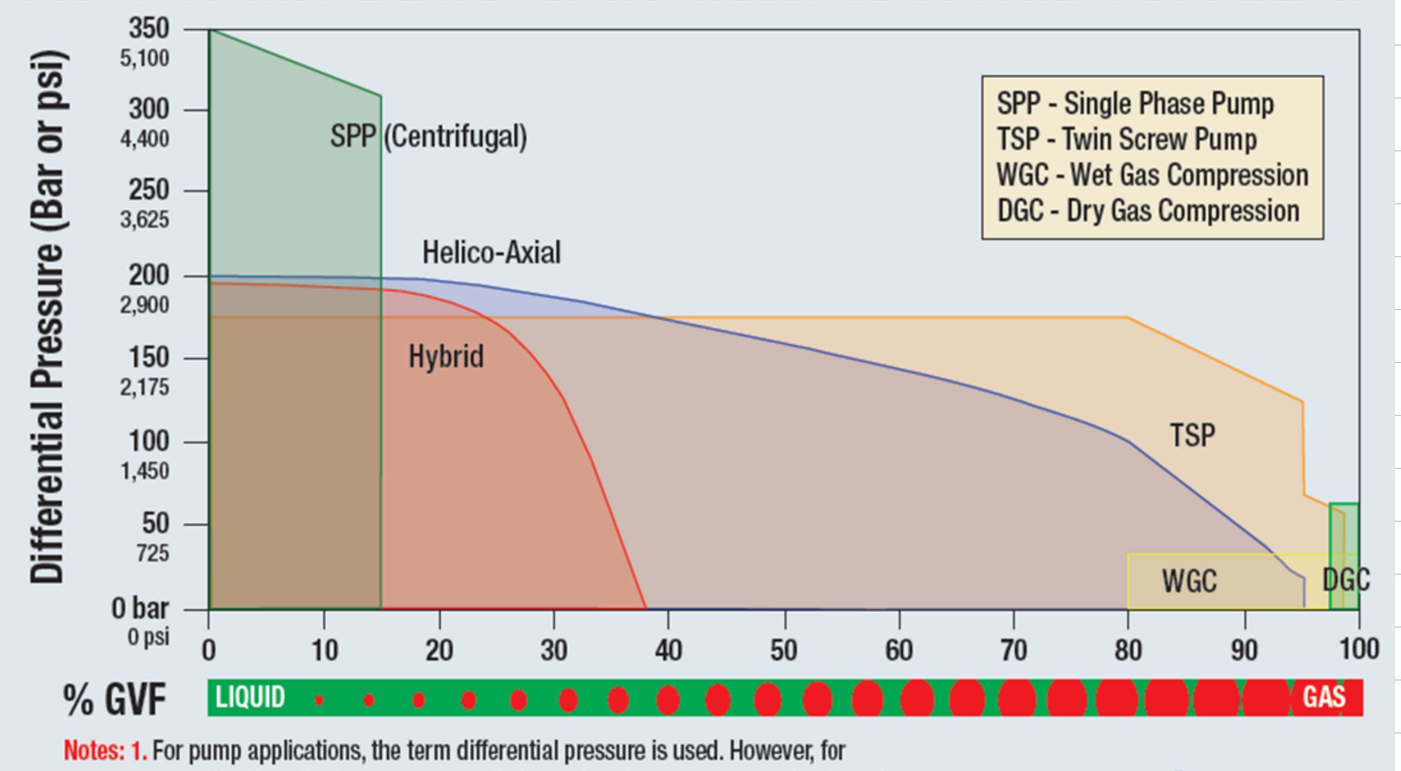
types of boosters (energy-giving device)

- in well → electric submersible pumps (ESP) ← (0-30%)
  → (NOT BOOSTER) gas lift (Artificial lift).
- out-of-well → dry gas compressor (upstream separation) (97-100%)
  → wet gas compressor (80-100%)
  → multiphase → helico-axial pump (0-95%)
    → twin screw pump (0-99%)
  → single phase liquid → centrifugal pumps (0-15%)

GVF (gas volume fraction) at suction of the booster $GVF = \frac{q_g}{q_g + q_L}$ ← @ local conditions of p, T

$0 \leq GVF \leq 1$

liquid gas



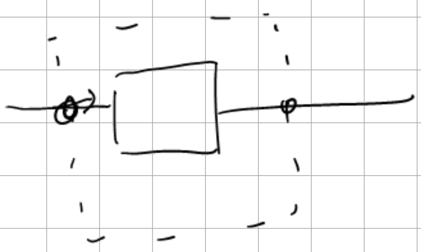
Notes: 1. For pump applications, the term differential pressure is used. However, for compressor applications the term pressure ratio is used. 2. Curves are approximate and assume a specific liquid throughput, identical for each pump type.

Electrical heater 2000 W → room

6000 W → house ~ MPP → 0.5 MW → 100 houses

What to consider when planning a boosting strategy?

- Required power $P = f(\underbrace{\Delta p, \dot{m}}_{q_{sc}})$



1st of open system

$h = u + \overset{f(T)}{\underline{P \cdot v}}$

$h = u + \frac{p}{\rho}$

$[W] = \left[\frac{J}{s}\right]$

(hp) (W) (kg/s)

$P = \underbrace{\dot{m}}_{q_{sc} \cdot \rho_{sc}} \underbrace{(h_{out} - h_{in})}\ \frac{J}{kg}\ \frac{kJ}{kg}$

$\dot{w} = \dot{m}(h_{out} - h_{in})$

$\dot{w}$ + if work is obtained from machine

− if work is required by machine

$\dot{m} = q_{\bar{o}} \rho_{\bar{o}} + q_{\bar{g}} \rho_{\bar{g}} + q_{\bar{w}} \cdot \rho_{\bar{w}}$ @ standard condition

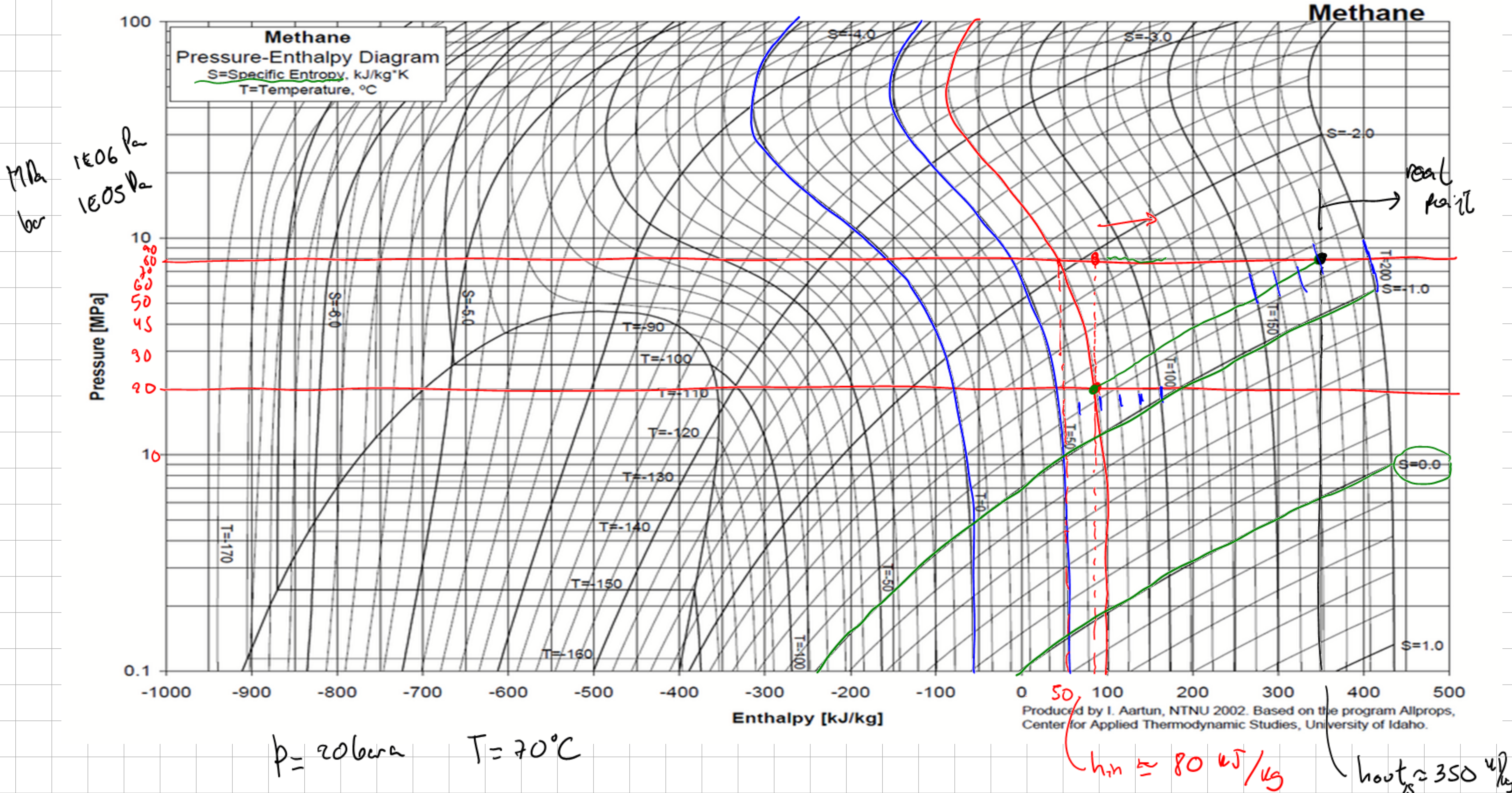
$\dot{m} = q_o \rho_o + q_g \rho_g + q_w \cdot \rho_w$ @ local conditions

h_{suc} ✓

p_{suc}, T_{suc} p_{disch}, T_{disch}?

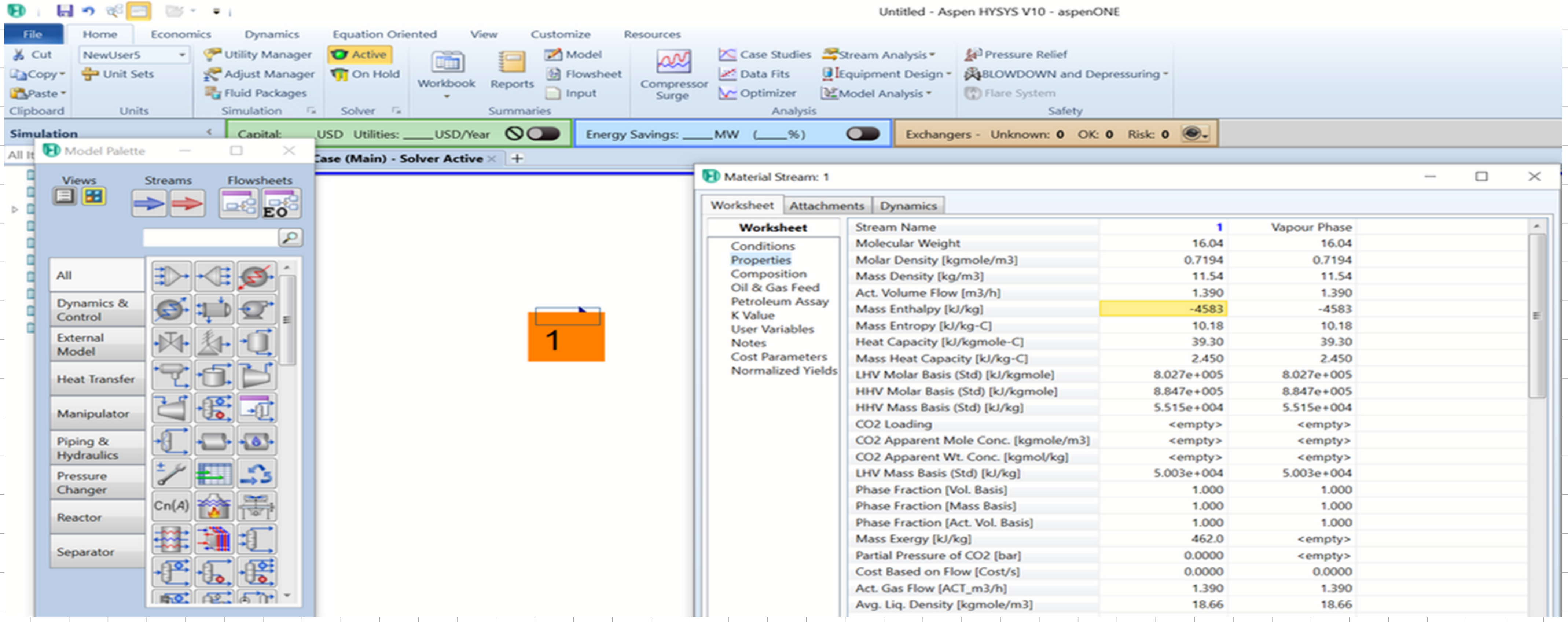
h (enthalpy) is a thermodynamic property $\rho = f(\underbrace{p, T}, z_i)$

$h = f(p, T)$



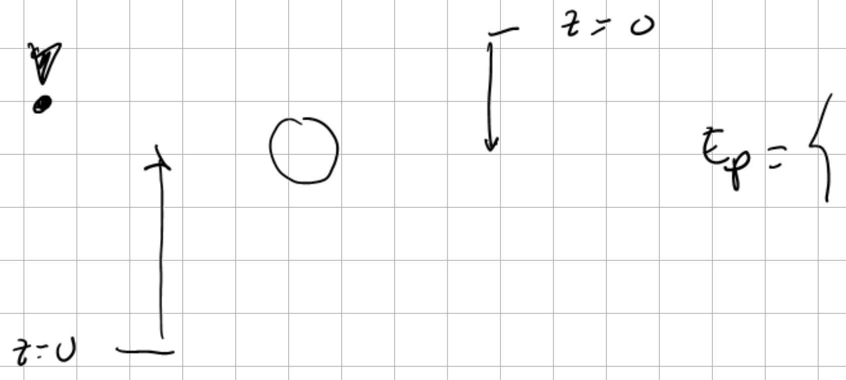
Produced by I. Aartun, NTNU 2002. Based on the program Allprops, Center for Applied Thermodynamic Studies, University of Idaho.

p = 20 bara T = 70°C



Stream Name	1	Vapour Phase
Molecular Weight	16.04	16.04
Molar Density [kgmole/m3]	0.7194	0.7194
Mass Density [kg/m3]	11.54	11.54
Act. Volume Flow [m3/h]	1.390	1.390
Mass Enthalpy [kJ/kg]	-4583	-4583
Mass Entropy [kJ/kg-C]	10.18	10.18
Heat Capacity [kJ/kgmole-C]	39.30	39.30
Mass Heat Capacity [kJ/kg-C]	2.450	2.450
LHV Molar Basis (Std) [kJ/kgmole]	8.027e+005	8.027e+005
HHV Molar Basis (Std) [kJ/kgmole]	8.847e+005	8.847e+005
HHV Mass Basis (Std) [kJ/kg]	5.515e+004	5.515e+004
CO2 Loading	<empty>	<empty>
CO2 Apparent Mole Conc. [kgmole/m3]	<empty>	<empty>
CO2 Apparent Wt. Conc. [kgmol/kg]	<empty>	<empty>
LHV Mass Basis (Std) [kJ/kg]	5.003e+004	5.003e+004
Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000
Mass Exergy [kJ/kg]	462.0	<empty>
Partial Pressure of CO2 [bar]	0.0000	<empty>
Cost Based on Flow [Cost/s]	0.0000	0.0000
Act. Gas Flow [ACT_m3/h]	1.390	1.390
Avg. Liq. Density [kgmole/m3]	18.66	18.66

value of h depends on the reference !



$E_p = \{$

$P_{disch} = 80$ bara

IF $T_{dis} = T_{suc} = 70°C$

$h_{disch} = 50$ kJ/kg

$\Delta h = (50 - 80) = -30$ kJ/k

$\underline{P} = < 0$

NOT A PUMP ✓
a turbine

$$\Delta h_{ideal} = \Delta h_{isen} = (h_{out_{isen}} - h_{in})$$

smallest pumping power

$h_{out_{ideal}} \rightarrow P_{out}, S_{out} = S_{in}$ $\quad T_{out,ideal} = 180°C$

$\Delta h_{ideal} = (350 - 80) = 270$ kJ/kg

$T_{out,real} > T_{out,ideal}$

$\underline{P}_{ideal} = \dot{m} \cdot \Delta h_{ideal}$

$\underline{P}_{real} = \dot{m}(\Delta h_{real})$

$\Delta h_{real} > \Delta h_{ideal}$

$$\eta_{adiab} = \left\{ \begin{matrix} 0.3 \rightarrow 0.8 \\ 0.7 \end{matrix} \right\} \qquad \eta_{adiab} = \frac{\underline{P}_{ideal}}{\underline{P}_{real}}$$

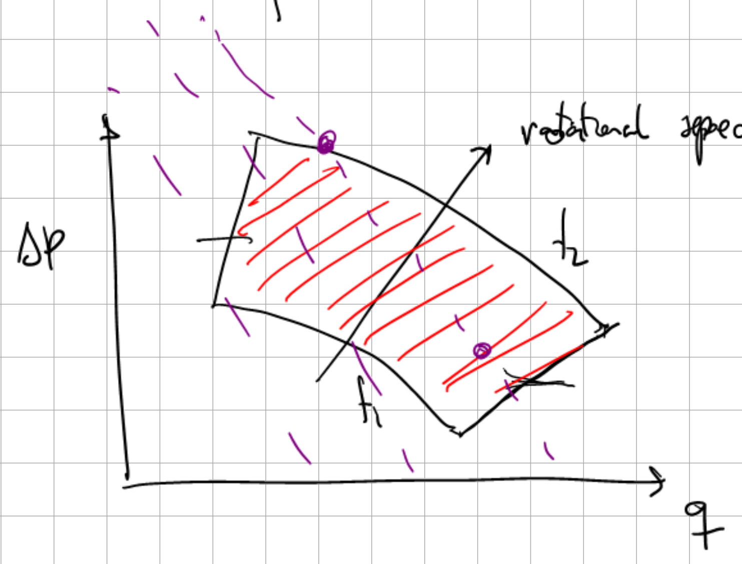
$$\underline{P}_{real} = \frac{\dot{m}(h_{out,IS} - h_{in})}{\eta_{adiab.}}$$

- for liquids $\Delta h_{IS} = \left(\frac{\Delta p}{\rho}\right)$ centrifugal pum $\underline{P}_{real} = \frac{\dot{m}\,\Delta p}{\rho\,\eta_{adiab}} = \frac{q_{in}\,\Delta p}{\eta_{adiab}}$

What to consider when planning a boosting strategy? (cont)

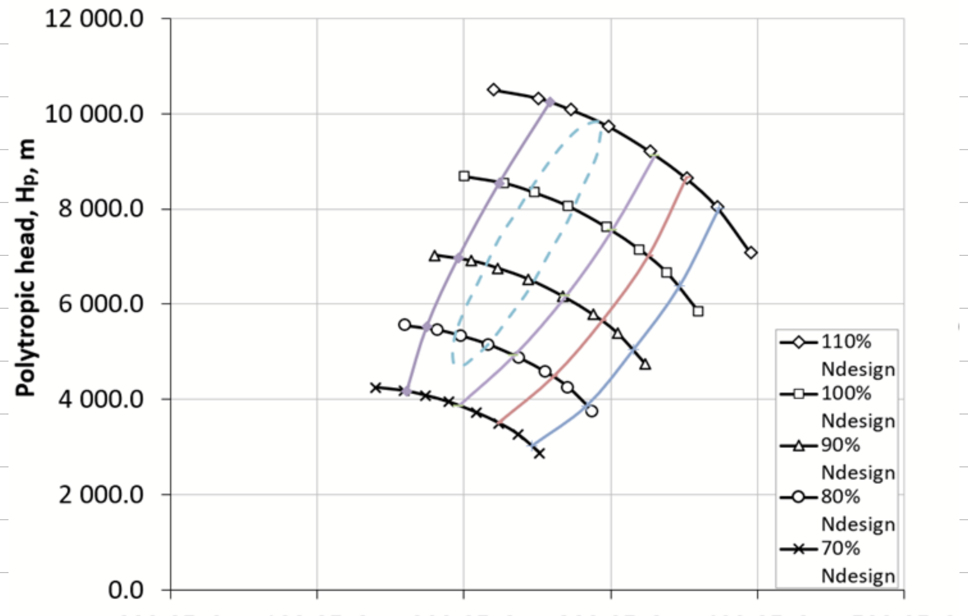
- minimum allowable suction pressure } for liquids $P_{suc} > P_b(T_{in})$ → typically used in simplified models of boosters
- maximum allowable discharge temperature (apply cooler when needed) → e.g. seals in machine; Trating of downstream piping; flow assurance → evaporation of MEG ← corrosion inhibitor
- operational map

for pump



$f_2 > f_1$

Dry gas compressor



for compressors r_p is important $r_p = \frac{P_{out}}{P_{in}} = \frac{P_{dis}}{P_{suc}}$

$\frac{m^3}{d} \quad \frac{1\,d}{24\,h} \quad \frac{1\,h}{3600\,s}$

$$\frac{\underline{P}_{ideal}}{\underline{P}_{real}} = \eta_{adiabatic} = \frac{\cancel{\dot m}\,(h_{out,is} - h_{in})}{\cancel{\dot m}\,(h_{out,real} - h_{in})}$$

$$h_{out,real} = h_{in} + \frac{(h_{out,is} - h_{in})}{\eta_{adc}}$$

method to calculate isentropic expansion for real gas

$$\kappa = \frac{C_p}{C_v}$$

$$\rightarrow \frac{T_{out,is}}{T_{in}} = (r_p)^{\frac{\kappa-1}{\kappa}}$$

(K) (K)

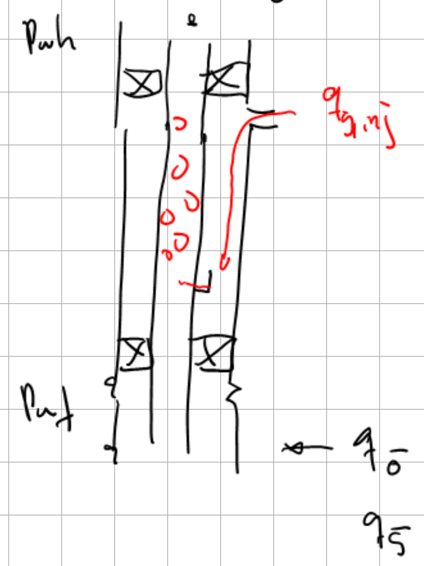
$$T_{out,is} = T_{in} (r_p)^{\frac{\kappa-1}{\kappa}}$$

κ CH_4 ~ 1.3

$$T_{out,is} = (70 + 273.15)(1.034)^{\frac{1.3-1}{1.3}} = 345.8079\ K$$

$$T_{out,is} = 345,8079 - 273.15 = 72.65\ °C$$

Artificial lift : gas lift

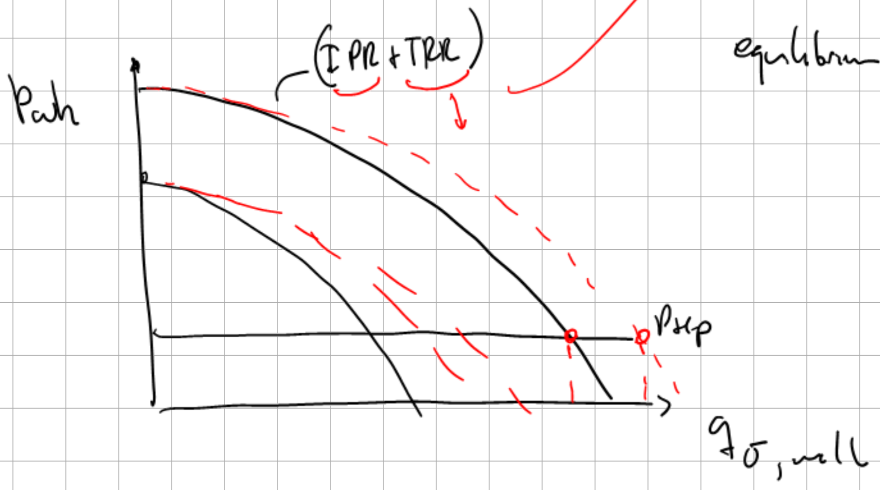


P_R

$$\Delta p = (P_{wf} - P_{wh}) \rightarrow \Delta p_{friction} + \underbrace{\Delta p_{HYDROSTATIC}}_{\rho_{mix}\, g\, h} + \Delta p_{accel}$$

$v^2 \rightarrow q_o, q_s, q_w$

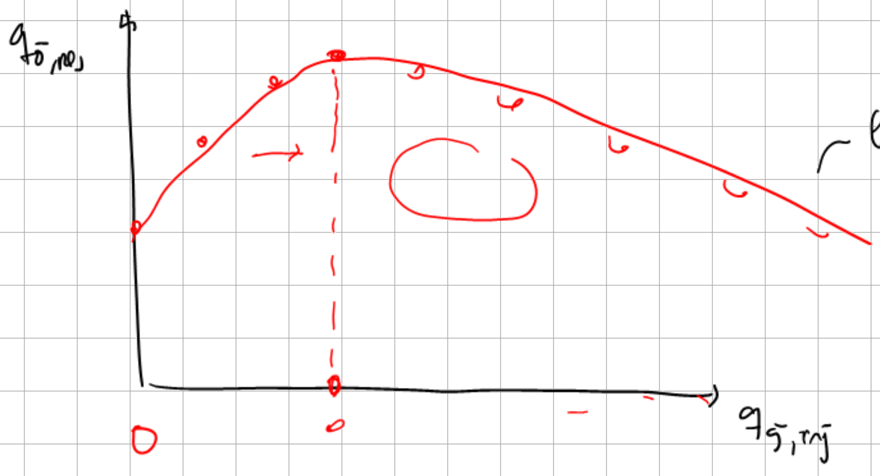
↑ Pwh available ↓ Δp apply gas lift ↓ $\rho_{mix} \rightarrow \rho_{gas}$



equilibrium at wellhead

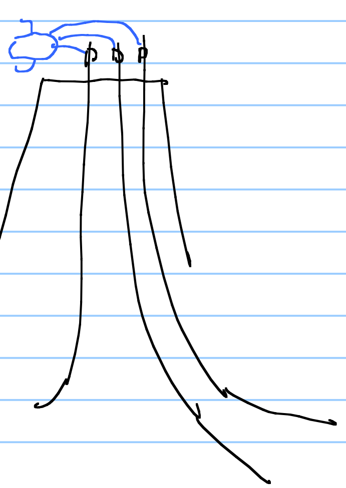
design of gas lift

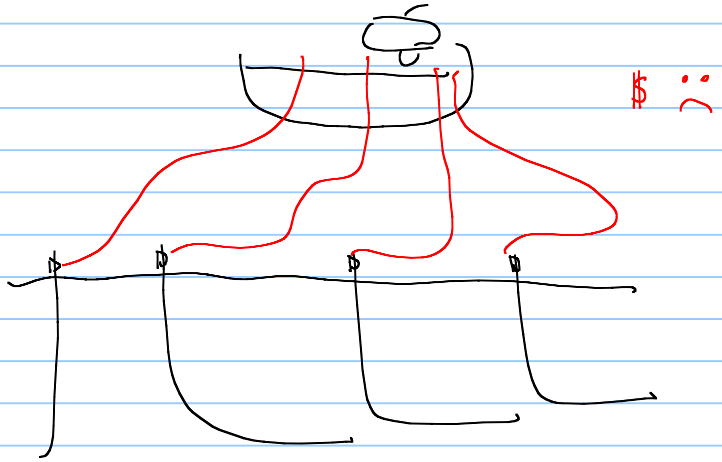
pwh = const

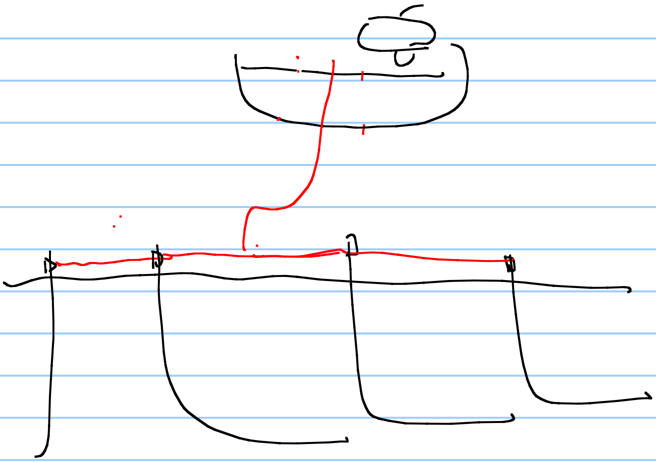


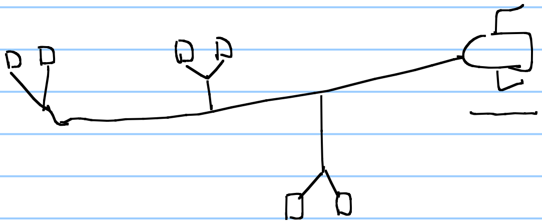
this curve is affected by depletion

- Networks collection of pipes, flowline, pipeline, valves, pumps, take the fluids from wells to the processing facilities.

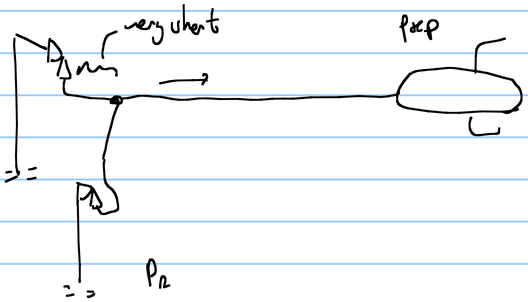








Example: 2 Dry gas wells

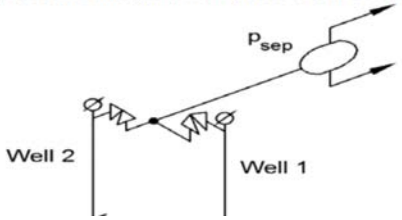


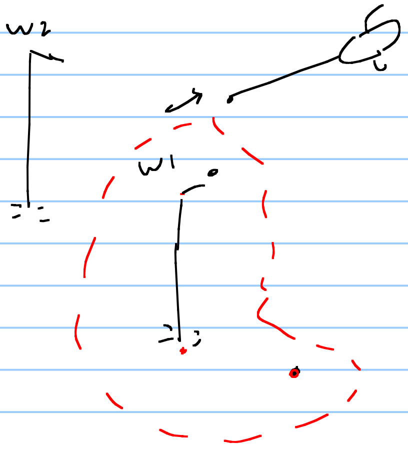
open choke $\Delta p_{c_1} = 0$ $\Delta p_{c_2} = 0$

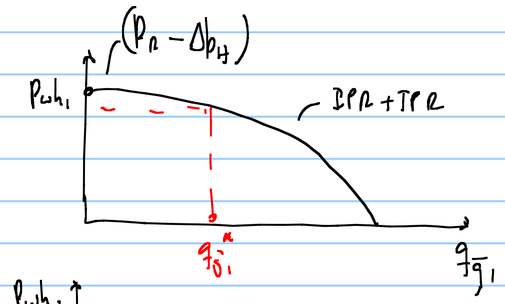
Equations	Nr equations	Nr unknowns
IPR, $q_{g_1} = C_{R_1}(P_{R_1}^2 - P_{wf_1}^2)^{n_1}$ $q_{g_2} = C_{R_2}(P_{R_2}^2 - P_{wf_2}^2)^{n_2}$	2	4
TPR $q_{g_1} = C_{T_1}\left(\frac{P_{wf_1}^2}{e^{S_1}} - P_{wh_1}^2\right)^{0.5}$ $q_{g_2} = C_{T_2}\left(\frac{P_{wf_2}^2}{e^{S_2}} - P_{wh_2}^2\right)^{0.5}$	2 └4	2 └6
FPR $q_{g_1} + q_{g_2} = C_{P_L}(P_j^2 - P_{sep}^2)^{0.5}$	1 └5	1 └7
$\Delta p_{c_1} = 0$ $P_{wh_1} = P_j$	1 └6	0 └7
$\Delta p_{c_2} = 0$ $P_{wh_2} = P_j$	1 └7	0 └7

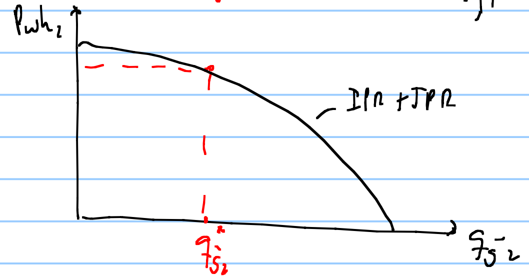
PROBLEM 4 (18 POINTS). Network solving. (2017) exam

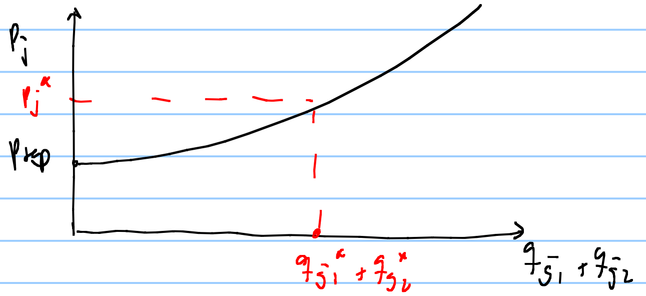
Consider the gas field with two wells, a manifold a pipeline and a separator shown in the figure below. The wellhead of the wells are very close to the junction so it can be safely assumed that the wellhead pressure and junction pressure are equal when the choke is open.











approach nr. 1

1: assume $q_{g_1}^*$ $q_{g_2}^*$

2: Read $P_{wh_1}^*$, $P_{wh_2}^*$, P_j^*
(WPR₁) (WPR₂) (PPR)

3: Verify $P_{wh_1}^* = P_{wh_2}^* = P_j^*$

not

yes

$q_{g_1}^*$, $q_{g_2}^*$ are solution

approach nr. 2

1. assume $P_j^* = P_{wh_1}^* = P_{wh_2}^*$

2. Read $q_{g_1}^*$ (WPR₁), $q_{g_2}^*$ (WPR₂), $q_{pipeline}^*$ (PPR)

3. Verify

$q_{g_1}^* + q_{g_2}^* = q_{pipeline}^*$ not

yes

solution

first iteration $p_j = 50$ bara

$q_{g_1}^* = 1.2 E06$ Sm^3/d

$q_{g_2}^* = 1.57 E06$ Sm^3/d + $2.77 E6$ Sm^3/d $\varepsilon = 0.97$ $1E06$ Sm^3/d

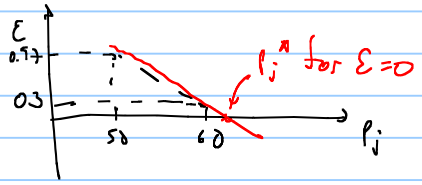
$q_{pipeline}^* = 1.8 E06$ Sm^3/d 1.8 $E06$ Sm^3/d

2nd $p_j = 60$ bara

$q_{pipeline}^* = 2.3 E06$ Sm^3/d 2.3 $E06$ Sm^3/d $\varepsilon = 0.3$ $1E06$ Sm^3/d

$q_{g_2}^* = 1.45 E06$ Sm^3/d + 2.60 $E06$ Sm^3/d

$q_{g_1}^* = 1.15$ $E06$ Sm^3/d



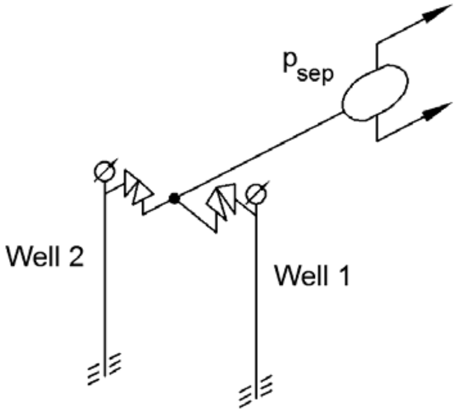
$$\frac{\varepsilon_1 - \varepsilon_2}{p_{j_1} - p_{j_2}} = \frac{\varepsilon_1 - 0}{p_{j_1} - p_j^*}$$

$p_j^* = \sim$

Where Δp [bara], q in [m^3/d]. Assume a constant pump efficiency (η) of 0.6. Assume an oil formation volume factor (Bo) at the pump suction of 1.2 m^3/Sm^3.

PROBLEM 4 (18 POINTS). Network solving.

Consider the gas field with two wells, a manifold a pipeline and a separator shown in the figure below. The wellhead of the wells are very close to the junction so it can be safely assumed that the wellhead pressure and junction pressure are equal when the choke is open.



Each well has a different H2S concentration as provided in the table below:

Well name	H2S concentration [mg/Sm^3]
Well 1	2.6
Well 2	10.0

The wellhead performance relationship (WPR, available pressure at the wellhead) of each well can be expressed with the following equation:

$$q = C_{wh} \cdot \left(p_{whs}{}^2 - p_{wh}{}^2\right)$$

Where p_{whs} is the static wellhead pressure recorded when the well is shut-in. The values for both wells are provided in the table below:

Well Name	C_{wh} [Sm^3/d/bara^2]	P_{whs} [bara]
Well 1	60	150
Well 2	100	135

The pipeline performance relationship (PPR, required pressure at the junction) can be expressed with the following equation:

$$q = C_{pl} \cdot \left(p_j{}^2 - p_{sep}{}^2\right)^{0.5}$$

Where

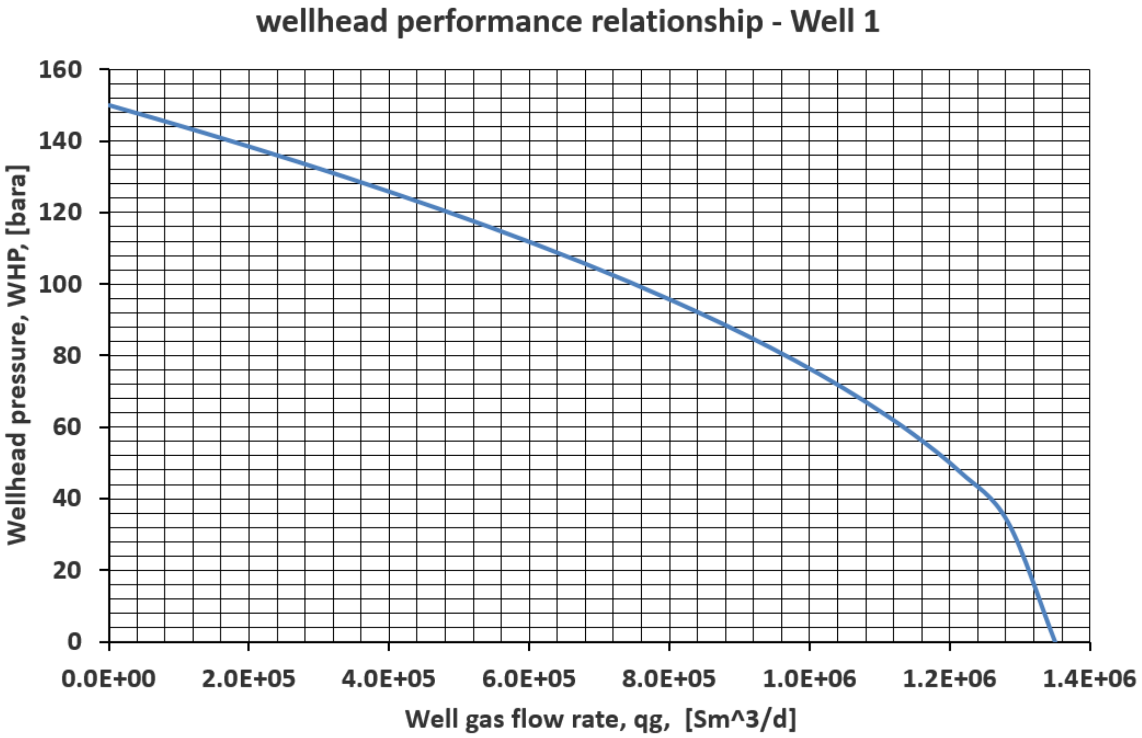
C_{pl} = 45 000 [Sm^3/d/bar^2]

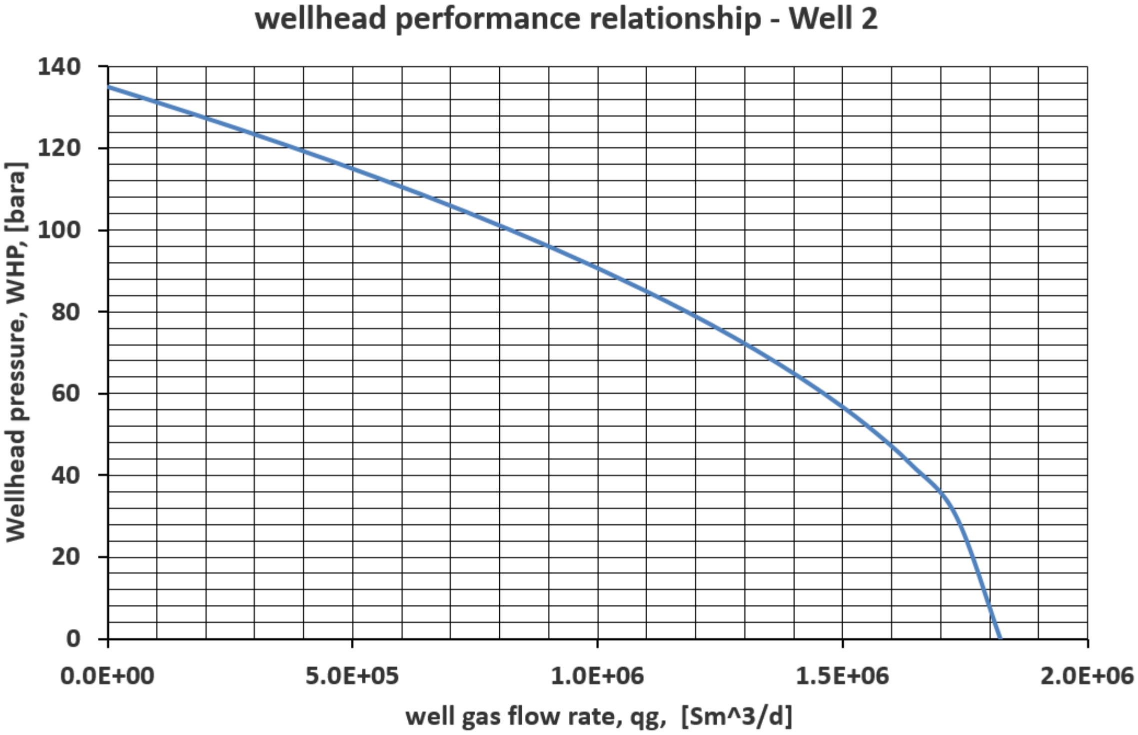
p_{sep} = 30 [bara]

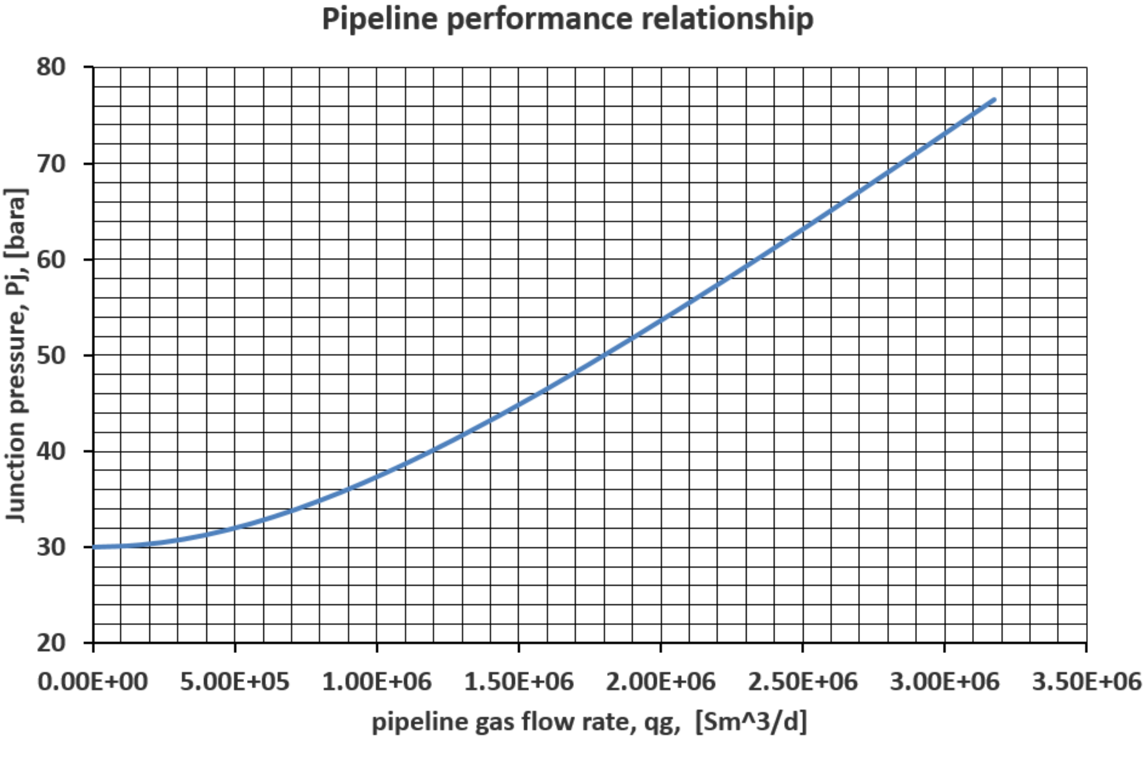
You can also solve this problem graphically, the available and required pressure curves are provided at the end of the exercise.

You tasks are:

Task 1 (9 POINTS). Calculate the operating flow rates when the chokes are fully open. Verify if the H2S concentration of the field is higher than the maximum value allowed (5.7 mg/Sm^3)
Task 2. (6 POINTS) If the H2S constraint is violated, please find an operational point that does not violate the H2S constraint (by choking one or two wells). Hint: Fix the rate on both wells. Report the pressure drop across the chokes.
Task 3. (3 POINTS) Will it be worth to apply model-based optimization to this problem?. Explain your answer. If yes, please explain how will you set up the optimization problem, what is the objective, what variables will you change and what are the constraints (In excel). Please specify where will you locate the input, output and in which cells are the objective, constraints and variables.




wellhead performance relationship - Well 2
Wellhead pressure, WHP, [bara]
140
120
100
80
60
40
20
0
0.0E+00
5.0E+05
1.0E+06
1.5E+06
2.0E+06
well gas flow rate, qg, [Sm^3/d]

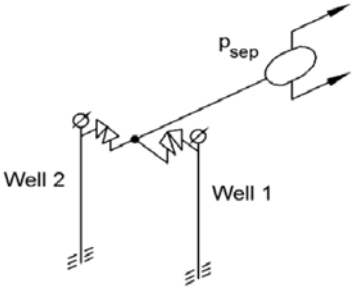

Pipeline performance relationship
Junction pressure, Pj, [bara]
80
70
60
50
40
30
20
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06
3.50E+06
pipeline gas flow rate, qg, [Sm^3/d]

Youtube video: Solving dry gas networks in Excel

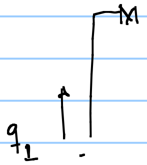
Exercise: using data from Problem 4 of the Exam 2017:

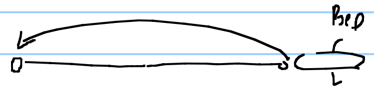
PROBLEM 4 (18 POINTS). Network solving.

Consider the gas field with two wells, a manifold a pipeline and a separator shown in the figure below. The wellhead of the wells are very close to the junction so it can be safely assumed that the wellhead pressure and junction pressure are equal when the choke is open.



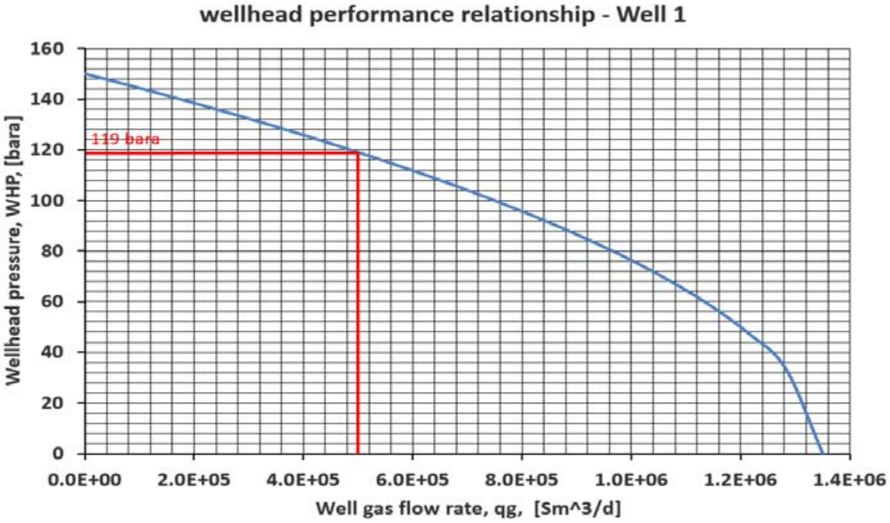
Will it be possible to produce 0.5 E06 Sm3/d from each well? if so, what is the choke deltap required in each well?

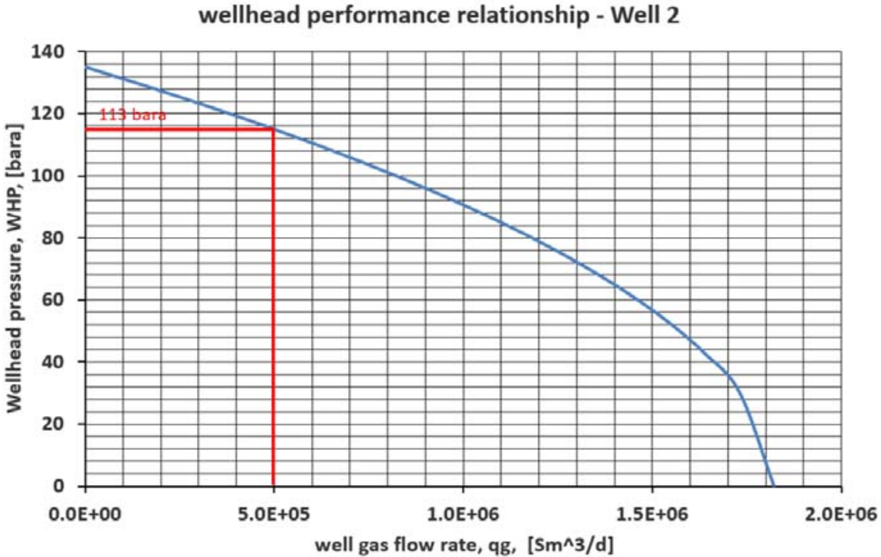


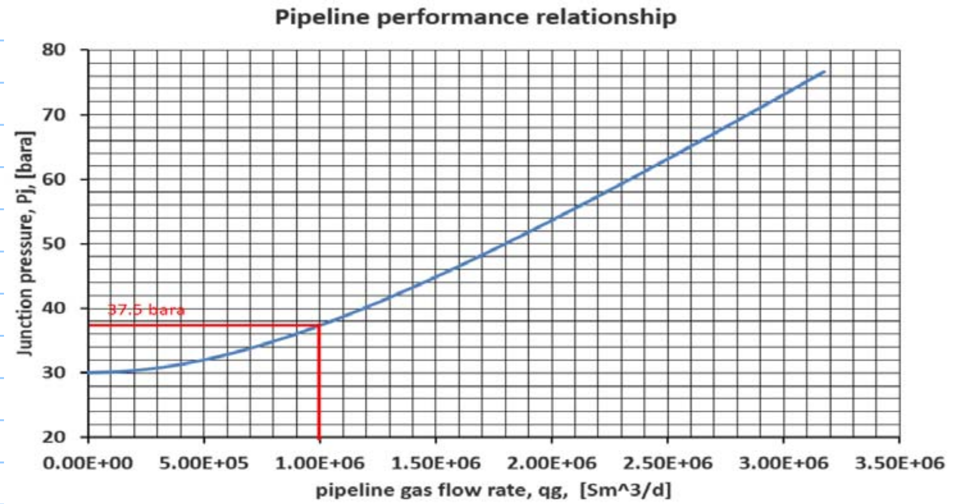


verify $\Delta p > 0$ then q_1 is feasible

if $\Delta p < 0$ then q_1 is no feasible



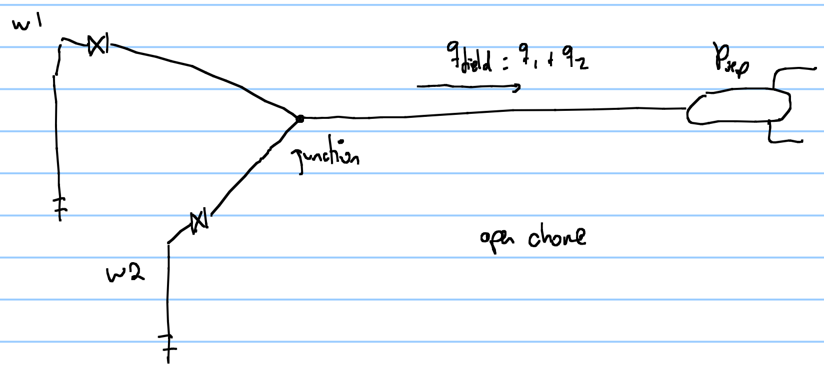




Deltap_choke1 = 119 - 37.5 = 81.5 bara
Deltap_choke2= 113-37.5 = 75.5 bara

Yes, it is possible to produce 0.5 E06 Sm3/d from well 1 and 2.

Exercise on Dry gas network using Excel



we have to assume either $\overline{q_1}$, $\overline{q_2}$

OR: P_{wf_1}, P_{wf_2} ← $P_{wf} < P_R$

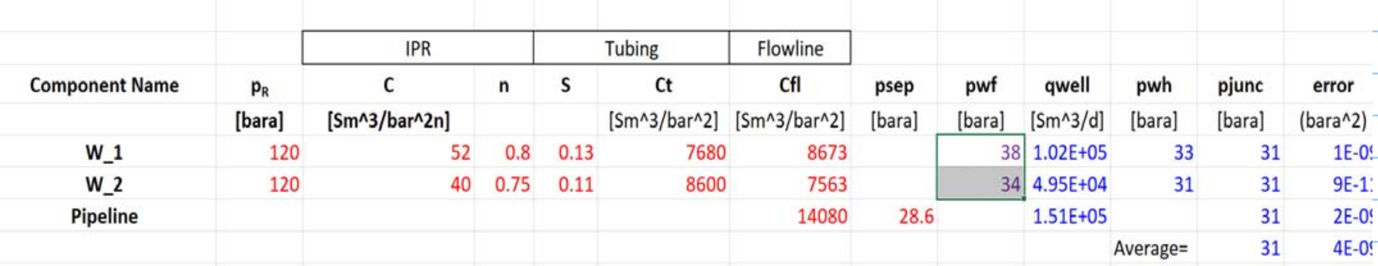
↳ we prefer to assume P_{wf} because I know the upper bound

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

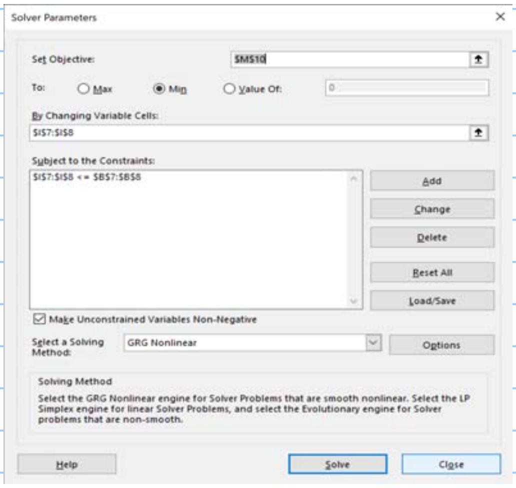
$$P_{wf} = \underbrace{\sqrt{P_R^2 - \left(\frac{q}{C_R}\right)^{1/n}}}_{\text{i don't know } q_{max}\text{, and can give problems in eq.}}$$

objective variable ;

$$\left(P_{j_{av}} - P_{j_1}\right)^2 + \left(P_{j_{av}} - P_{j_2}\right)^2 + \left(P_{j_{av}} - P_{j_{sep}}\right)^2$$



		IPR		Tubing		Flowline						
Component Name	**p_R**	**C**	**n**	**S**	**Ct**	**Cfl**	**psep**	**pwf**	**qwell**	**pwh**	**pjunc**	**error**
	[bara]	[Sm^3/bar^2n]			[Sm^3/bar^2]	[Sm^3/bar^2]	[bara]	[bara]	[Sm^3/d]	[bara]	[bara]	(bara^2)
W_1	120	52	0.8	0.13	7680	8673		38	1.02E+05	33	31	1E-0
W_2	120	40	0.75	0.11	8600	7563		34	4.95E+04	31	31	9E-1
Pipeline						14080	28.6		1.51E+05		31	2E-0
										Average=	31	4E-0



Solver Parameters

Set Objective: $M$10

To: ○ Max ● Min ○ Value Of: 0

By Changing Variable Cells: $I$7:$I$8

Subject to the Constraints:

$I$7:$I$8 <= $B$7:$B$8

☑ Make Unconstrained Variables Non-Negative

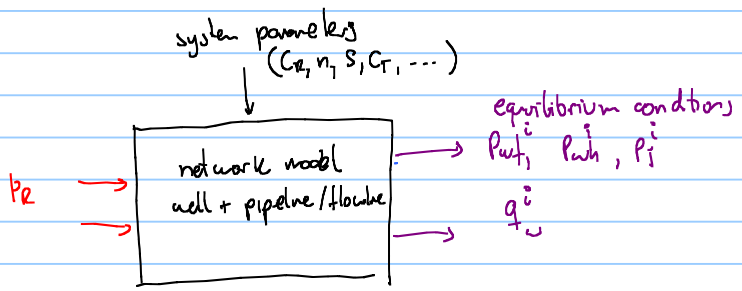
Select a Solving Method: GRG Nonlinear

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

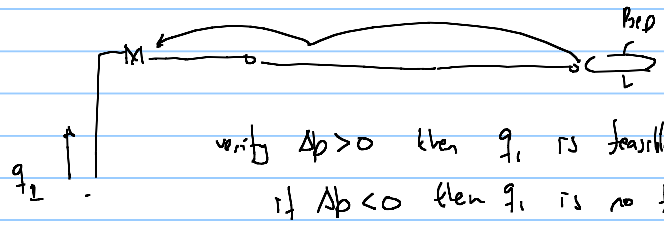
If solver is not available

Activate solver → exel menu → options
↓
Add in
↓
"go"
↓
tick on "solver"
or "problem solver"



solving the network
with choke

- option 1, fixing rates
(option usually not available in
commercial software)

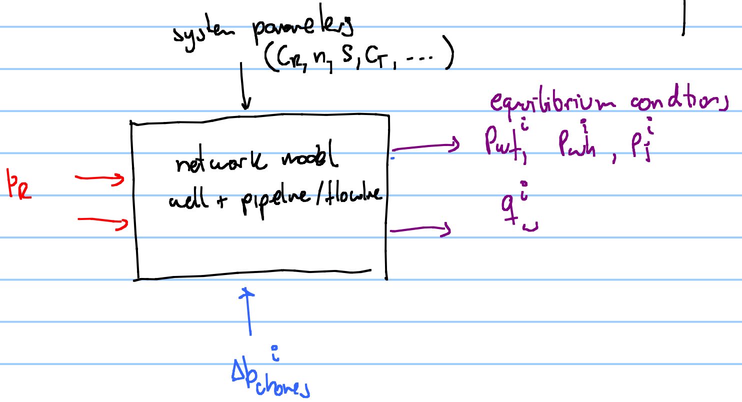


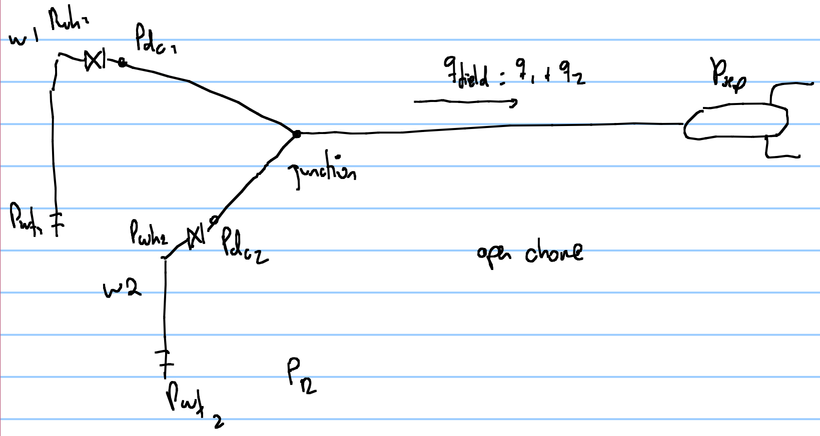
verify $\Delta p > 0$ then q_1 is feasible
if $\Delta p < 0$ then q_1 is no feasible

for example, it is desirable to
produce $\left\{ \begin{array}{l} q_1 = 80000 \ Sm^3/d \\ q_2 = 40000 \ Sm^3/d \end{array} \right.$

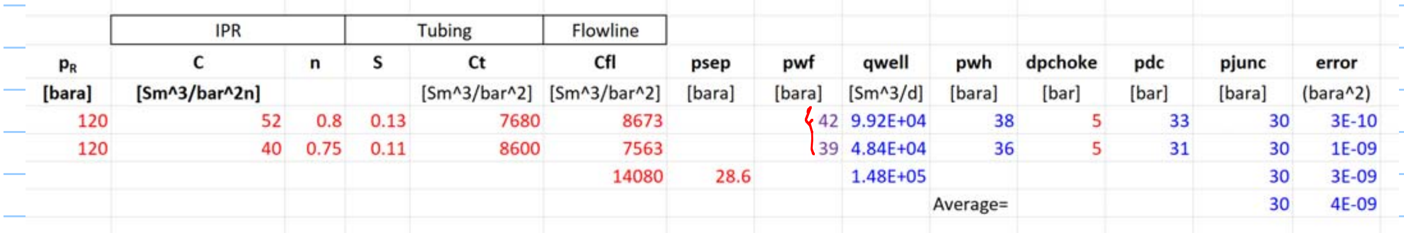
		IPR		Tubing		Flowline							
Component Name	p_R	C	n	S	Ct	Cfl	psep	pwf	qwell	pwh	dpchoke	pdc	pjunc
	[bara]	[Sm^3/bar^2n]			[Sm^3/bar^2]	[Sm^3/bar^2]	[bara]	[bara]	[Sm^3/d]	[bara]	[bar]	[bar]	[bara]
W_1	120	52	0.8	0.13	7680	8673		69	8.00E+04	64	33	31	30
W_2	120	40	0.75	0.11	8600	7563		66	4.00E+04	63	32	30	30
Pipeline						14080	28.6		1.20E+05				30

- option 2: include the choke "model" → 2 options
  - Δp_{choke} ← this option will be discussed next
  - choke opening $\Delta p_{choke} = f(q_g, \text{Opening}, P_1)$

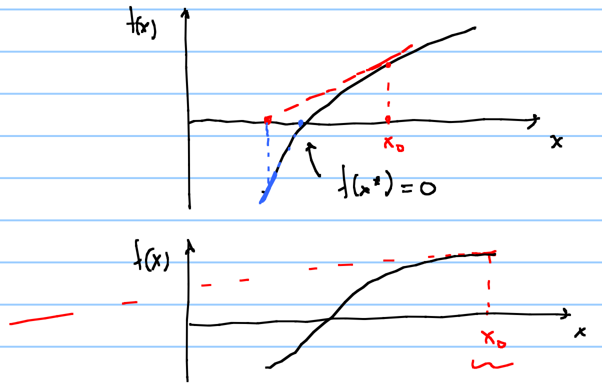




open choke

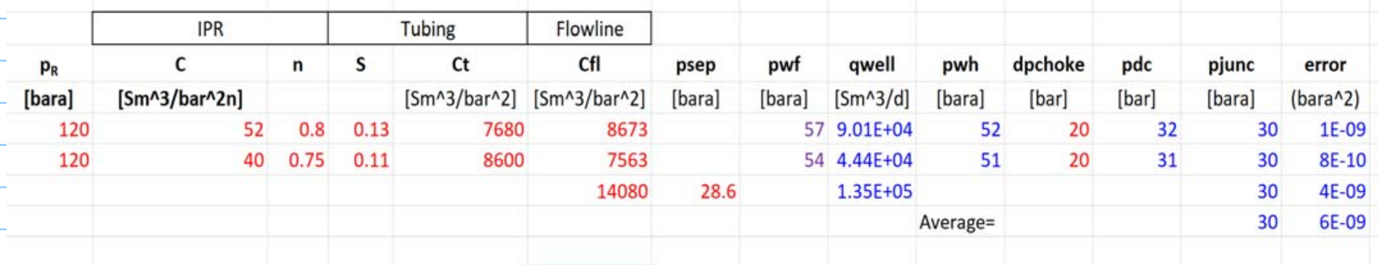


	IPR		Tubing		Flowline								
p_R	C	n	S	Ct	Cfl	psep	pwf	qwell	pwh	dpchoke	pdc	pjunc	error
[bara]	[Sm^3/bar^2n]			[Sm^3/bar^2]	[Sm^3/bar^2]	[bara]	[bara]	[Sm^3/d]	[bara]	[bar]	[bar]	[bara]	(bara^2)
120	52	0.8	0.13	7680	8673		42	9.92E+04	38	5	33	30	3E-10
120	40	0.75	0.11	8600	7563		39	4.84E+04	36	5	31	30	1E-09
					14080	28.6		1.48E+05				30	3E-09
									Average=			30	4E-09



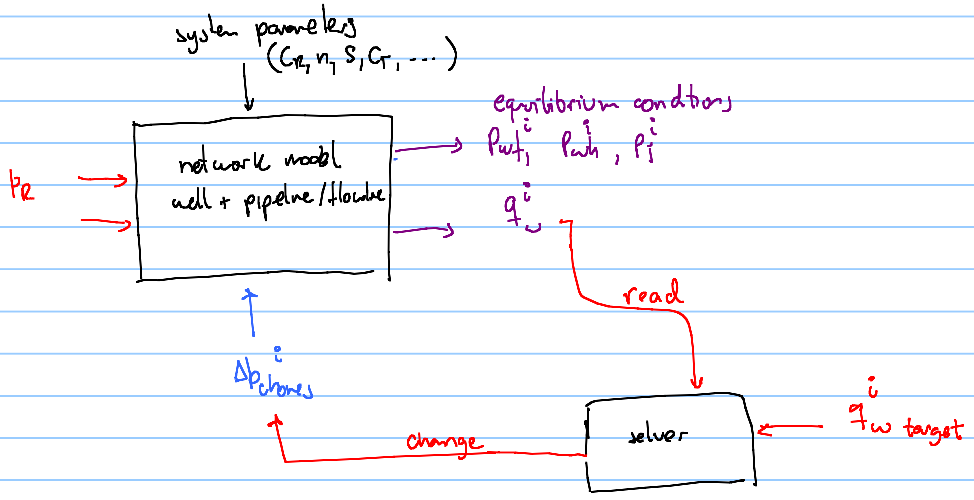
-- step 1
--- step 2

for derivative based solver
it is necessary to give a good
initial seed

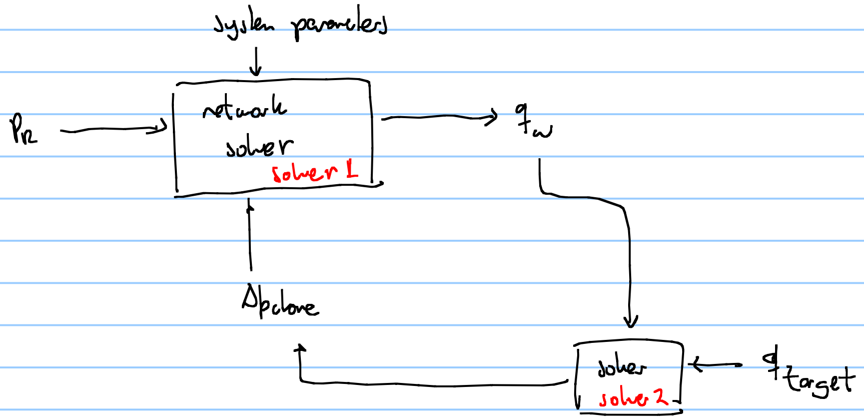


	IPR		Tubing		Flowline								
p_R	C	n	S	Ct	Cfl	psep	pwf	qwell	pwh	dpchoke	pdc	pjunc	error
[bara]	[Sm^3/bar^2n]			[Sm^3/bar^2]	[Sm^3/bar^2]	[bara]	[bara]	[Sm^3/d]	[bara]	[bar]	[bar]	[bara]	(bara^2)
120	52	0.8	0.13	7680	8673		57	9.01E+04	52	20	32	30	1E-09
120	40	0.75	0.11	8600	7563		54	4.44E+04	51	20	31	30	8E-10
					14080	28.6		1.35E+05				30	4E-09
									Average=			30	6E-09

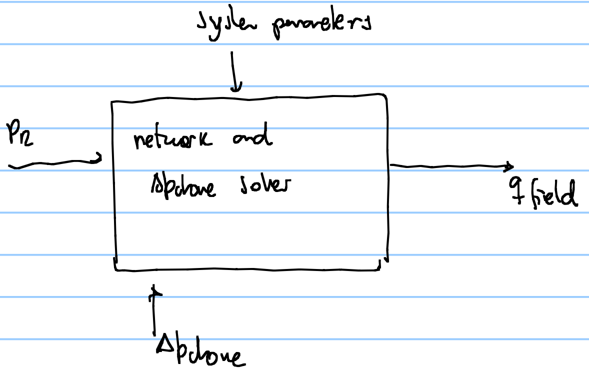
- How to use this model to find Δp_{choke} such that $q_1 = 80000$ Sm³/d
  $q_2 = 40000$ Sm³/d



in excel it is not possible to have two levels of solver



"Merging the two solvers"



objective variable :

$$(P_{j_{av}} - P_{j_1})^2 + (P_{j_{av}} - P_{j_2})^2 + (P_{j_{av}} - P_{j_{sep}})^2$$

variables changing P_{wf_1}

P_{wf_2}

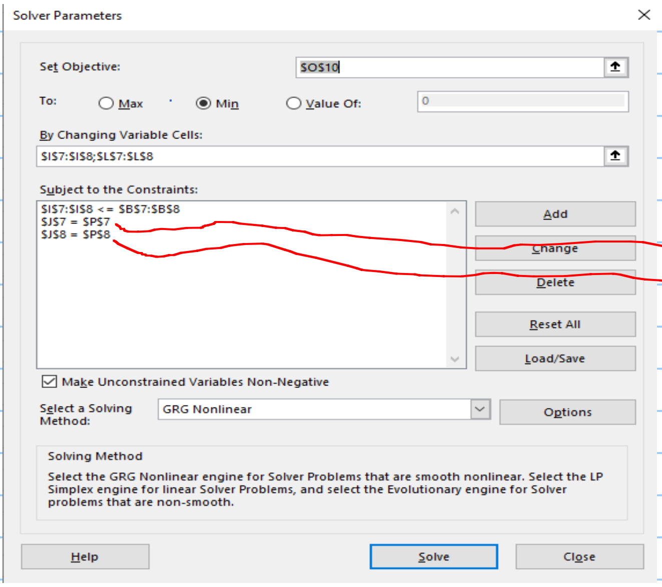
$\Delta p_{choke\ 1}$

$\Delta p_{choke\ 2}$

constraints

$q_1 = q_{1\,target}$

$q_2 = q_{2\,target}$



Solver Parameters

Set Objective: $O$10

To: ○ Max ● Min ○ Value Of: 0

By Changing Variable Cells: $I$7:$I$8;$L$7:$L$8

Subject to the Constraints:

```
$I$7:$I$8 <= $B$7:$B$8
$J$7 = $P$7
$J$8 = $P$8
```

☑ Make Unconstrained Variables Non-Negative

Select a Solving Method: GRG Nonlinear

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

	IPR		Tubing		Flowline									
p_R	C	n	S	Ct	Cfl	psep	pwf	qwell	pwh	dpchoke	pdc	pjunc	error	qtarget
[bara]	[Sm^3/bar^2n]			[Sm^3/bar^2]	[Sm^3/bar^2]	[bara]	[bara]	[Sm^3/d]	[bara]	[bar]	[bar]	[bara]	(bara^2)	[Sm3/d]
120	52	0.8	0.13	7680	8673		69	8.00E+04	64	33	31	30	9E-11	80000
120	40	0.75	0.11	8600	7563		87	3.00E+04	82	52	30	30	5E-11	30000
					14080	28.6		1.10E+05				30	7E-12	
									Average=			30	2E-10	

Lecture 20220301

Useful links:

- General information about python: https://en.wikipedia.org/wiki/Python_(programming_language)
- Creator of python: https://en.wikipedia.org/wiki/Guido_van_Rossum
- Origin of the name: https://en.wikipedia.org/wiki/Monty_Python
- To install python, Jupyter Notebook, libraries, etc. on your computer: https://www.anaconda.com/
- Online jupyter notebook by Google (no need to install): https://colab.research.google.com/
- Desktop editors for python: https://www.jetbrains.com/pycharm/ , https://code.visualstudio.com/ , spyder (included in Anaconda) https://www.spyder-ide.org/
- Information about code version control and backup: https://www.w3schools.com/git/git_intro.asp?remote=github , https://github.com/
- Course that Milan took on python: https://www.coursera.org/specializations/python#courses , https://www.dr-chuck.com/ , https://www.py4e.com/lessons
- numpy documentation: https://numpy.org/doc/stable/index.html

Notes to Youtube video Dealing with uncertain parameters - frequency and probability distribution

How to deal and quantify uncertainty in field development

for example in our Snøhvit case

↳ $\underbrace{G, N}$, $q_g = C_R(P_R^2 - P_{wf}^2)^n$

$

uptime 90 - 100%

$\left(\frac{\text{nr day producing in year}}{365}\right)$

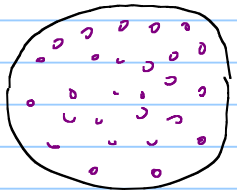
↳ cause additional OPEX

↳ cut in production → cut in Revenue

input variables used in engineering studies in FD are highly uncertain

$\Phi_{min} \leq \Phi \leq \Phi_{max}$ and affect the value of KPIs that are used to discriminate and select development alternatives.

Φ



number sample	Φ
–	–
–	–
–	–
–	–
–	–
–	–

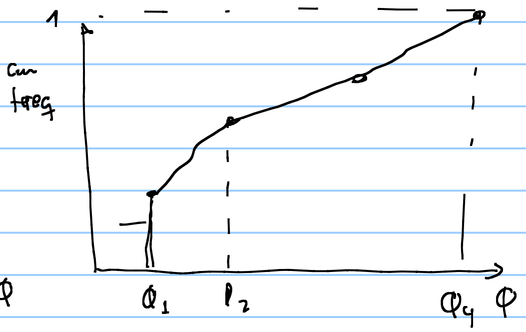
→ discrete frequency analysis

create bins min Φ_1 (0.15) — 0.175 if $\underline{\Phi_i = 0.18}$

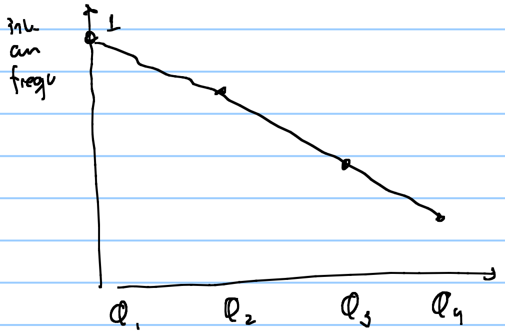
Φ_2 (0.20) $\Phi_1 \leq \Phi_i \leq \Phi_2$

Φ_3 (0.25) if $\Phi_i < \frac{(\Phi_2 - \Phi_1)}{2} + \Phi_1$ → counted as part of Φ_1

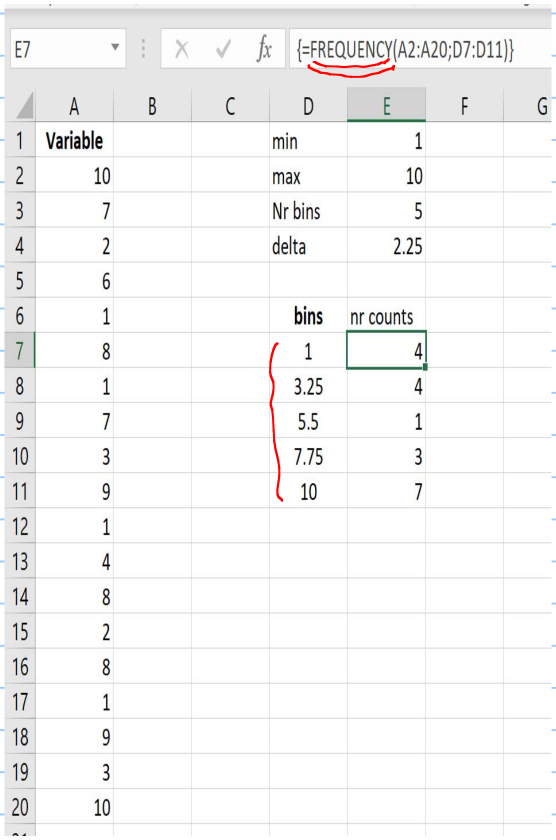
max Φ_4 (0.30)



bin	Nr counts	rel. frequency	cum frequency	inv. cum frequency
Q_1	x	x/N	x/N	(x+w+z+y)/N → 1
Q_2	y	y/N	y/N + x/N	(w+z+y)/N
Q_3	z	z/N	y/N + x/N + z/N	(w+z)/N
Q_4	w	w/N	(x+y+z+w)/N	w/N
	N			



how to do frequency analysis in excel:


E7 {=FREQUENCY(A2:A20;D7:D11)}

	A	B	C	D	E	F	G
1	Variable			min	1		
2	10			max	10		
3	7			Nr bins	5		
4	2			delta	2.25		
5	6						
6	1			bins	nr counts		
7	8			1	4		
8	1			3.25	4		
9	7			5.5	1		
10	3			7.75	3		
11	9			10	7		
12	1						
13	4						
14	8						
15	2						
16	8						
17	1						
18	9						
19	3						
20	10						

to create bins:

find max

find min

define Nr bins

calculate $delta = \frac{(max - min)}{(Nr\ bins - 1)}$

compute each bin

$bin^i = bin^{i-1} + delta$

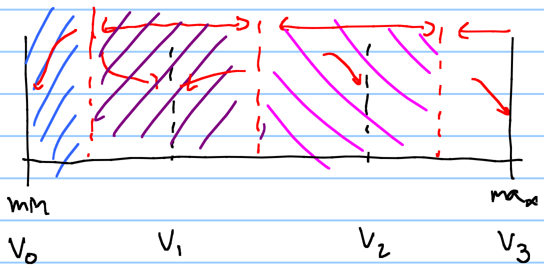
starting from $bin^0 = min$

to apply frequency function:

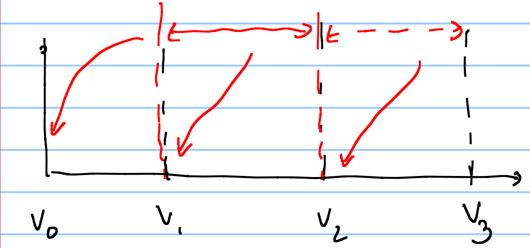
ctrl + shift + enter (in sequence and leave it pressed)

selecting bins must take into account

∘ nr data points



be careful how the frequency is accounted for



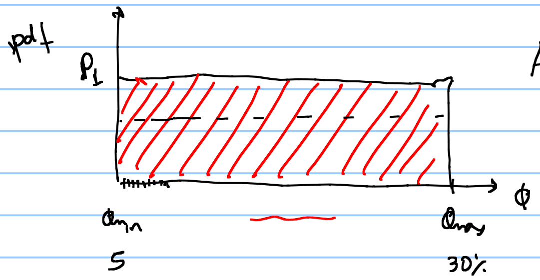
what happens if there are no measurements?

frequency ⇝ probability

rel frequency ⇝ pdf probability density function

cum frequency plot ⇝ cdf cumulative distribution function

poor boy, no data pdf Φ continuous probability



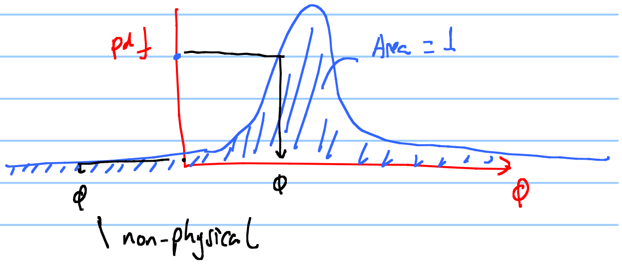
$$\text{Area} = (\Phi_{max} - \Phi_{min}) \cdot P_1 = 1$$

$$\underline{P_1} = \frac{1}{(\Phi_{max} - \Phi_{min})}$$

Continuous distributions are advantageous because:
-There is an analytical expression
-I need only few values to define the distribution
-There is no data to determine a discrete distribution

Warning: many continuous distributions go from −∞ → +∞

There are many parameters in FD that exhibit typical distributions:
-cost ---Normal
-Porosity --- Normal
-Initial oil/gas in place --- Log Normal



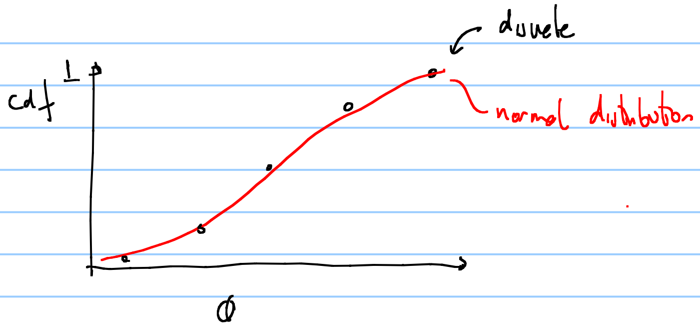
so bounding is necessary

discrete distribution ⟶ continuous distribution

$$\left.\begin{matrix}\Phi\\ \Phi_1\\ \Phi_2\\ \vdots\end{matrix}\right\} \begin{matrix}\mu\\ \sigma\end{matrix} \rightarrow$$ parameters of a normal distribution

- calculate directly using population data

- tune parameters in the continuous distribution to represent the discrete distribution

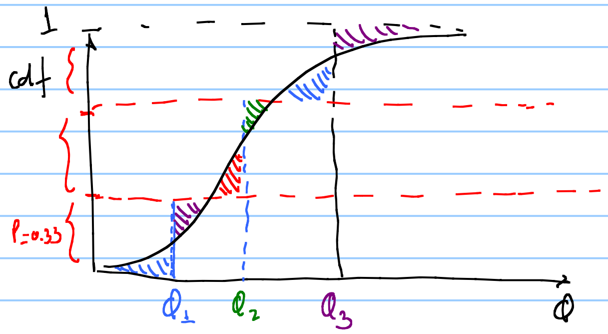


$$\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

change μ, σ until diff discrete and continuous is minimal

continuous distribution → discrete distribution

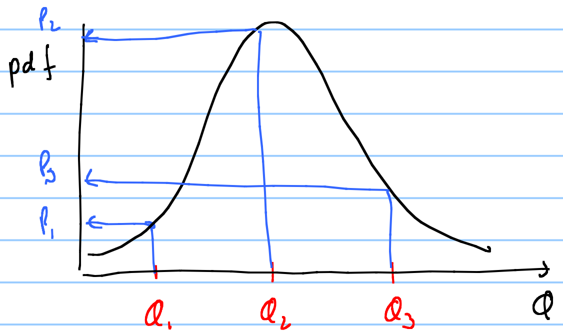
- Bracket mean
  - define nr. bins
  - define probability of bins



Q	P
Q_1	0.33
Q_2	0.33
Q_3	0.33

find Q_1, such that ▨ = ▨

- value discretization
- pick nr. bins in Q
- read probabilities from pdf



Q	P
Q_1	P_1^*
Q_2	P_2^*
Q_3	P_3^*

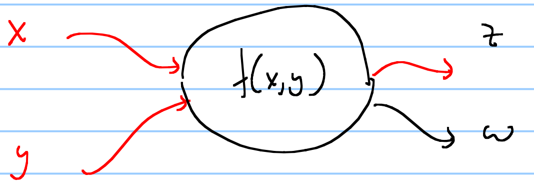
- Normalize probabilities using the sum

$$P_1^* = \frac{P_1}{P_1+P_2+P_3}$$

$$P_2^* = \frac{P_2}{P_1+P_2+P_3}$$

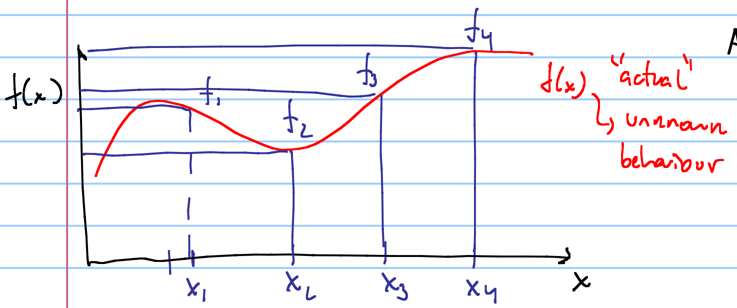
Notes to Youtube video How to handle uncertain parameters: Monte Carlo and LHS

How to handle uncertain parameters in our FD calculations



deterministic calculation: x and y have a unique known value

stochastic/probabilistic calculation: x and y exhibit a probabilistic distribution

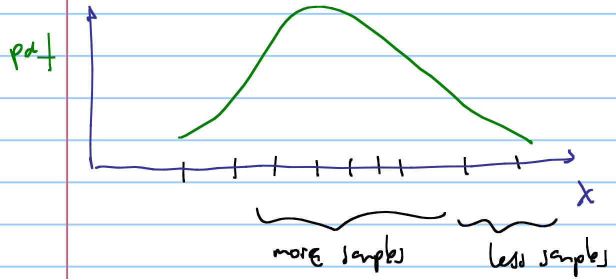


Approach to deal with uncertainty:

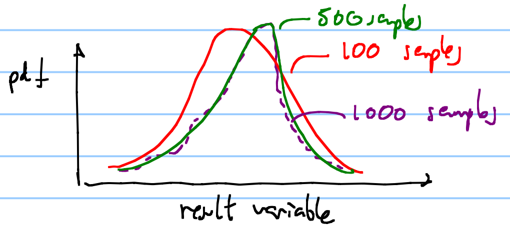
- create samples
- evaluate the function at samples
- calculate pdf and cdf of the results

1: How many samples are needed?

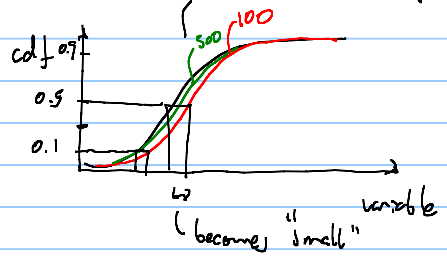
2: How to generate the samples?



1: Increase the number of samples and see how the results change (pdf, cdf)



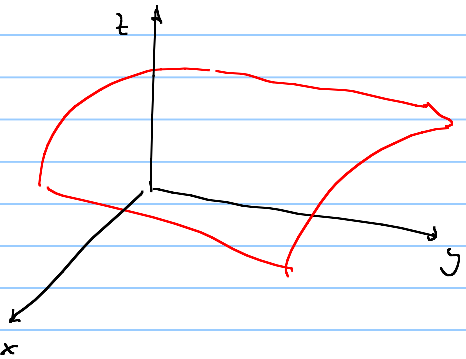
for this case, it seems 500 samples is enough

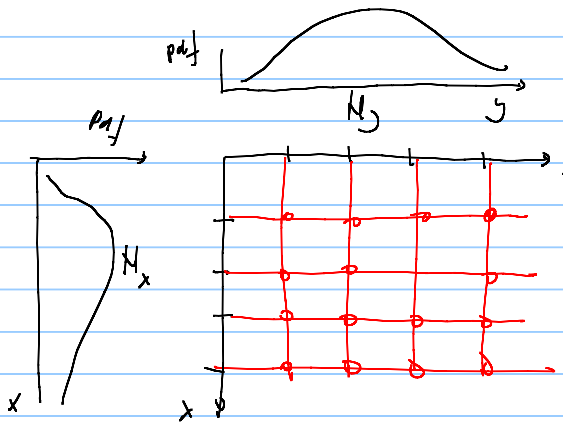


2: how to generate the samples

- Monte Carlo method
- Latin hypercube sampling

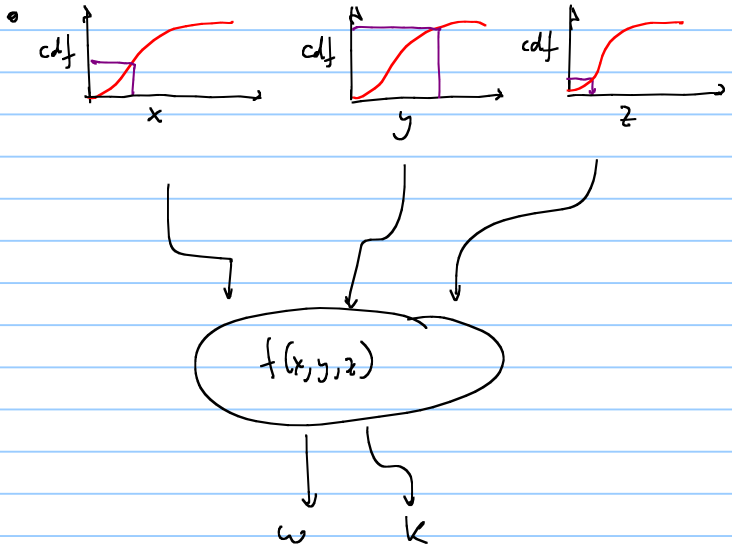
} efficient sampling → less number of samples to achieve convergence brute-force sampling





$N_{total} = N_x \cdot N_y$

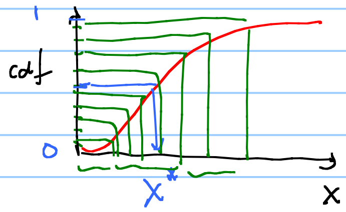
It is impractical for large number of variables/samples



① For each variable

1.1 pick a random number between 0 - 1

1.2 enter cdf and read the value of the variable



② perform a simulation with the samples

③ repeat "many" times steps 1-2

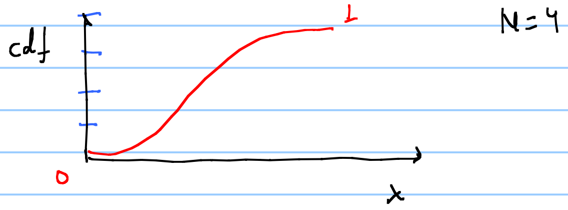
④ perform a frequency analysis on the results → pdf cdf

- Latin hypercube sampling (LHS)

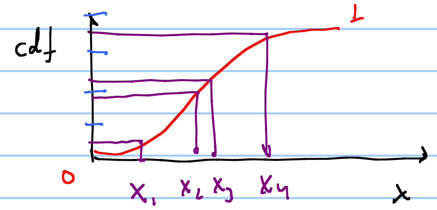
① Define a number of samples "N"

① For each variable

1.1. subdivide the cumulative probability in "N" intervals (equally-spaced)



1.2. Pick a random number in the interval find the corresponding value of the variable



$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} \quad \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{pmatrix} \quad \begin{pmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{pmatrix}$$

1.3. shuffle randomly the sample vector(s)

sim 1	x_3	y_1	z_3
sim 2	x_1	y_3	z_2
sim 3	x_4	y_4	z_1
sim 4	x_2	y_2	z_4

② perform simulations for sampled variables that are in the same row

③ perform a frequency analysis on the results
↳ cdf, pdf

Notes to Youtube video Exercise - Reserve estimation in a spreadsheet using Monte Carlo

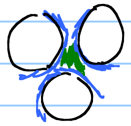
Reserve estimation : case undersaturated oil reservoir

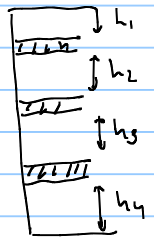
$$TRR = N_{pu} = \frac{V_R \cdot \phi \cdot N_{TG}\, S_o \cdot F_{RU}}{B_o}$$

total recoverable reserves

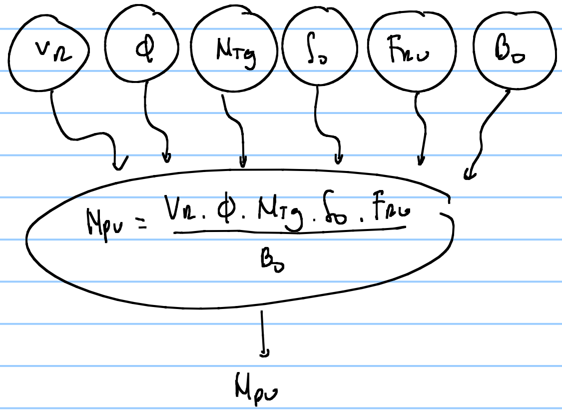
ultimate cumulative production

recovery factor

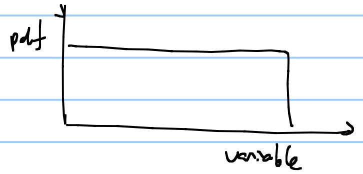


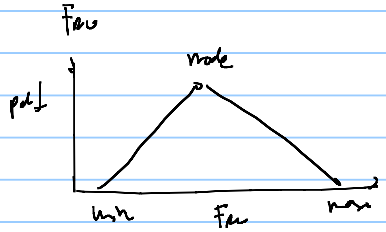


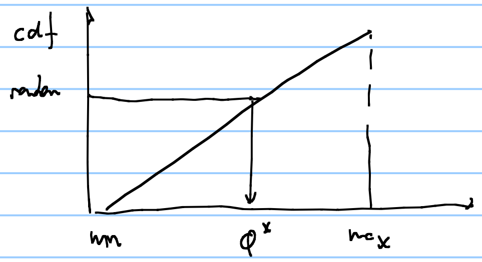
$$N_{TG} = \frac{h_1 + h_2 + h_3 + h_4}{h_{total}}$$



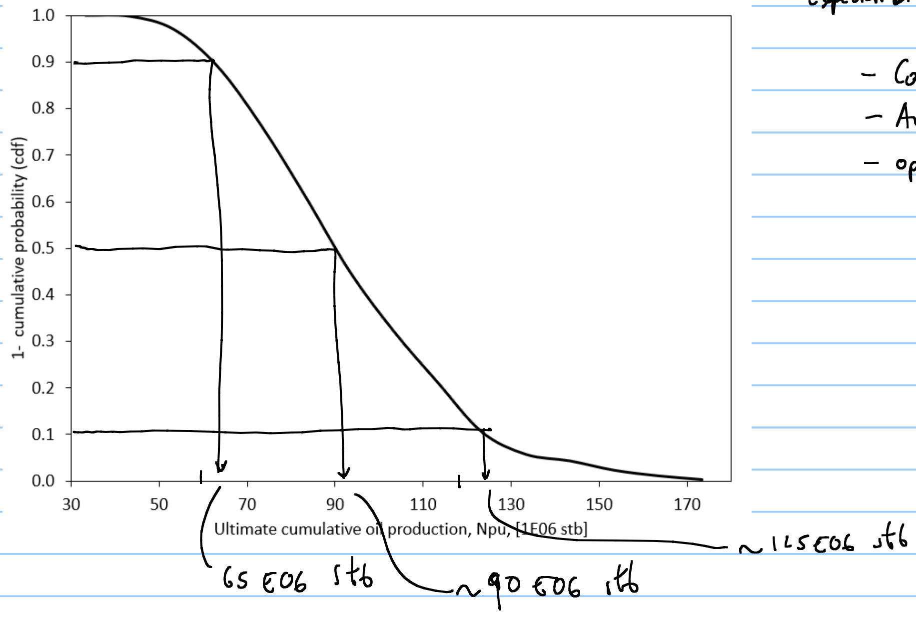
V_R, ϕ, N_{Tg}, S_o, B_o have a uniform pdf







expectation curve



- Conservative estimate (90%) P90 }
- Average estimate (50%) P50
- optimistic estimate (10%) P10

Live lecture 08.03.2022

```
Probalistic_estimation_of_reserves_MCS

#importing needed libraries
import numpy as np #for math operations
import matplotlib.pyplot as plt #library for plotting
import pandas as pd #for creating and displaying a table

#declaring necessary functions
def Npu(por,RV,NTG,So,Bo,Fr):
  #returns ultimate cumulative oil production in [stb, Sm3]
  #input:
  #por, porosity in [-]
  #RV, rock volume, in [bbl, m3]
  #NTG, net to gross ratio, [-]
  #So, oil saturation, [-]
  #Bo, oil formation volume factor [bbl/stb, m3/Sm3]
  #Fr, ultimate recovery factor in [-]
  TRR=por*RV*NTG*So*Fr/Bo
  return TRR

#defining input
#porosity
por_min=0.18
por_max=0.3
#rock volume [1E06 bbl]
RV_min=5000
RV_max=6250
#Net to gross [-]
NTG_min=0.3
NTG_max=0.5
#oil saturation [-]
So_min=0.8
So_max=0.9
#Oil formation volume factor [bbl/stb]
Bo_min=1.35
Bo_max=1.6
#recovery factor, Fr, [-]
Fr_min=0.18
Fr_max=0.35
Fr_mode=0.25


#creating random samples
n=1000  #number of samples
por_v=np.random.uniform(por_min,por_max,n)
```

```
RV_v=np.random.uniform(RV_min,RV_max,n)
NTG_v=np.random.uniform(NTG_min,NTG_max,n)
So_v=np.random.uniform(So_min,So_max,n)
Bo_v=np.random.uniform(Bo_min,Bo_max,n)
Fr_v=np.random.triangular(Fr_min,Fr_mode,Fr_max,n)

#MC simulation
Npu_v=Npu(por_v,RV_v,NTG_v,So_v,Bo_v,Fr_v)


#frequency analysis on the results
nr_bins=15
bins=np.linspace(Npu_v.min(),Npu_v.max(),nr_bins)
counts=np.histogram(Npu_v,bins)[0]
pdf=counts/n
bins_for_pdf_plotting=0.5*(bins[0:-1]+bins[1:])
#plot pdf
plt.xlabel('ultimate cumulative oil production, Npu, [1E06 stb]')
plt.ylabel('frequency')
plt.plot(bins_for_pdf_plotting,pdf,label='pdf')
plt.legend()
plt.show()


#plot cdf
cdf=np.cumsum(pdf)
bins_for_cdf_plotting=bins[1:]
plt.xlabel('ultimate cumulative oil production, Npu, [1E06 stb]')
plt.ylabel('cumulative probability distribution, cdf')
plt.plot(bins_for_cdf_plotting,cdf,label='cdf')
plt.legend()
plt.show()


#create a summary table

Npu_mode= bins_for_pdf_plotting[np.argmax(pdf)]

P90= np.percentile(Npu_v,10)

P10= np.percentile(Npu_v,90)

P50= np.percentile(Npu_v,50)

Npu_max= Npu_v.max()

Npu_min= Npu_v.min()

Npu_mean= Npu_v.mean()
```

```
summary_table=pd.DataFrame({
    "Variable":['Mean [1E06 stb]','Mode [1E06 stb]','Minimum [1E06 stb]','
Maximum [1E06 stb]','P90 [1E06 stb]','P50 [1E06 stb','P10 [1E06 stb]'],
    "Value":[Npu_mean,Npu_mode, Npu_min,Npu_max,P90,P50,P10]
})
summary_table

#exporting results
output=np.vstack((pdf_bins,pdf))
np.savetxt('data.txt',output.T)


#how to make a function run element-wise for all members of an array
def test_function(a):
  if a>0:
    result=0
  else:
    result=1
  return result
a=np.linspace(-6,6,10)
V_test_function=np.vectorize(test_function)
V_test_function(a)
```

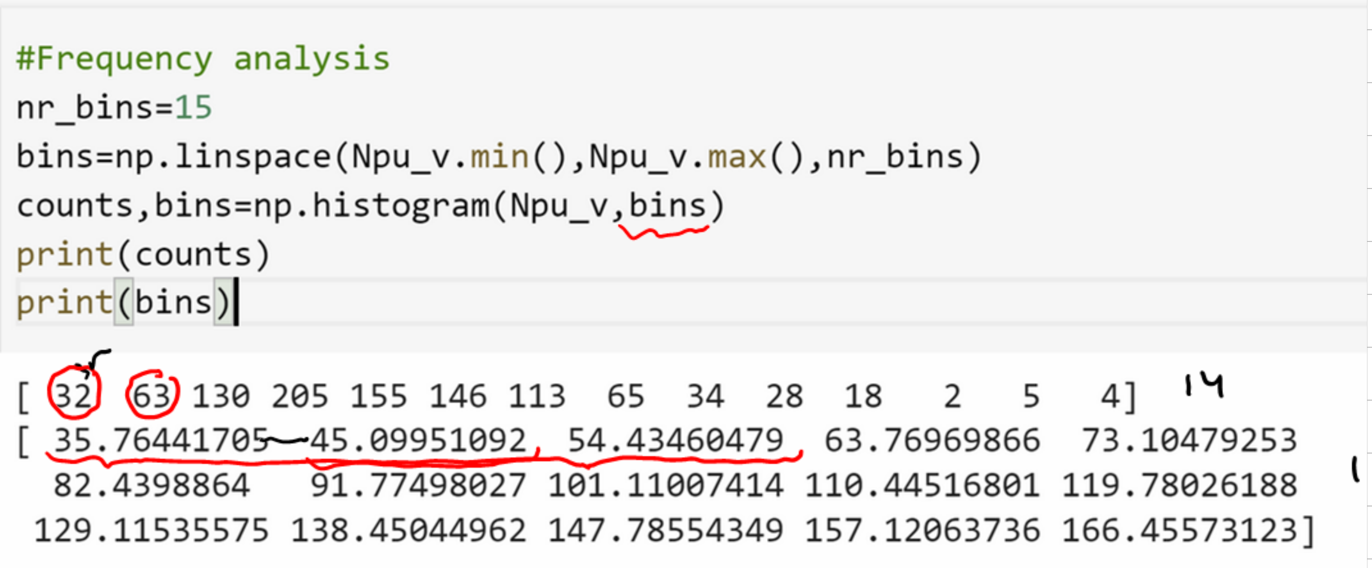
a_{min}

a_{max}

Nr bin

$$\Delta a = \frac{a_{max} - a_{min}}{(\text{Nr bins} - 1)}$$

$$a_i = a_{min} + \Delta a \cdot (i-1)$$



```
#Frequency analysis
nr_bins=15
bins=np.linspace(Npu_v.min(),Npu_v.max(),nr_bins)
counts,bins=np.histogram(Npu_v,bins)
print(counts)
print(bins)
```

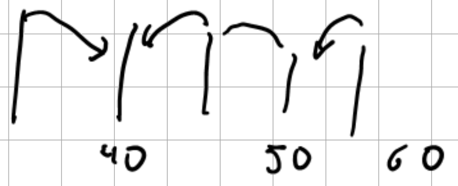
```
[ 32  63 130 205 155 146 113  65  34  28  18   2   5   4]
[ 35.76441705  45.09951092  54.43460479  63.76969866  73.10479253
  82.4398864   91.77498027 101.11007414 110.44516801 119.78026188
 129.11535575 138.45044962 147.78554349 157.12063736 166.45573123]
```

14

15

(a, b) = np.histogram(Npu_v, bins) = (result1, result2)

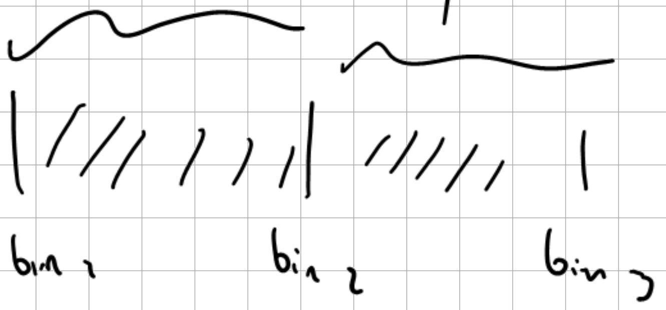
((counts), (bins))

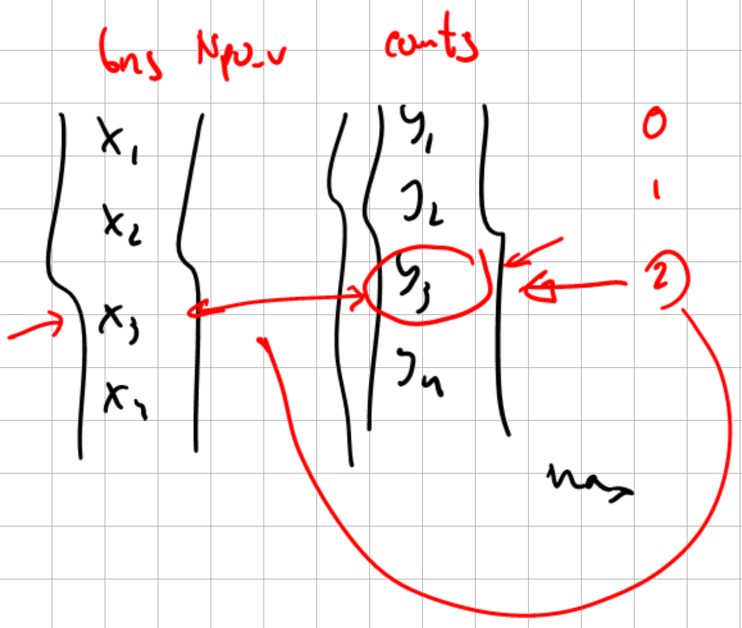


$$\begin{pmatrix}1\\2\\3\\4\end{pmatrix} \quad \begin{matrix}1.5\\2.5\\3.5\end{matrix}$$

$$\left(\begin{pmatrix}1\\2\\3\end{pmatrix} + \begin{pmatrix}2\\3\\4\end{pmatrix}\right)0.5 = \begin{matrix}1.5\\2.5\\3.5\end{matrix}$$

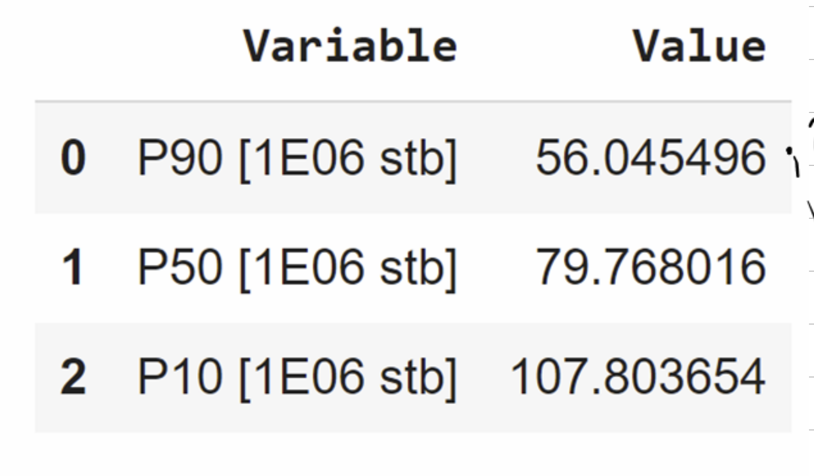
$$\text{pdf} \begin{pmatrix}a_1\\a_2\\a_3\\a_4\\a_5\end{pmatrix} \qquad \text{cdf} \begin{pmatrix}a_1\\a_1+a_2\\a_1+a_2+a_3\\ \vdots\end{pmatrix}$$





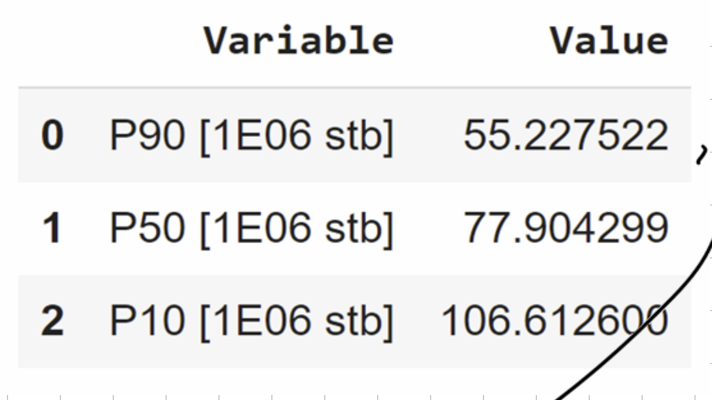
$X[2]$

500 iteration



	Variable	Value
0	P90 [1E06 stb]	56.045496
1	P50 [1E06 stb]	79.768016
2	P10 [1E06 stb]	107.803654

1000 iteration



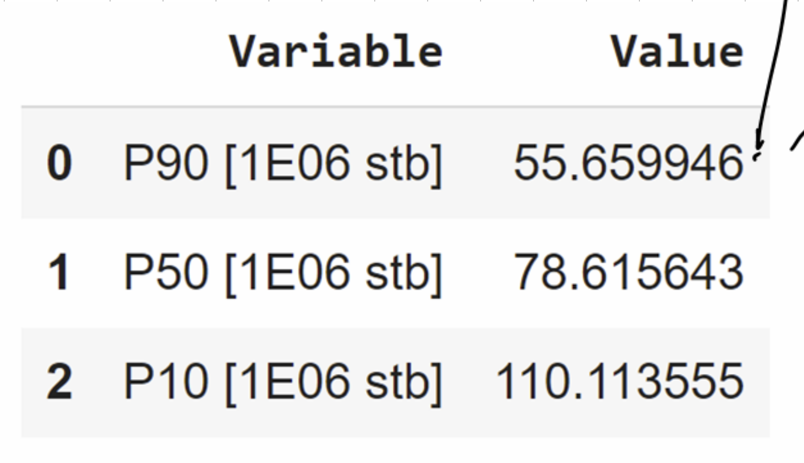
	Variable	Value
0	P90 [1E06 stb]	55.227522
1	P50 [1E06 stb]	77.904299
2	P10 [1E06 stb]	106.612600

10%

$$\underline{\left|\left(\frac{56.04-55.22}{55.22}\right)\right|}.100 \simeq \underline{2\,\%}$$

0.1%

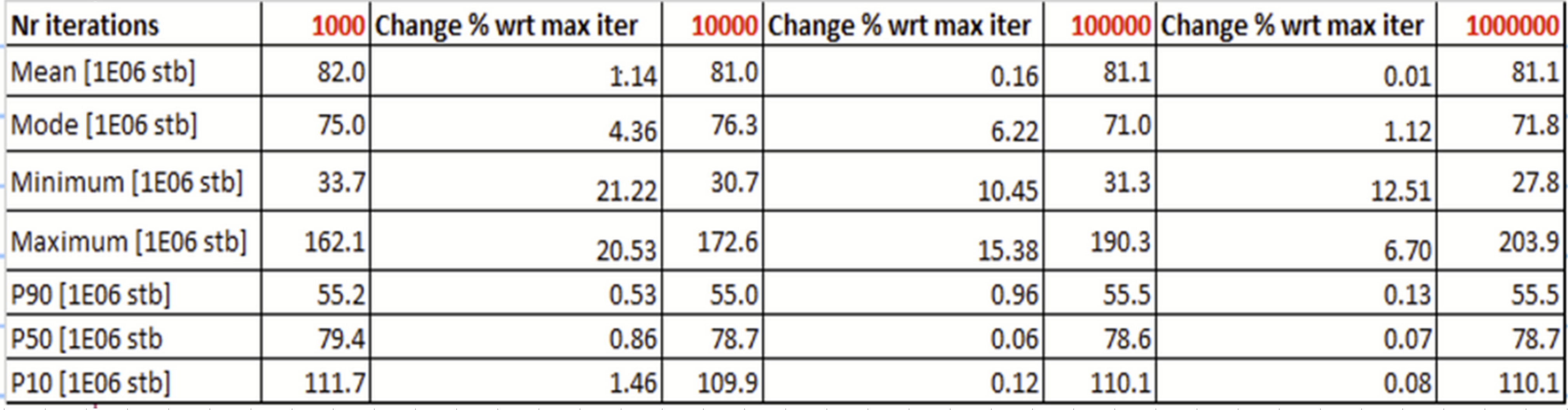
10000 iteration



	Variable	Value
0	P90 [1E06 stb]	55.659946
1	P50 [1E06 stb]	78.615643
2	P10 [1E06 stb]	110.113555

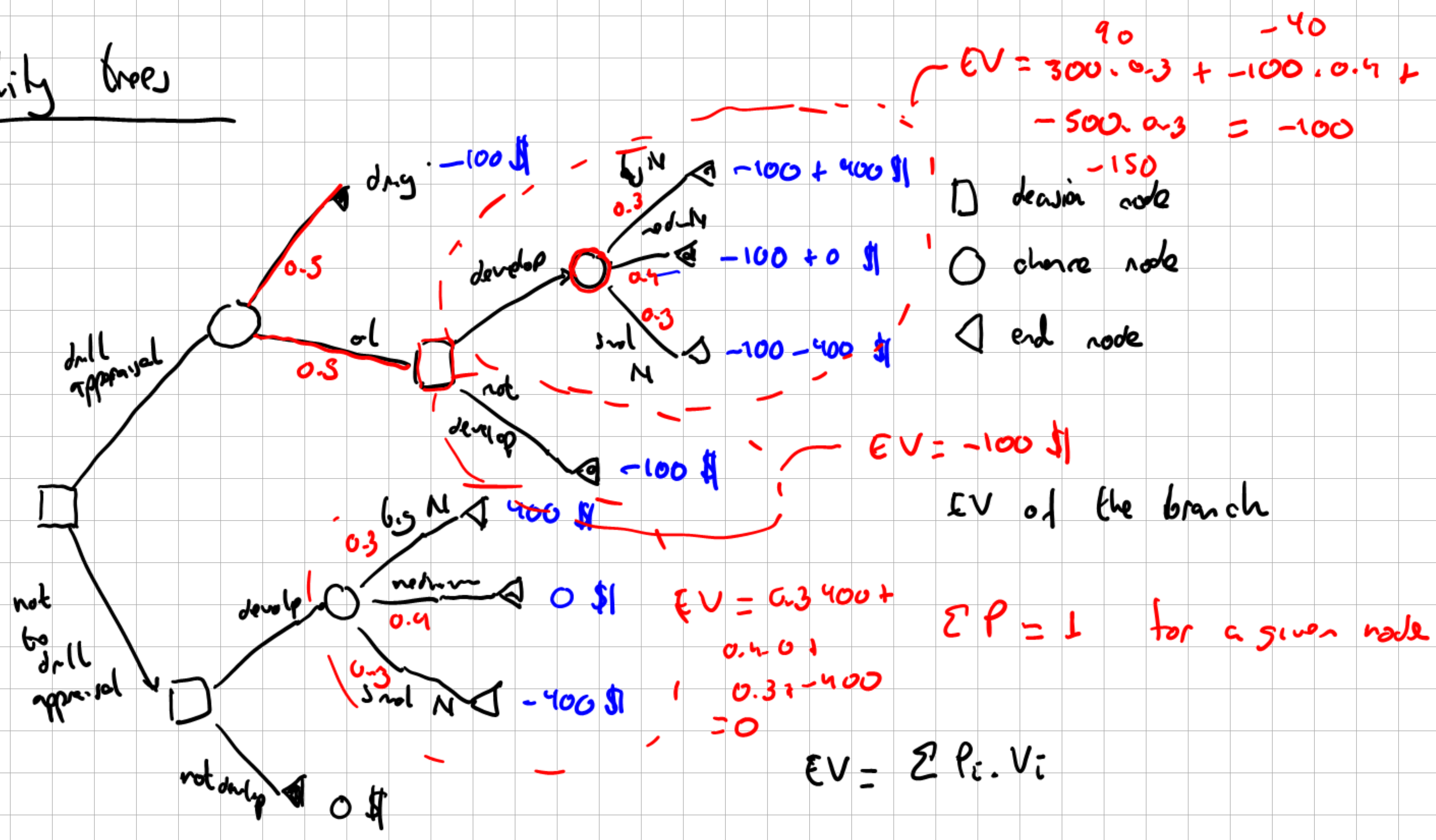
nr. Iterations	500.0	error [%]	1000.0	error [%]	10000.0	error [%]	1000000.0
Mean [1E06 stb]	81.7	0.71	81.2	0.09	81.6	0.56	81.1
Mode [1E06 stb]	74.2	7.91	77.9	13.39	76.1	10.71	68.7
Minimum [1E06 stb]	35.5	31.01	36.3	34.00	28.0	3.51	27.1
Maximum [1E06 stb]	155.8	19.54	165.8	14.37	177.5	8.32	193.6
P90 [1E06 stb]	55.4	0.27	56.0	0.85	55.6	0.11	55.5
P50 [1E06 stb	78.7	0.04	78.5	0.27	79.0	0.44	78.7
P10 [1E06 stb]	111.9	1.69	109.7	0.33	111.0	0.83	110.1

(2021)



Nr iterations	1000	Change % wrt max iter	10000	Change % wrt max iter	100000	Change % wrt max iter	1000000
Mean [1E06 stb]	82.0	1.14	81.0	0.16	81.1	0.01	81.1
Mode [1E06 stb]	75.0	4.36	76.3	6.22	71.0	1.12	71.8
Minimum [1E06 stb]	33.7	21.22	30.7	10.45	31.3	12.51	27.8
Maximum [1E06 stb]	162.1	20.53	172.6	15.38	190.3	6.70	203.9
P90 [1E06 stb]	55.2	0.53	55.0	0.96	55.5	0.13	55.5
P50 [1E06 stb	79.4	0.86	78.7	0.06	78.6	0.07	78.7
P10 [1E06 stb]	111.7	1.46	109.9	0.12	110.1	0.08	110.1

Probability trees

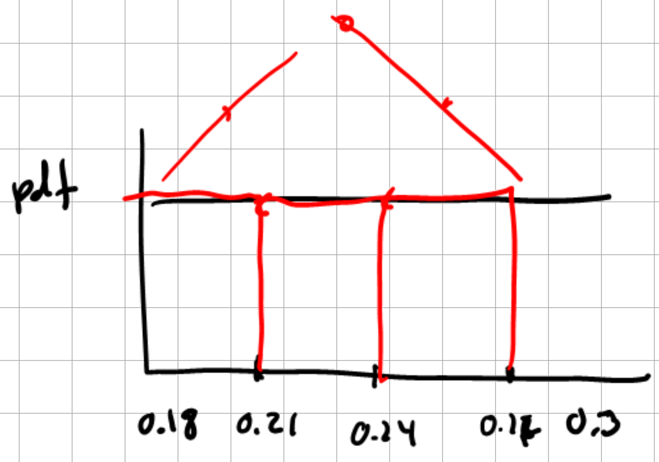


$\Sigma P = 1$ for a given node

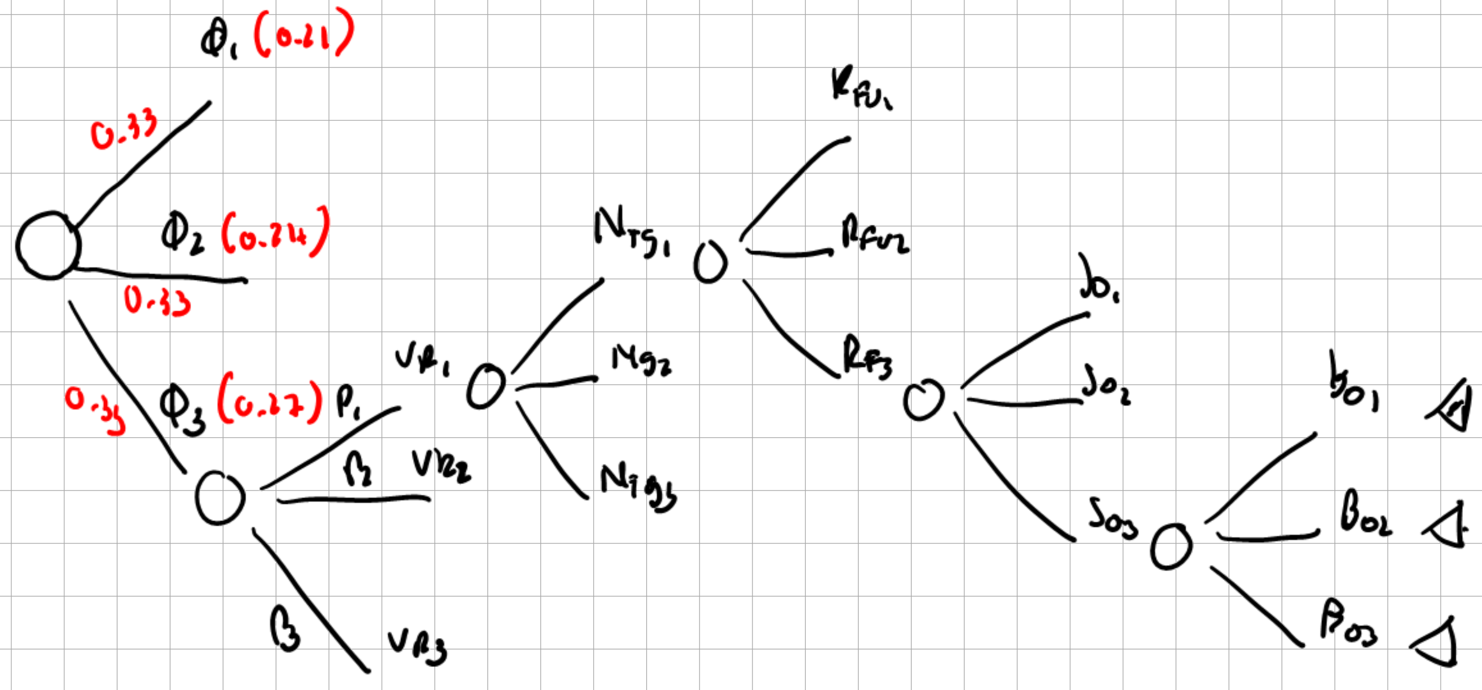
$EV = \Sigma P_i . V_i$

Estimation of Npv using probability trees?

$\phi, V_R, N_{TG}, R_{fu}, S_o, B_o$



ϕ	ϕ	p
ϕ_1	0.21	0.33
ϕ_2	0.24	0.33
ϕ_3	0.27	0.33



$$N_{pu} = \frac{V_R \cdot \phi \cdot S_o \, N_{TG} \, R_{fu}}{B_o}$$

$3 \times 3 \times 3 \times 3 \times 3 \times 3 = 729$ N_{pu}

small → large

cdf →

Case nr.	N_{pu}	p	cdf
1	N_{pu_1}	P_1	P_1
2	N_{pu_2}	P_2	$P_1 + P_2$
3	N_{pu_3}	P_3	$P_1 + P_2, P_3$
4	N_{pu_4}	P_4	⋮
⋮	⋮	⋮	⋮
729			

$= p^{\phi} \cdot p^{V_R} \cdot p^{B_o} \cdot p^{N_{TG}} \cdot p^{R_{fu}} \cdot p^{S_o}$

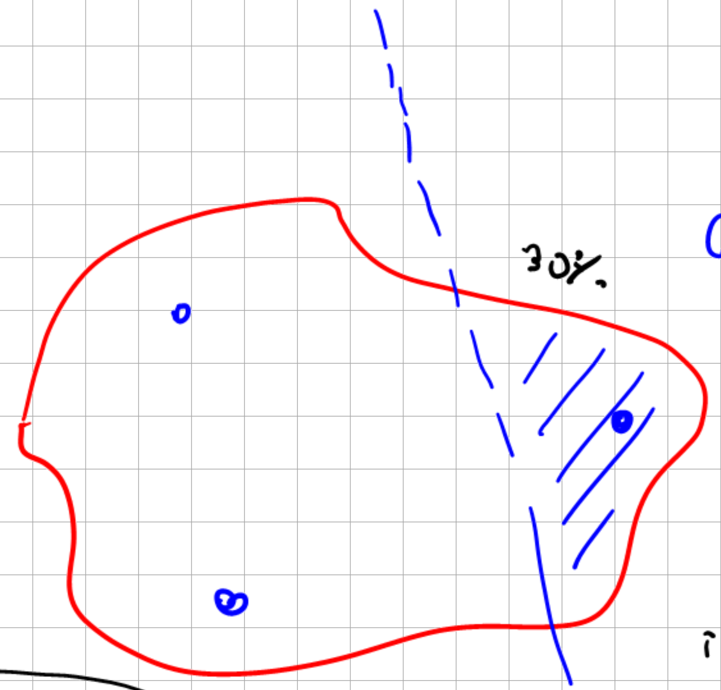
$$NPV = \underbrace{N_{pu}}_{\downarrow} \cdot \underset{?}{\underline{P_o}} - \underset{?}{\underline{Cost}}$$

(CAPEX + OPEX)

P_o: 60 USD/bbl

Cost: 1 E9 USD

Drill or not appraisal well



Cost well

100 E06 USD

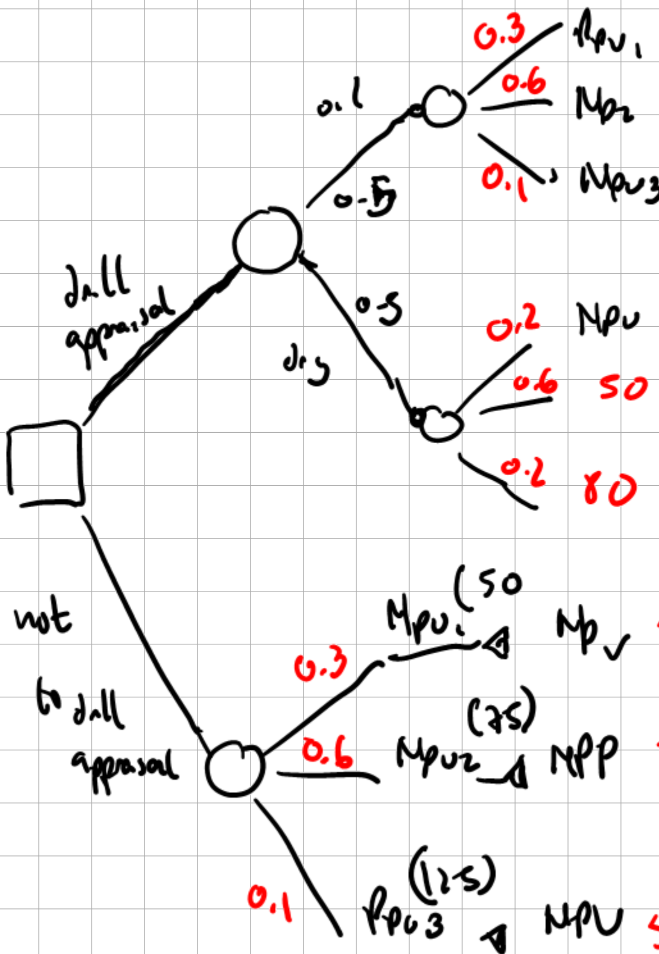
if oil

max V_R

6250 E06 std

if dry

5000	6250
0.7	0.7
3500	4375



Npu1 ◁ 8E09 USD - 100 E06 = 1.9 E09

Npu2 ◁ 3.5E09 USD - 100 E06 = 3.4 E09

Npu3 ◁ 6.5 E09 USD - 100 E06 = 6.4 E09

NPV = Npu . Po - Cost - Appraisal well

Npu 30 ◁ 30 1E06 . 60 - 1E09 - 100E6 = 0.7 E09 USD

60 1E09 USD

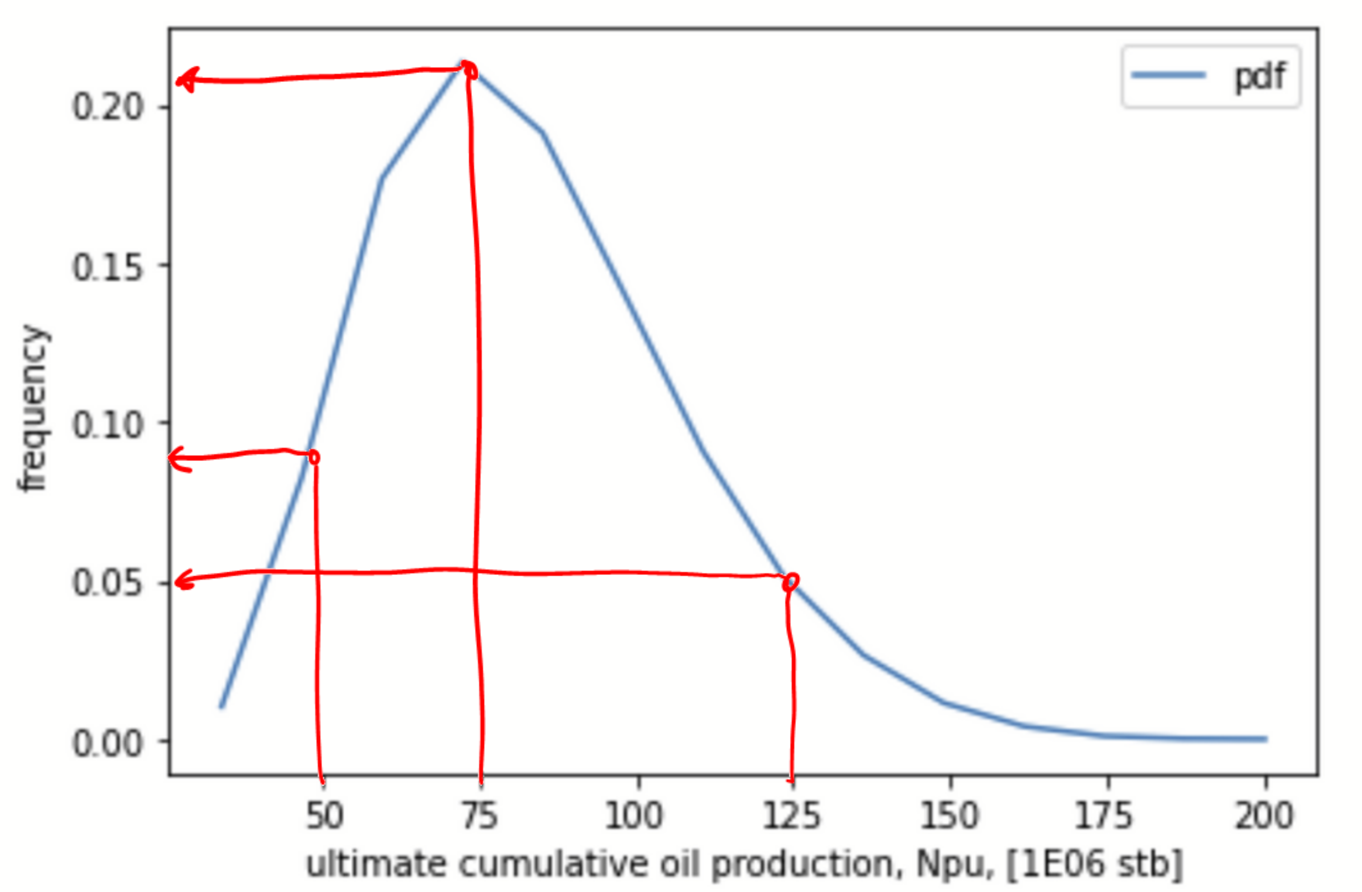
50 ◁ 50 1E06 . 60 - 1E09 - 100E6 = 1.9 E09 USD

80 ◁ 80E06 . 60 - 1E09 - 100 E6 = 3.7 E09 USD

Npu1 (50 ◁ Npv = 50 1E06 stb . 60 - 1E09 USD = 2 E09 USD

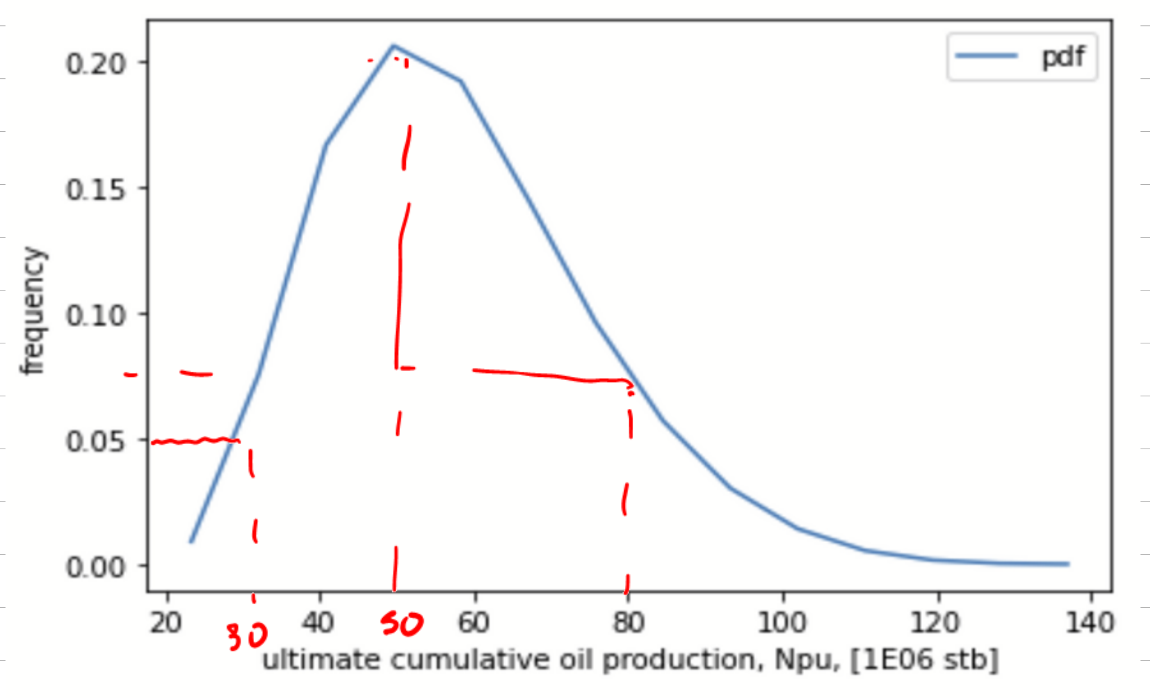
Npu2 (75) ◁ NPP = 75 1E06 . 60 - 1E09 USD = 3.5 E09 USD

Npu3 (125) ◁ NPV = 125 1E06 . 60 - 1E09 USD = 6.5 E09 USD



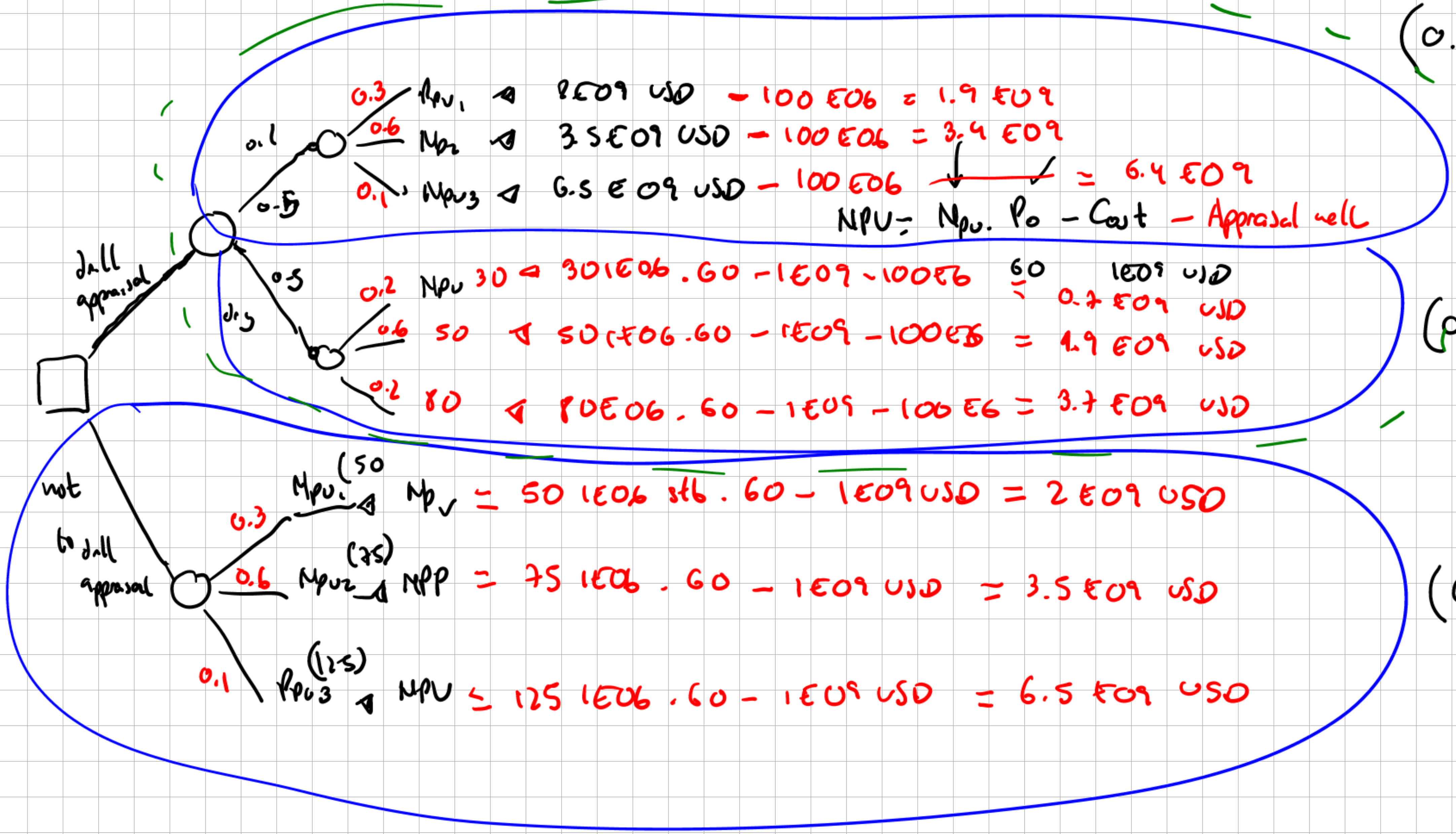
Npu	P	P*
50	0.09	0.3
75	0.21	0.6
125	0.05	0.1

Dry appraisal well → Ve is 30% smaller than initially thought



Nu	P	P*
30	0.05	0.2
50	0.20	0.6
80	0.075	0.2

0.5.3.25 + 0.5.2.02 = 2.635



(0.3.1.9 + 0.6.3.4 + 0.1 6.4)
=
3.25

(0.2.0.7 + 0.6.1.9 + 3.7.0.2)
=
2.02

(0.3.2 + 0.6.3.5 + 0.1.6.5)
=
3.35

15.03.2022 Presentation by Inflow control

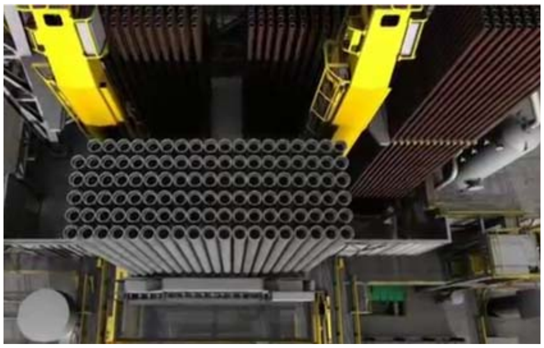
Notes for Youtube video offshore structures 1

Offshore structures for oil and gas production

Prof. Milan Stanko (NTNU)

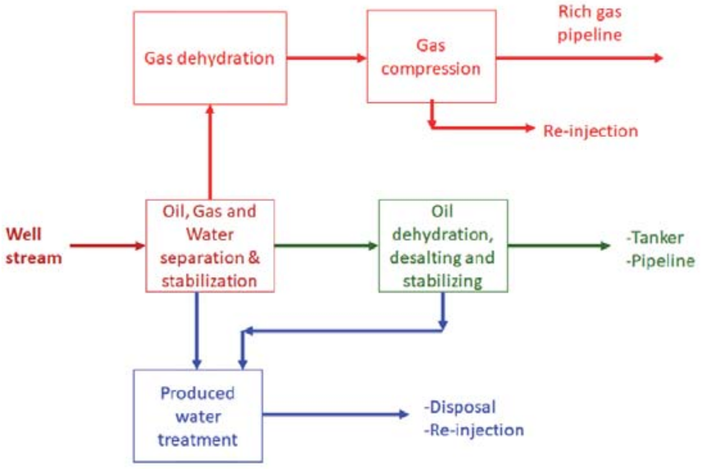
Components

- Facilities for drilling and full intervention. This includes drilling tower, BOP, drilling floor, mud package, cementing pumps, storage deck for drill pipes and tubulars, drilling risers.



Components

- Facilities for light well intervention.
- Processing facilities: separator trains for primary oil, gas and water separation, gas processing train, water processing train.
- Gas injection system
- Gas compression units for pipeline transport
- Water injection system



Components

- Facilities for light well intervention.
- Processing facilities: separator trains for primary oil, gas and water separation, gas processing train, water processing train.
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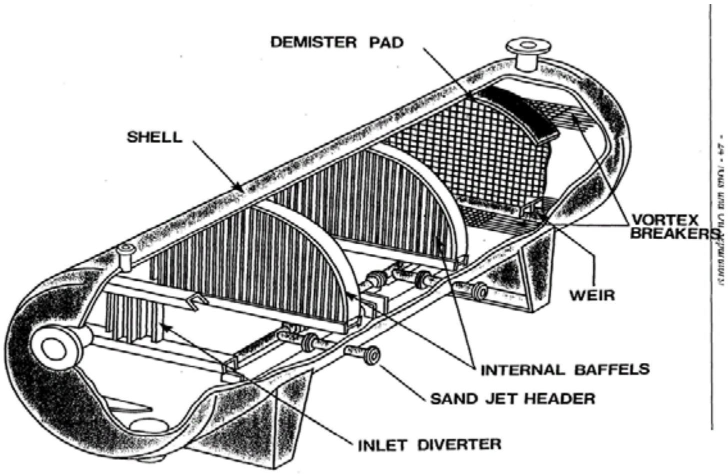

Components

- Living quarters
- Helideck.
- Power generation.
- Flare system.
- Utilities (hydraulic power fluid, compressed air, drinking water unit, air condition system, ventilation and heating system)

Components

- Bay for wellheads and X-mas trees
- Production manifolds
- Oil storage
- Facilities for oil offloading
- Control system
- Monitoring system
- System for storage, injection and recovery of production chemicals (wax, scale, hydrate or corrosion inhibitors)
- Repair workshop

Components

- Bay for wellheads and X-mas trees
- Production manifolds
- Oil storage
- Facilities for oil offloading
- Control system
- Monitoring system
- System for storage, injection and recovery of production chemicals (wax, scale, hydrate or corrosion inhibitors)
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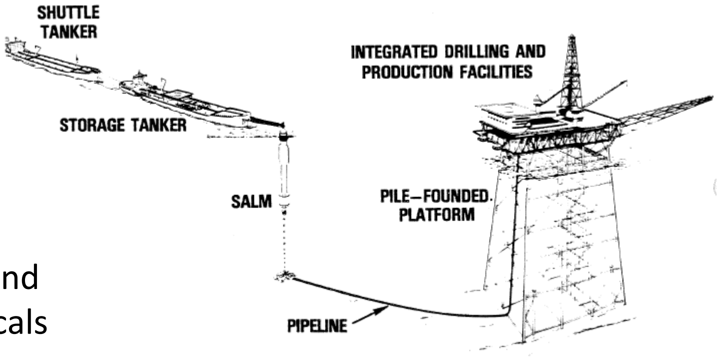


Components

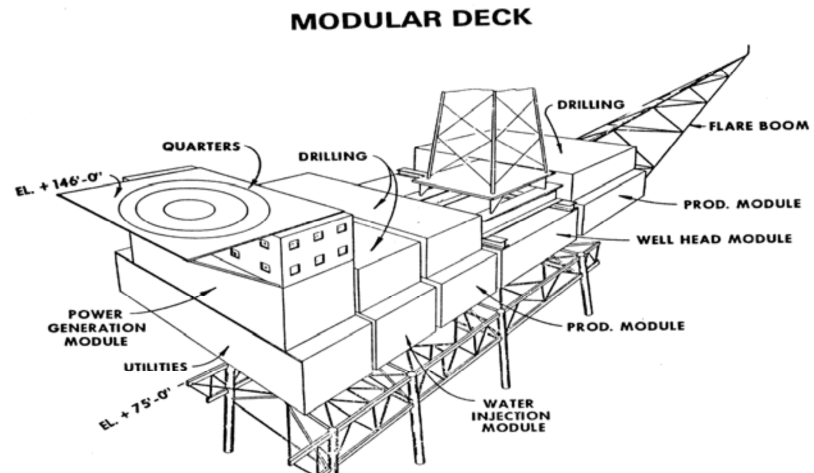


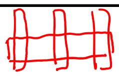
FIGURE B-2

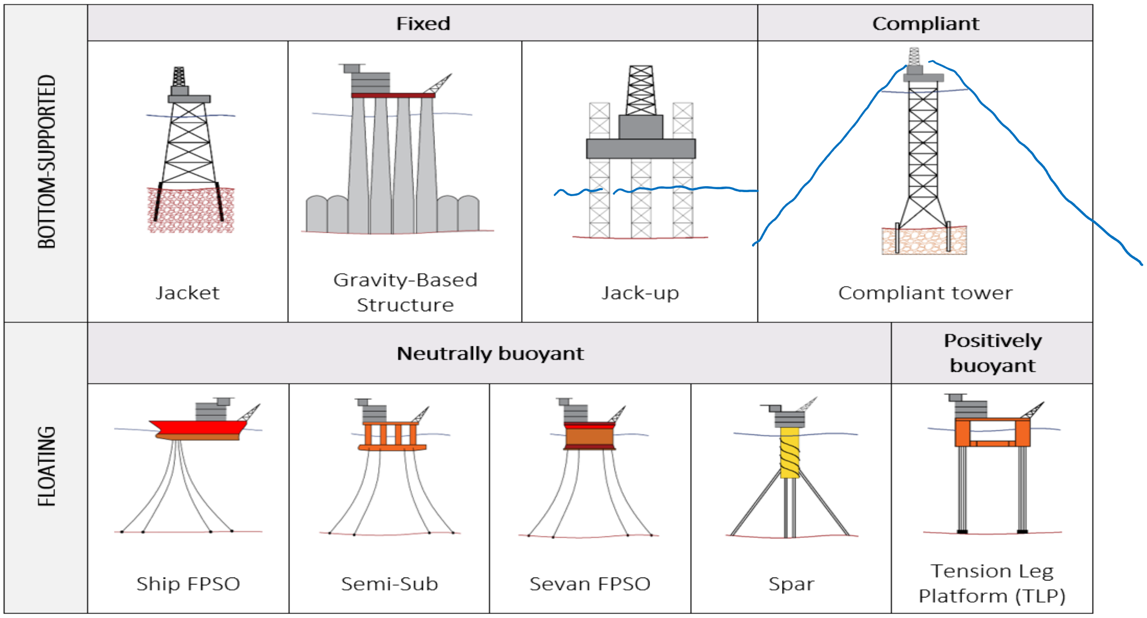
Components – can be spread

https://www.akerbp.com/produksjon/valhall/

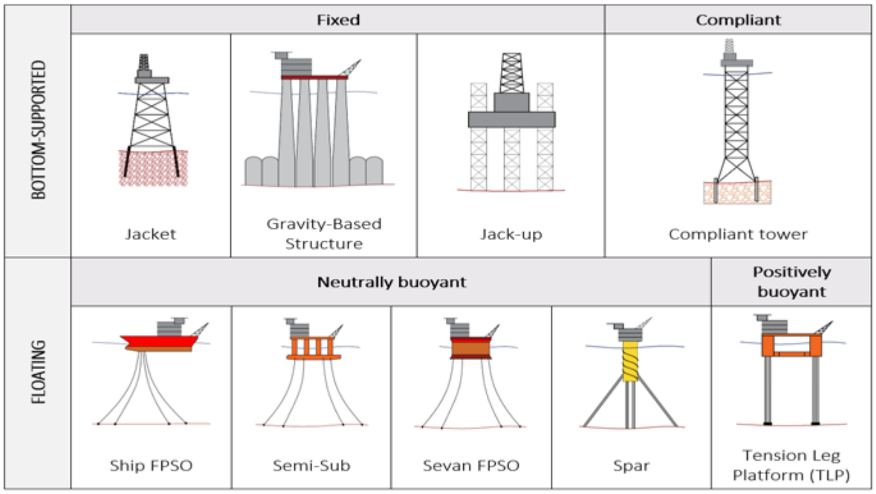
Types

suction anchor



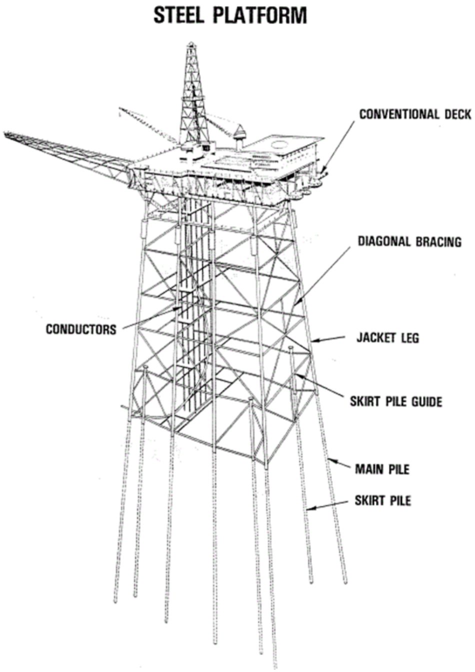


Types

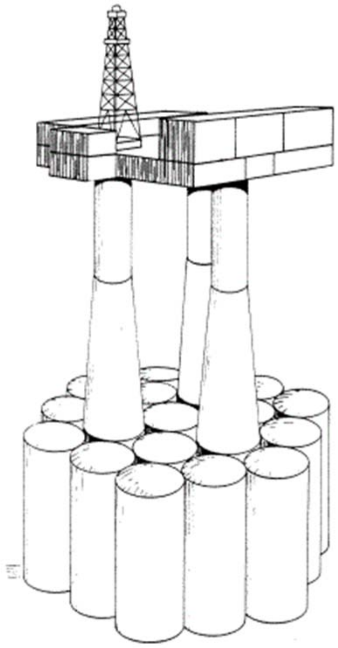


- Have significant movement
- Are usually moored
- Buoyancy is controlled actively with ballast

Jacket

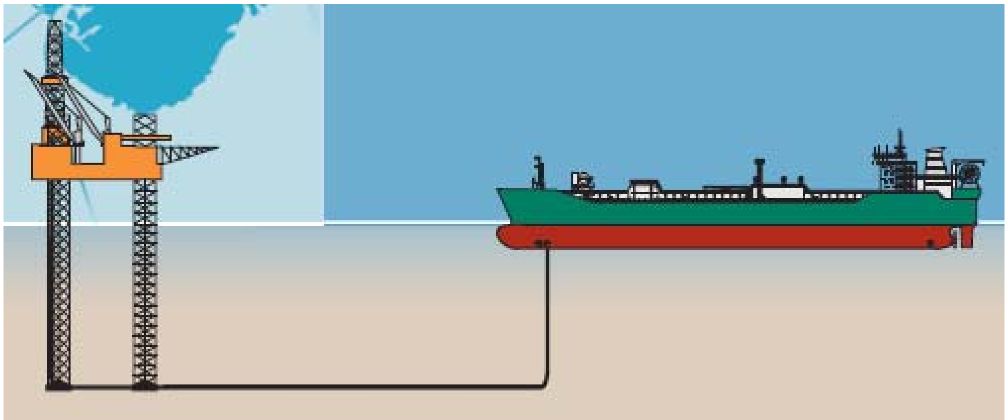


GBS



13

JACKUP

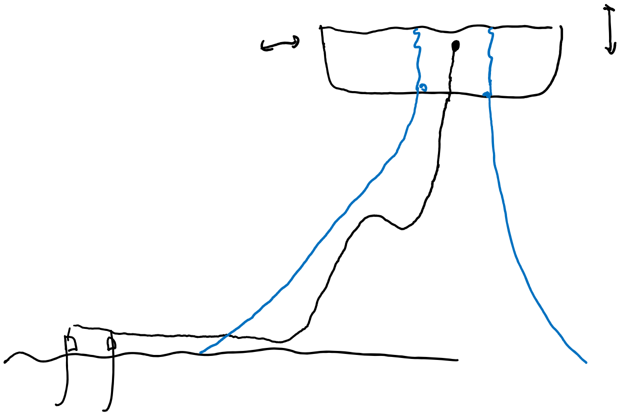


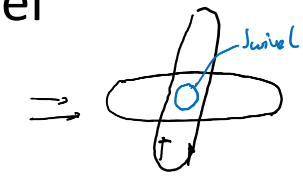
Taken from Volve PDO

14

FPSO

FPSO - Comment about swivel





the Swivel allows to adjust the orientation of the FPSO to wind, waves and current

FPSO - Swivel

https://www.youtube.com/watch?v=70XwYmmZFWs

FPSO - Swivel

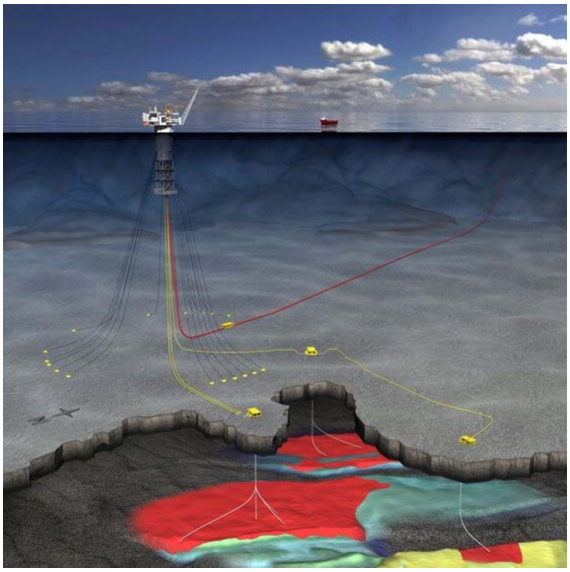
https://www.youtube.com/watch?v=cCiUggjUhY0

https://www.youtube.com/watch?v=Sfjay0Rt3hU

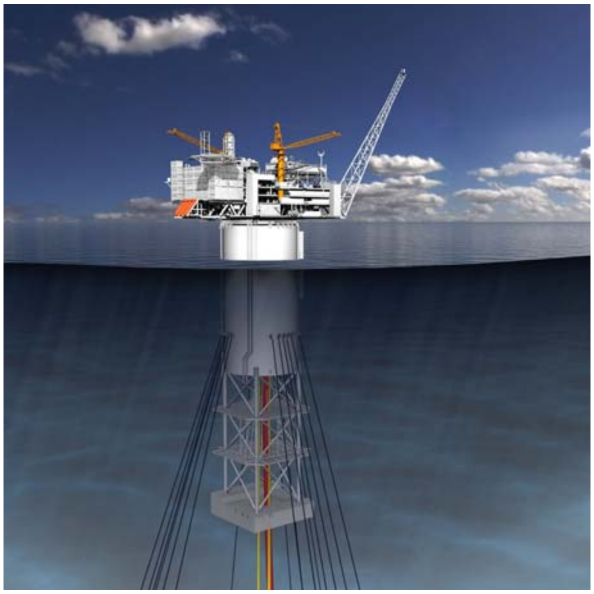
FPSO - Swivel

https://www.youtube.com/watch?v=HbJh1ar0u1s

SPAR

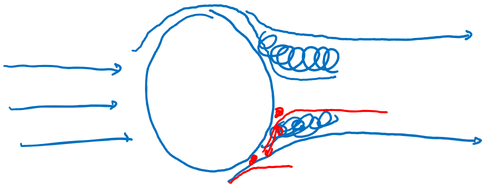


https://www.tu.no/artikler/industri-kvaerner-sikrer-enda-et-aasta-hansteen-oppdrag/225940



https://www.tu.no/artikler/industri-kvaerner-sikrer-enda-et-aasta-hansteen-oppdrag/225940

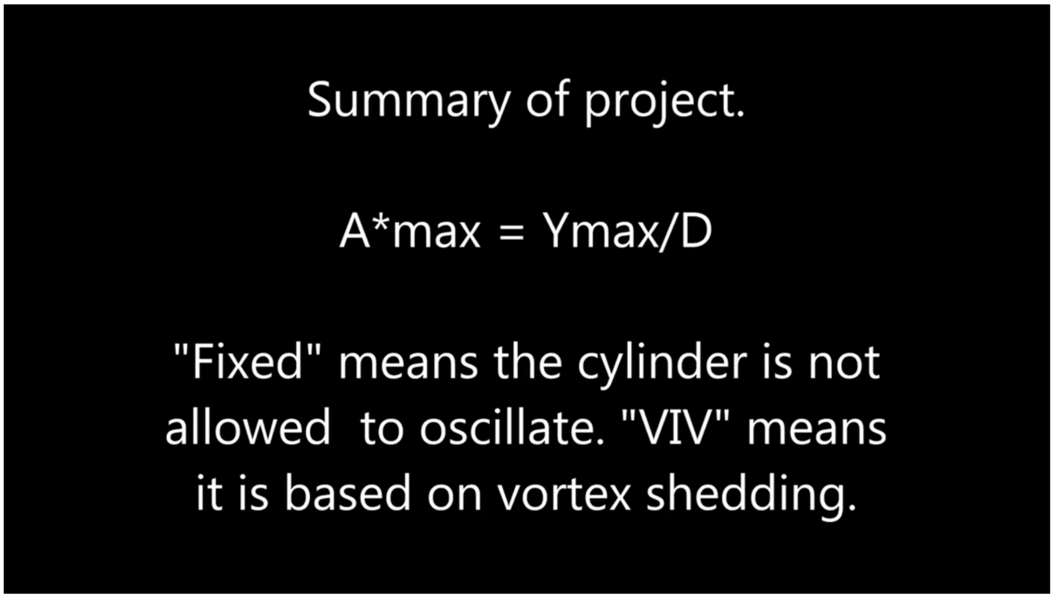
Vortex shedding



SPAR – Vortex induced vibrations

https://www.youtube.com/watch?v=_Hbbkd2d3H8&feature=youtu.be

SPAR – Vortex induced vibrations



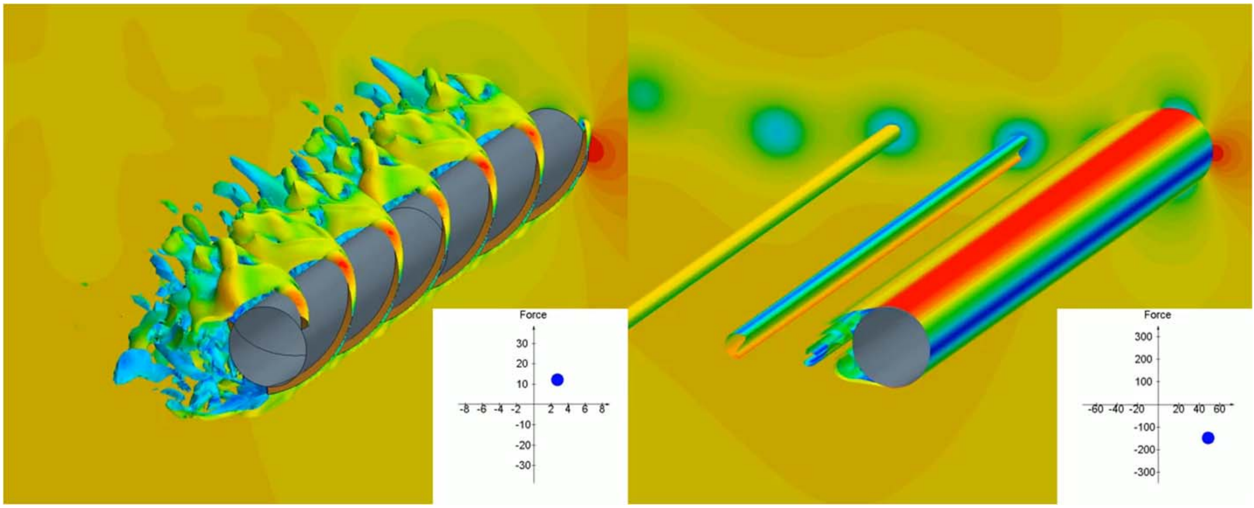
Summary of project.

A*max = Ymax/D

"Fixed" means the cylinder is not allowed to oscillate. "VIV" means it is based on vortex shedding.

https://www.youtube.com/watch?v=24tBX_UD3fM

SPAR – Effect of helical strakes

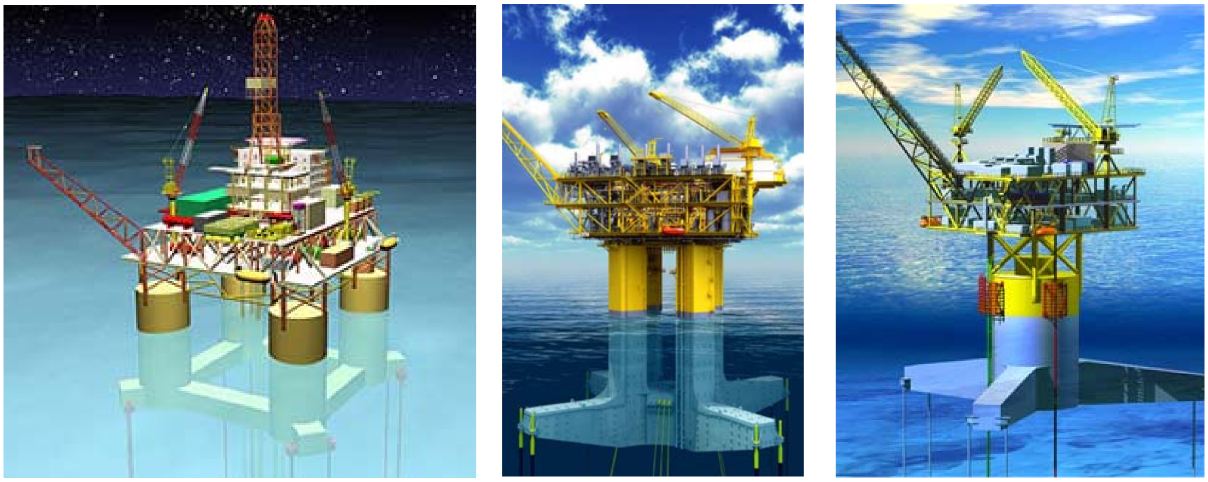


https://www.youtube.com/watch?v=W-zXwPT2r14

SEVAN FPSO

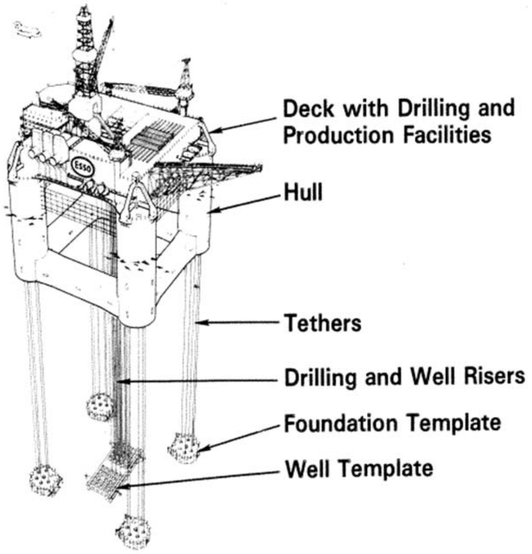
https://www.upstreamonline.com/epaper/sevan-fpso-selected-for-bream/1-1-1160389

Tension leg platform

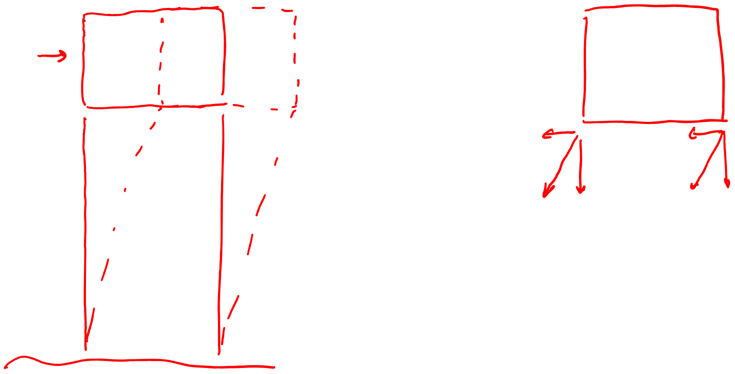


https://www.rigzone.com/training/insight.asp?insight_id=305&c_id=

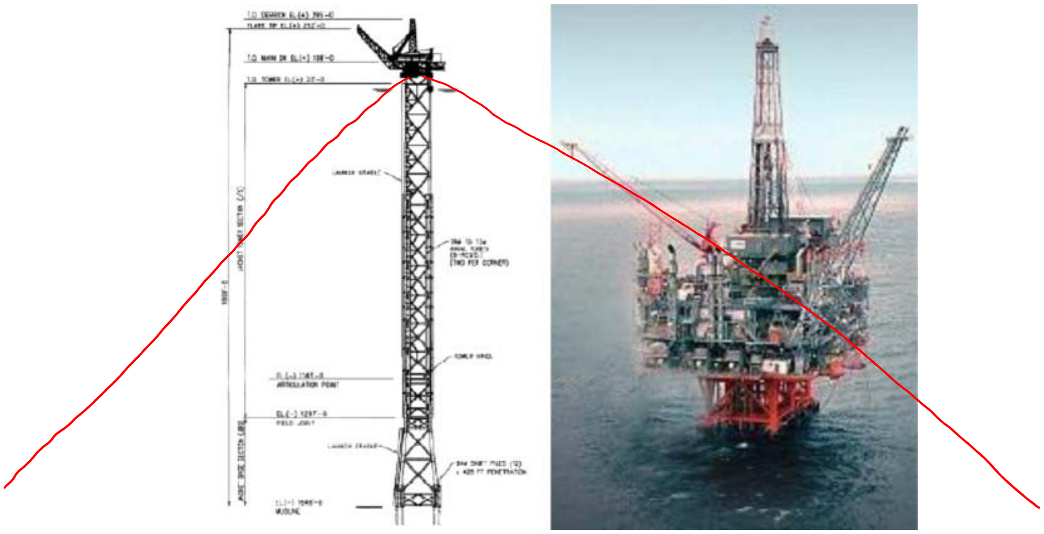
Tension leg platform



Comment about Tension leg platform



Compliant tower



https://www.sciencedirect.com/science/article/pii/S0951833914000148

Semi-Sub

https://www.oedigital.com/news/453987-jack-st-malo-flows-for-chevron

https://www.bairdmaritime.com/work-boat-world/offshore-world/offshore-extraction-and-processing/offshore-drilling/awilco-orders-second-semi-submersible-drilling-rig-from-keppel-fels/

Some selection criteria for offshore structures

- Water depth
- Type of X-mas tree
  - Well intervention needs
    - Tubing replacement
    - Completion modifications
    - Artificial lift (ESP)
  - Infill drilling needs
  - Reservoir spread and structure
- Need for oil/condensate storage
- Marine loads Oceanographic environment
  - Wind, waves, current

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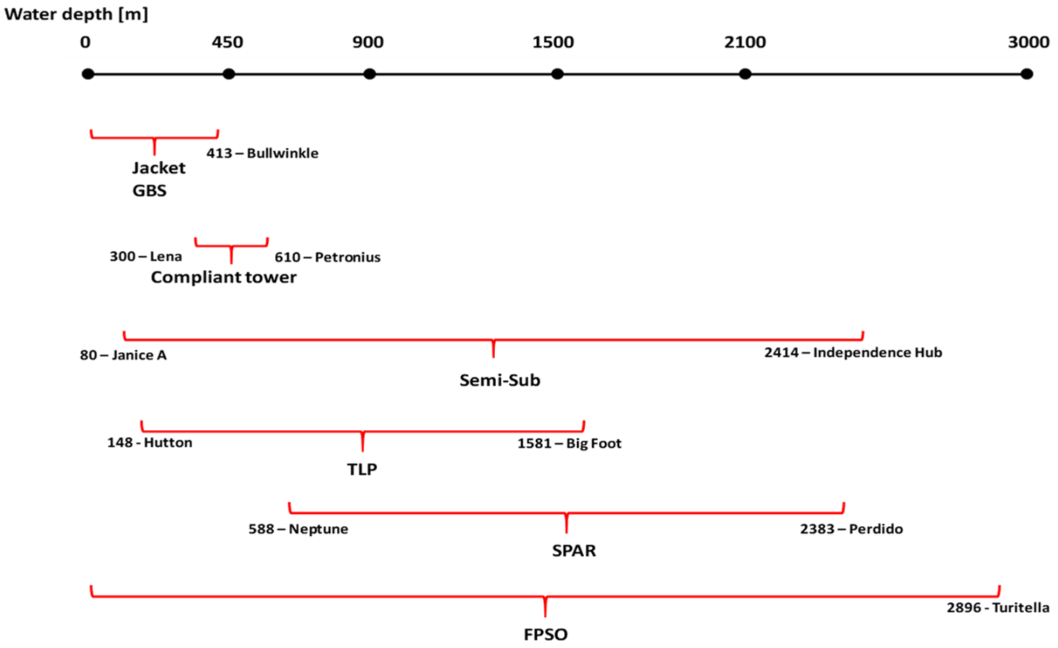
Water depth



Water depth [m]

0 450 900 1500 2100 3000

413 – Bullwinkle

Jacket
GBS

300 – Lena
610 – Petronius
Compliant tower

80 – Janice A
2414 – Independence Hub
Semi-Sub

148 - Hutton
1581 – Big Foot
TLP

588 – Neptune
2383 – Perdido
SPAR

2896 - Turitella
FPSO

Some selection criteria for offshore structures

- Water depth
- **Type of X-mas tree**
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- Need for oil/condensate storage
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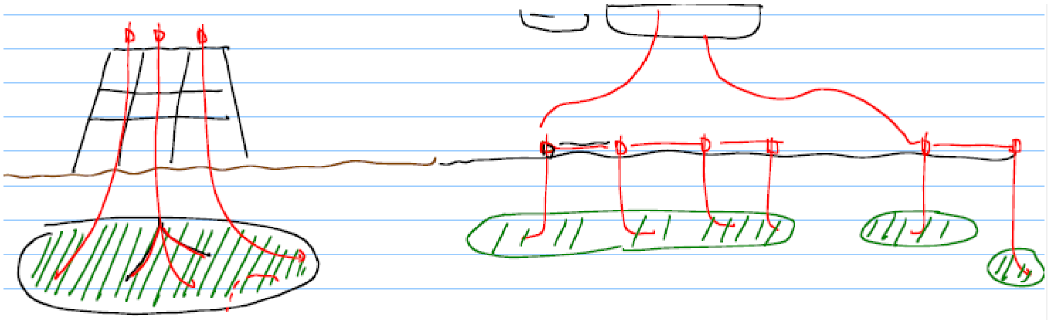
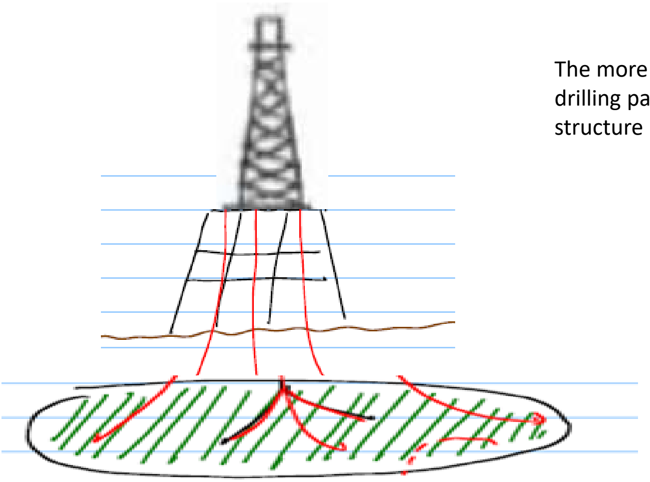
Reservoir spread and structure



- Long deviated wells ($$$)
- Wells are drilled from one location, no need to spend mobilization time ($$)
- Production startup must be delayed until all wells are drilled

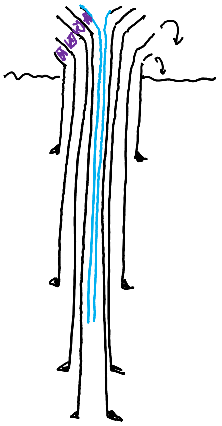
- Shorter, vertical wells ($)
- The drilling rig must be mobilized often which costs money ($$$)
- Production can start in ramp up mode (if topside is in place)

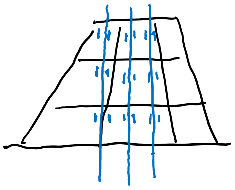
Reservoir spread and structure



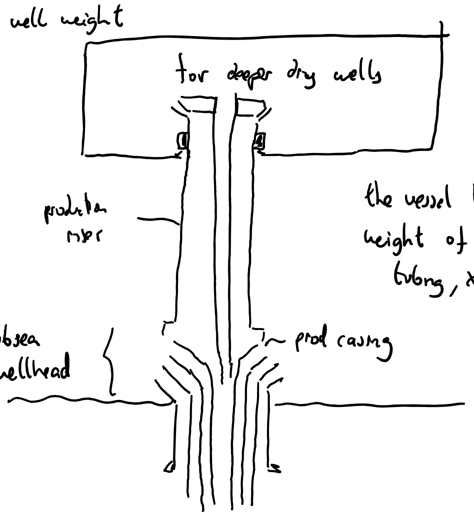
The more spread - requires a bigger and more costly drilling package – more weight on the structure, bigger structure ($$$)

Transfer of well weight to soil and to offshore structure



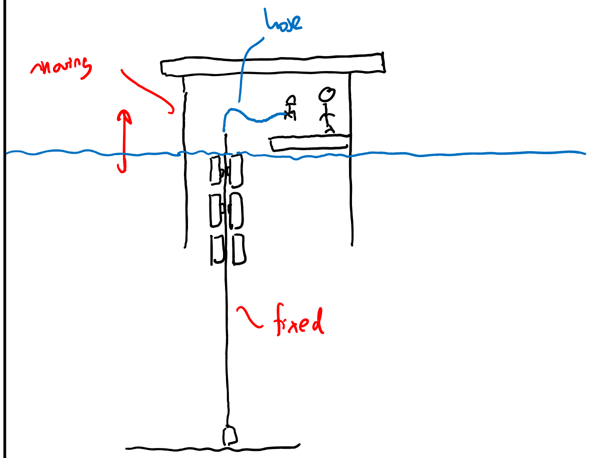


for "shallow" water depth
dry well are
drilled just like onshore well,
the structure doesn't take
the well weight

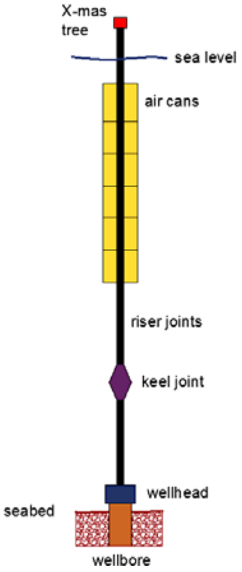


the vessel hold the
weight of riser and
tubing, x-mas tree

Transfer of well weight to soil and to offshore structure



Support system for dry X-mas trees – deep water



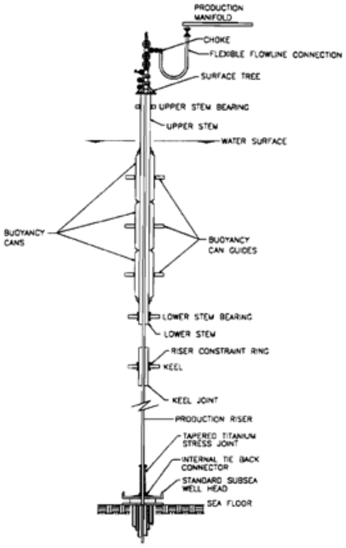
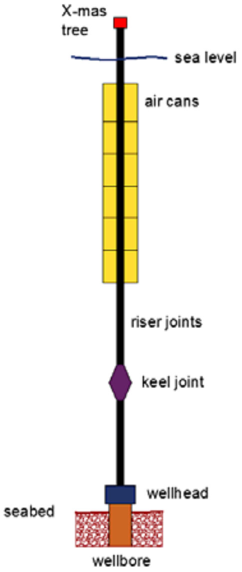


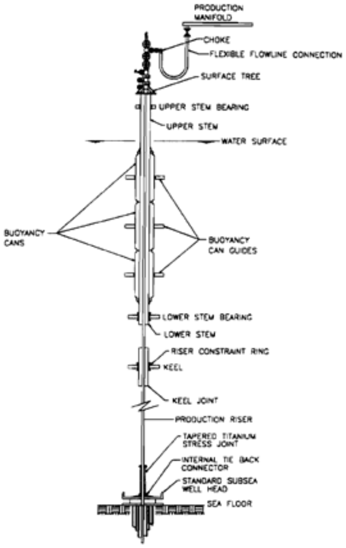
Figure 6 - Well System

OTC 8382

Neptune Project: Spar History and Design Considerations
R.S. Glanville, J.E. Halkyard, R.L. Davies, A. Steen, F. Frimm, Deep Oil Technology, Inc.

Support system for dry X-mas trees – deep water





Real State on offshore structure is critical, not more slots than what is needed!

Figure 6 - Well System

OTC 8382

Neptune Project: Spar History and Design Considerations
R.S. Glanville, J.E. Halkyard, R.L. Davies, A. Steen, F. Frimm, Deep Oil Technology, Inc.

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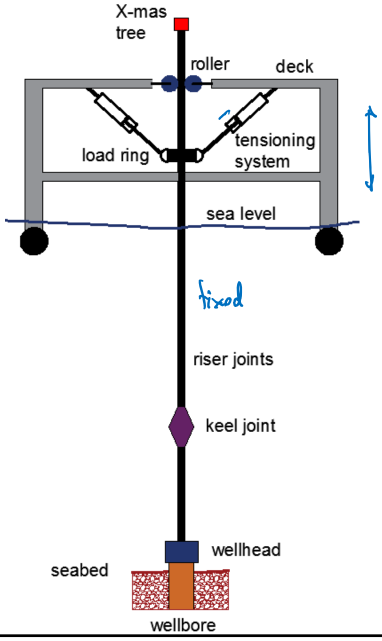

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Only floating structures SPAR, TLPs and Semi-subs have "small" movement ranges suitable for dry X-mas trees

Possibility for jackets without drilling package

https://www.youtube.com/watch?v=-vJmAvqn6dU

43

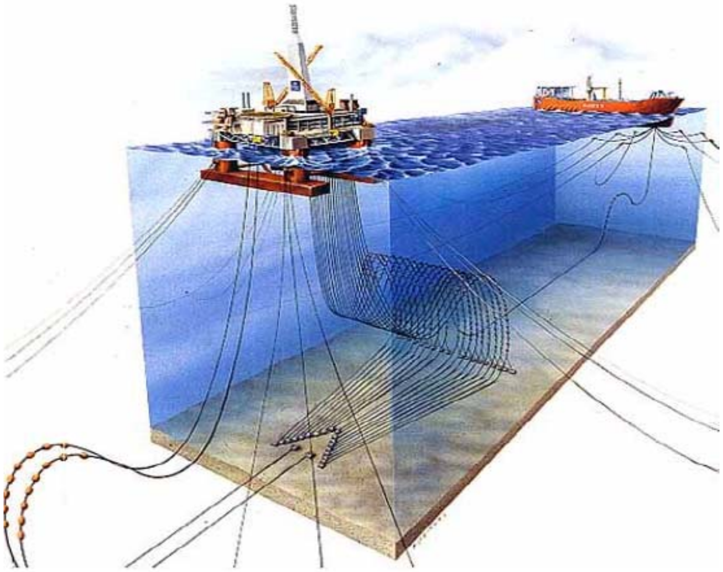
Possibility for jackets without drilling package

44

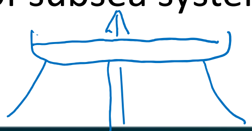
Possibility for jackets without drilling package

https://www.offshoreenergytoday.com/offshore-safety-watchdog-to-investigate-maersk-invincible-incident/

Njord: subsea wells with well intervention possibility



Layout of subsea systems – template wells



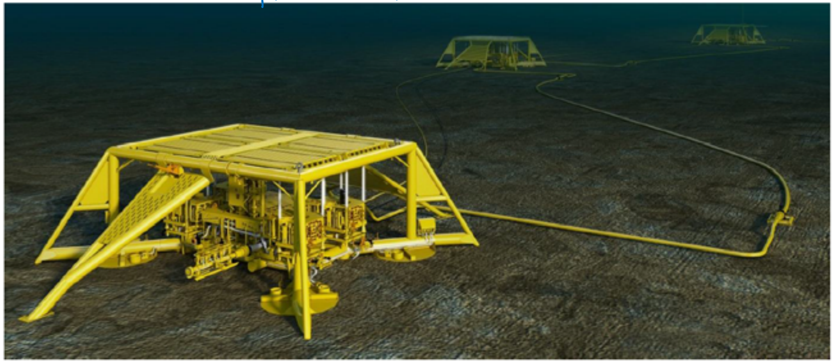
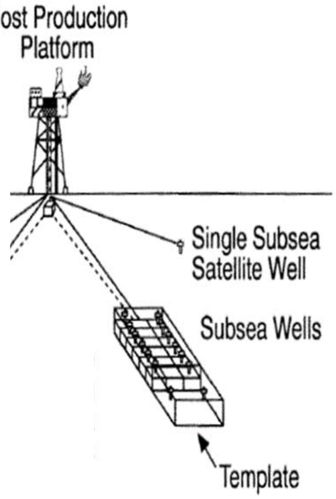
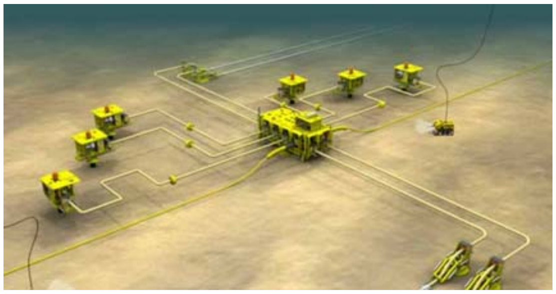


Figure 3.3 Typical NCS tie-back solution (Image: Statoil ASA)

Layout of subsea systems – template wells



Satellite wells



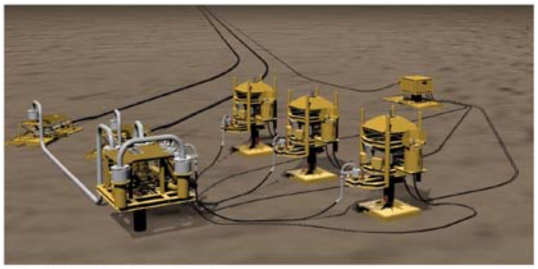
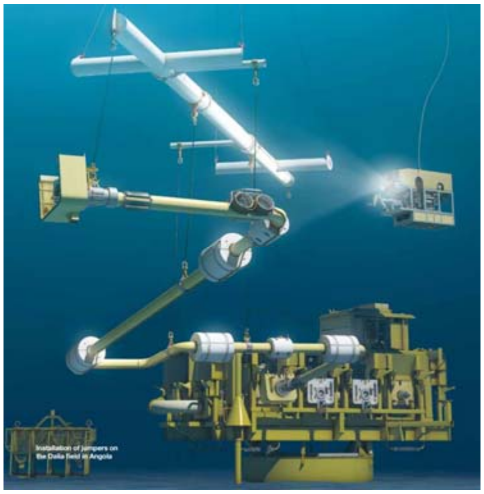
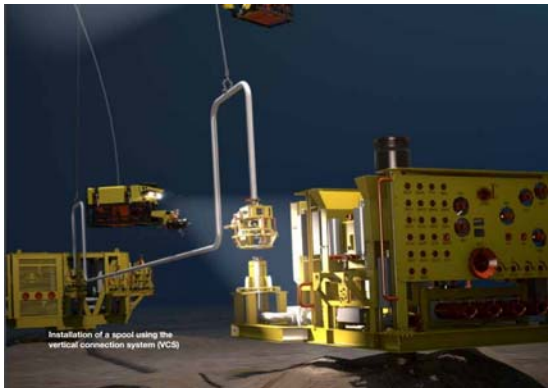


Figure 3.4 Typical GOM subsea tie-back

Jumpers for satellite wells (if close)



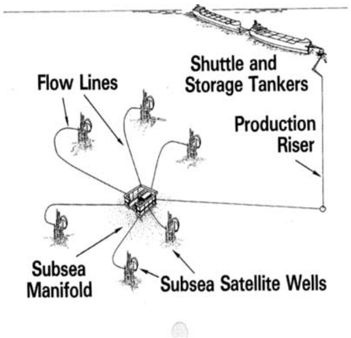
Installation of jumpers on the Dalia field in Angola



Installation of a spool using the vertical connection system (VCS)

Template wells vs satellite wells – similar dilemma to dry versus wet X-mas tree

Figure 3.3 Typical NCS tie-back solution (Image: Statoil ASA)

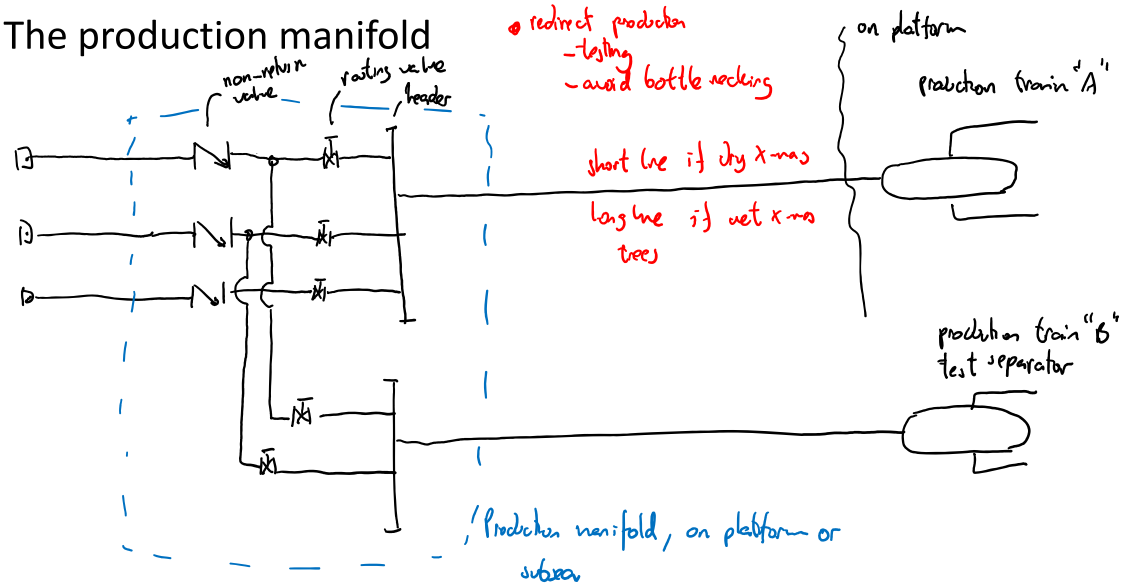


- Long deviated wells
- Wells are drilled from one location, no need to spend rig mobilization time
- Less subsea equipment

- Shorter, vertical wells
- The drilling rig must be mobilized often which costs money
- More flowlines, pipelines. Manifolds are required

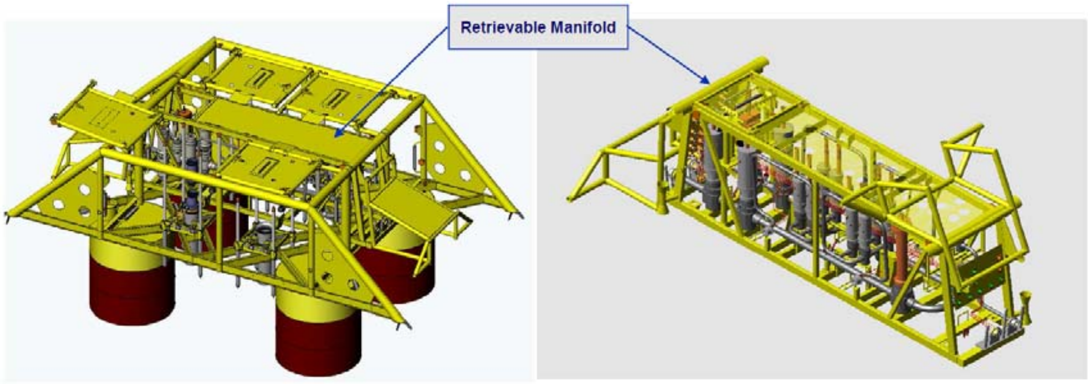
The production manifold

- Commingle production
- redirect production
  - testing
  - avoid bottle necking



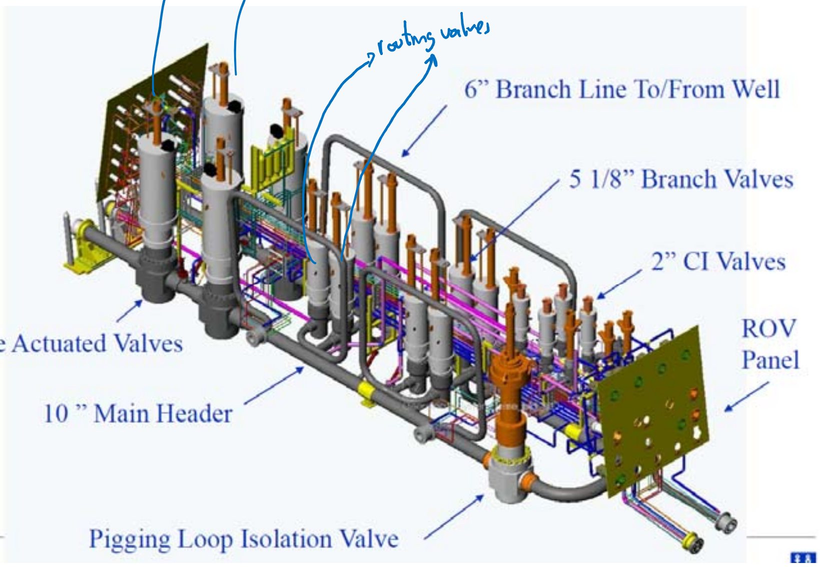
The production manifold

4 well template – the production manifold



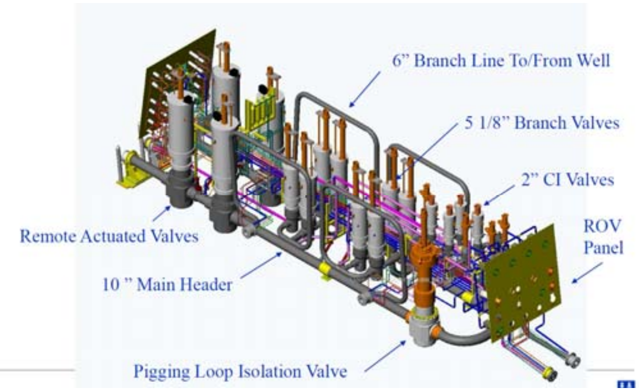
The manifold

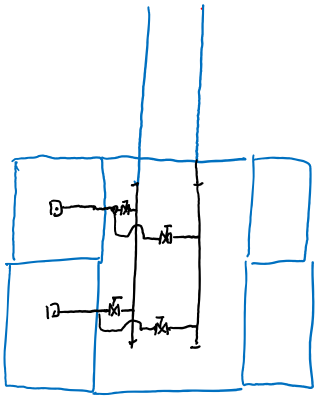
integrity
HIPPS (high pressure protection system)



55

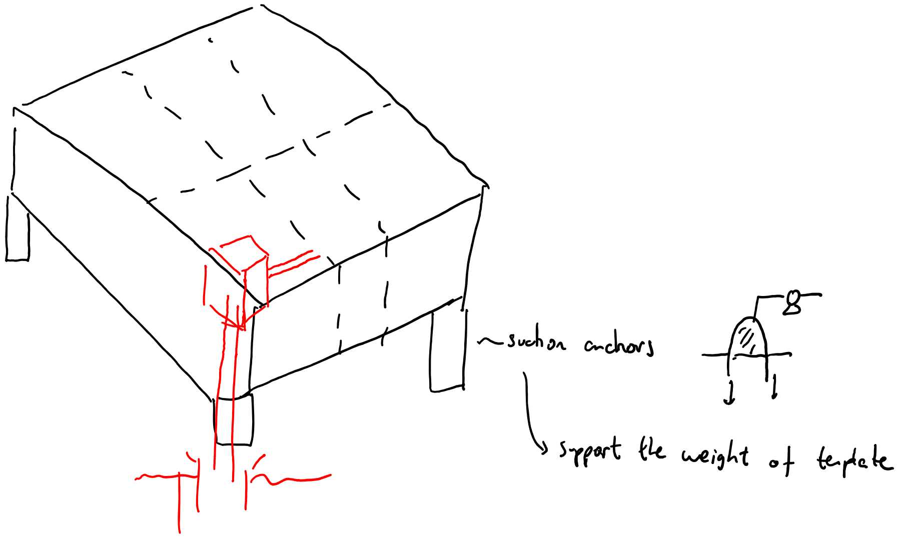
The manifold – reality vs sketch





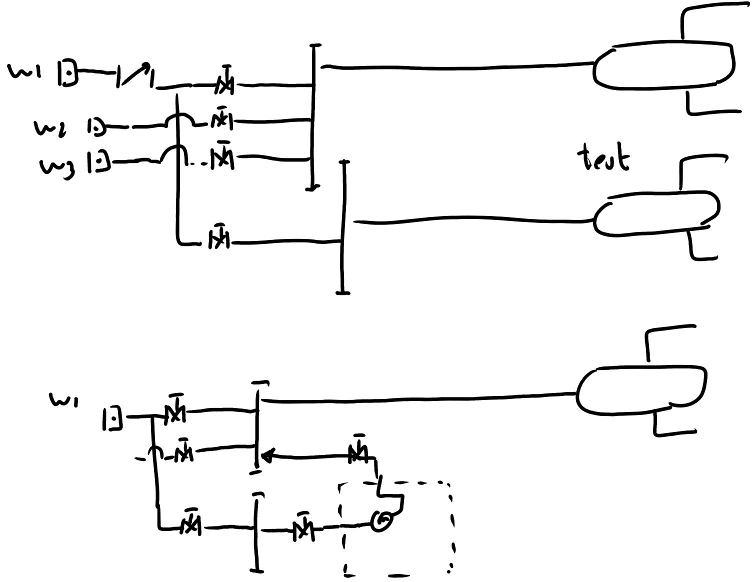
56

4 well template – weight transfer



notes for Youtube video offshore structures 2

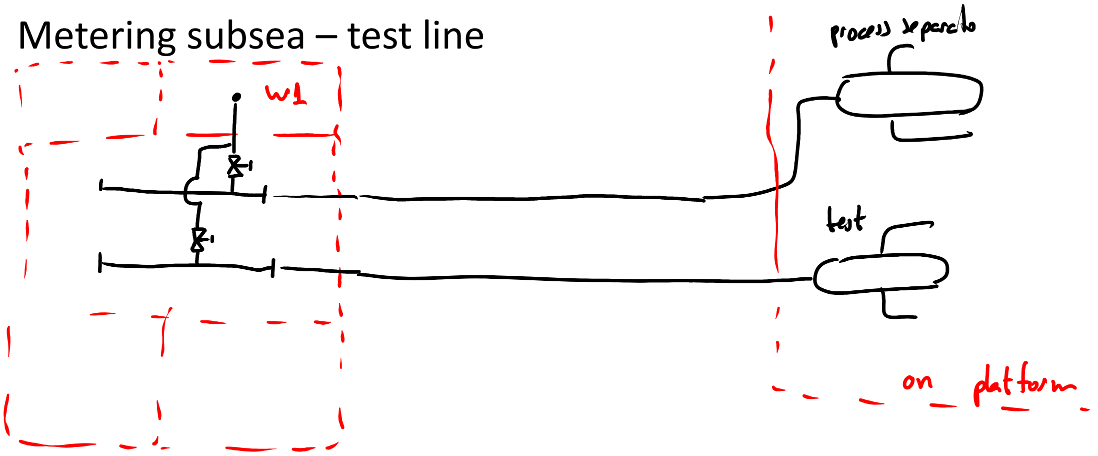
Metering - onshore



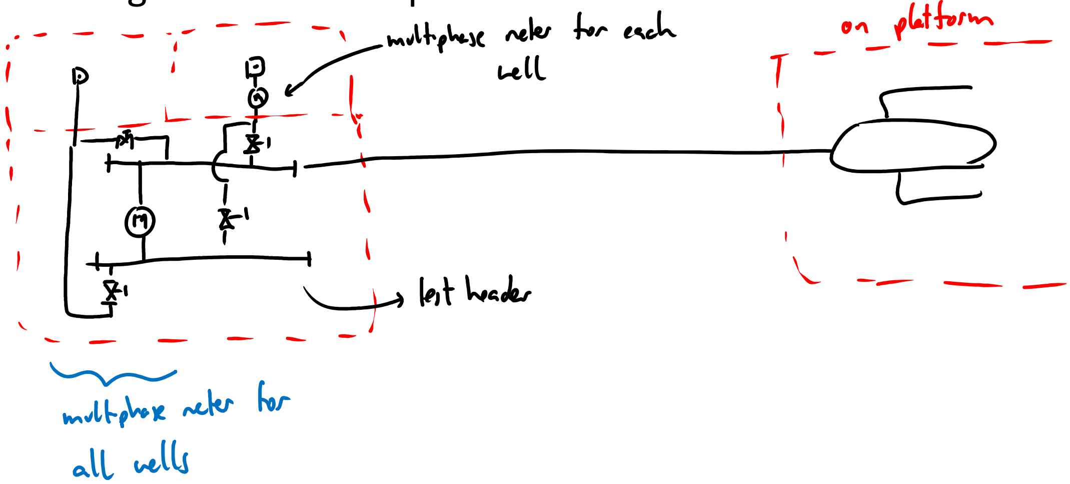
instead of separating, a multiphase meter can also be used, instead of a test separator

Metering onshore – test separator

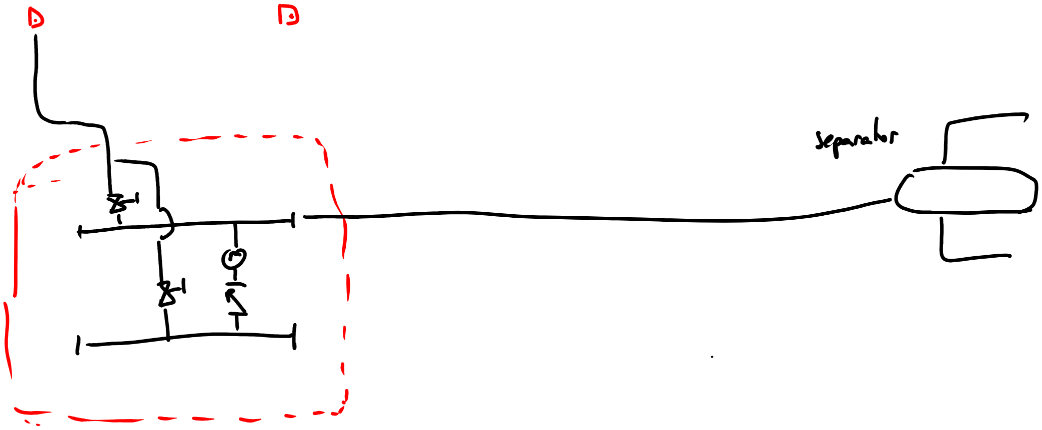
Metering subsea – test line



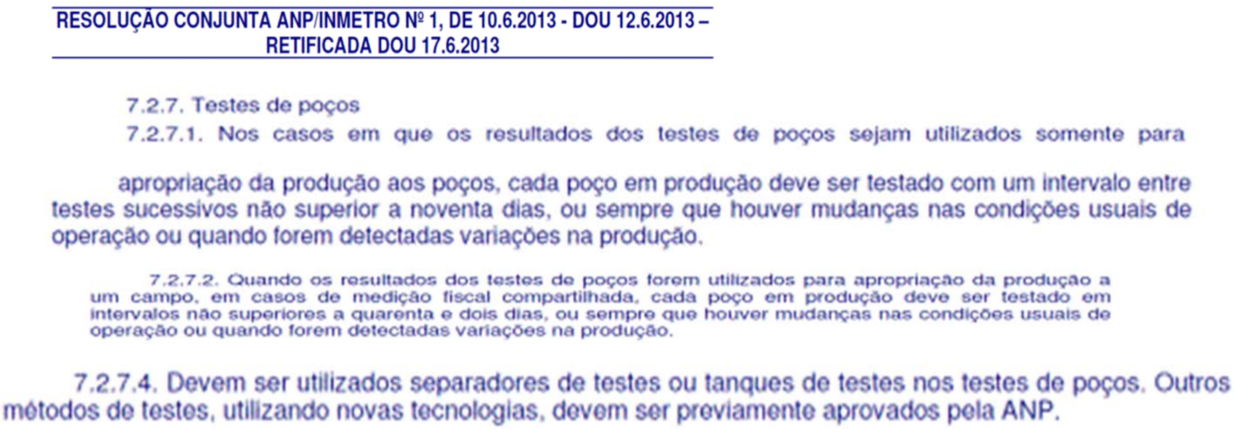
Metering subsea – multiphase meter



multiphase meter - satellite wells



Metering requirements affect field layout - Brazil



RESOLUÇÃO CONJUNTA ANP/INMETRO Nº 1, DE 10.6.2013 - DOU 12.6.2013 – RETIFICADA DOU 17.6.2013

7.2.7. Testes de poços

7.2.7.1. Nos casos em que os resultados dos testes de poços sejam utilizados somente para apropriação da produção aos poços, cada poço em produção deve ser testado com um intervalo entre testes sucessivos não superior a noventa dias, ou sempre que houver mudanças nas condições usuais de operação ou quando forem detectadas variações na produção.

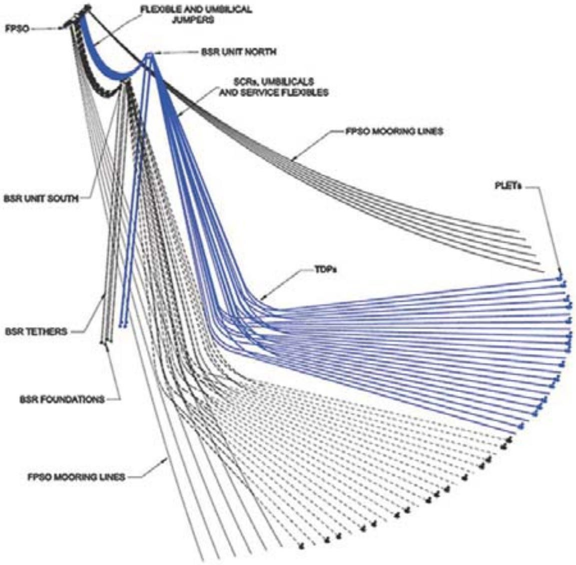
7.2.7.2. Quando os resultados dos testes de poços forem utilizados para apropriação da produção a um campo, em casos de medição fiscal compartilhada, cada poço em produção deve ser testado em intervalos não superiores a quarenta e dois dias, ou sempre que houver mudanças nas condições usuais de operação ou quando forem detectadas variações na produção.

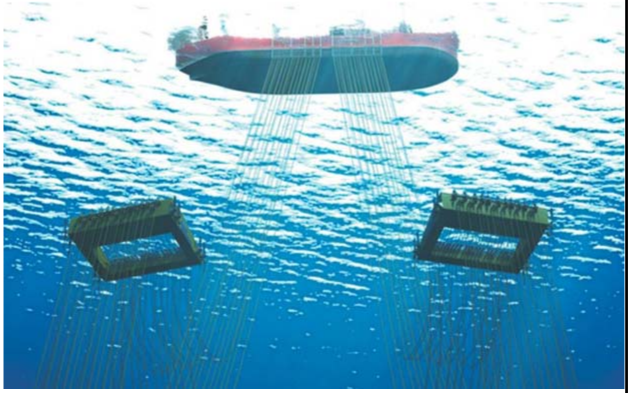
7.2.7.4. Devem ser utilizados separadores de testes ou tanques de testes nos testes de poços. Outros métodos de testes, utilizando novas tecnologias, devem ser previamente aprovados pela ANP.

http://www.anp.gov.br/wwwanp/?dw=66648

Metering requirements - Brazil

$$$

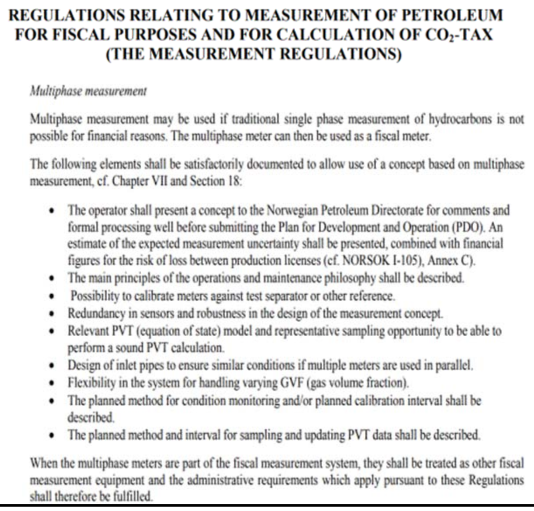




https://www.marinetechnologynews.com/news/reviewing-sapinho-system-564661

Metering requirements - Norway

http://www.npd.no/Global/Engelsk/5-Rules-and-regulations/NPD-regulations/Maaleforskriften_e.pdf



REGULATIONS RELATING TO MEASUREMENT OF PETROLEUM FOR FISCAL PURPOSES AND FOR CALCULATION OF CO_2-TAX (THE MEASUREMENT REGULATIONS)

Multiphase measurement

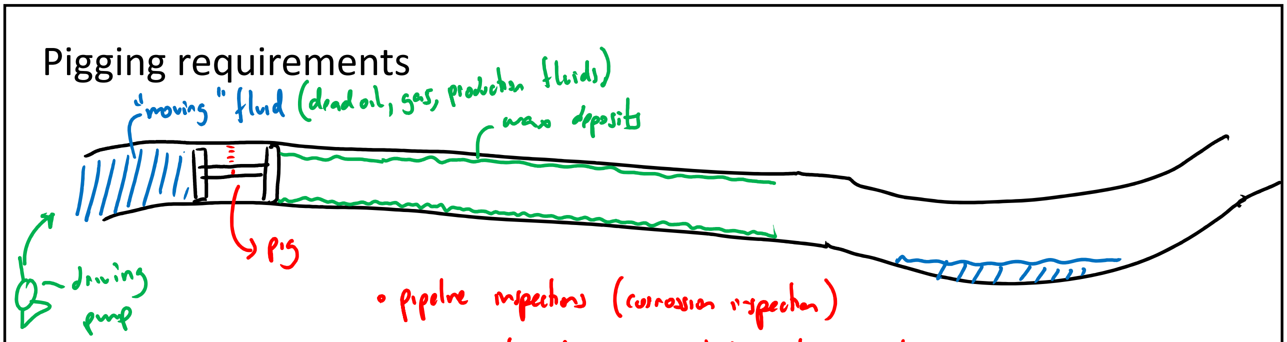
Multiphase measurement may be used if traditional single phase measurement of hydrocarbons is not possible for financial reasons. The multiphase meter can then be used as a fiscal meter.

The following elements shall be satisfactorily documented to allow use of a concept based on multiphase measurement, cf. Chapter VII and Section 18:

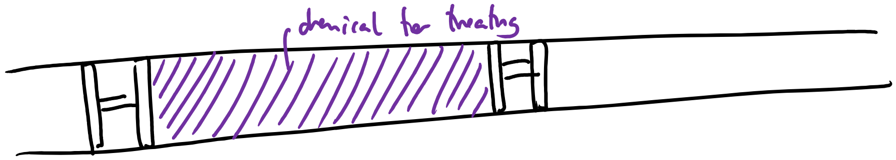
- The operator shall present a concept to the Norwegian Petroleum Directorate for comments and formal processing well before submitting the Plan for Development and Operation (PDO). An estimate of the expected measurement uncertainty shall be presented, combined with financial figures for the risk of loss between production licenses (cf. NORSOK I-105), Annex C).
- The main principles of the operations and maintenance philosophy shall be described.
- Possibility to calibrate meters against test separator or other reference.
- Redundancy in sensors and robustness in the design of the measurement concept.
- Relevant PVT (equation of state) model and representative sampling opportunity to be able to perform a sound PVT calculation.
- Design of inlet pipes to ensure similar conditions if multiple meters are used in parallel.
- Flexibility in the system for handling varying GVF (gas volume fraction).
- The planned method for condition monitoring and/or planned calibration interval shall be described.
- The planned method and interval for sampling and updating PVT data shall be described.

When the multiphase meters are part of the fiscal measurement system, they shall be treated as other fiscal measurement equipment and the administrative requirements which apply pursuant to these Regulations shall therefore be fulfilled.

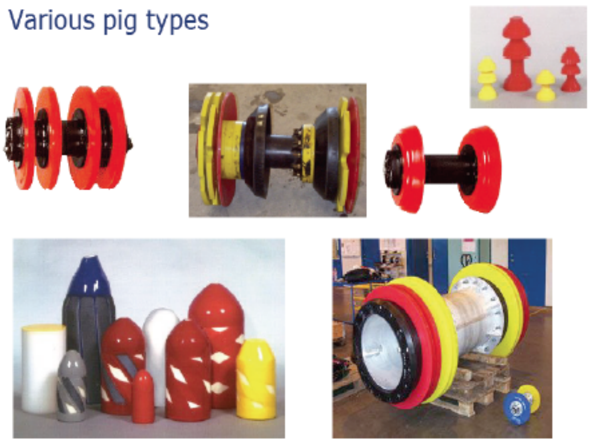
Pigging requirements



- pipeline inspections (corrosion inspection)
- remove liquid accumulated in low points
- chemical treatment
- wax scraping

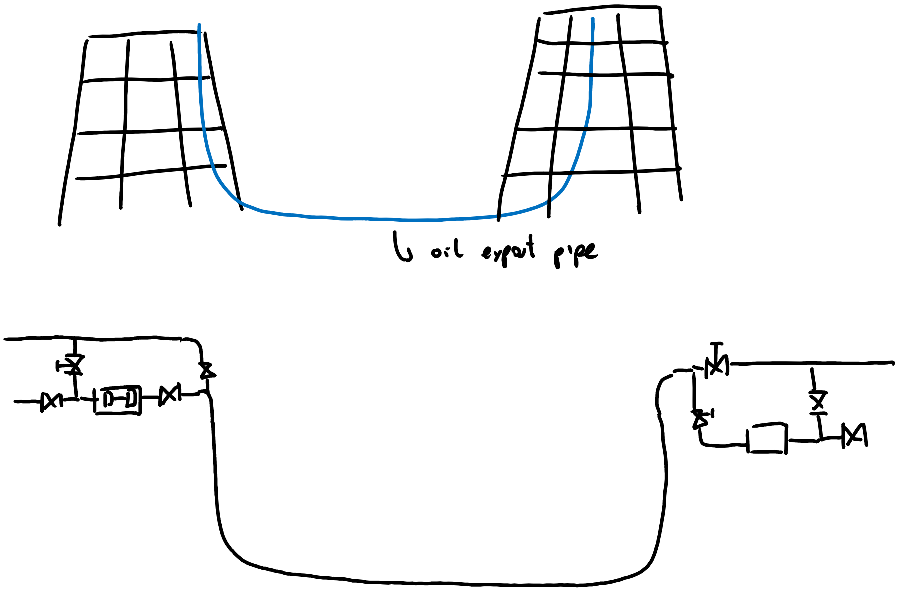


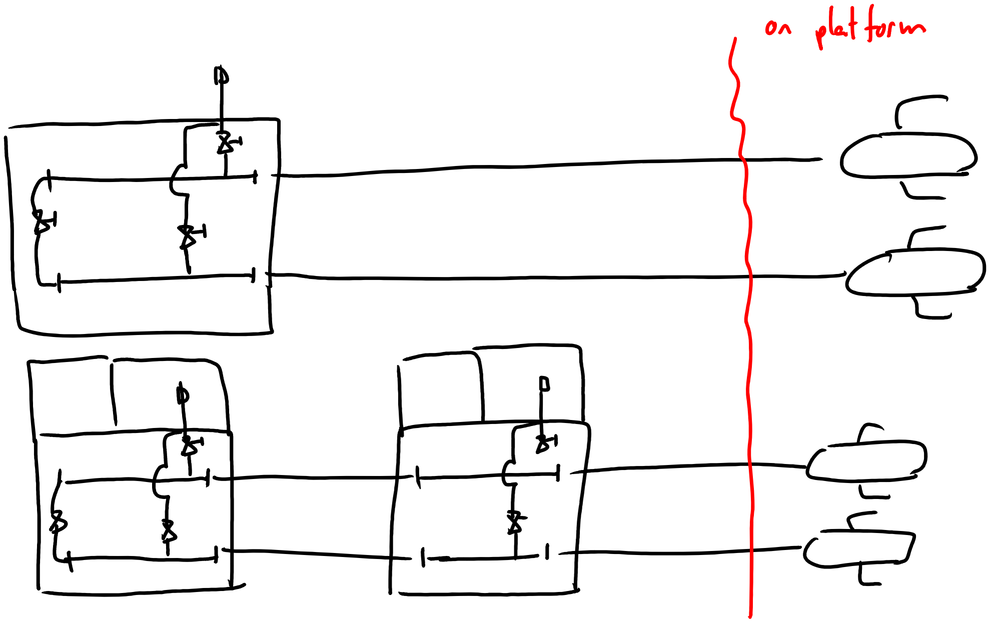
Pigs


Various pig types

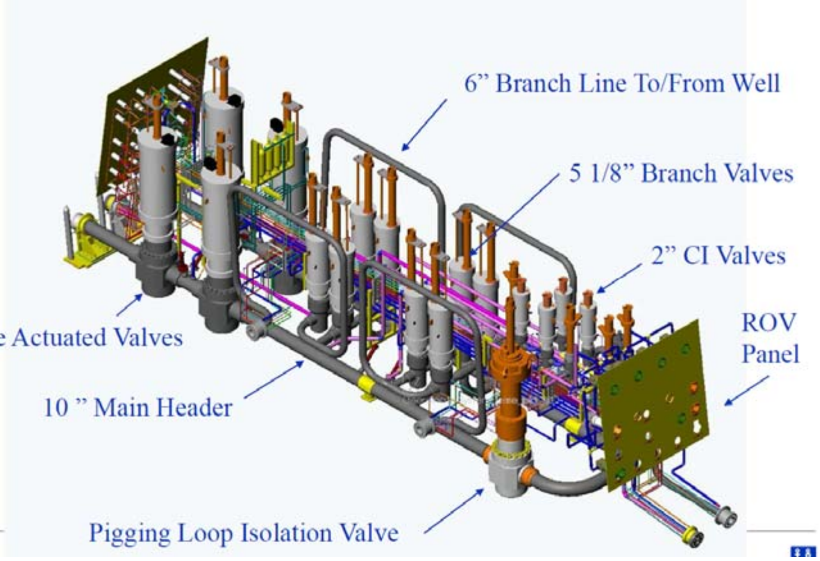

Wax plug-North Sea line pigging

Pigging loop and subsea pig launcher

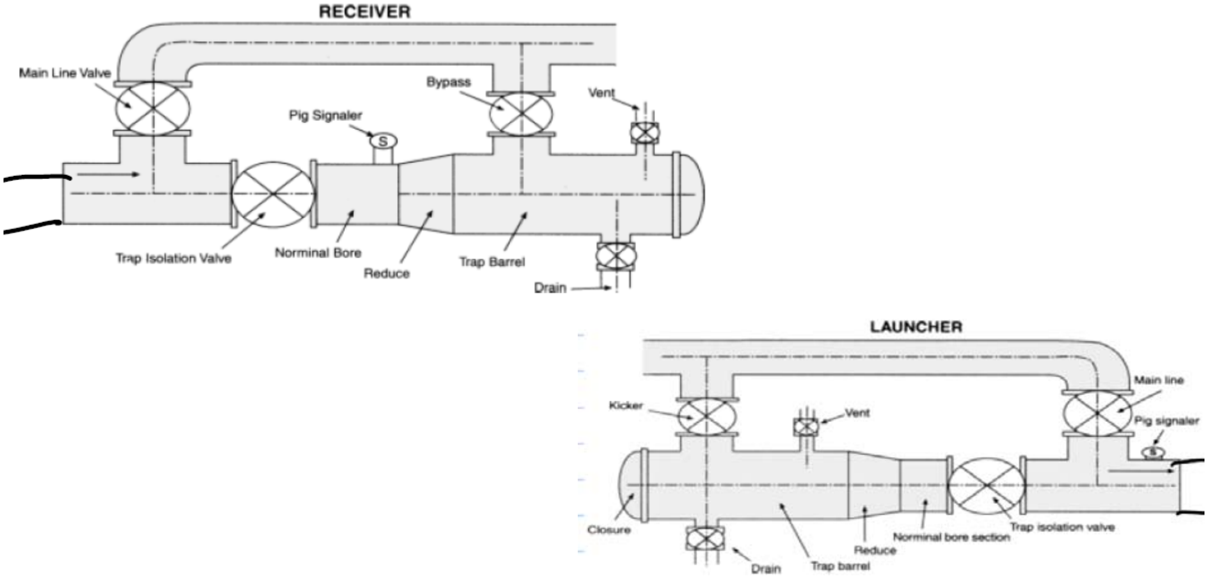




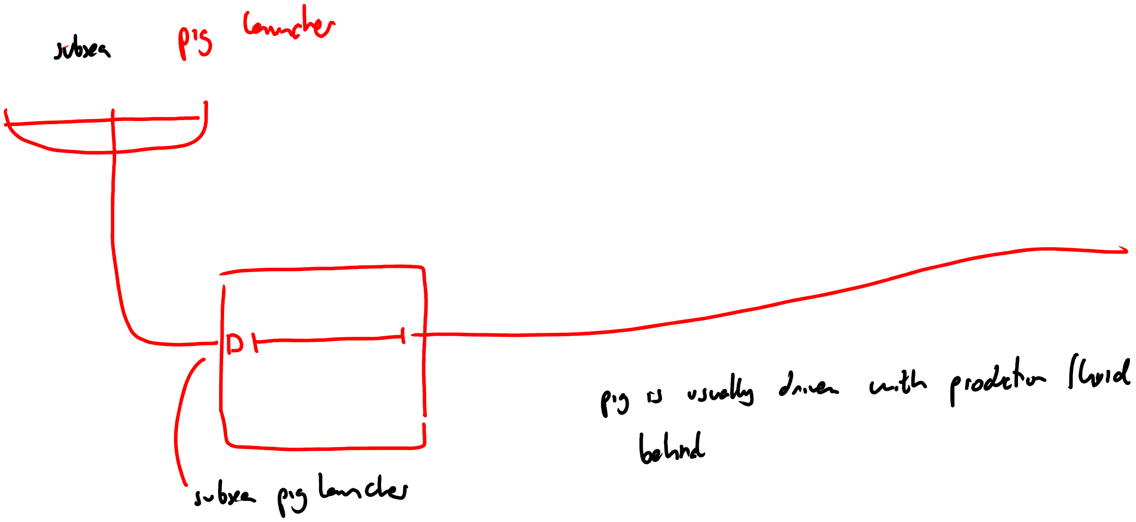
The pigging valve



Pig launcher and receiver



Pigging - video



pig is usually driven with production fluid behind

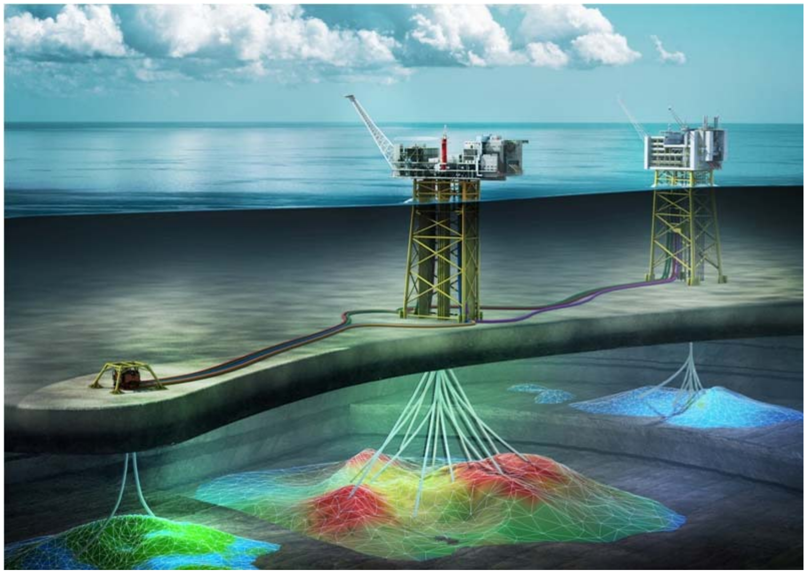
Summary table

	Dry X-mas trees	**Wet X-mas trees**
Deep water (1700 m+)		X
Reservoir is “spread” or multiple reservoirs		X
Frequent well intervention	X	
Flow assurance concerns	X	
Plans for infill drilling (and coping with reservoir uncertainty)*	X	X
Progressive production startup		X

Jacket, GBS, SPAR, TLP

ALL

Combinations can be used

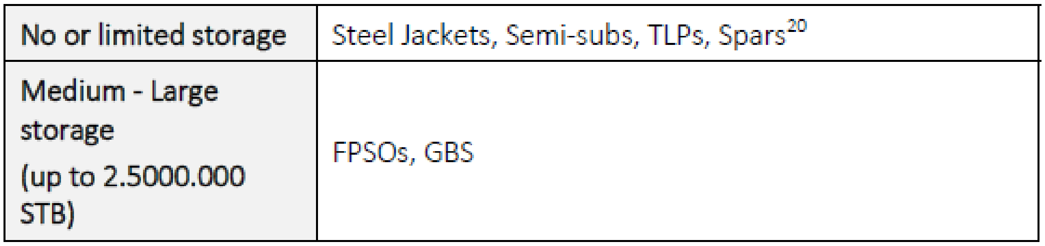


https://www.akerbp.com/en/our-assets/production/ivar-aasen/the-development-solution/

Some selection criteria for offshore structures

- Water depth
- Type of X-mas tree
  - Well intervention needs
    - Tubing replacement
    - Completion modifications
    - Artificial lift (ESP)
  - Infill drilling needs
  - Reservoir spread and structure
- **Need for oil/condensate storage**
- Marine loads – Oceanographic environment
  - Wind, waves, current

Need for liquid storage



No or limited storage	Steel Jackets, Semi-subs, TLPs, Spars[20]
Medium - Large storage (up to 2.5000.000 STB)	FPSOs, GBS

Other selection criteria for offshore structures

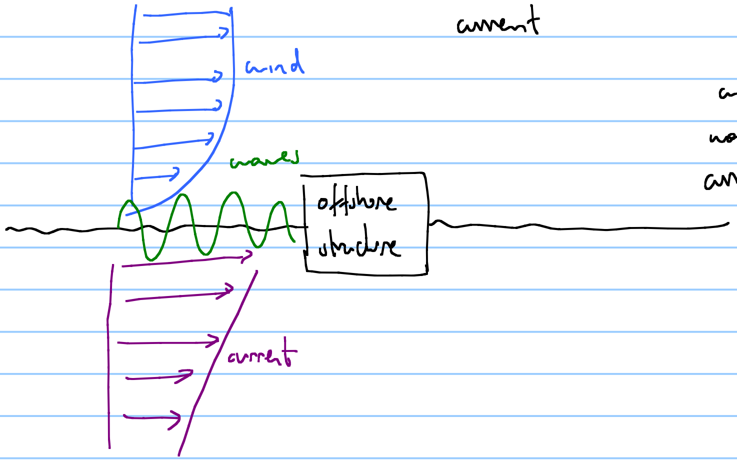
- Previous experience
- Riser issues
- Topside upgrade flexibility
- Manufacturing workshop availability
- Maturity of technology
- Maintenance and OPEX

Note Title

Notes for Youtube video Marine loads and offshore structures for hydrocarbon production

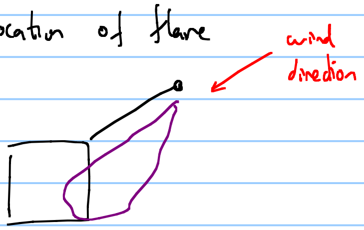
Offshore structures for oil and gas production

- effect of oceanographic environment: wind
  waves
  current

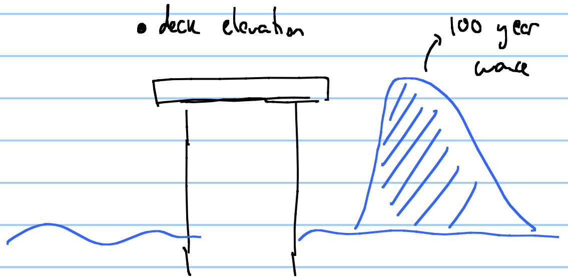


wind
waves
current
must be taken into account when designing the offshore structure

- Location of flare



- deck elevation

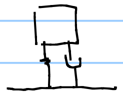


- design wave, for a range of periods
  ↳ most likely in the area
- storm (100 year storm)
- long term variations ⇝ fatigue

forces and marine loads on structure (t)
- magnitude
- frequency
- direction

→ structure (mechanical system) → movement (t)
stress (t) → maximum stress
fatigue design

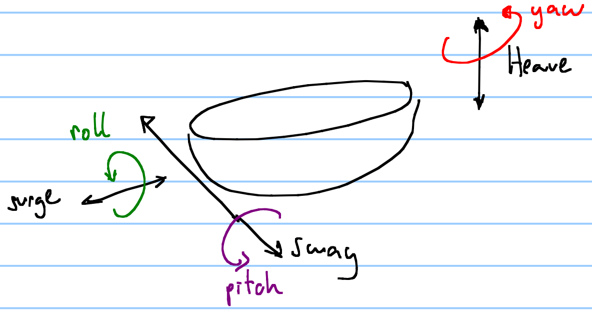
each structure, depending on it characteristics (mass, flexibility, dampening)

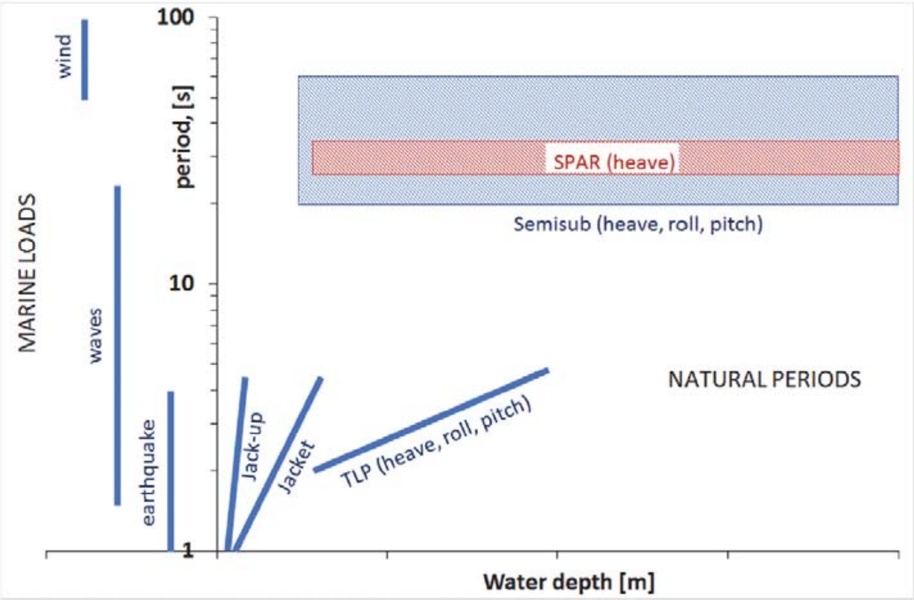


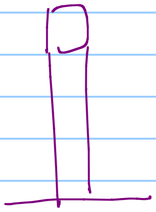
will have a natural frequency that if excited at this frequency might exhibit maximum movement and stress.

fixed structure

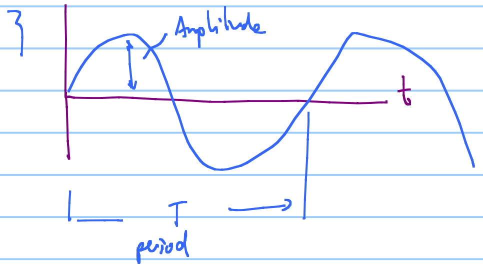
floating structure





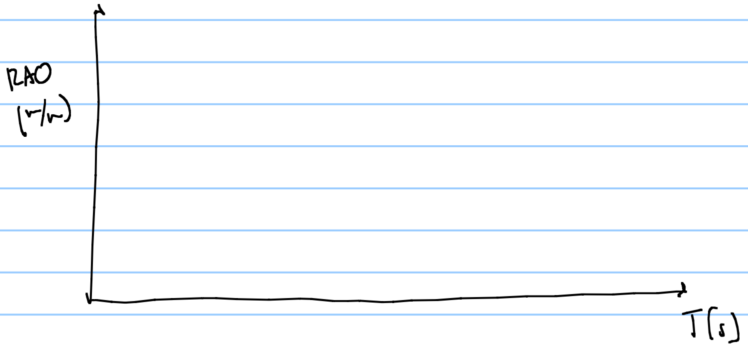


$$\text{Response amplitude operator (RAO)} = \frac{\text{amplitude of response}}{\text{amplitude of excitation}} = \frac{\text{Heave [m]}}{\text{wave amplitude [m]}}$$



RAO = 2

$f = \frac{1}{T}$ $\frac{\text{cycle}}{s}$



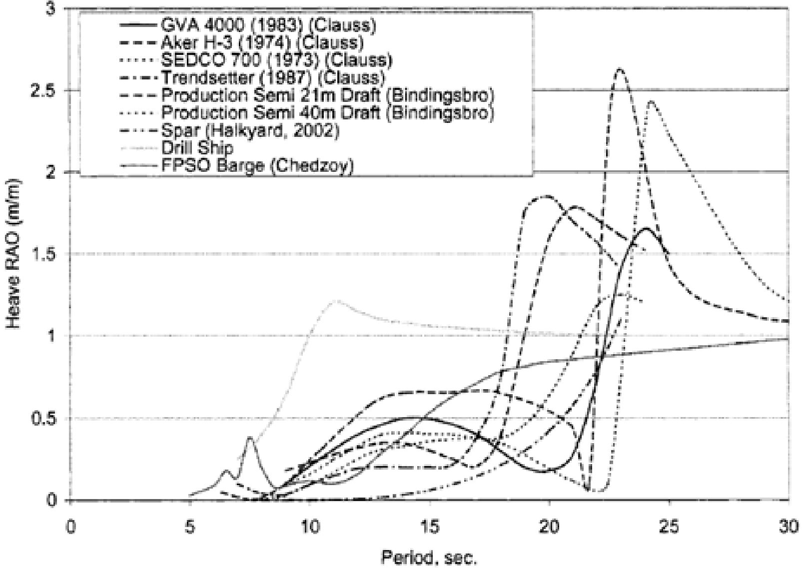
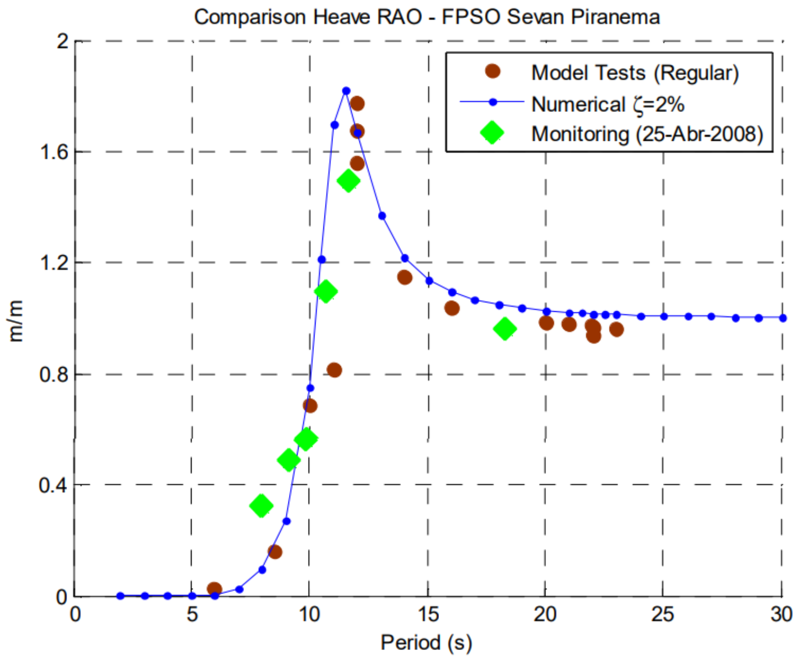


Figure 7.3 Example heave RAOs of various floaters



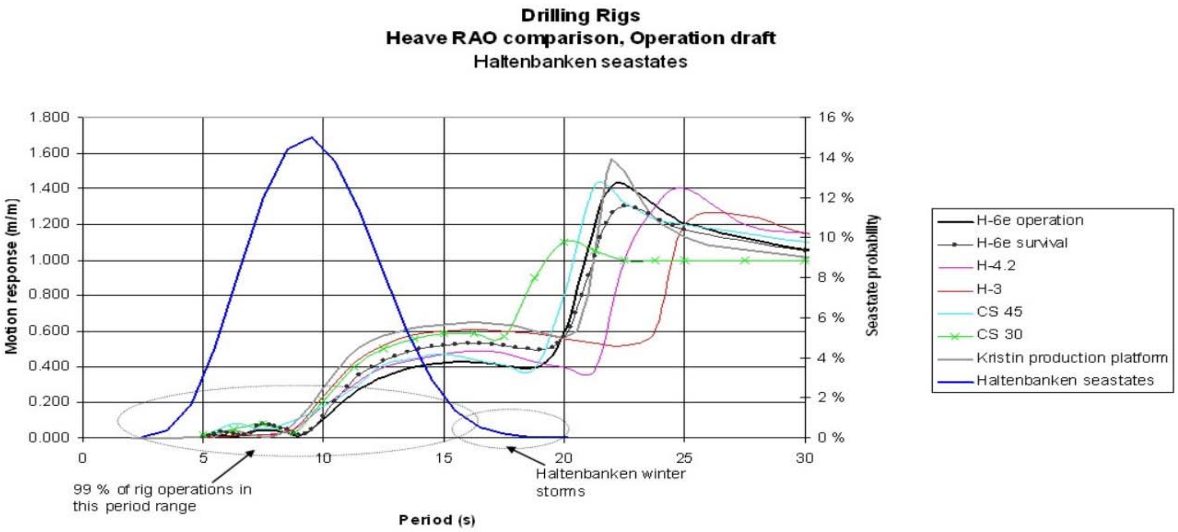


Figure 16.2: *RAO published on the AKER Drilling website.*

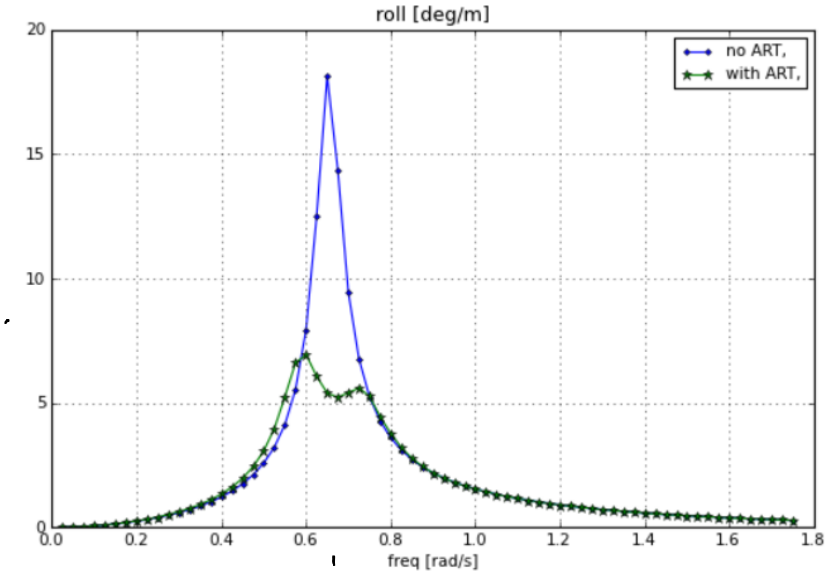
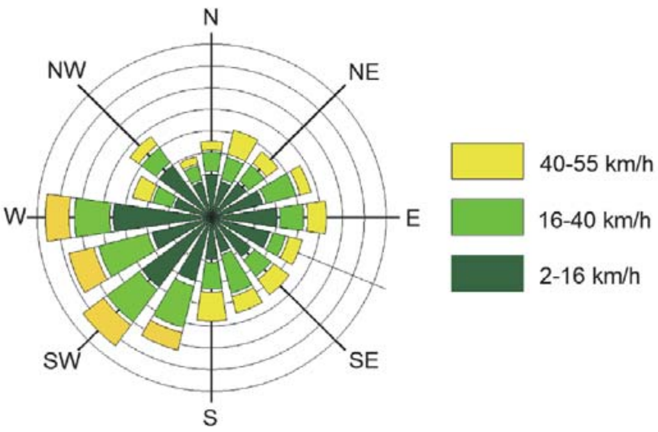


Figure 1: Typical RAO of roll of a ship with and without ART.

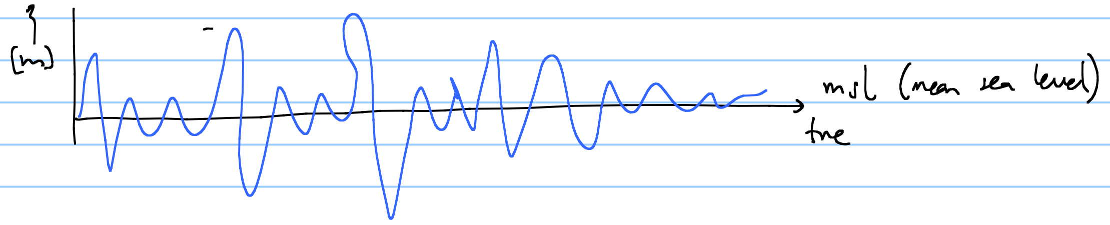
Wind

wind rose



wind and current are typically assumed constant and using the maximum value. (wind direction also must be taken into account)

Waves

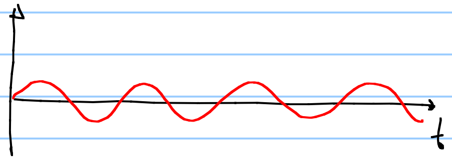


Fourier

$$f(t) = \sum_{i=1}^{N} \underbrace{A_i}_{\text{amplitude (m)}} \sin(\omega_i t + \overset{\text{phase shift}}{\phi_i})$$

angular frequency $\omega_i = 2\pi f_i$

$\omega_i = \frac{rad}{s}$ $\left[\frac{\cancel{cycle}}{s}\right]\left[\frac{2\pi\ rad}{1\ \cancel{cycle}}\right]$



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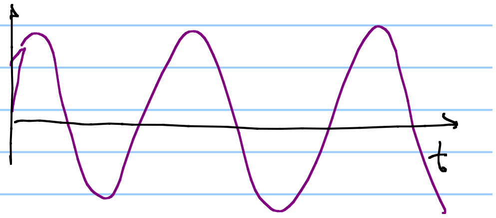

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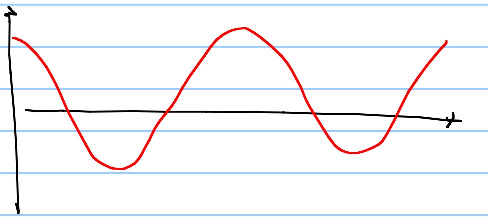
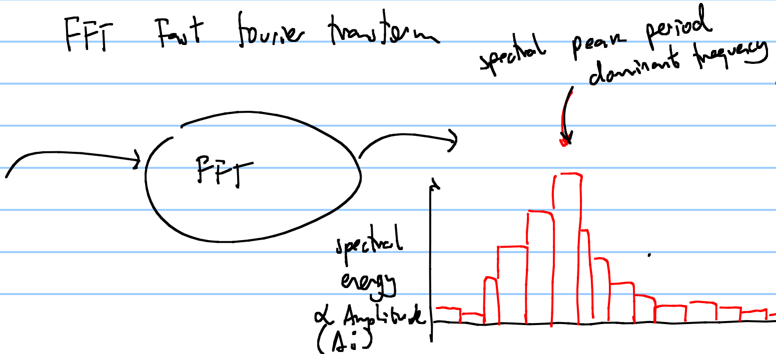


Discrete Fourier transform

FFT Fast fourier transform

t	value
□	□
□	□
□	□
□	□



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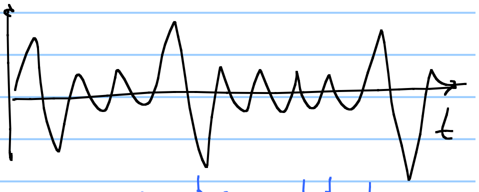
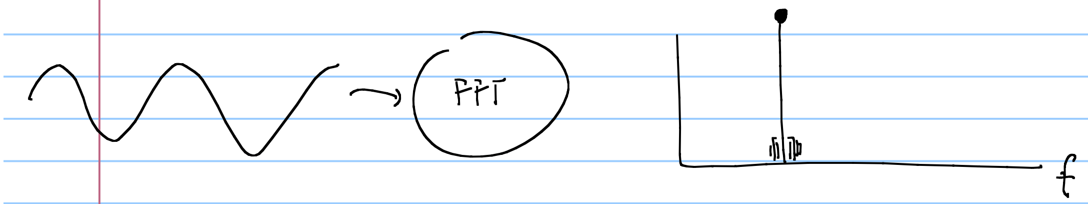


→ sometimes analytical equations are used

Pierson Moskowitz, JONSWAP



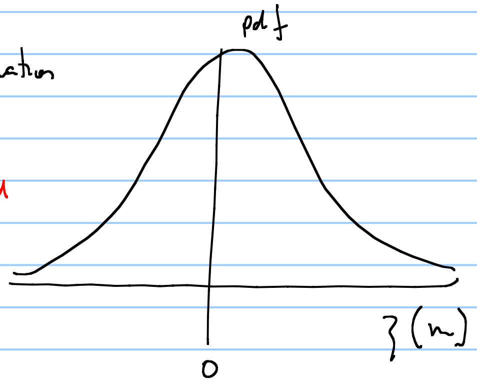
to deal with the variability of waves in time, we apply FFT on the signal and report spectral peak period

the spectral peak period does not change significantly in 3 hours

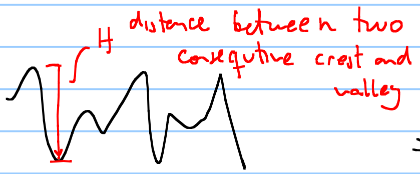
sea state

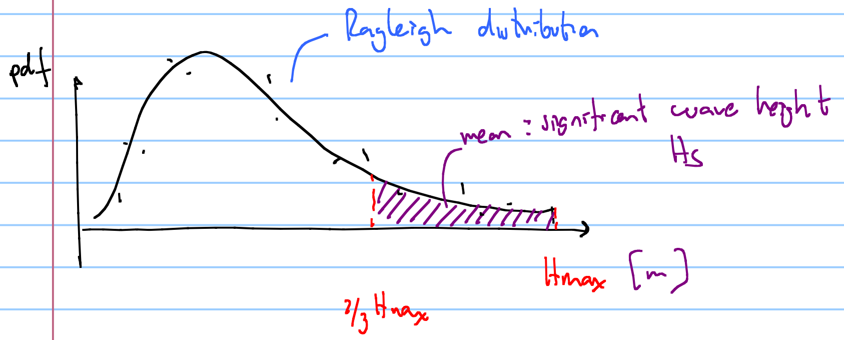
what to do with amplitudes?

statistics on wave elevation



wave height



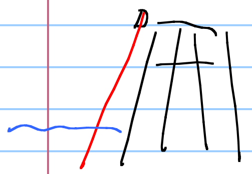


to characterize a sea state (3 hrs) Hs and Tp are used

wave Data must be gathered for at least 2 years to obtain a representative sample of wave conditions in the area

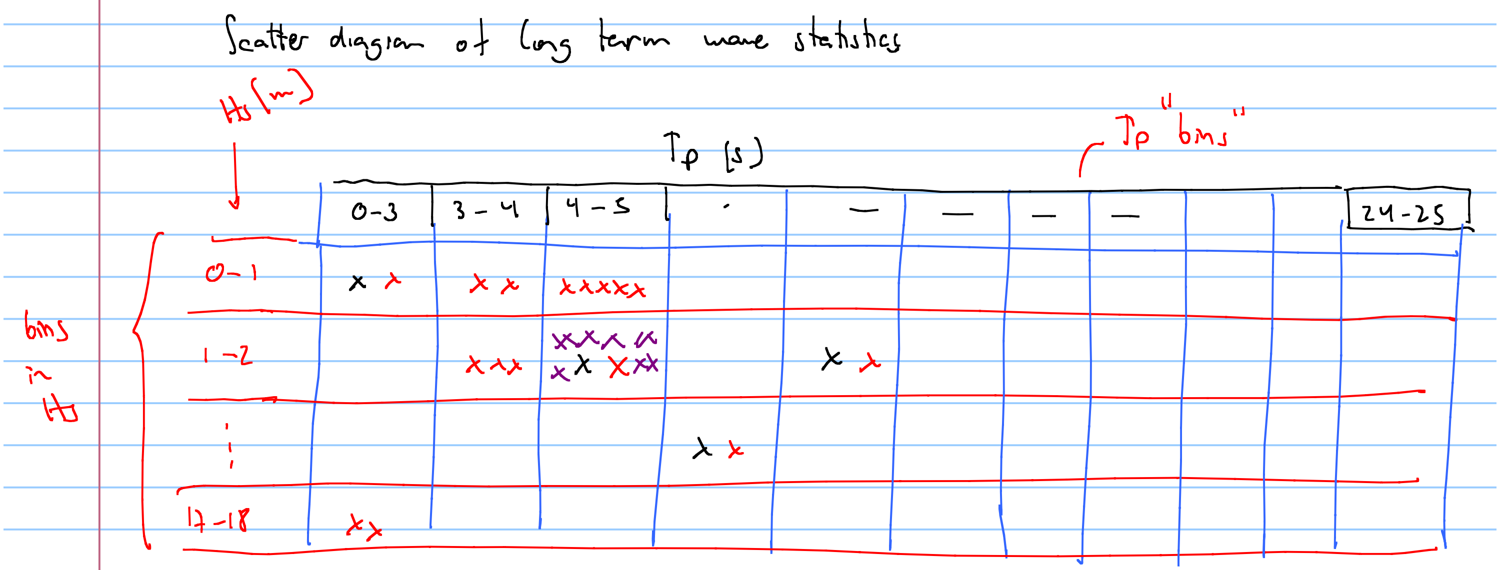
How many sea states are in 2 years

$$2\,\text{years}\ \frac{365\ \text{day}}{\text{year}}\ \frac{24\ \text{hrs}}{1\,\text{day}}\ \frac{1\ \text{sea state}}{3\,\text{hr}} = 5840$$

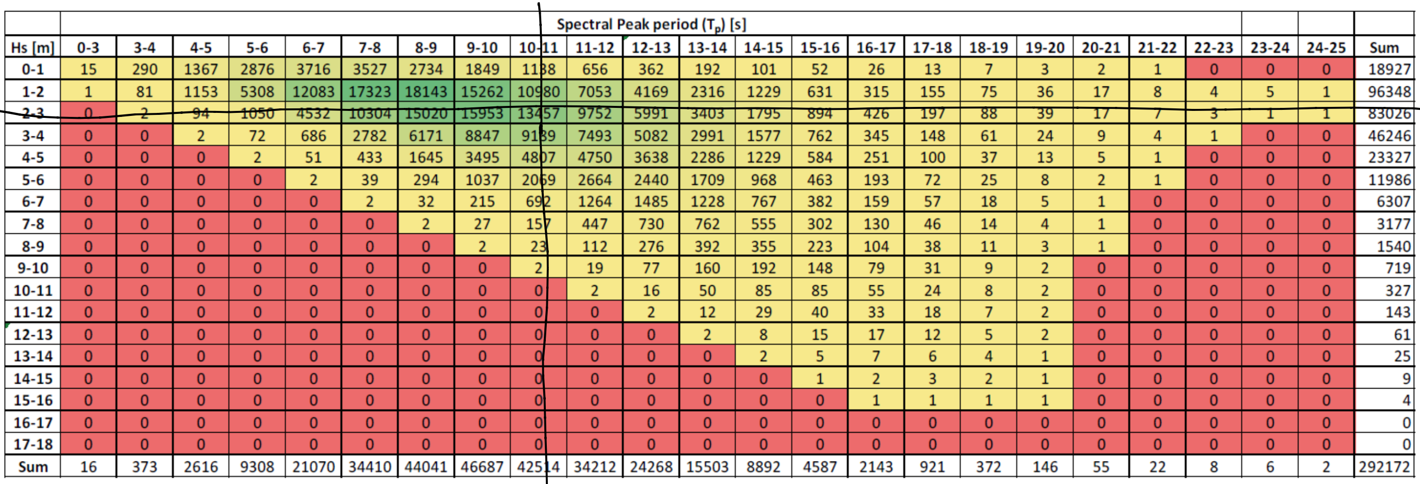


with all measured data, compute Tp, Hs for all

Scatter diagram of long term wave statistics



classify each data point i have in each box

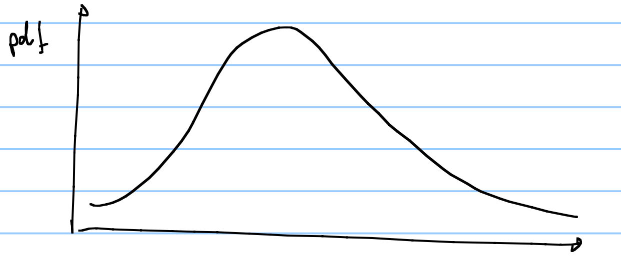


Hs [m]	0-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	Sum
	Spectral Peak period (T_p) [s]																							
0-1	15	290	1367	2876	3716	3527	2734	1849	1138	656	362	192	101	52	26	13	7	3	2	1	0	0	0	18927
1-2	1	81	1153	5308	12083	17323	18143	15262	10980	7053	4169	2316	1229	631	315	155	75	36	17	8	4	5	1	96348
~~2-3~~	~~0~~	~~2~~	~~94~~	~~1050~~	~~4532~~	~~10304~~	~~15020~~	~~15953~~	~~13457~~	~~9752~~	~~5991~~	~~3403~~	~~1795~~	~~894~~	~~426~~	~~197~~	~~88~~	~~39~~	~~17~~	~~7~~	~~3~~	~~1~~	~~1~~	~~83026~~
3-4	0	0	2	72	686	2782	6171	8847	9139	7493	5082	2991	1577	762	345	148	61	24	9	4	1	0	0	46246
4-5	0	0	0	2	51	433	1645	3495	4807	4750	3638	2286	1229	584	251	100	37	13	5	1	0	0	0	23327
5-6	0	0	0	0	2	39	294	1037	2069	2664	2440	1709	968	463	193	72	25	8	2	1	0	0	0	11986
6-7	0	0	0	0	0	2	32	215	692	1264	1485	1228	767	382	159	57	18	5	1	0	0	0	0	6307
7-8	0	0	0	0	0	0	2	27	157	447	730	762	555	302	130	46	14	4	1	0	0	0	0	3177
8-9	0	0	0	0	0	0	0	2	23	112	276	392	355	223	104	38	11	3	1	0	0	0	0	1540
9-10	0	0	0	0	0	0	0	0	2	19	77	160	192	148	79	31	9	2	0	0	0	0	0	719
10-11	0	0	0	0	0	0	0	0	0	2	16	50	85	85	55	24	8	2	0	0	0	0	0	327
11-12	0	0	0	0	0	0	0	0	0	0	2	12	29	40	33	18	7	2	0	0	0	0	0	143
12-13	0	0	0	0	0	0	0	0	0	0	0	2	8	15	17	12	5	2	0	0	0	0	0	61
13-14	0	0	0	0	0	0	0	0	0	0	0	0	2	5	7	6	4	1	0	0	0	0	0	25
14-15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	2	1	0	0	0	0	0	9
15-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	4
16-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	16	373	2616	9308	21070	34410	44041	46687	42514	34212	24268	15503	8892	4587	2143	921	372	146	55	22	8	6	2	292172

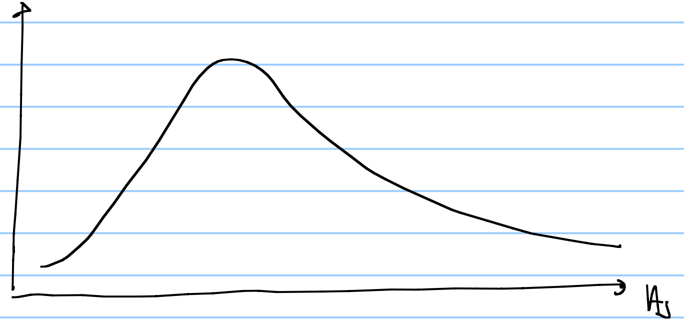
FIGURE 6-18. SCATTER DIAGRAM OF LONG TERM WAVE STATISTICS

$$\frac{292172}{2420\left(\frac{\text{states}}{1\text{year}}\right)} = 120 \text{ years}$$

for a fixed wave Hs



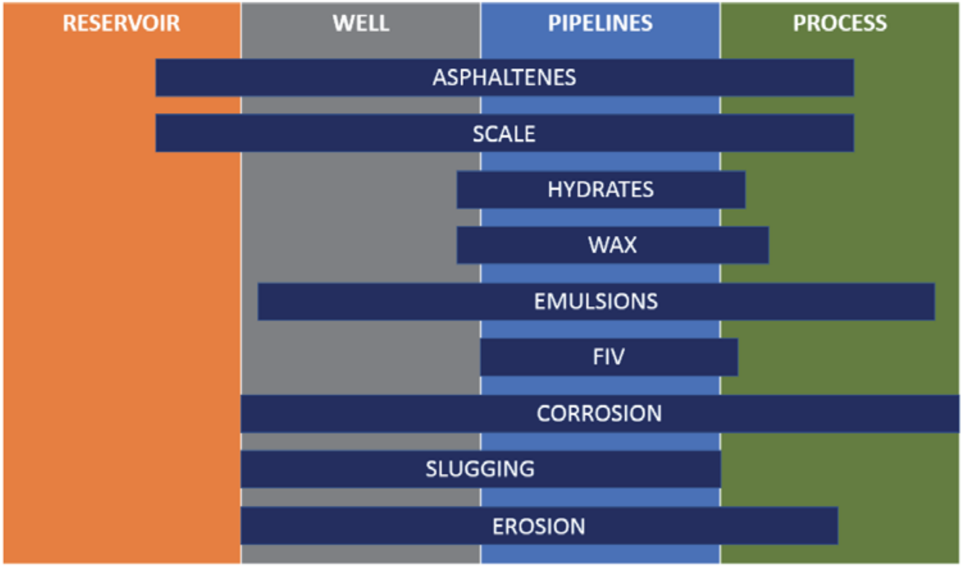
for a fixed Tp



Flow assurance considerations in hydrocarbon field development and planning

Prof. Milan Stanko (NTNU)

Issues



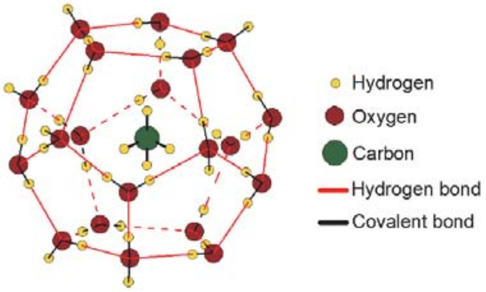
Naphtenates

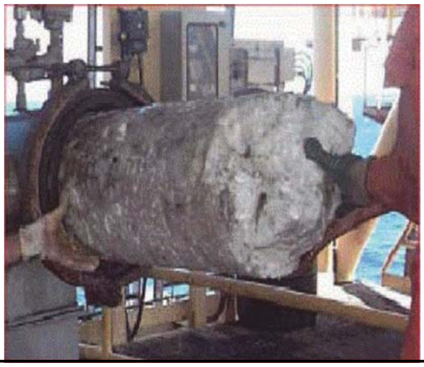
Foam

- microorganism growth

Hydrates

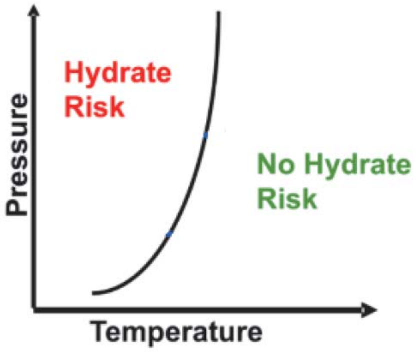
https://www.youtube.com/watch?v=Oz4NLXfdqpA





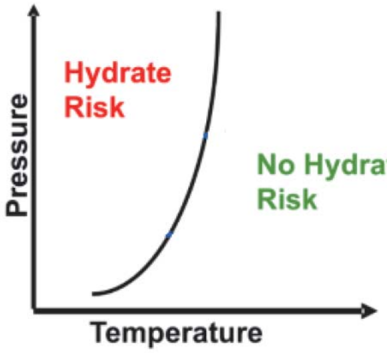
Hydrates - conditions

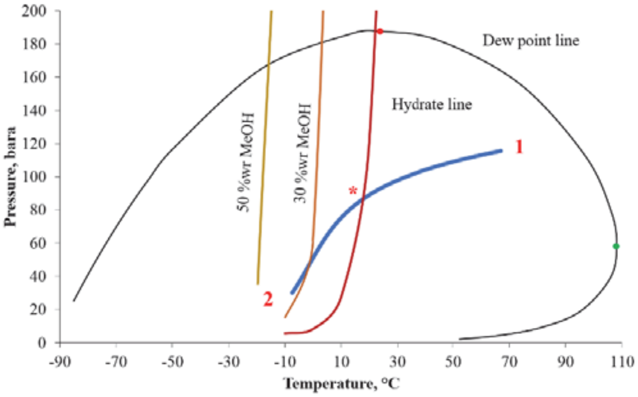
- Free water (in liquid phase)
- Small hydrocarbon molecules
- Particular range of pressure and temperature.



Hydrates - conditions

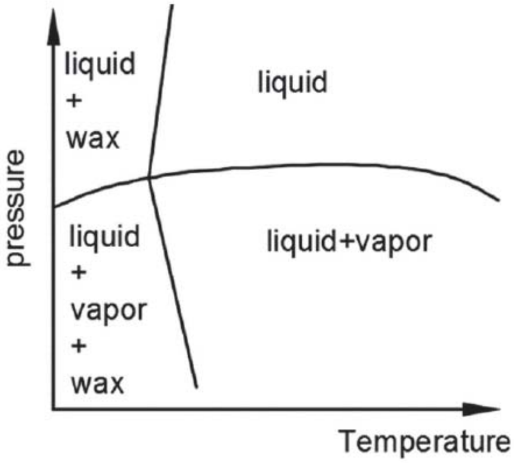
- Free water (in liquid phase)
- Small hydrocarbon molecules
- Particular range of pressure and temperature.





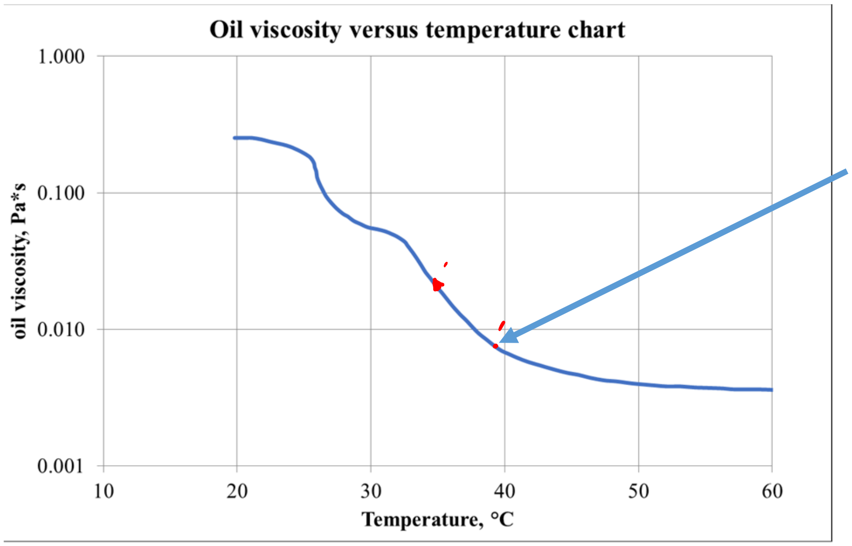
Wax

TAKEN FROM EQUINOR



Paraffins (C18 - C36)

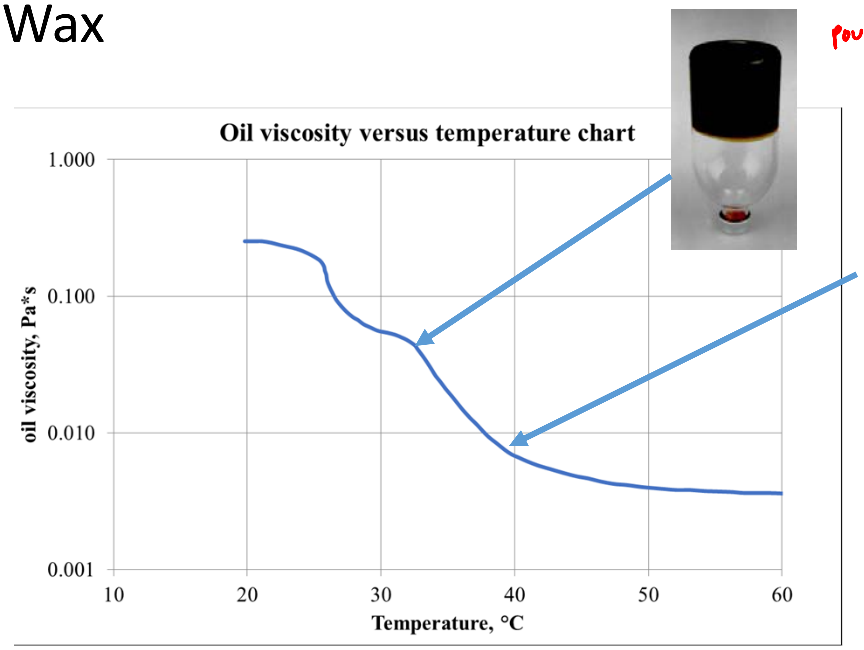
Wax



cloud point
WAT (wax apperance temperature)

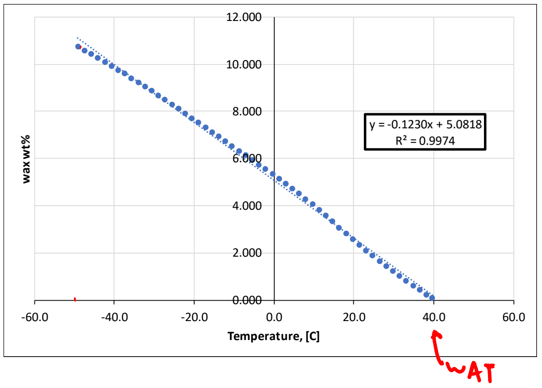
Wax

pour point

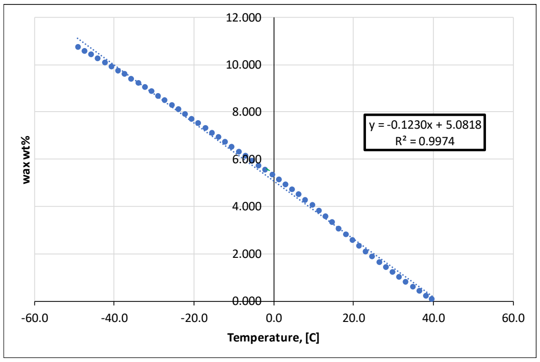


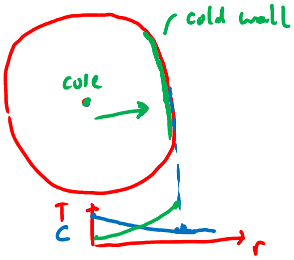
Wax

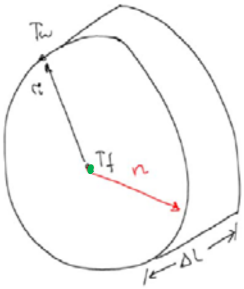
$$\frac{\text{weight of wax particles}}{\text{total weight}} \times 100$$



Wax







r_i : internal pipe diameter

T_f : fluid temperature

T_w : wall Temperature

n : mass flux of wax from fluid to wall [Kg/s.m²]

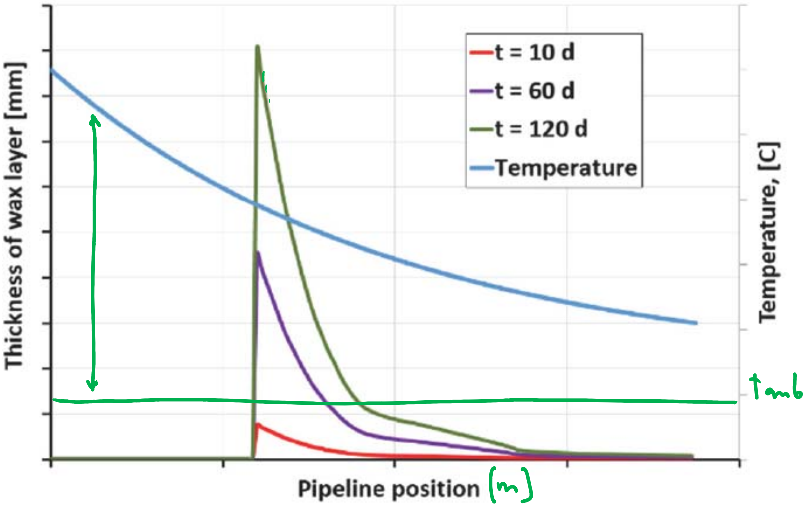
$dA = 2\pi r_i dL$

total mass flow of wax (m_w) deposited in a section

$m_w = n.dA$

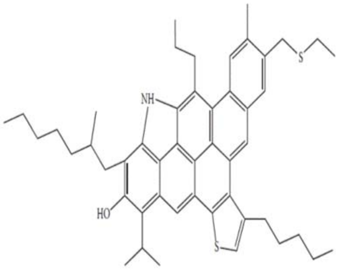
$$n = \rho_{wax} \cdot \frac{B}{\mu_o} \cdot \frac{dC}{dT} \cdot \frac{dT}{dr}$$

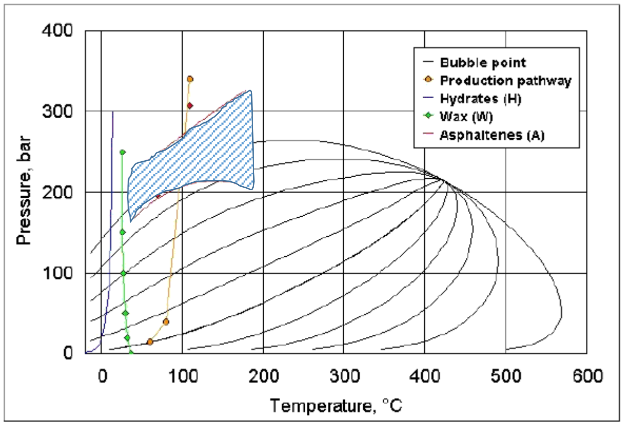
Wax



Asphaltenes

TAKEN FROM EQUINOR (KALLEVIK)





Scale

Ion	Formasjonsvann [mg/l]
Na	14 800
K	520
Mg	13
Ca	378
Ba	410
Sr	228
Fe	58
Cl	23 600
SO4	0

+

Ion	Seawater [mg/l]
Na	10 680
K	396
Mg	1 279
Ca	409
Ba	8
Sr	0
Fe	0
Cl	19 220
SO4	2 689

$$Ba^{2+} + SO_4^{2-} = BaSO_4(s)$$

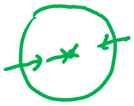
$$Ca^{2+} + CO_3^{2-} = CaCO_3(s)$$

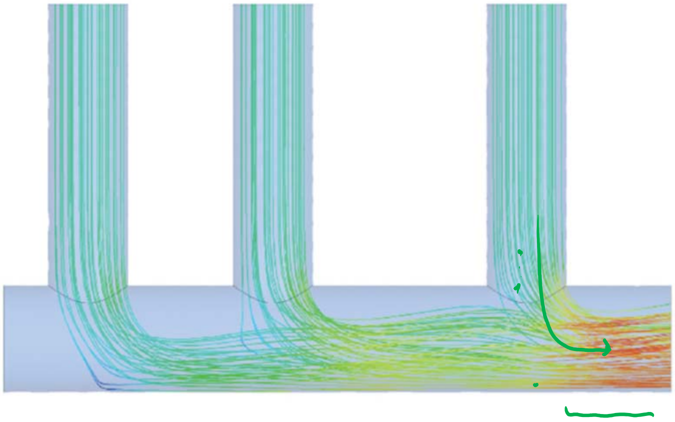
$p\downarrow$
$T\uparrow$ →

$BaSO_4$ $CaCO_3$ NaCl

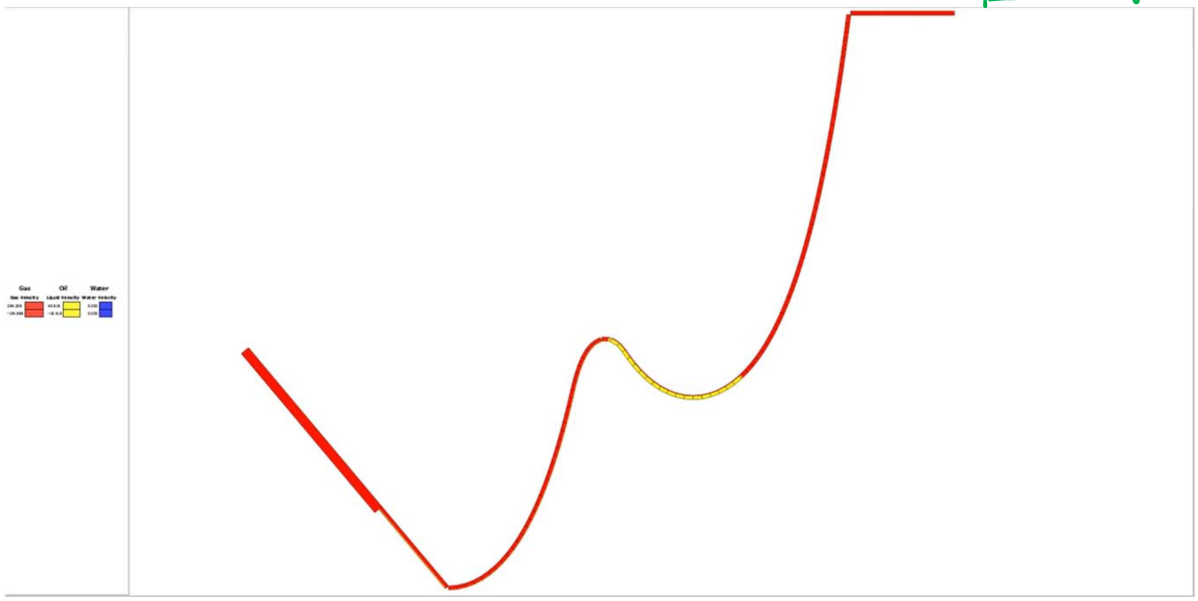
TAKEN FROM EQUINOR (SANDENGEN)

Erosion



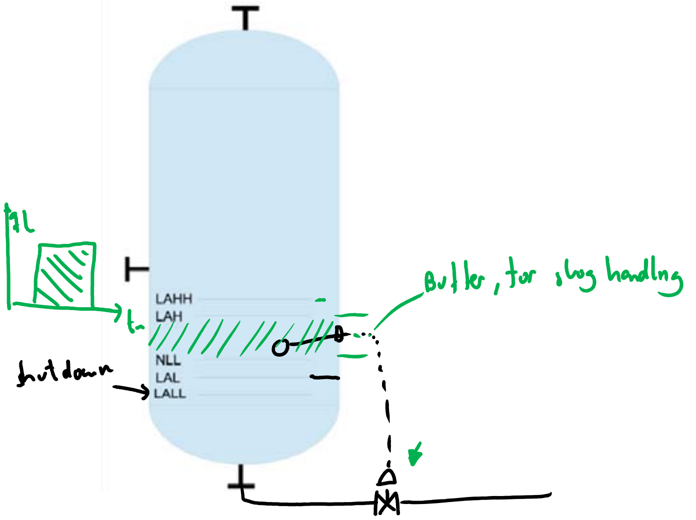


Slugging



https://www.youtube.com/watch?v=j59QLHsTs_c

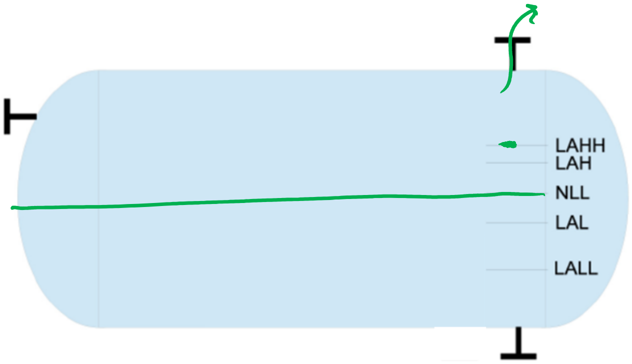
Slugging – impact on separator operation



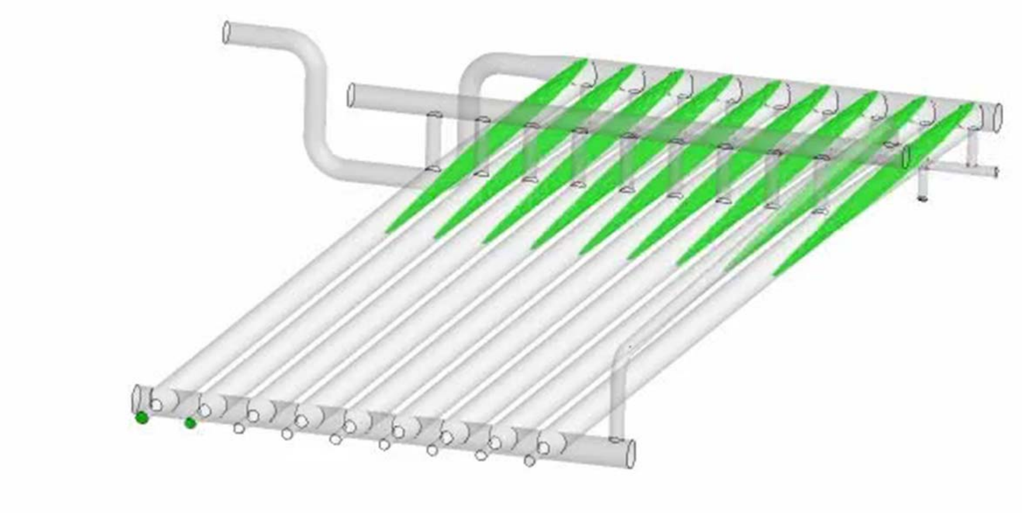
LAL: Level alarm low
LAH: Level alarm high
LALL: Level alarm low low
LAHH: Level alarm high high

https://pubs.spe.org/en/ogf/ogf-article-detail/?art=1028

Slugging – impact on separator operation

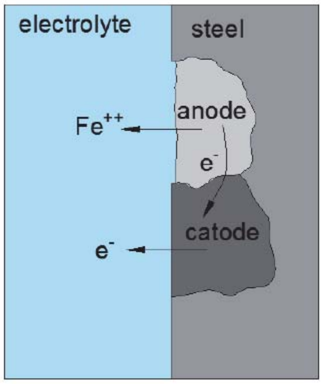


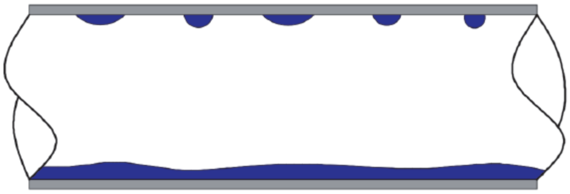
Slugging – slugcatcher handling slugs



https://www.youtube.com/watch?v=LKLW5284adI

Corrosion



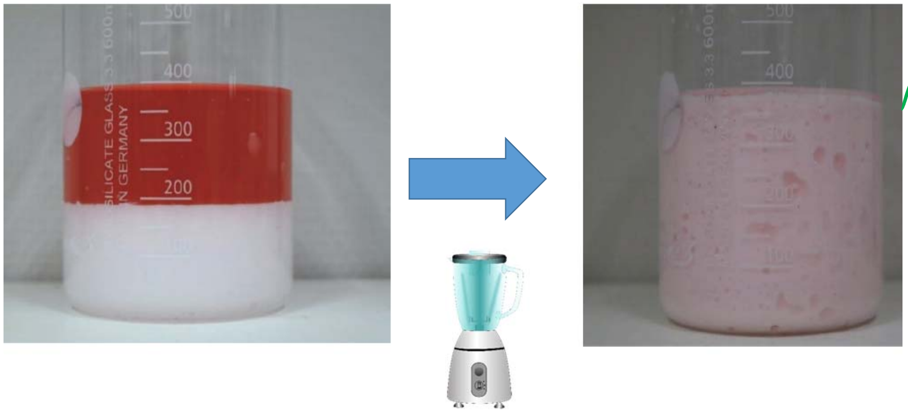


TOP of line corrossion

Oil-water emulsions

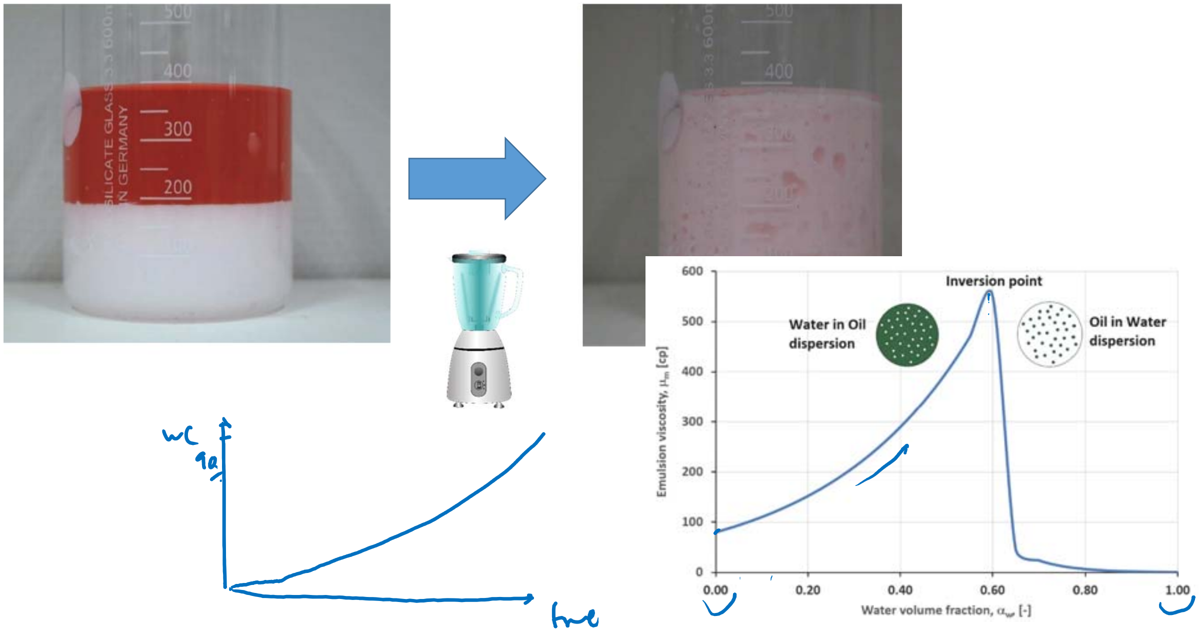
water

Oil-water emulsions

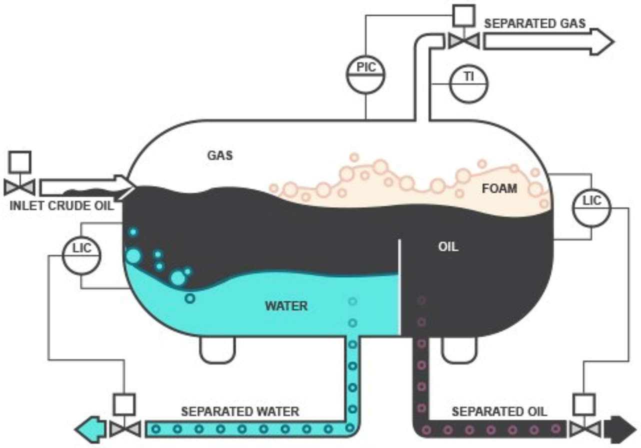


fine and stable dispersion

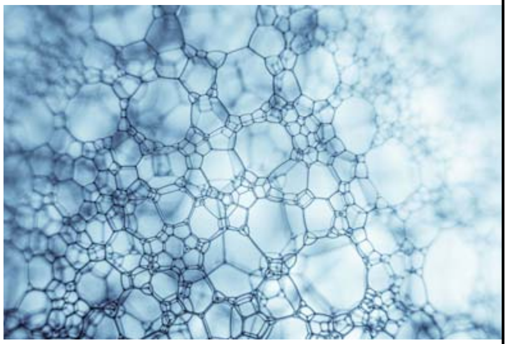
Oil-water emulsions



Foam



https://www.arab-oil-naturalgas.com/foam-in-oil-gas-separators/



https://www.crodaoilandgas.com/en-gb/discovery-zone/functions/foamers

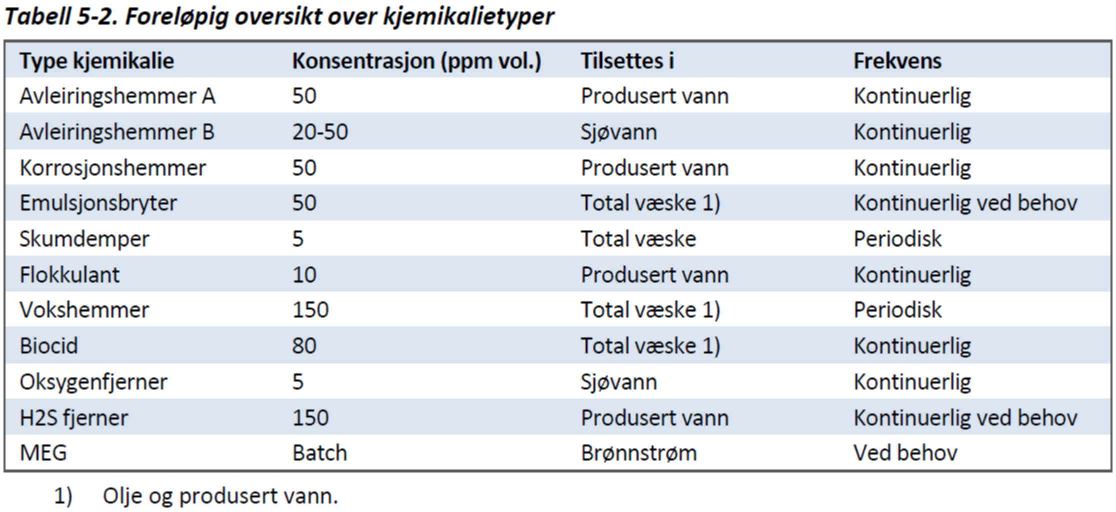
Flow assurance issue	Causes	Potential Consequences	Prevention/solution	Tools available for analysis
Hydrates	- Small gas HC molecules - Free water - Begin to form at a given p and T (low T, high P) given by thermodynamic equilibrium of the hydrate phase.	- Blockage of flowlines and pipelines	Reduce the hydrate formation region: •Continuous or on-demand injection of chemical inhibitor (MEG or MEOH) Stay out of hydrate formation region: •Improve thermal insulation •Electric heating Others: •Cold flow* •Water removal and gas dehydration*	To determine Hydrate formation conditions: •Laboratory tests •Empirical correlations •Thermodynamic simulators (e.g. Hysys, PVTsim, Unisim) To determine p and T along the pipe: •Multiphase simulator (Olga, LedaFlow). •Computational fluid dynamics (CFD)
Wax	- Composition of the crude oil - Begins to form at given p and T due to changes in solubility - Cold wall	In wells, flowlines and pipelines: •Increase pressure drop (pipe roughness) •Reduction of cross section area •Pipe blockage •Changes fluid rheology •Gelling (problem for startup)	- Pigging - Thermal insulation - Electric heating - Chemical inhibitors - Chemical dissolvers - Pipe coating - Cold flow*	- Laboratory tests - Transient multiphase simulators (e.g. Olga, LedaFlow) - Computational fluid dynamics (CFD)
Slugging	- Dynamics of multiphase flow of liquid and gas - Reduction of rate - Liquid accumulation on low points	- Fluctuating liquid and gas input to processing facilities In flowlines and pipelines: - Vibration - Added pressure drop - Fatigue	- Change separator size - Pipeline dimensioning - Maintain flow above minimum flow rate - Gas lift in riser base - Choking topside - Pipeline re-routing - Subsea separation*	- Transient multiphase simulator (OLGA, LEDA) - Structural analysis (usually with FEA, e.g. Ansys) - Laboratory experiments
Scaling	- Changes in solubility (e.g. changes in P and T conditions, changes in pH, mixture of incompatible water, CO2 injection).. - Irregularities on surface	In wells, pipelines and flowlines: •Reduction of cross section area •Pipe blockage •Malfunctioning of valves and equipment	- Continuous injection of chemical inhibitors - Dilution by adding more water - Chemical dissolvers - Mechanical removal - Coating	- Laboratory tests - Simulation tools

Flow assurance issue	Causes	Potential Consequences	Prevention/solution	Tools available for analysis
Erosion	• Sand production • High flow velocities • Liquid droplets in the gas • Gas droplets in the liquid	In wells, pipelines and flowlines: •Structural damage •Vibration •Leaks •Corrosion	• Change geometry • Replacement and maintenance of components • Reduce flow rate (reduce formation drawdown) • Sand separation* • Coatings	• Standards (DNV-RP-0501) • Computational fluid dynamics • Laboratory testing
Corrosion	• Water • O_2 • CO_2 • H_2S	• Leaks • Integrity	• Coatings • Material selection • Surface passivation	• Laboratory testing
Emulsions	• Emulsification agents in the crude • Mixing, shear when flowing through valves, chokes, etc	• Added pressure drop • Increased separation time	• Injection of demulsifiers • Heating	• Laboratory tests • Multiphase models
Asphaltenes	• Crude with asphaltenes • Pressure reduction • Addup of light hydrocarbon components	• Blockage of formation, well, flowline and pipeline • Loss of equipment functionality • Emulsification and foamification	• Mechanical removal • Chemical injection	• Laboratory tests • Some simulation tools

Measures and consequences

- **Chemical injection**
- System design, e.g.
  - pipe and component insulation
  - heat tracing
  - dead legs
  - pipeline routing
- Well intervention needs
- Water injection strategy
- Define procedures when shutting down and starting up
- Ensure proper distribution of chemicals

Example of chemical injection program



Tabell 5-2. Foreløpig oversikt over kjemikalietyper

Type kjemikalie	Konsentrasjon (ppm vol.)	Tilsettes i	Frekvens
Avleiringshemmer A	50	Produsert vann	Kontinuerlig
Avleiringshemmer B	20-50	Sjøvann	Kontinuerlig
Korrosjonshemmer	50	Produsert vann	Kontinuerlig
Emulsjonsbryter	50	Total væske 1)	Kontinuerlig ved behov
Skumdemper	5	Total væske	Periodisk
Flokkulant	10	Produsert vann	Kontinuerlig
Vokshemmer	150	Total væske 1)	Periodisk
Biocid	80	Total væske 1)	Kontinuerlig
Oksygenfjerner	5	Sjøvann	Kontinuerlig
H2S fjerner	150	Produsert vann	Kontinuerlig ved behov
MEG	Batch	Brønnstrøm	Ved behov

1) Olje og produsert vann.

Release and disposal of chemicals

Tabell 7-1 Klassifisering av kjemikalier i henhold til OSPAR

⬛	Svart kategori: Stoffer som er lite nedbrytbare og samtidig viser høyt potensial for bioakkumulering og/eller er svært akutt giftige. I utgangspunktet er det ikke er lov å slippe ut kjemikalier i svart kategori. Tillatelse til bruk og utslipp til spesifikke kjemikalier gis dersom det er nødvendig av sikkerhetsmessige og tekniske grunner.
🟥	Rød kategori: Stoffer som brytes sakte ned i det marine miljøet, og viser potensiale for bioakkumulering og/eller er akutt giftige. Kjemikalier i rød kategori kan være miljøfarlige og skal derfor prioriteres for utskifting med mindre miljøfarlige alternativer. Tillatelse til bruk og utslipp gis kun av sikkerhetsmessige og tekniske hensyn.
🟨	Gul kategori: Kjemikalier i gul kategori omfatter stoffer som ut ifra iboende egenskaper ikke defineres i svart eller rød kategori og som ikke er oppført på PLONOR-listen (se under). Ren gul kategori er uorganiske kjemikalier med lav giftighet eller kjemikalier som brytes ned >60% innen 28 dager. Gul-Y1 er 20-60% nedbrutt og forventes å brytes ned fullstendig over tid. Gul-Y2 er moderat nedbrytbare til ikke giftige og ikke-nedbrytbare komponenter. Y2 skal forsøkes substituert på lik linje med røde kjemikalier.
🟩	Grønn kategori: Stoffer som er oppført på OSPAR-konvensjonens PLONOR-liste (Substances used and discharged offshore which are considered to Pose Little Or No Risk to the Environment). Disse kjemikaliene vurderes å ha ingen eller svært liten negativ miljøeffekt. Kjemikalier i grønn kategori omfatter også vann som inngår i kjemikaliene.

From Ivar Aasen PDO,
Del 2

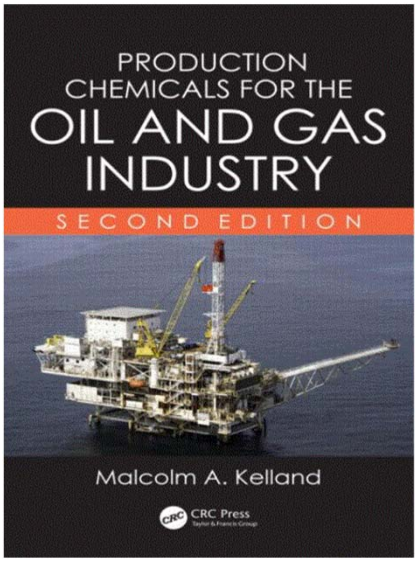
Release and disposal of chemicals

Tabell 7-4 Miljømessige egenskaper til produksjonskjemikalier som vil følge produsert vann fra Johan Castberg-feltet

Type kjemikal	Vannfase/oljefase	Klassifisering
Avleiringshemmer	Vannløselig. Følger produsert vann.	Det er antatt at gult kjemikalie (i klassen Y2) kan velges. Kjemikaliet er moderat bionedbrytbart til ikke bionedbrytbart Det er ikke giftig og vil ikke bioakkumuleres i næringskjeden.
Emulsjonsbryter	Oljeløselig. Følger hovedsakelig oljefasen (95%). 5% følger produsert vann.	Alle disse kjemikaliene er klassifisert som røde, pga det ikke er bionedbrytbart. De er ikke giftige og vil ikke bioakkumulers i næringskjeden.
Vokshemmer	Oljeløselig. Følger oljefasen.	
Skumdemper	Oljeløselig. Følger i all hovedsak oljefasen, lave konsentrasjoner i produsert vann.	
Flokkulant	Vannløselig, men binder seg til oljedråper. Følger hovedsakelig oljefasen (80%). 20% er antatt å følge produsert vann.	
Biocid/Glutaraldehyd	Vannløselig. Følger injeksjonsvannet eller produsert vann.	Kjemikalie er klassifisert som gult pga giftighet. Det er ikke nedbrytbart og vil ikke bioakkumuleres i næringskjeden.

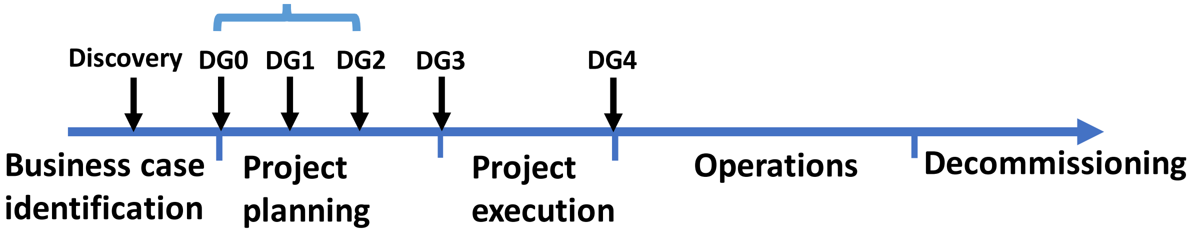
From Johan Castberg PDO, Del 2

More about production chemicals



Flow assurance evaluation during field planning

- Detect potential showstoppers and communicate technical constraints and repercussions to field planner
- Laboratory tests

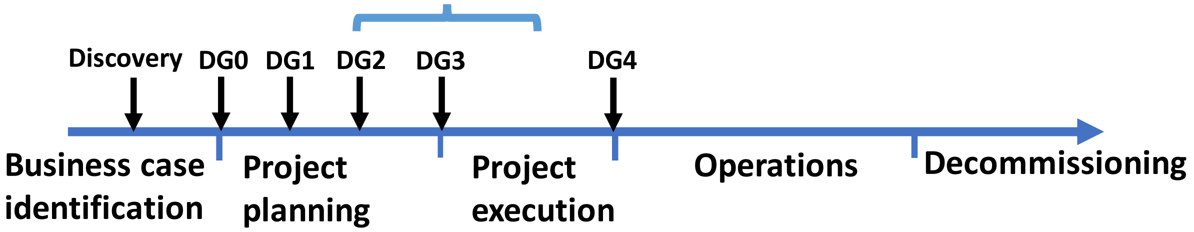


Discovery **DG0** **DG1** **DG2** **DG3** **DG4**

Business case identification **Project planning** **Project execution** **Operations** **Decommissioning**

Flow assurance evaluation during field planning

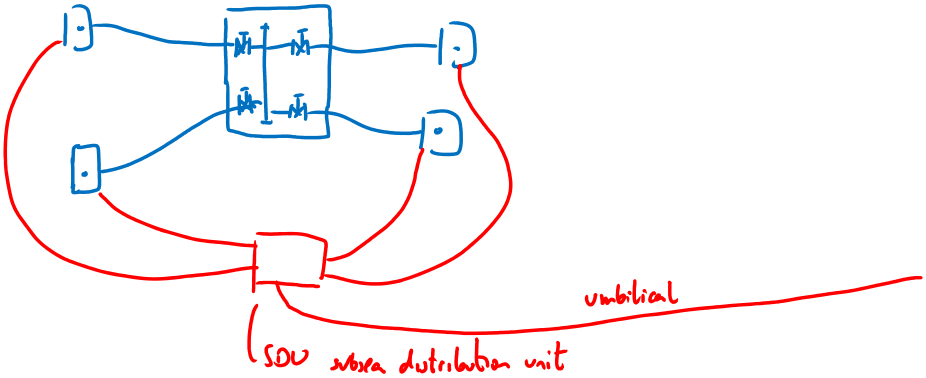
Refine the flow assurance strategy
-More laboratory tests
-Management plan
-prediction of p and T
-Study of startup and shutdown
-System design and verification
-FIV



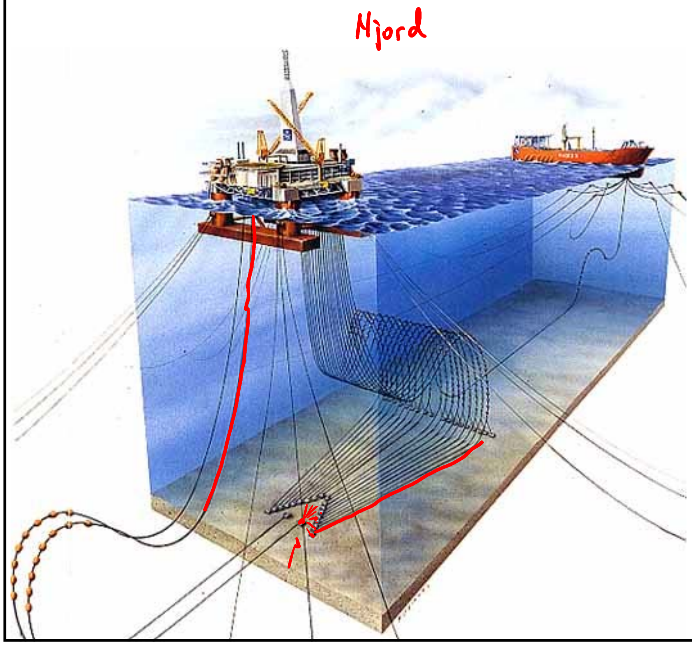
Discovery **DG0** **DG1** **DG2** **DG3** **DG4**

Business case identification **Project planning** **Project execution** **Operations** **Decommissioning**

Injection of production chemicals subsea



Injection of production chemicals



Umbilicals, injection of production chemicals

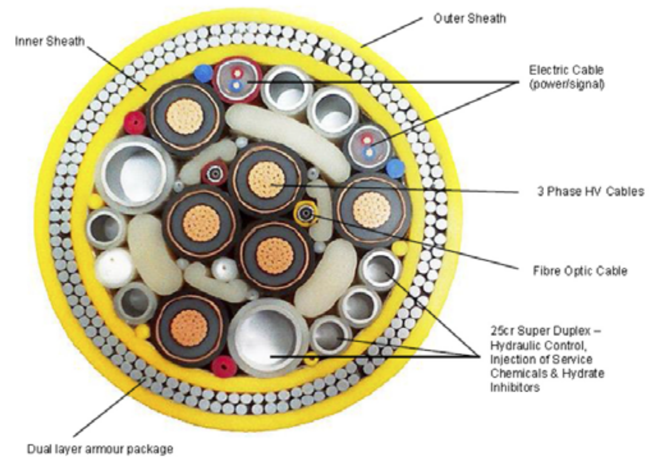
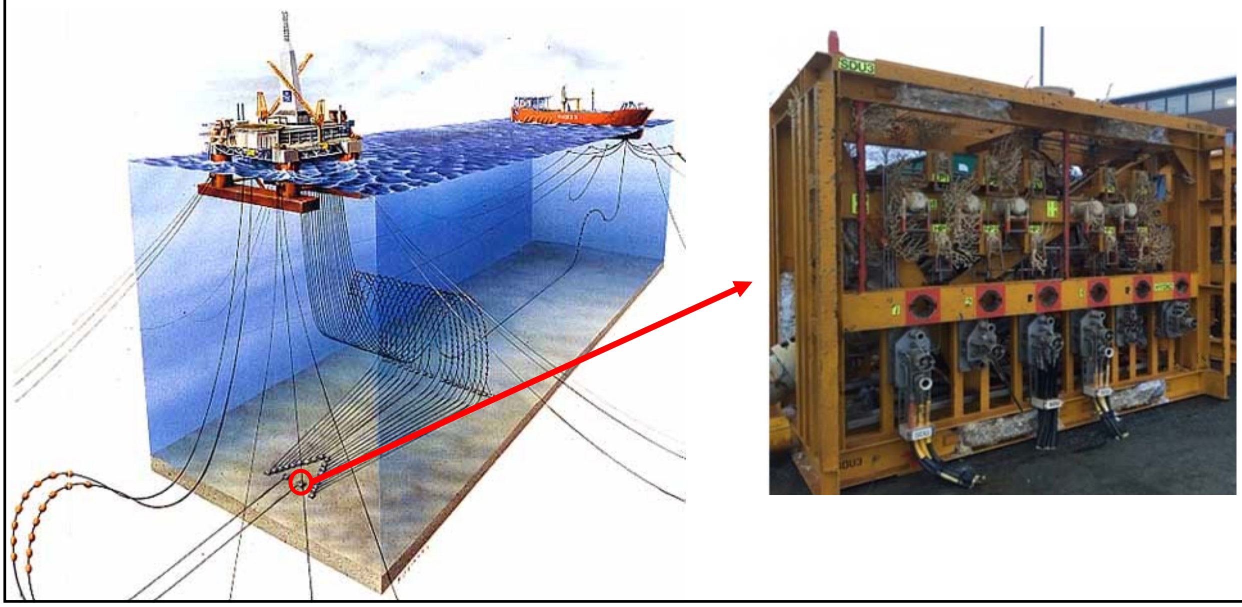
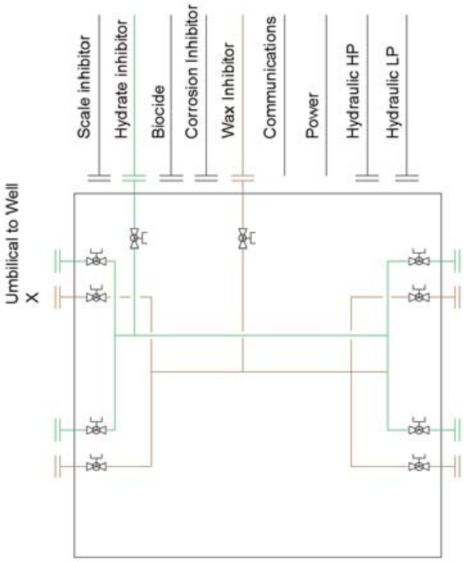


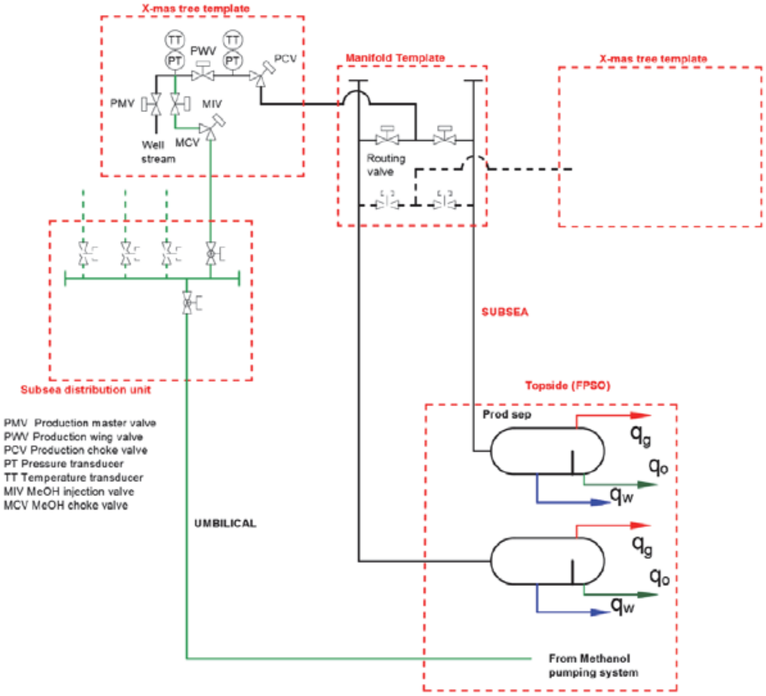
Figure 3 – Umbilical Cross Section Example

Umbilicals, injection of production chemicals

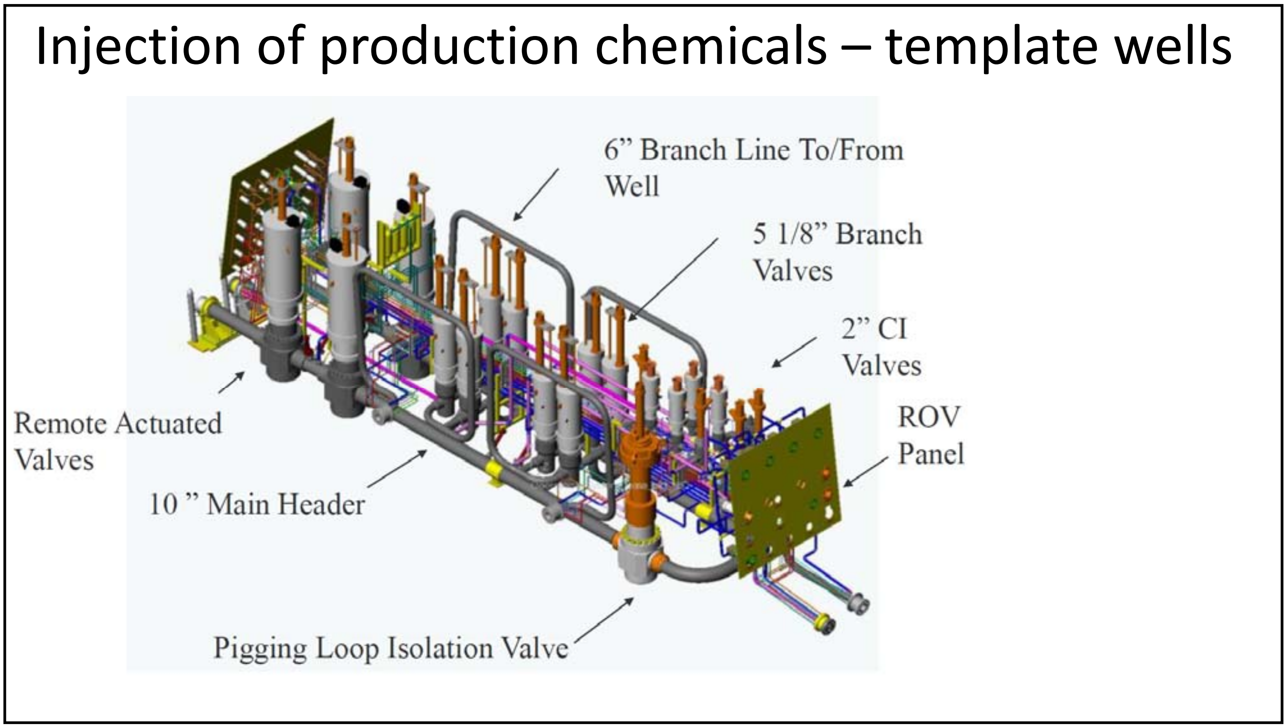


Release and disposal of chemicals

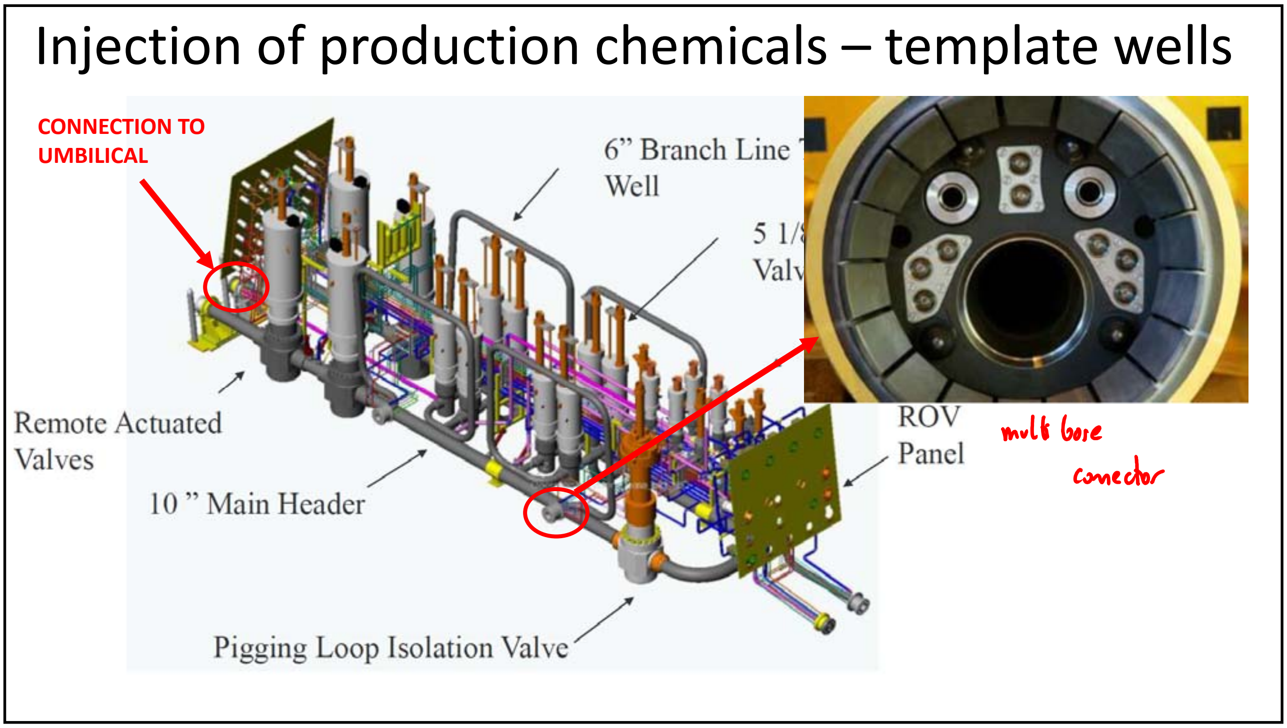




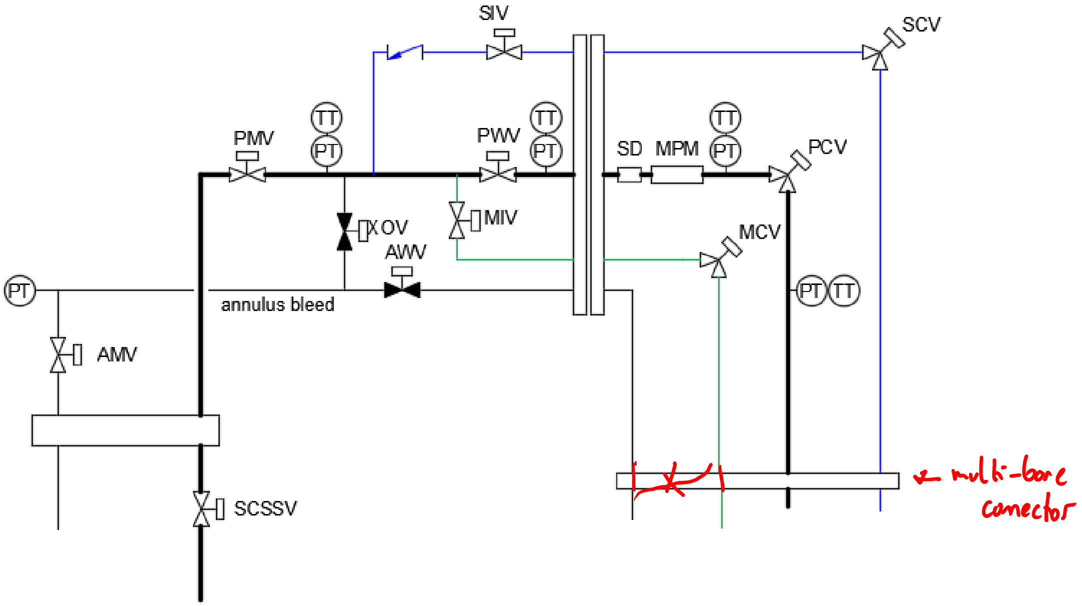
PMV	Production master valve
PWV	Production wing valve
PCV	Production choke valve
PT	Pressure transducer
TT	Temperature transducer
MIV	MeOH injection valve
MCV	MeOH choke valve



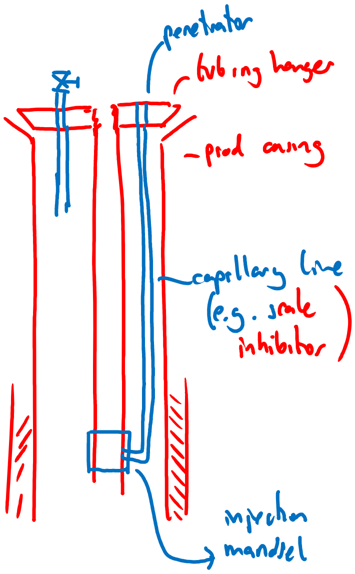
Injection of production chemicals – template wells

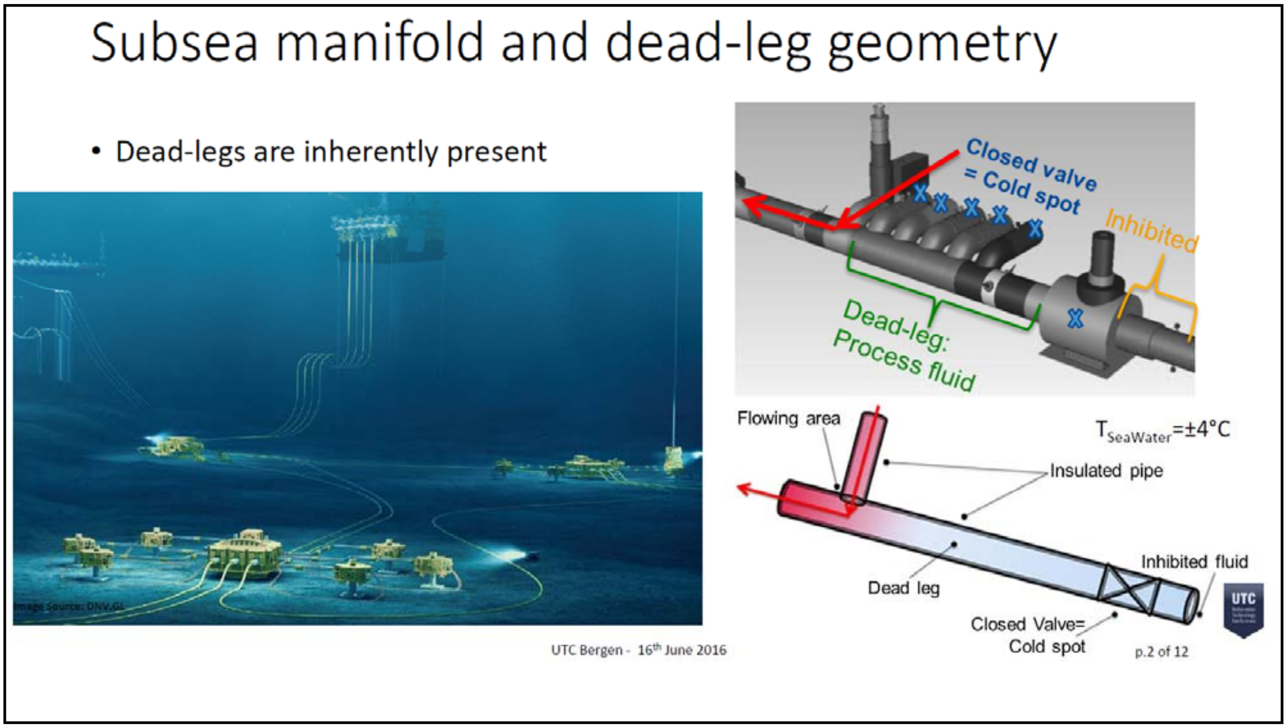


Injection of production chemicals – template wells



Injection of production chemicals in well



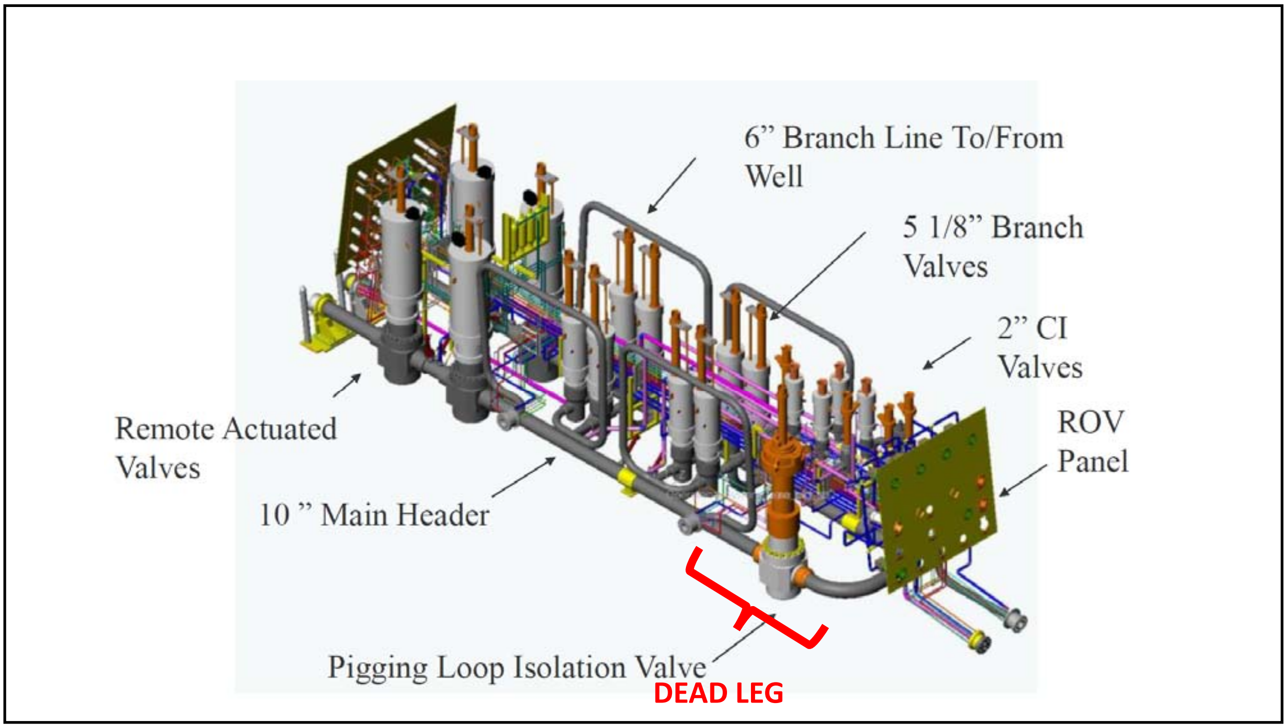


Subsea manifold and dead-leg geometry

- Dead-legs are inherently present

UTC Bergen - 16th June 2016

p.2 of 12



Tools for analysis

- Laboratory tests of fluids (oil, gas, water)
- Steady state flow simulators (Hysys, Gap, Pipesim, Olga, Leda, FlowManager)
- Transient flow simulators (Olga, LedaFlow, FlowManager, Hysys)
- Thermodynamic or PVT simulators (PVTsim, Hysys)
- Standards (DNV, API)
- CFD simulation for 3D flow analysis of pressure and temperature (Comsol, Ansys)
- Finite element analysis for structural analysis and heat transfer in solids (Abacus, Ansys)

NTNU

Kunnskap for en bedre verden

Introduction to PETEX

5 April 2022

Prepared by:
- Agung Gedde Angga
- Milan Stanko
- Salma Alkindira

Presented by:
- Leonardo Sales

Outline

- Licensing
- PROSPER
- MBAL
- GAP: Set up Production Network
- GAP: Solve Production Network

Outline

- Licensing
- PROSPER
- MBAL
- GAP: Set up Production Network
- GAP: Solve Production Network

Licensing

Licensing Setup Wizard MF

IPM programs require a licensing system to run.

The licensing system can either be a bitlock that is plugged into your computer that only you can use OR a server on your network that shares licenses with other users on your network.

The license setup wizard is used to help you configure your PC to use your chosen licensing system.

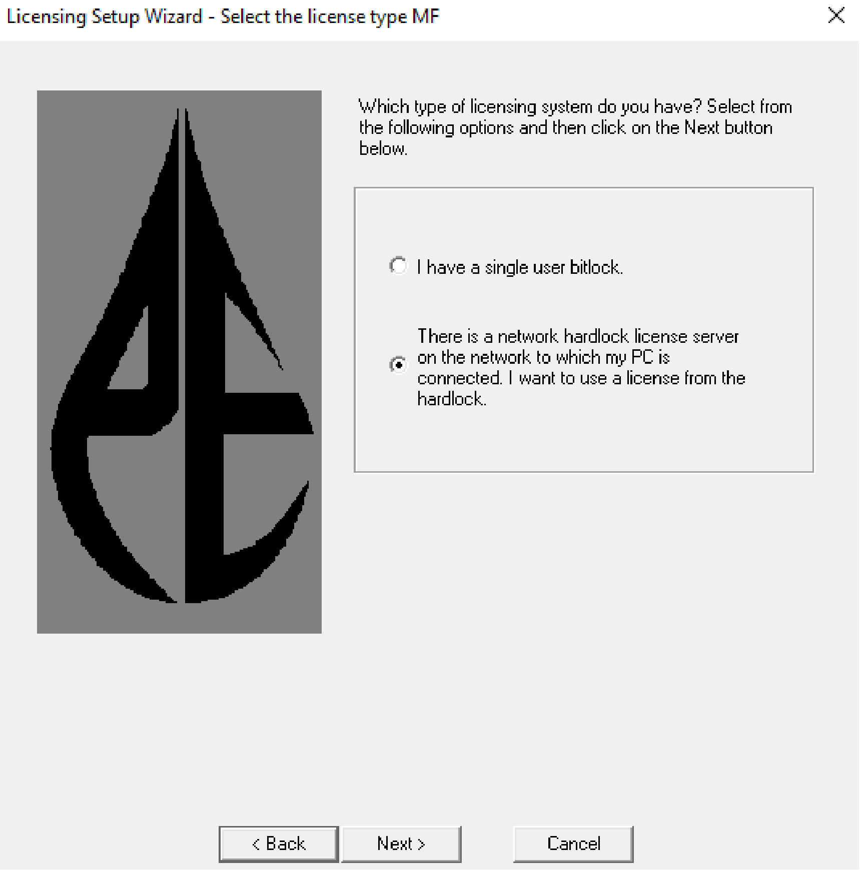
You wil be asked questions about your licensing system and PC. The Wizard will try to configure your PC to use the licensing system.

If you wish to stop the Wizard at any time, click Cancel.

If you want to re-run the Wizard in the future, select Start-Programs-Petroleum Experts IPM X-Utilities-Setup Licensing Wizard

-only 10 licenses are available
-please work in groups (9)

Licensing



Licensing Setup Wizard - Select the license type MF

Which type of licensing system do you have? Select from the following options and then click on the Next button below.

○ I have a single user bitlock.

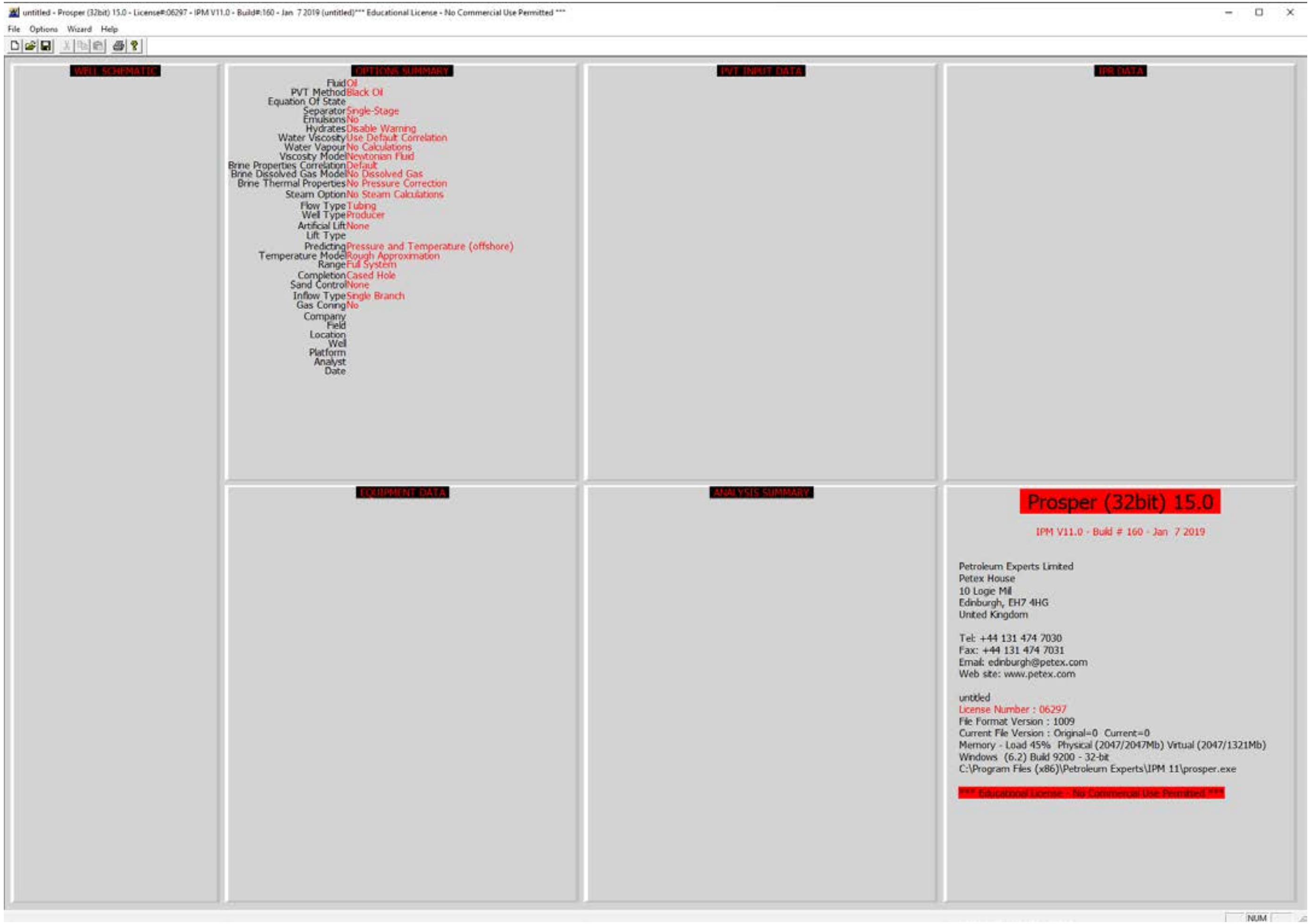
● There is a network hardlock license server on the network to which my PC is connected. I want to use a license from the hardlock.

-only 10 licenses are available

-please work in groups (9)

Outline

- Licensing
- PROSPER
- MBAL
- GAP: Set up Production Network
- GAP: Solve Production Network



untitled - Prosper (32bit) 15.0 - License#:06297 - IPM V11.0 - Build#:160 - Jan 7 2019 (untitled)*** Educational License - No Commercial Use Permitted ***

Fluid	Oil
PVT Method	Black Oil
Equation Of State	
Separator	Single-Stage
Emulsions	No
Hydrates	Disable Warning
Water Viscosity	Use Default Correlation
Water Vapour	No Calculations
Viscosity Model	Newtonian Fluid
Brine Properties Correlation	Default
Brine Dissolved Gas Model	No Dissolved Gas
Brine Thermal Properties	No Pressure Correction
Steam Option	No Steam Calculations
Flow Type	Tubing
Well Type	Producer
Artificial Lift	None
Lift Type	
Predicting	Pressure and Temperature (offshore)
Temperature Model	Rough Approximation
Range	Full System
Completion	Cased Hole
Sand Control	None
Inflow Type	Single Branch
Gas Coning	No
Company	
Field	
Location	
Well	
Platform	
Analyst	
Date	

Prosper (32bit) 15.0

IPM V11.0 - Build # 160 - Jan 7 2019

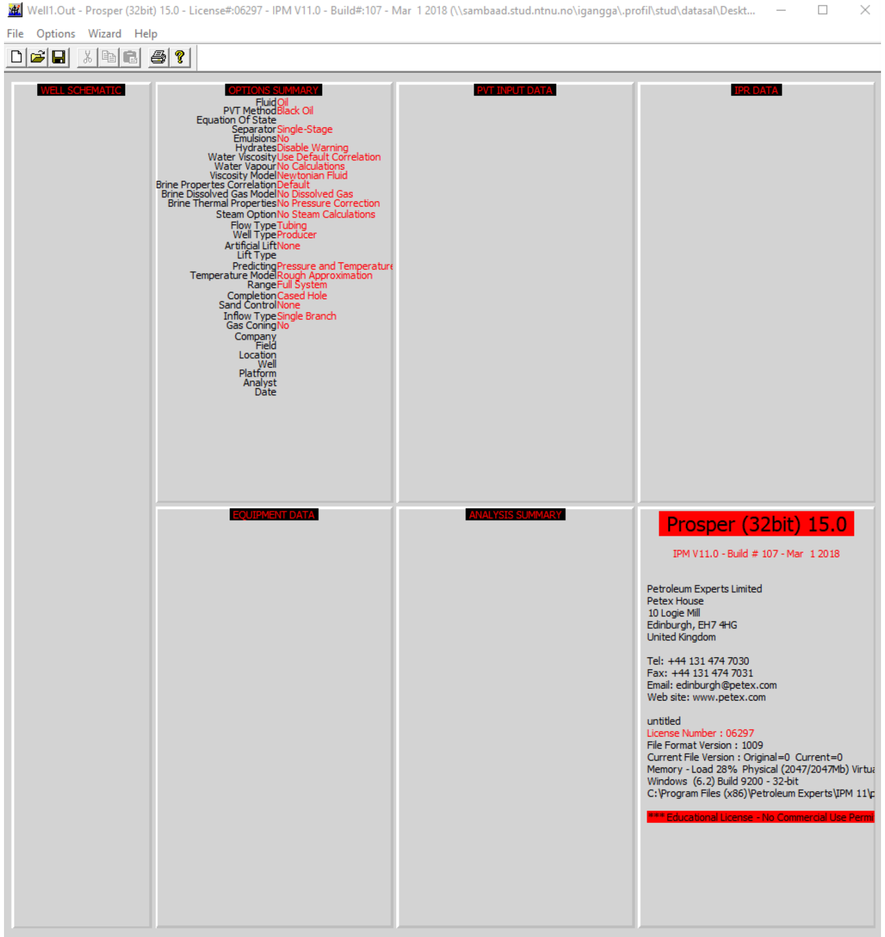
Petroleum Experts Limited
Petex House
10 Logie Mill
Edinburgh, EH7 4HG
United Kingdom

Tel: +44 131 474 7030
Fax: +44 131 474 7031
Email: edinburgh@petex.com
Web site: www.petex.com

untitled
License Number : 06297
File Format Version : 1009
Current File Version : Original=0 Current=0
Memory - Load 45% Physical (2047/2047Mb) Virtual (2047/1321Mb)
Windows (6.2) Build 9200 - 32-bit
C:\Program Files (x86)\Petroleum Experts\IPM 11\prosper.exe

*** Educational License - No Commercial Use Permitted ***

Prosper (Well Model)



Well1.Out - Prosper (32bit) 15.0 - License#:06297 - IPM V11.0 - Build#:107 - Mar 1 2018 (\\sambaad.stud.ntnu.no\igangga\.profil\stud\datasal\Deskt...

Fluid	Oil
PVT Method	Black Oil
Equation Of State	
Separator	Single-Stage
Emulsions	No
Hydrates	Disable Warning
Water Viscosity	Use Default Correlation
Water Vapour	No Calculations
Viscosity Model	Newtonian Fluid
Brine Propertes Correlation	Default
Brine Dissolved Gas Model	No Dissolved Gas
Brine Thermal Properties	No Pressure Correction
Steam Option	No Steam Calculations
Flow Type	Tubing
Well Type	Producer
Artificial Lift	None
Lift Type	
Predicting	Pressure and Temperature
Temperature Model	Rough Approximation
Range	Full System
Completion	Cased Hole
Sand Control	None
Inflow Type	Single Branch
Gas Coning	No
Company	
Field	
Location	
Well	
Platform	
Analyst	
Date	

Prosper (32bit) 15.0

IPM V11.0 - Build # 107 - Mar 1 2018

Petroleum Experts Limited
Petex House
10 Logie Mill
Edinburgh, EH7 4HG
United Kingdom

Tel: +44 131 474 7030
Fax: +44 131 474 7031
Email: edinburgh@petex.com
Web site: www.petex.com

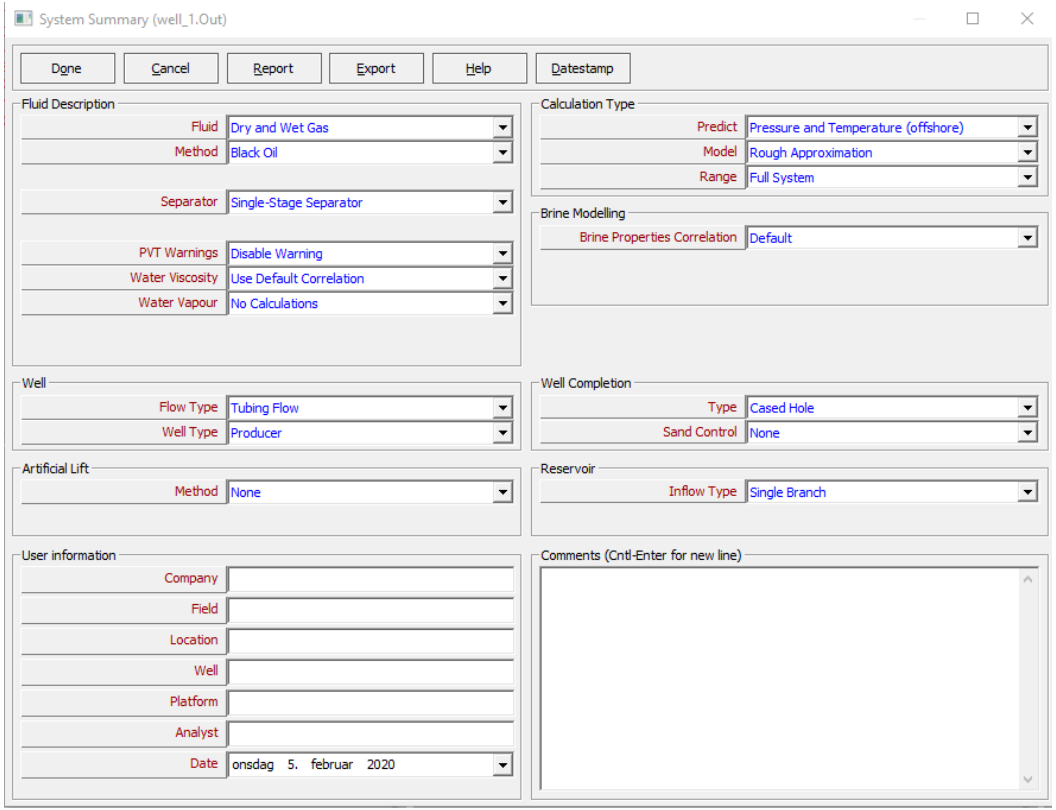
untitled
License Number : 06297
File Format Version : 1009
Current File Version : Original=0 Current=0
Memory - Load 28% Physical (2047/2047Mb) Virtua
Windows (6.2) Build 9200 - 32-bit
C:\Program Files (x86)\Petroleum Experts\IPM 11\p

*** Educational License - No Commercial Use Permi

-open PROSPER

-save as

Prosper – System Summary



Fluid Description

Fluid	Dry and Wet Gas
Method	Black Oil
Separator	Single-Stage Separator
PVT Warnings	Disable Warning
Water Viscosity	Use Default Correlation
Water Vapour	No Calculations

Calculation Type

Predict	Pressure and Temperature (offshore)
Model	Rough Approximation
Range	Full System

Brine Modelling

Brine Properties Correlation	Default

Well

Flow Type	Tubing Flow
Well Type	Producer

Well Completion

Type	Cased Hole
Sand Control	None

Artificial Lift

Method	None

Reservoir

Inflow Type	Single Branch

User information

Company	
Field	
Location	
Well	
Platform	
Analyst	
Date	onsdag 5. februar 2020

Comments (Cntl-Enter for new line)

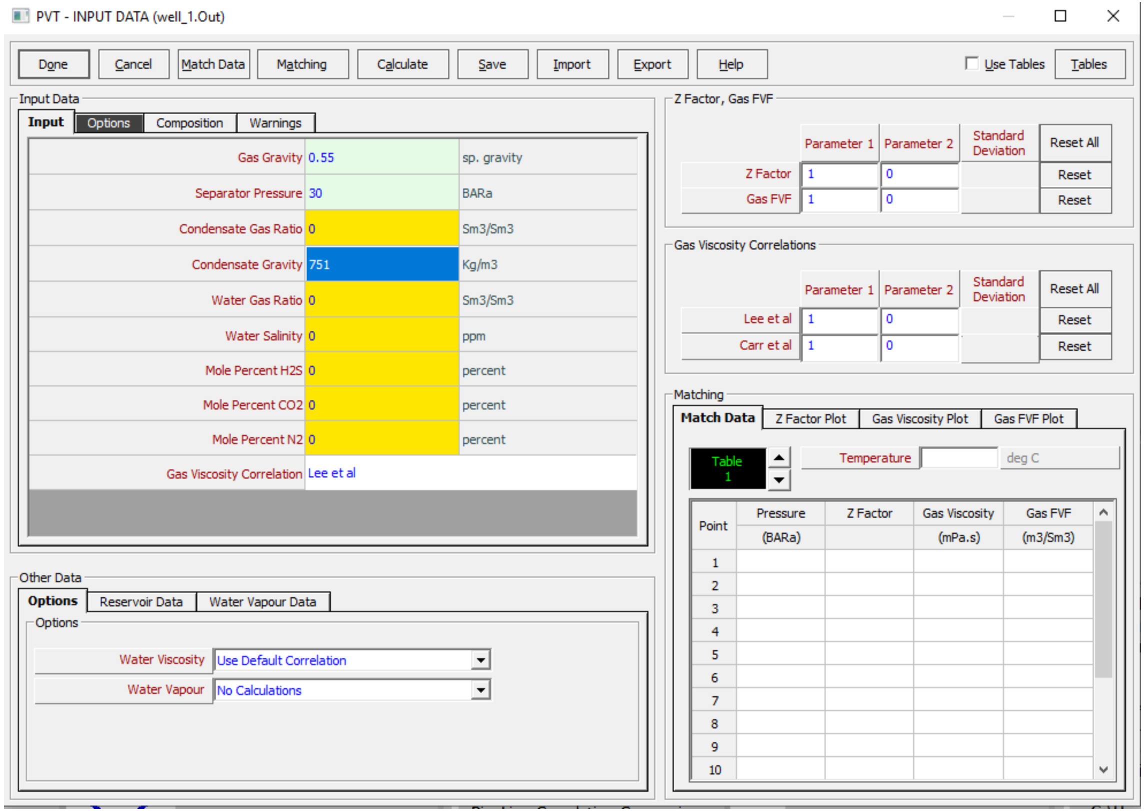
-use default setting

-Fluid: dry and wet gas

-Method: Black Oil

-change unit system to Norwegian S.I.

Prosper – PVT Input Data



Gas Gravity	0.55	sp. gravity
Separator Pressure	30	BARa
Condensate Gas Ratio	0	Sm3/Sm3
Condensate Gravity	751	Kg/m3
Water Gas Ratio	0	Sm3/Sm3
Water Salinity	0	ppm
Mole Percent H2S	0	percent
Mole Percent CO2	0	percent
Mole Percent N2	0	percent
Gas Viscosity Correlation	Lee et al	

	Parameter 1	Parameter 2	Standard Deviation
Z Factor	1	0	
Gas FVF	1	0	

	Parameter 1	Parameter 2	Standard Deviation
Lee et al	1	0	
Carr et al	1	0	

Temperature deg C

Point	Pressure (BARa)	Z Factor	Gas Viscosity (mPa.s)	Gas FVF (m3/Sm3)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Water Viscosity: Use Default Correlation

Water Vapour: No Calculations

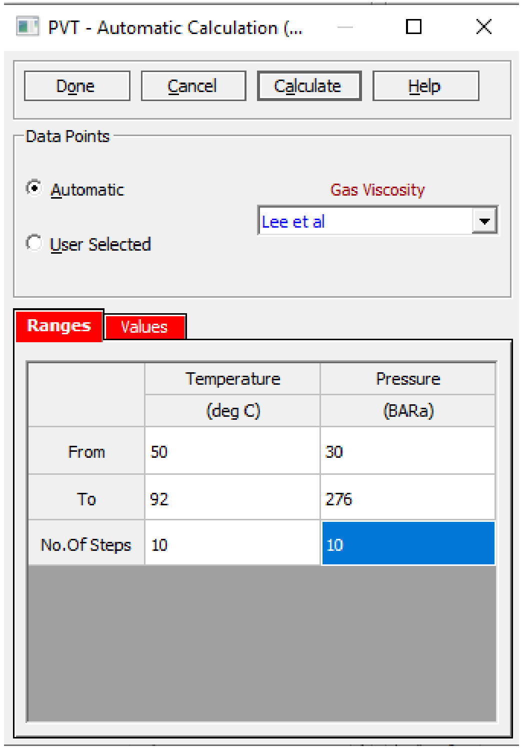
-input PVT data (gas gravity, psep, condensate gravity)

-choose PVT correlation

Prosper – PVT Input Data

-calculate PVT properties

-input Tres & Pres



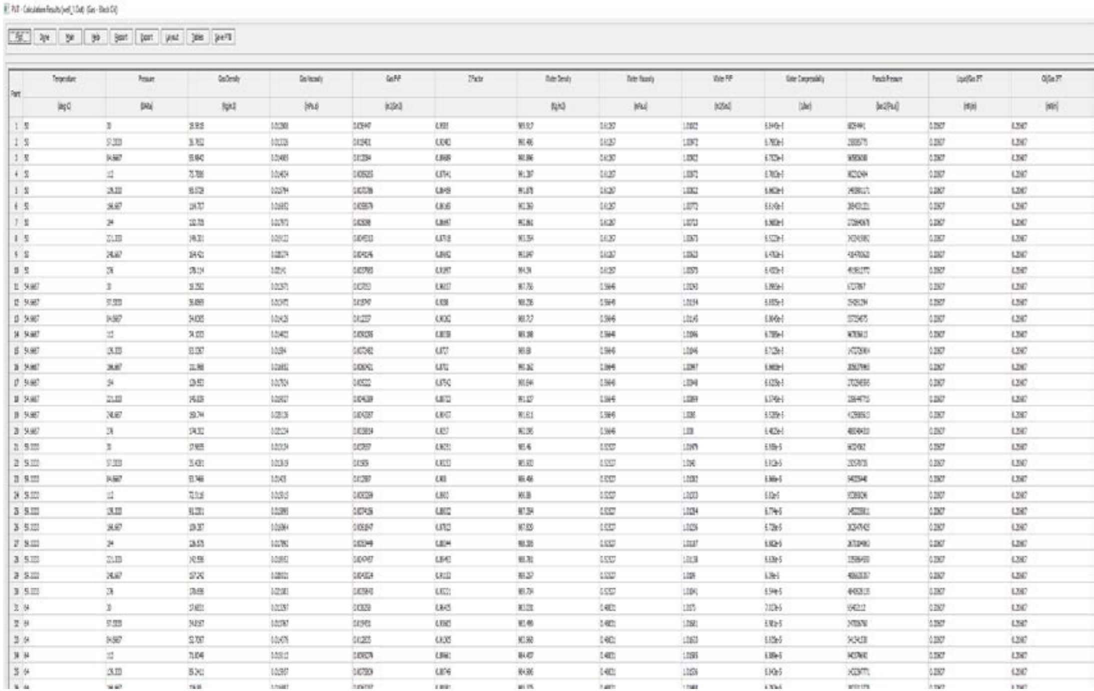
Data Points

● Automatic

○ User Selected

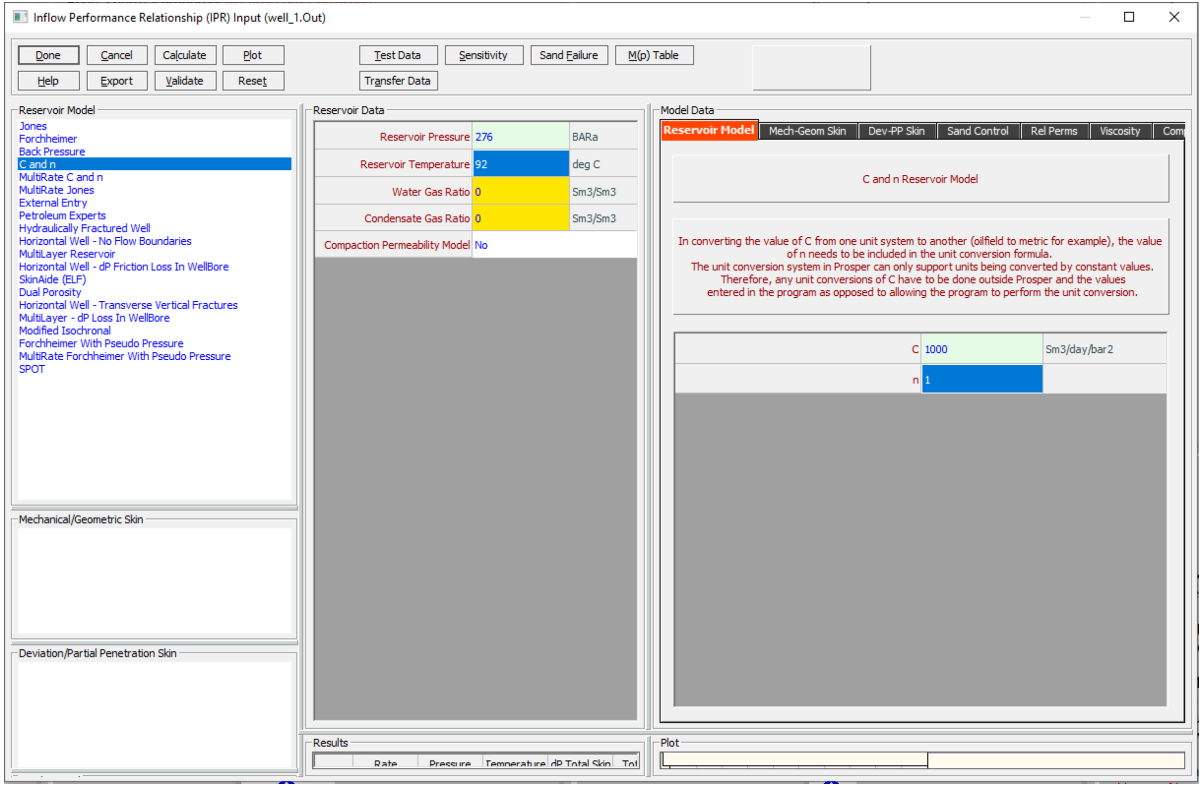
Gas Viscosity: Lee et al

	Temperature (deg C)	Pressure (BARa)
From	50	30
To	92	276
No.Of Steps	10	10



Prosper – IPR Data

-Reservoir model: C and n
-input reservoir data (Pres, Tres, C, n)



Inflow Performance Relationship (IPR) Input (well_1.Out)

Reservoir Model: C and n

Reservoir Data

Reservoir Pressure	276	BARa
Reservoir Temperature	92	deg C
Water Gas Ratio	0	Sm3/Sm3
Condensate Gas Ratio	0	Sm3/Sm3
Compaction Permeability Model	No	

Model Data

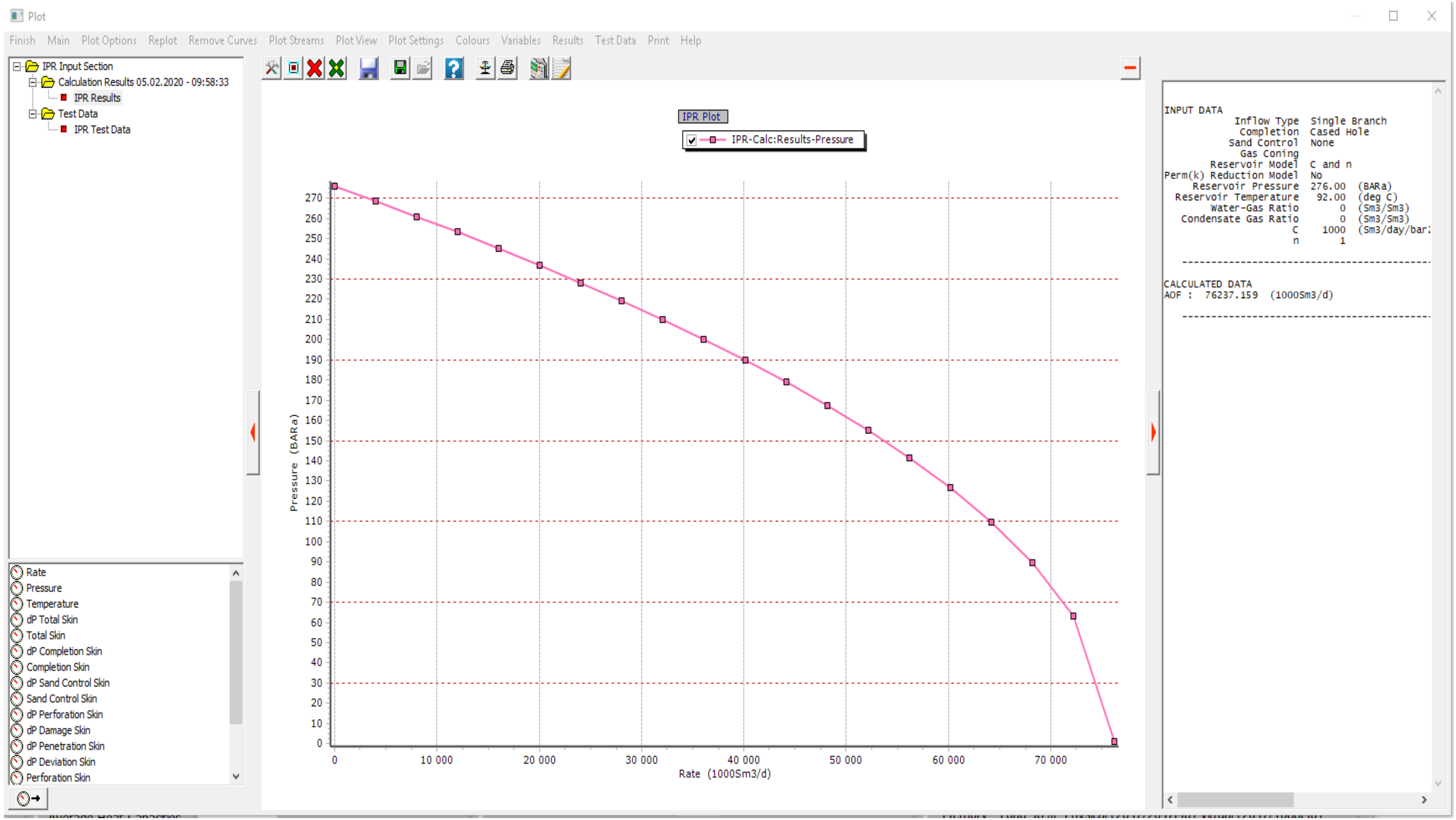
C and n Reservoir Model

In converting the value of C from one unit system to another (oilfield to metric for example), the value of n needs to be included in the unit conversion formula.
The unit conversion system in Prosper can only support units being converted by constant values.
Therefore, any unit conversions of C have to be done outside Prosper and the values entered in the program as opposed to allowing the program to perform the unit conversion.

C	1000	Sm3/day/bar2
n	1	

Prosper – IPR Data

-calculate & plot



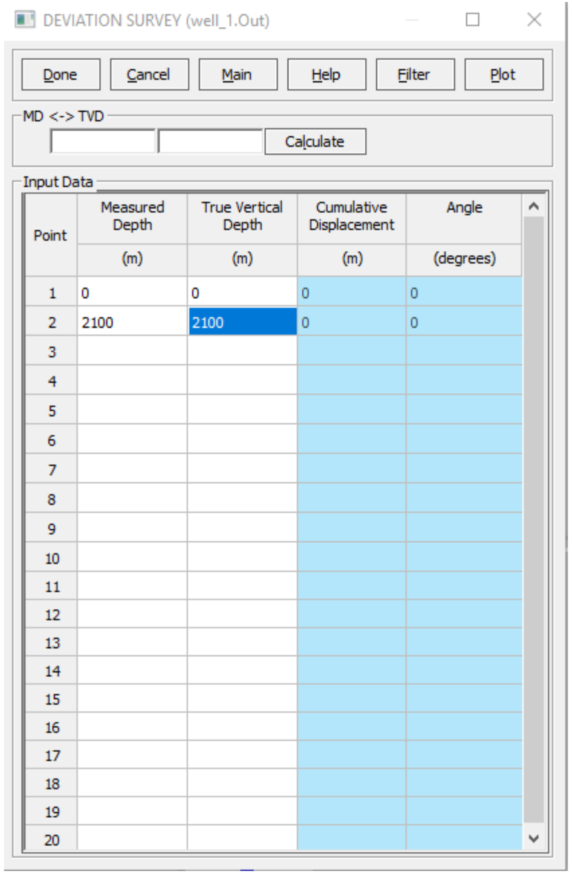
```
INPUT DATA
            Inflow Type  Single Branch
             Completion  Cased Hole
           Sand Control  None
             Gas Coning
        Reservoir Model  C and n
Perm(k) Reduction Model  No
     Reservoir Pressure  276.00  (BARa)
  Reservoir Temperature   92.00  (deg C)
        Water-Gas Ratio       0  (Sm3/Sm3)
   Condensate Gas Ratio       0  (Sm3/Sm3)
                      C    1000  (Sm3/day/bar:
                      n       1

   -------------------------------------------

CALCULATED DATA
AOF :  76237.159  (1000Sm3/d)

   -------------------------------------------
```

Prosper – Equipment Data



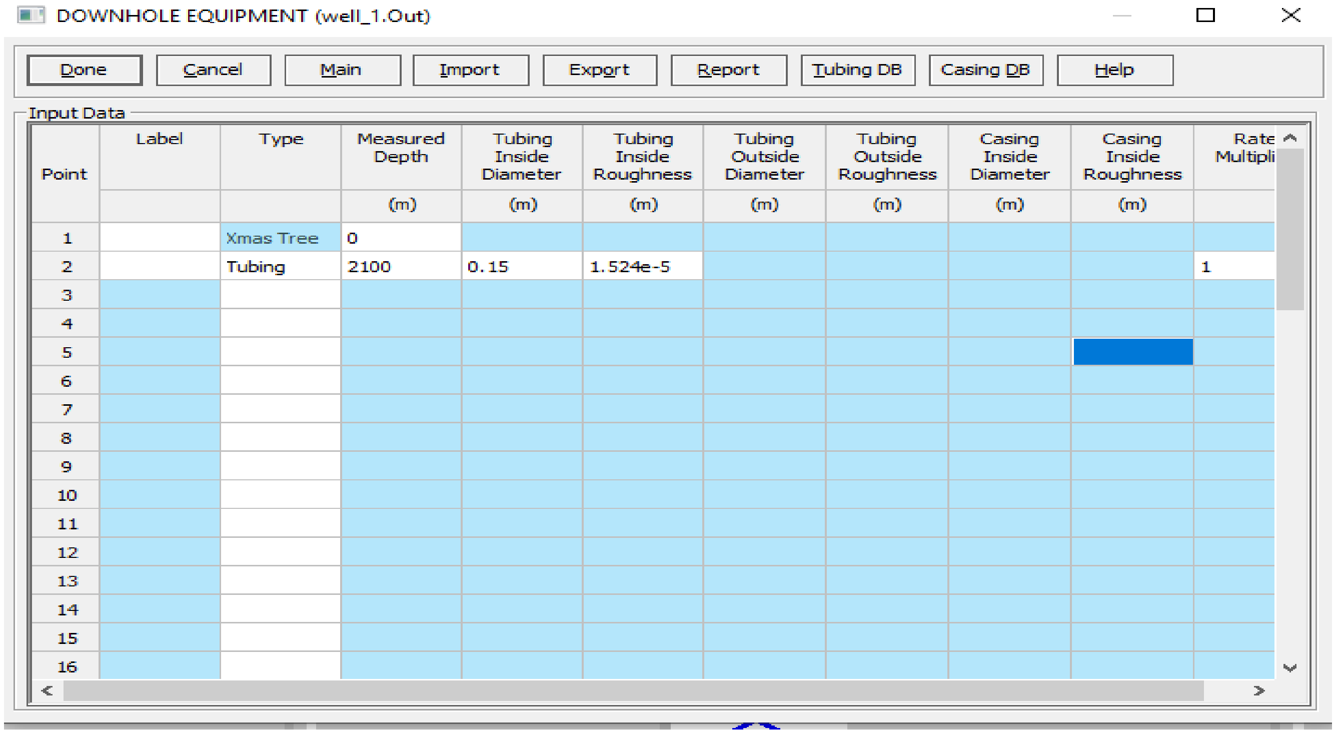
Point	Measured Depth (m)	True Vertical Depth (m)	Cumulative Displacement (m)	Angle (degrees)
1	0	0	0	0
2	2100	2100	0	0
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

-input deviation survey

-neglect surface equipment (since we only consider the flow to wellhead)

Prosper – Equipment Data

-input downhole equipment
-pay attention with the measured depth, unit of tubing ID, & roughness

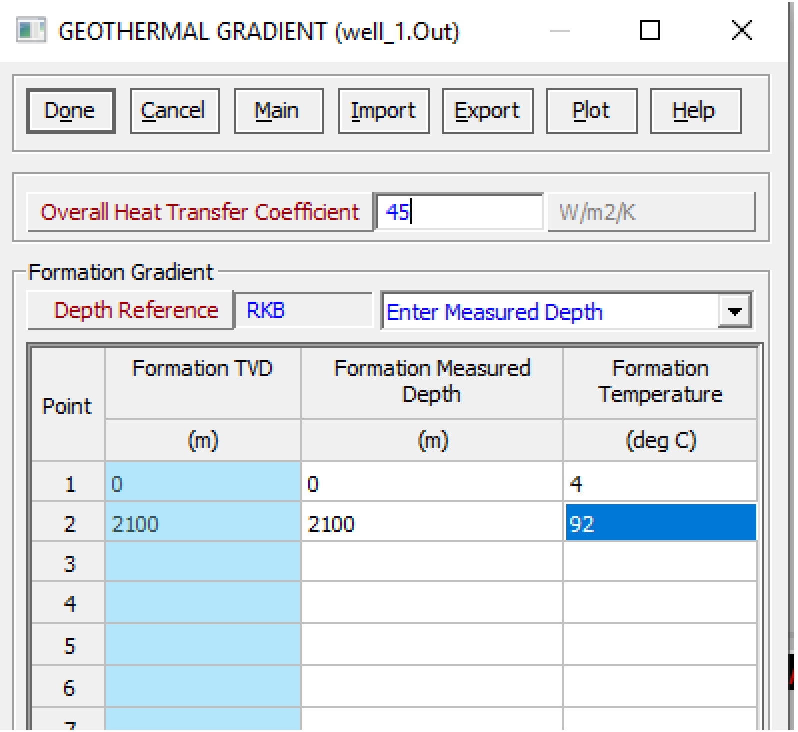


DOWNHOLE EQUIPMENT (well_1.Out)

Input Data

Point	Label	Type	Measured Depth (m)	Tubing Inside Diameter (m)	Tubing Inside Roughness (m)	Tubing Outside Diameter (m)	Tubing Outside Roughness (m)	Casing Inside Diameter (m)	Casing Inside Roughness (m)	Rate Multipli
1		Xmas Tree	0							
2		Tubing	2100	0.15	1.524e-5					1
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										

Prosper – Equipment Data



Overall Heat Transfer Coefficient 45 W/m2/K

Formation Gradient

Depth Reference RKB Enter Measured Depth

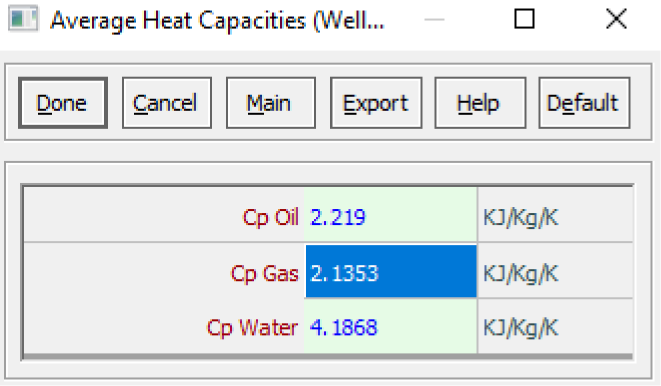
Point	Formation TVD (m)	Formation Measured Depth (m)	Formation Temperature (deg C)
1	0	0	4
2	2100	2100	92
3			
4			
5			
6			

-input geothermal gradient & overall heat transfer coefficient

Prosper – Equipment Data

-input average heat capacities

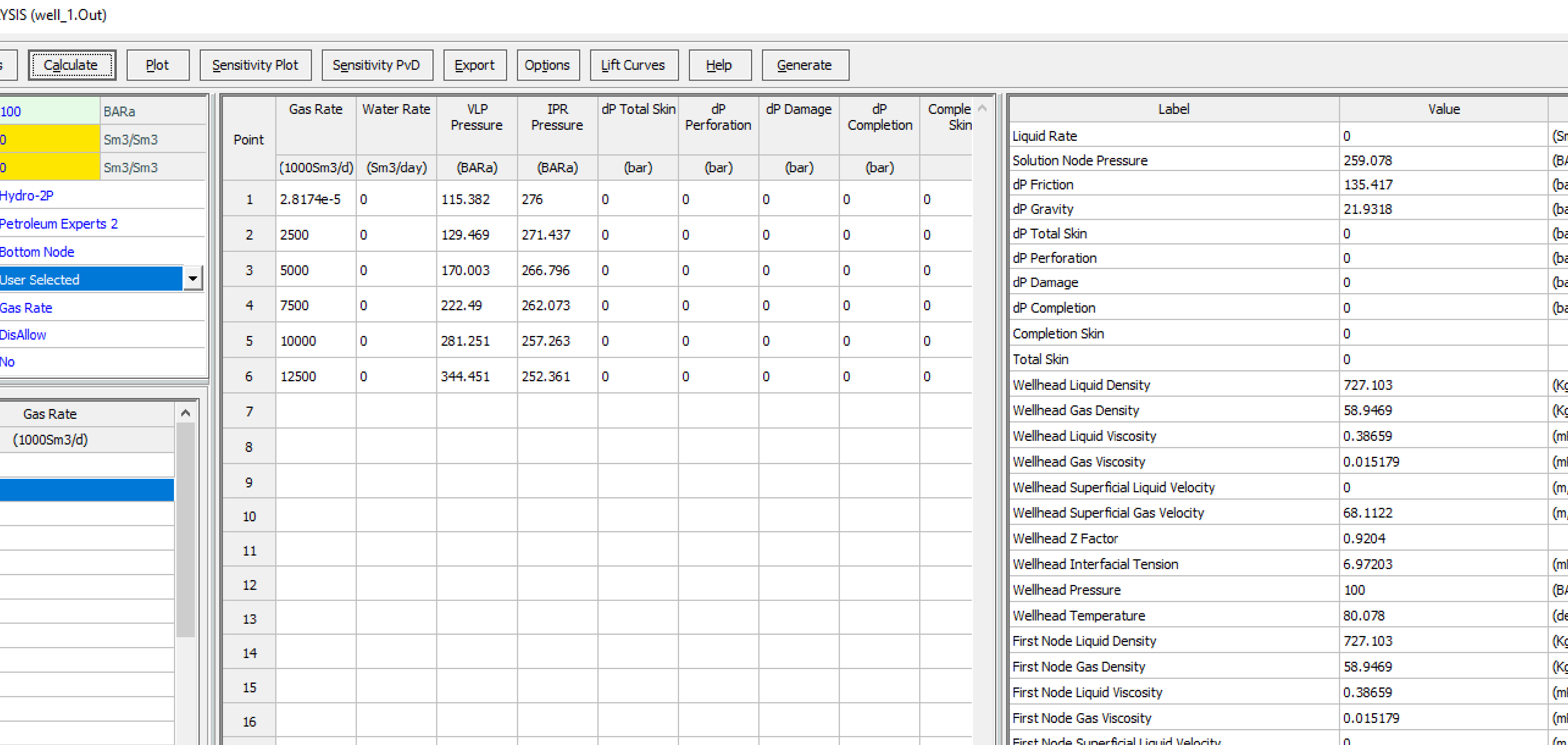
-neglect gauge details



Cp Oil	2.219	KJ/Kg/K
Cp Gas	2.1353	KJ/Kg/K
Cp Water	4.1868	KJ/Kg/K

Prosper – Analysis Summary

-select “system” option



100	BARa
0	Sm3/Sm3
0	Sm3/Sm3
Hydro-2P	
Petroleum Experts 2	
Bottom Node	
User Selected	
Gas Rate	
DisAllow	
No	

Gas Rate
(1000Sm3/d)

Point	Gas Rate	Water Rate	VLP Pressure	IPR Pressure	dP Total Skin	dP Perforation	dP Damage	dP Completion	Comple Skin
	(1000Sm3/d)	(Sm3/day)	(BARa)	(BARa)	(bar)	(bar)	(bar)	(bar)	
1	2.8174e-5	0	115.382	276	0	0	0	0	0
2	2500	0	129.469	271.437	0	0	0	0	0
3	5000	0	170.003	266.796	0	0	0	0	0
4	7500	0	222.49	262.073	0	0	0	0	0
5	10000	0	281.251	257.263	0	0	0	0	0
6	12500	0	344.451	252.361	0	0	0	0	0
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									

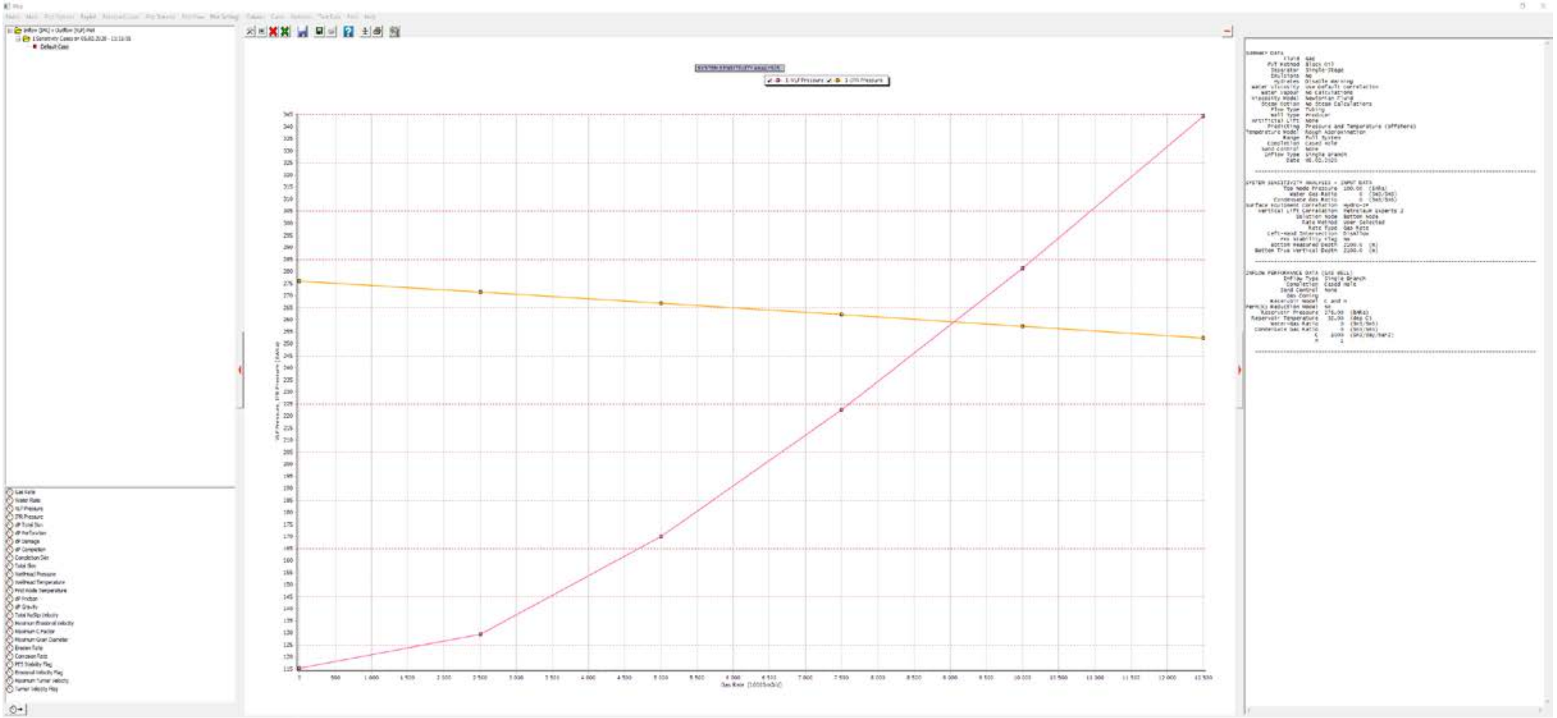
Label	Value	
Liquid Rate	0	(Sr
Solution Node Pressure	259.078	(BA
dP Friction	135.417	(ba
dP Gravity	21.9318	(ba
dP Total Skin	0	(ba
dP Perforation	0	(ba
dP Damage	0	(ba
dP Completion	0	(ba
Completion Skin	0	
Total Skin	0	
Wellhead Liquid Density	727.103	(Kg
Wellhead Gas Density	58.9469	(Kg
Wellhead Liquid Viscosity	0.38659	(ml
Wellhead Gas Viscosity	0.015179	(ml
Wellhead Superficial Liquid Velocity	0	(m,
Wellhead Superficial Gas Velocity	68.1122	(m,
Wellhead Z Factor	0.9204	
Wellhead Interfacial Tension	6.97203	(ml
Wellhead Pressure	100	(BA
Wellhead Temperature	80.078	(de
First Node Liquid Density	727.103	(Kg
First Node Gas Density	58.9469	(Kg
First Node Liquid Viscosity	0.38659	(ml
First Node Gas Viscosity	0.015179	(ml
First Node Superficial Liquid Velocity	0	(m

Prosper – Analysis Summary

- Estimate the producing rate using flow equilibrium assuming that the well is producing against a constant wellhead pressure of 100 bar.

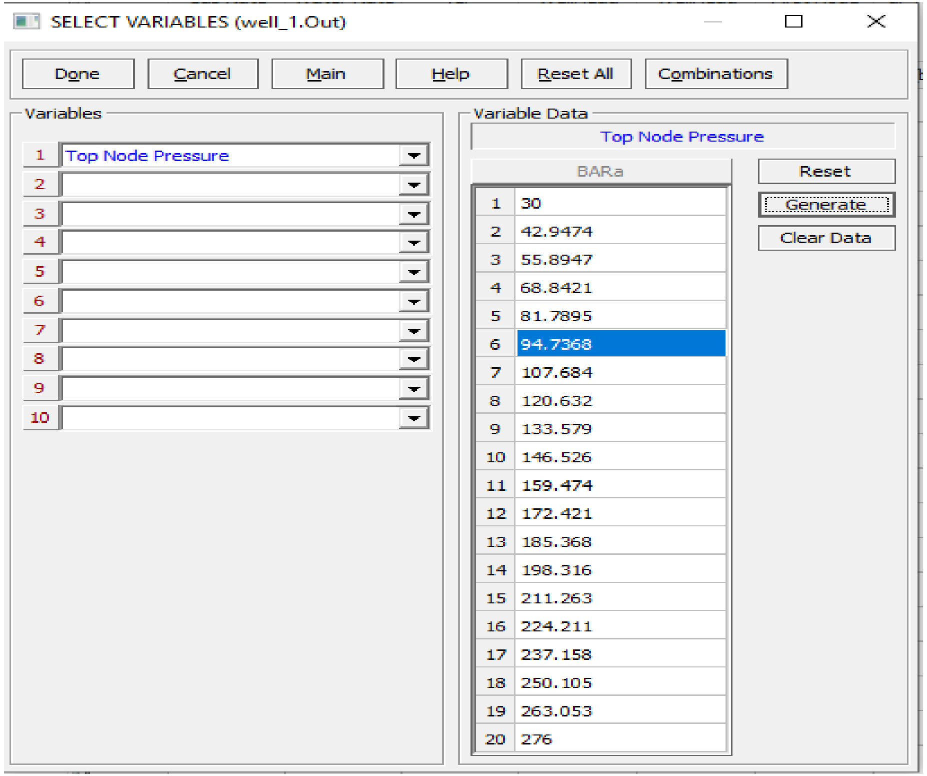
-calculate

-plot → system plot → plot all cases → X-axis: liquid rate, Y-axis: VLP & IPR pressure



Prosper – Analysis Summary

- Generate and export lift curves to be used in GAP (in the following exercise). p_{wh} range: 30-276 bara



SELECT VARIABLES (well_1.Out)

Variables

1 Top Node Pressure
2
3
4
5
6
7
8
9
10

Variable Data

Top Node Pressure

	BARa
1	30
2	42.9474
3	55.8947
4	68.8421
5	81.7895
6	94.7368
7	107.684
8	120.632
9	133.579
10	146.526
11	159.474
12	172.421
13	185.368
14	198.316
15	211.263
16	224.211
17	237.158
18	250.105
19	263.053
20	276

-generate VLP table
-select “VLP” option
-go to “cases”
-select variables & generate variable data (you can use linear spacing & 20 breakpoints). Then you have 20 cases

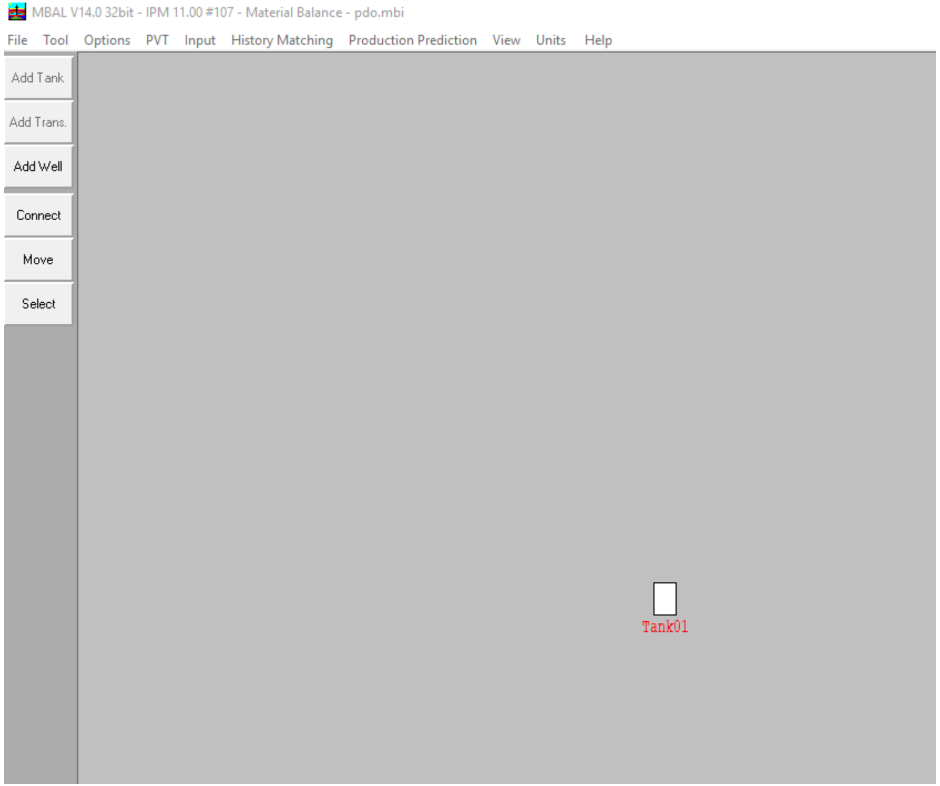
Prosper – Analysis Summary

-input Pwh = 100 bara (just to avoid it complaining)
-calculate
-select “export lift curve” → choose “Petroleum Experts – GAP/MBAL” → save in the same directory as your prosper file, and with the same name
-done

Outline

- Licensing
- PROSPER
- MBAL
- GAP: Set up Production Network
- GAP: Solve Production Network

MBAL (Reservoir Model)

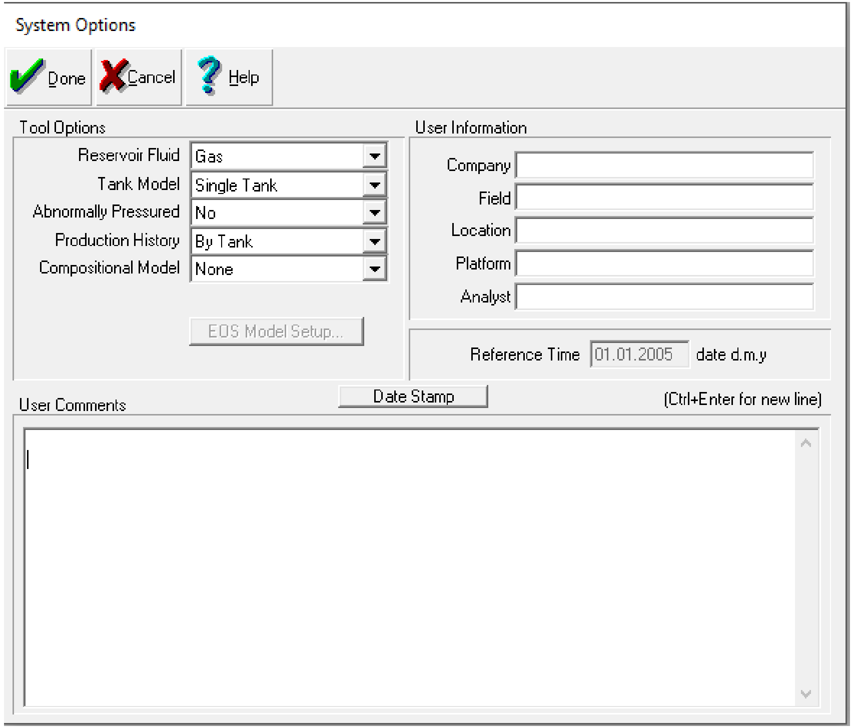


-open MBAL

-save as

-select “tool” → “material balance”

MBAL - Options



Reservoir Fluid: Gas
Tank Model: Single Tank
Abnormally Pressured: No
Production History: By Tank
Compositional Model: None

Company:
Field:
Location:
Platform:
Analyst:

Reference Time: 01.01.2005 date d.m.y

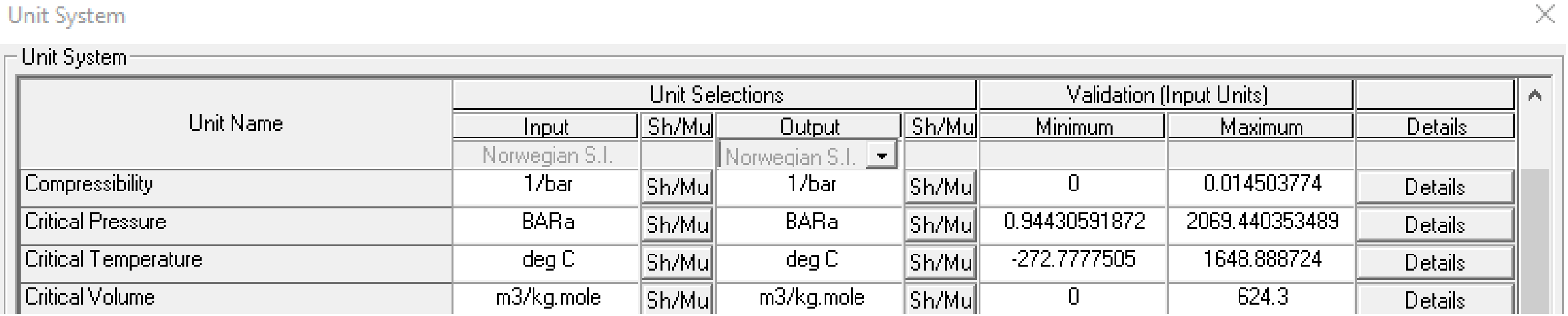
-select “options”

-use default setting

MBAL – Unit System

-select “Units”

-change unit system to Norwegian S.I.



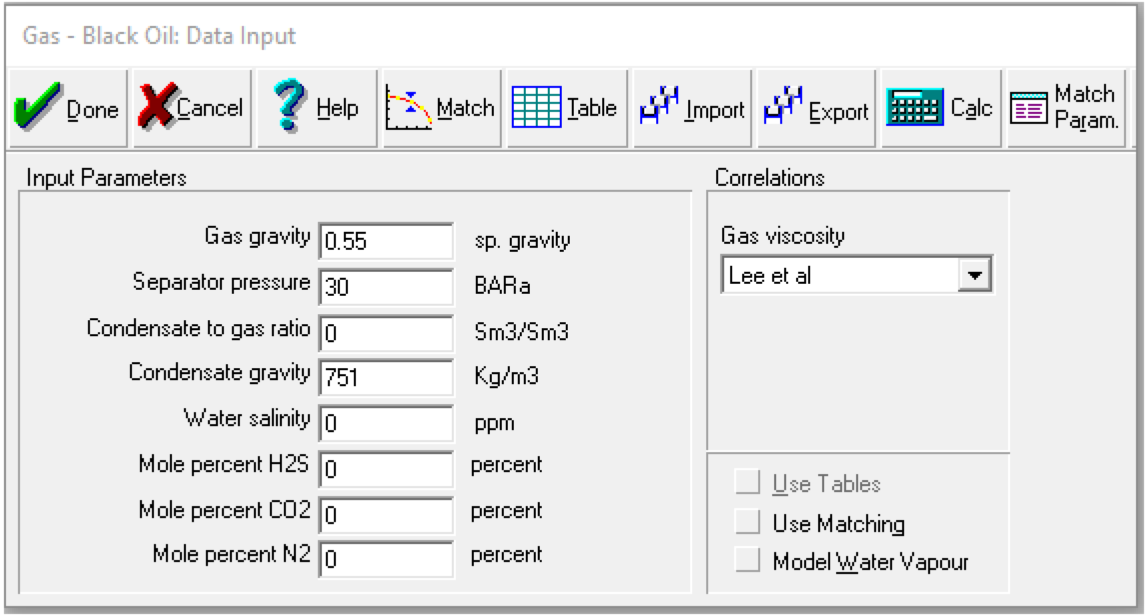
Unit System

Unit System

Unit Name	Unit Selections				Validation (Input Units)		
	Input	Sh/Mu	Output	Sh/Mu	Minimum	Maximum	Details
	Norwegian S.I.		Norwegian S.I.				
Compressibility	1/bar	Sh/Mu	1/bar	Sh/Mu	0	0.014503774	Details
Critical Pressure	BARa	Sh/Mu	BARa	Sh/Mu	0.94430591872	2069.440353489	Details
Critical Temperature	deg C	Sh/Mu	deg C	Sh/Mu	-272.7777505	1648.888724	Details
Critical Volume	m3/kg.mole	Sh/Mu	m3/kg.mole	Sh/Mu	0	624.3	Details

MBAL - PVT

-select “PVT” → fluid properties
-input PVT data
-select PVT correlations



Input Parameters

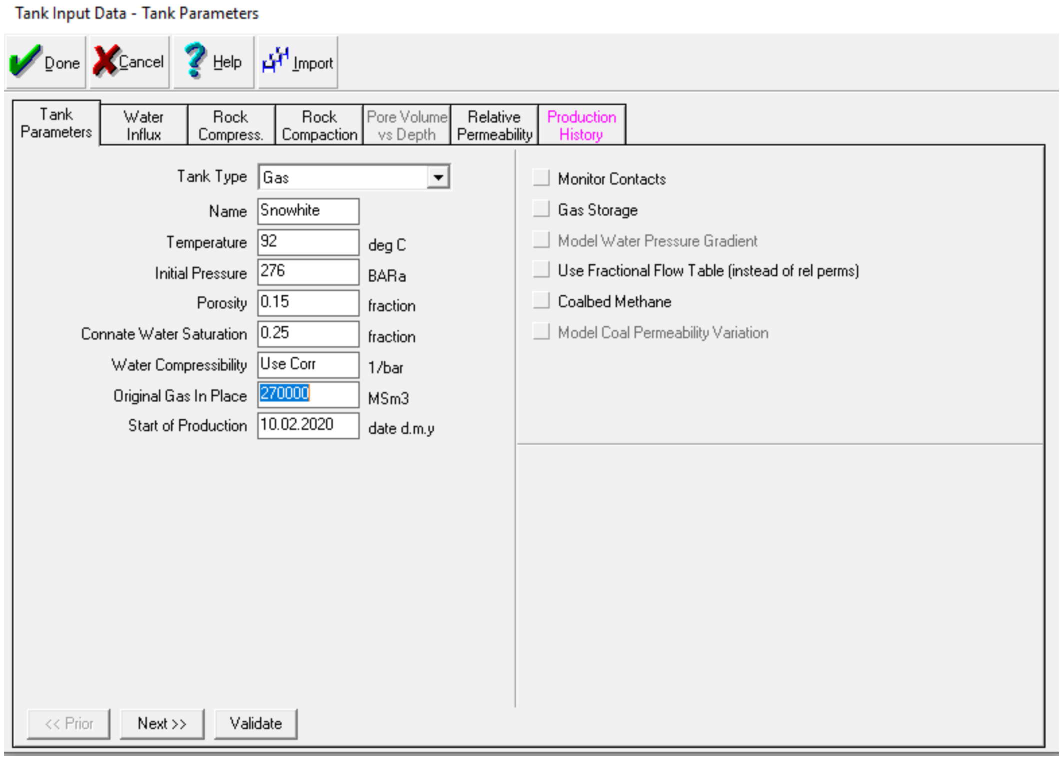
Gas gravity	0.55	sp. gravity
Separator pressure	30	BARa
Condensate to gas ratio	0	Sm3/Sm3
Condensate gravity	751	Kg/m3
Water salinity	0	ppm
Mole percent H2S	0	percent
Mole percent CO2	0	percent
Mole percent N2	0	percent

Correlations

Gas viscosity: Lee et al

☐ Use Tables
☐ Use Matching
☐ Model Water Vapour

MBAL - Input



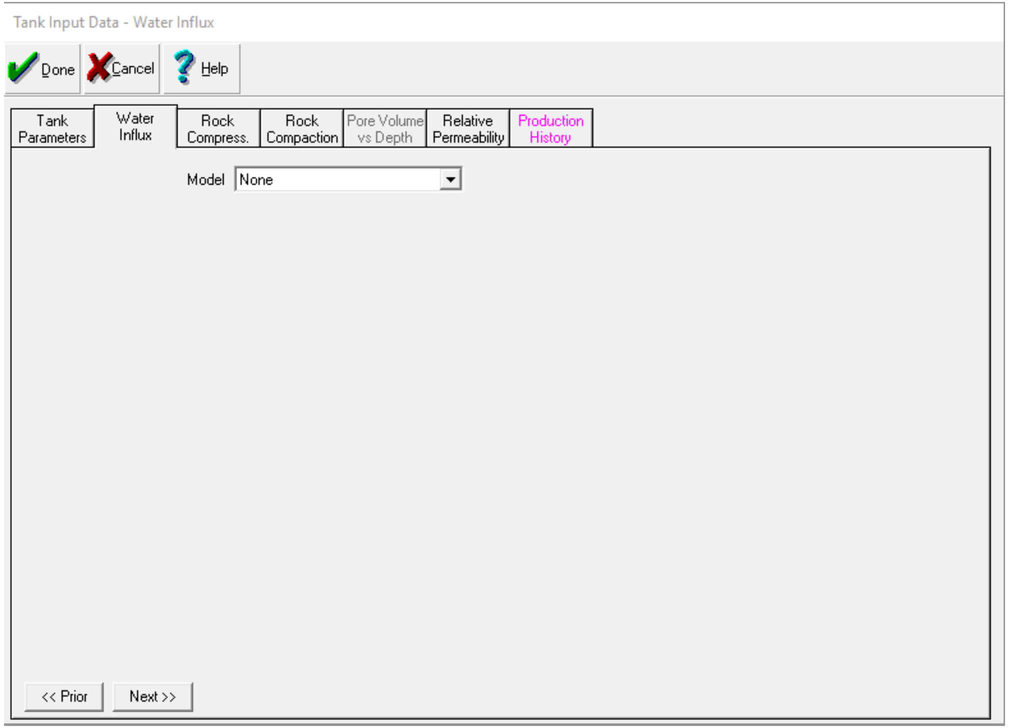
Tank Type	Gas	
Name	Snowhite	
Temperature	92	deg C
Initial Pressure	276	BARa
Porosity	0.15	fraction
Connate Water Saturation	0.25	fraction
Water Compressibility	Use Corr	1/bar
Original Gas In Place	270000	MSm3
Start of Production	10.02.2020	date d.m.y

☐ Monitor Contacts
☐ Gas Storage
☐ Model Water Pressure Gradient
☐ Use Fractional Flow Table (instead of rel perms)
☐ Coalbed Methane
☐ Model Coal Permeability Variation

-select “Input” → tank data
-input tank parameters
-be careful with the unit of OOIP

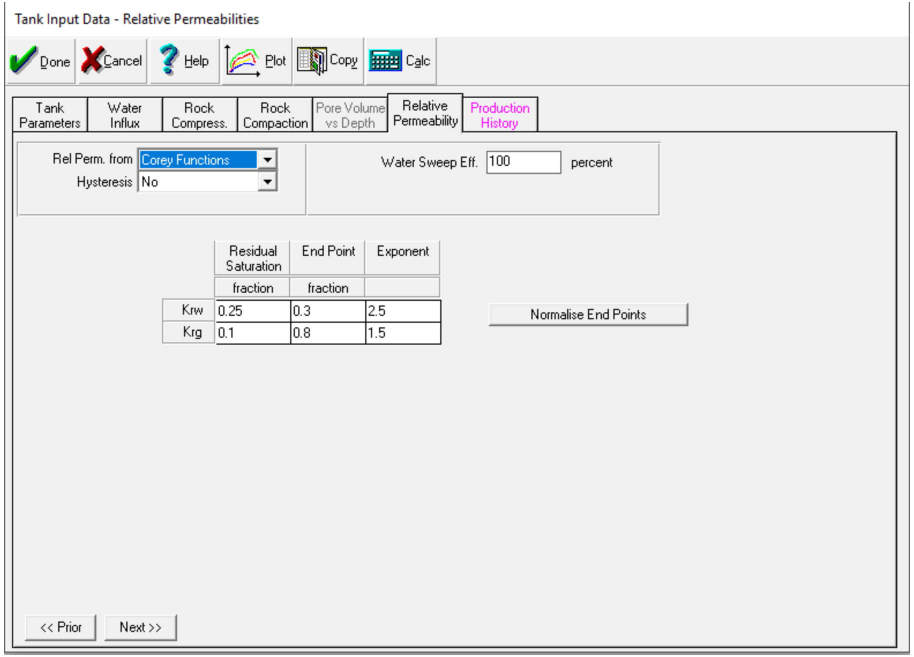
MBAL - Input

-input water influx



Model: None

MBAL - Input



Tank Input Data - Relative Permeabilities

Rel Perm. from: Corey Functions

Hysteresis: No

Water Sweep Eff. 100 percent

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.25	0.3	2.5
Krg	0.1	0.8	1.5

-input relative permeability

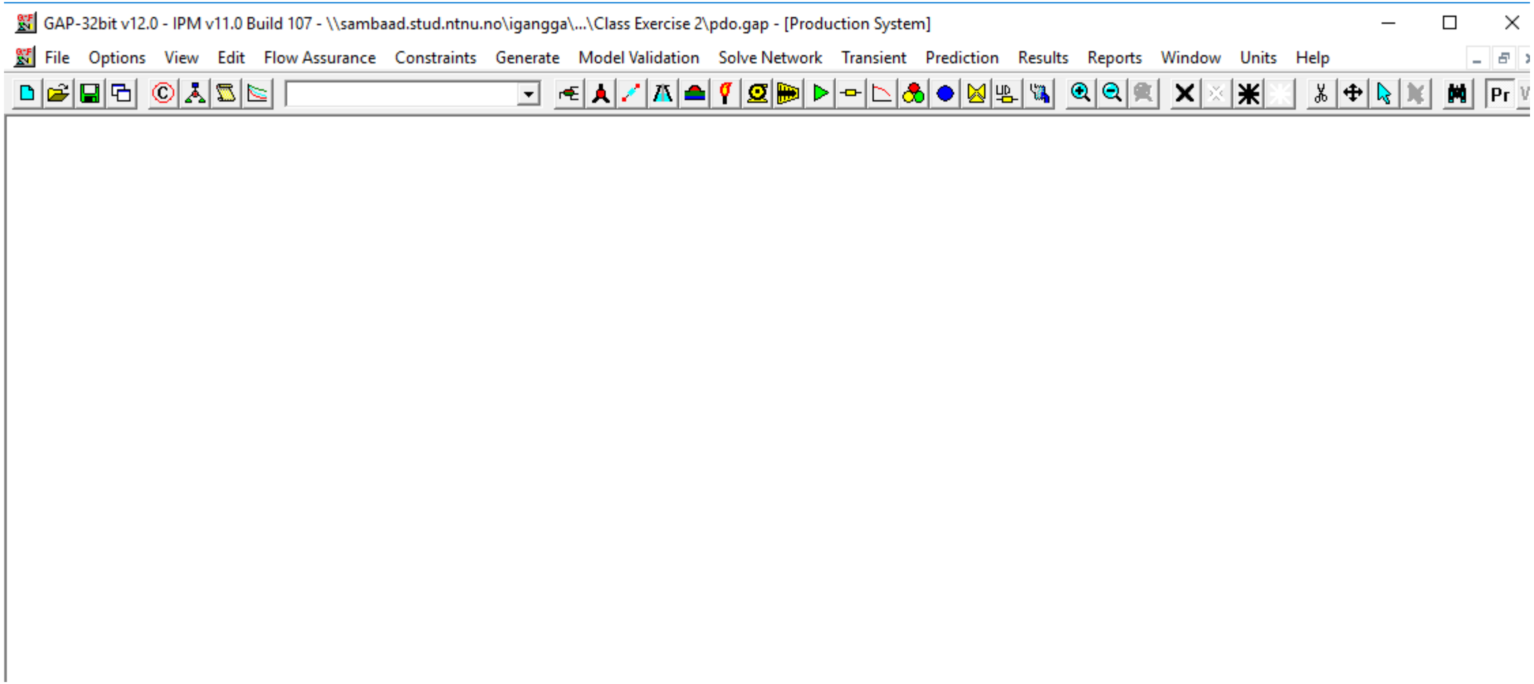
Outline

- Licensing
- PROSPER
- MBAL
- GAP: Set up Production Network
- GAP: Solve Production Network

GAP (Network Model)

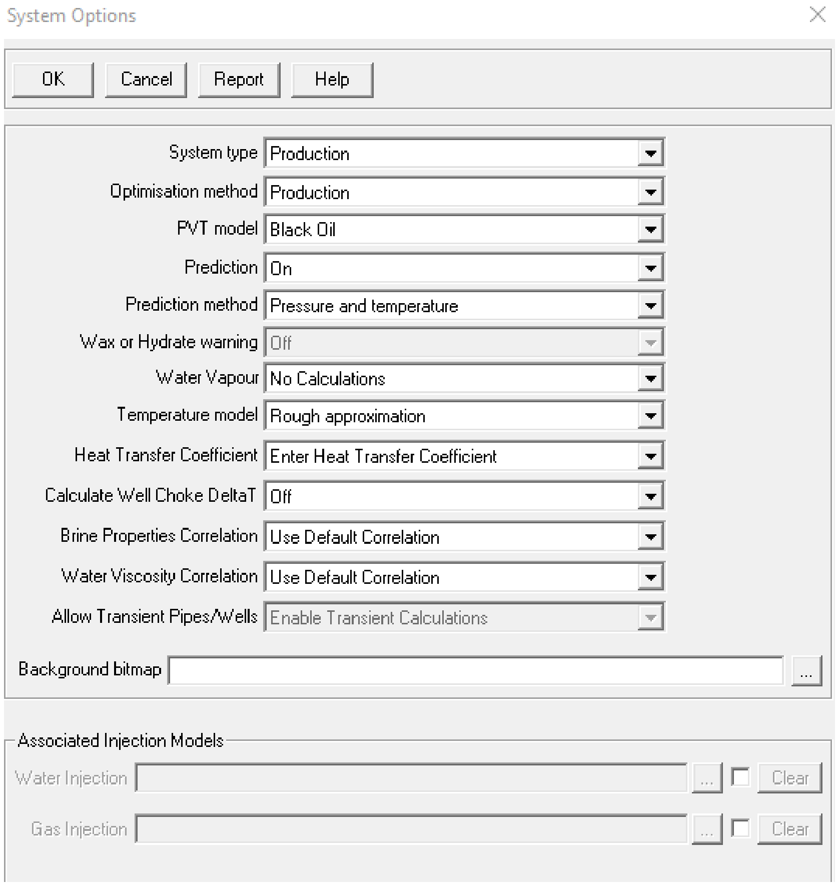
-open GAP

-save as



GAP-32bit v12.0 - IPM v11.0 Build 107 - \\sambaad.stud.ntnu.no\igangga\...\Class Exercise 2\pdo.gap - [Production System]

GAP



System type	Production
Optimisation method	Production
PVT model	Black Oil
Prediction	On
Prediction method	Pressure and temperature
Wax or Hydrate warning	Off
Water Vapour	No Calculations
Temperature model	Rough approximation
Heat Transfer Coefficient	Enter Heat Transfer Coefficient
Calculate Well Choke DeltaT	Off
Brine Properties Correlation	Use Default Correlation
Water Viscosity Correlation	Use Default Correlation
Allow Transient Pipes/Wells	Enable Transient Calculations
Background bitmap	

Associated Injection Models

Water Injection ☐

Gas Injection ☐

-open “options” → “method”

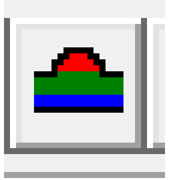
-system type: production

-PVT model: black oil

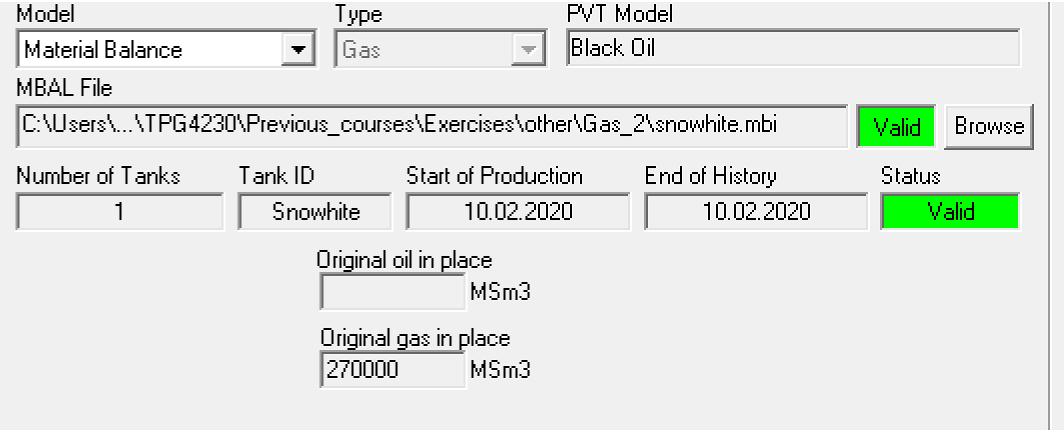
-for the rest, use default setting

-change unit system to Norwegian S.I.

GAP: Reservoir: Summary tab



- -add tank icon → rename the tank
- -double click to edit tank properties
- -include MBAL model
- -done



Model: Material Balance

Type: Gas

PVT Model: Black Oil

MBAL File: C:\Users\...\TPG4230\Previous_courses\Exercises\other\Gas_2\snowhite.mbi Valid

Number of Tanks: 1

Tank ID: Snowhite

Start of Production: 10.02.2020

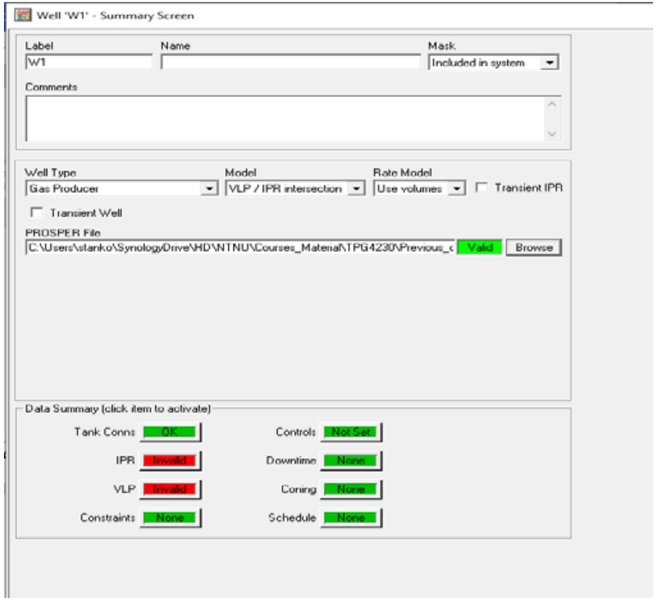
End of History: 10.02.2020

Status: Valid

Original oil in place: MSm3

Original gas in place: 270000 MSm3

GAP: Well: Summary tab



Well 'W1' - Summary Screen

Label: W1

Name:

Mask: Included in system

Comments:

Well Type: Gas Producer

Model: VLP / IPR intersection

Rate Model: Use volumes

☐ Transient IPR

☐ Transient Well

PROSPER File: C:\Users\stanko\SynologyDrive\HD\NTNU\Courses_Material\TPG4230\Previous_(Valid

Data Summary (click item to activate)

Tank Conns: OK

IPR: Invalid

VLP: Invalid

Constraints: None

Controls: Not Set

Downtime: None

Coning: None

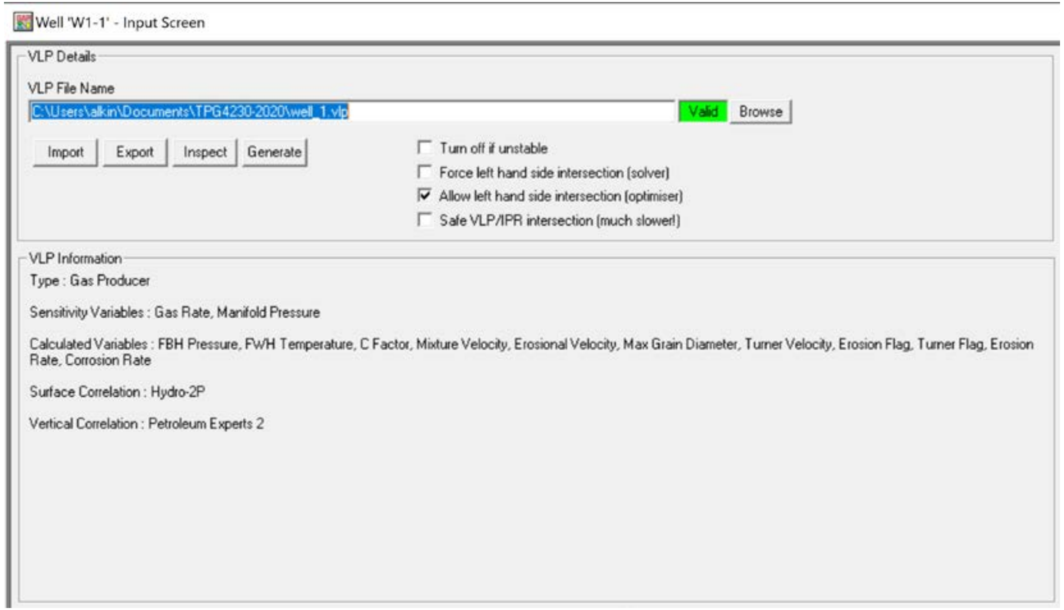
Schedule: None

-add well icon → rename the well

-double click to edit well properties

-’summary’ tab → change welltype and add path to prosper file

GAP: Well: Input tab: VLP Tab



Well 'W1-1' - Input Screen

VLP Details

VLP File Name: C:\Users\alkin\Documents\TPG4230-2020\well_1.vlp

☐ Turn off if unstable
☐ Force left hand side intersection (solver)
☑ Allow left hand side intersection (optimiser)
☐ Safe VLP/IPR intersection (much slower!)

VLP Information

Type : Gas Producer

Sensitivity Variables : Gas Rate, Manifold Pressure

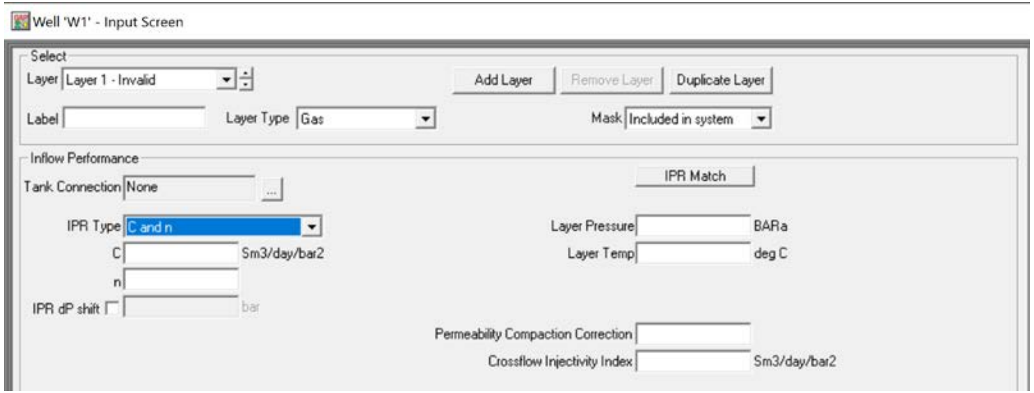
Calculated Variables : FBH Pressure, FWH Temperature, C Factor, Mixture Velocity, Erosional Velocity, Max Grain Diameter, Turner Velocity, Erosion Flag, Turner Flag, Erosion Rate, Corrosion Rate

Surface Correlation : Hydro-2P

Vertical Correlation : Petroleum Experts 2

-'input' tab → 'VLP' tab → 'import' VLP table in **TPD format**
-done

GAP: Well: Input tab: IPR Tab



Well 'W1' - Input Screen

Select

Layer: Layer 1 - Invalid

Label:

Layer Type: Gas

Mask: Included in system

Inflow Performance

Tank Connection: None

IPR Type: C and n

C: Sm3/day/bar2

n:

IPR dP shift ☐ bar

Layer Pressure: BARa

Layer Temp: deg C

Permeability Compaction Correction:

Crossflow Injectivity Index: Sm3/day/bar2

- ’input’ tab → ‘”IPR” tab
- Choose IPR type to “C and n” to have the same expression in PROSPER

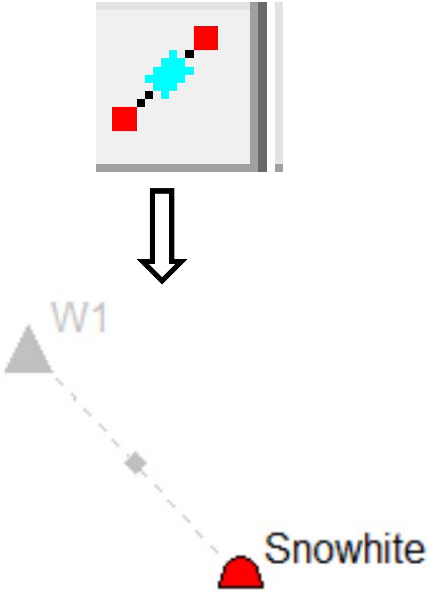
GAP: Well

Transfer IPR data

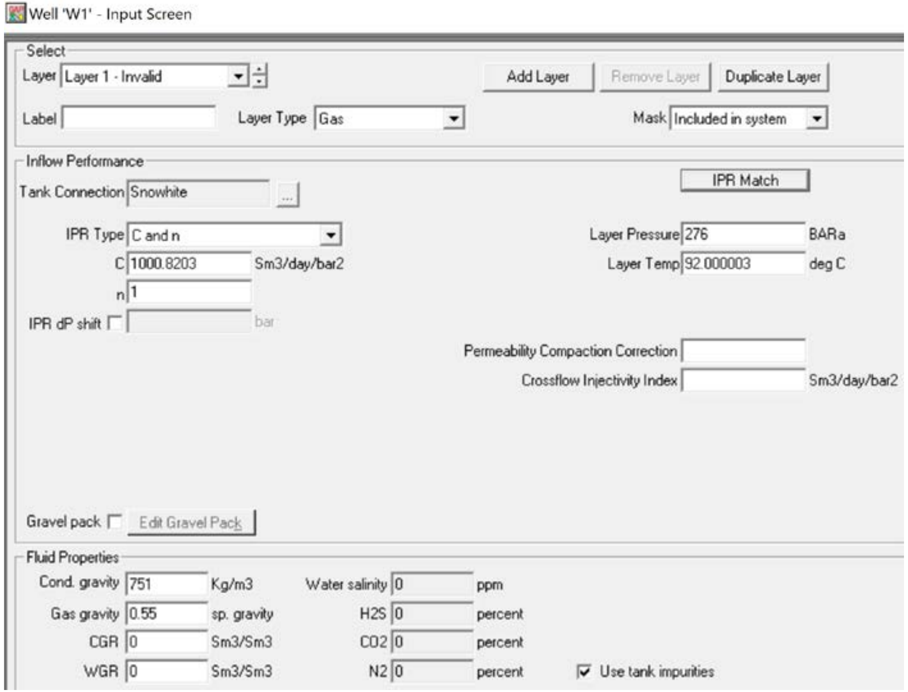
Menu: generate – well IPR from Prosper –All - Generate

GAP: Well

-add connection between reservoir and well



GAP: Well: Input tab: IPR Tab



Well 'W1' - Input Screen

Select

Layer: Layer 1 - Invalid

Label:

Layer Type: Gas

Mask: Included in system

Inflow Performance

Tank Connection: Snowhite

IPR Type: C and n

C: 1000.8203 Sm3/day/bar2

n: 1

IPR dP shift ☐ bar

Layer Pressure: 276 BARa

Layer Temp: 92.000003 deg C

Permeability Compaction Correction:

Crossflow Injectivity Index: Sm3/day/bar2

Gravel pack ☐

Fluid Properties

Cond. gravity: 751 Kg/m3

Gas gravity: 0.55 sp. gravity

CGR: 0 Sm3/Sm3

WGR: 0 Sm3/Sm3

Water salinity: 0 ppm

H2S: 0 percent

CO2: 0 percent

N2: 0 percent

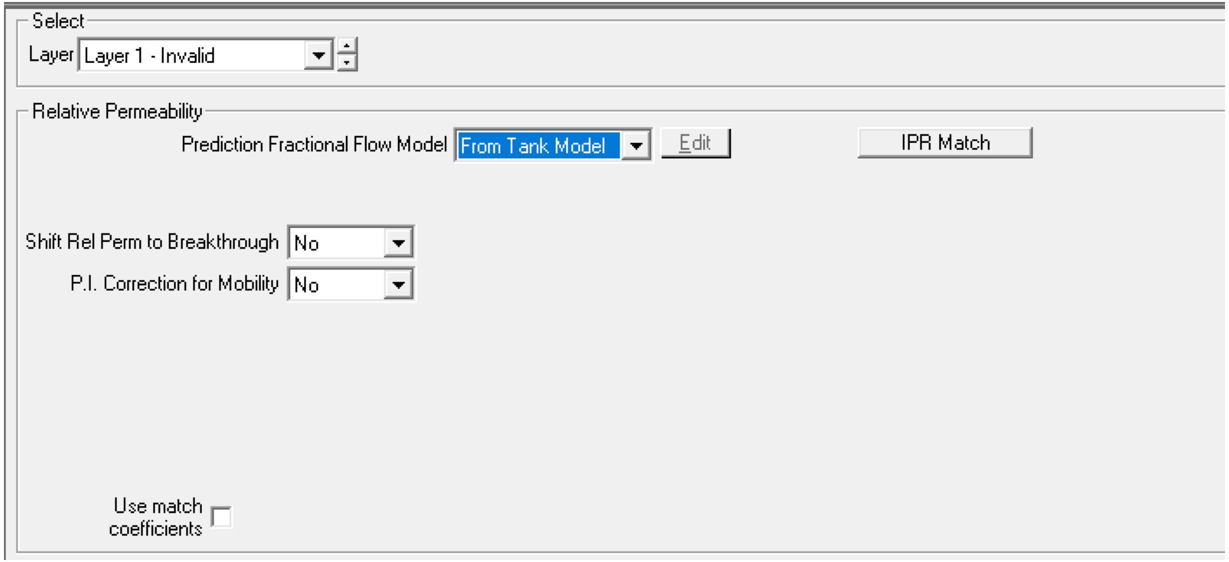
☑ Use tank impurities

Checking the IPR quality:

- 'input' tab → "IPR" tab

GAP: Well: Input tab: More… Tab

Prediction fractional flow model:
From Tank Model



Select

Layer: Layer 1 - Invalid

Relative Permeability

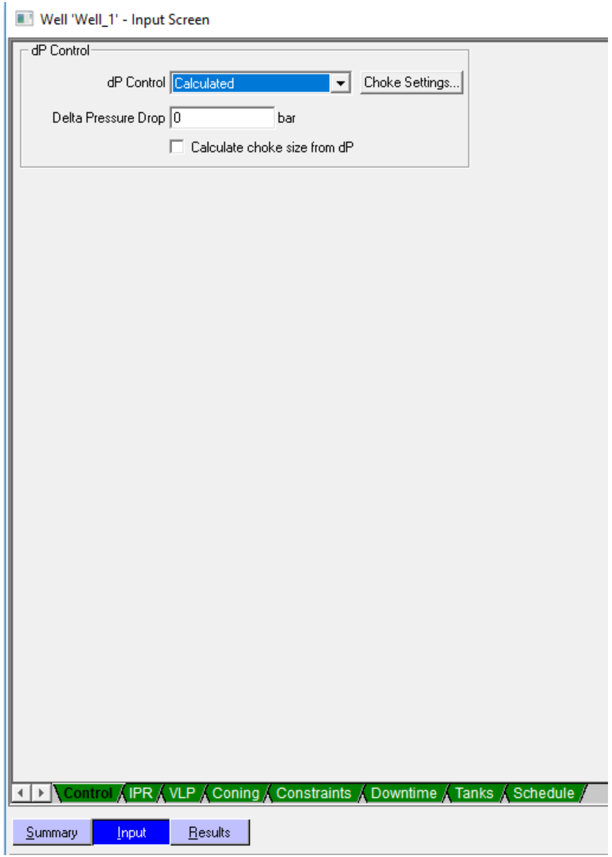
Prediction Fractional Flow Model: From Tank Model

Shift Rel Perm to Breakthrough: No

P.I. Correction for Mobility: No

Use match coefficients ☐

GAP: Well: Input tab: Control Tab



Well 'Well_1' - Input Screen

dP Control

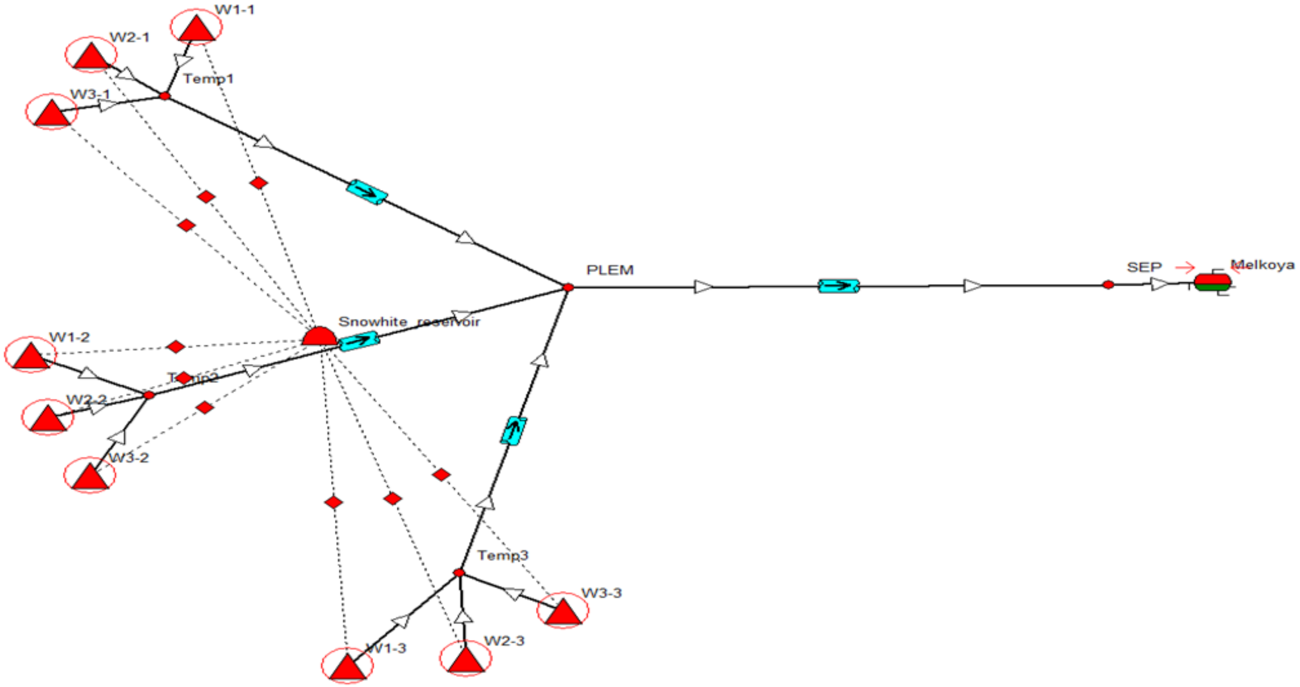
dP Control: Calculated

Delta Pressure Drop: 0 bar

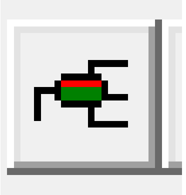
☐ Calculate choke size from dP

-'input' tab → 'control' tab
-change dp Control to allow well choking
-done

GAP: Production Layout

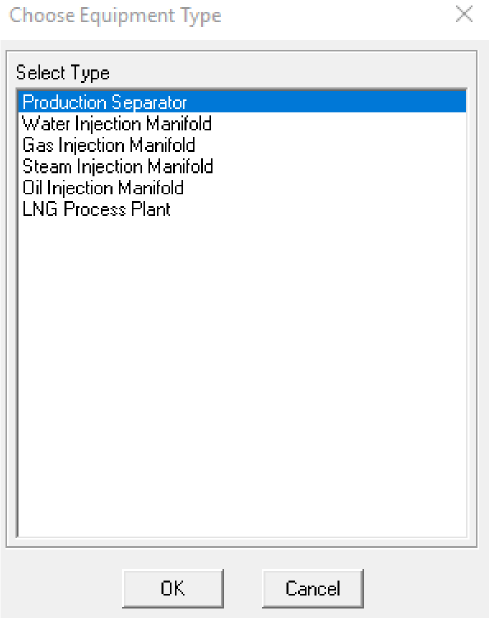


GAP: Separator



-add separator icon → choose ‘production separator’ → rename it

-connect the system with the separator

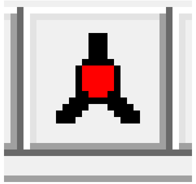


Choose Equipment Type

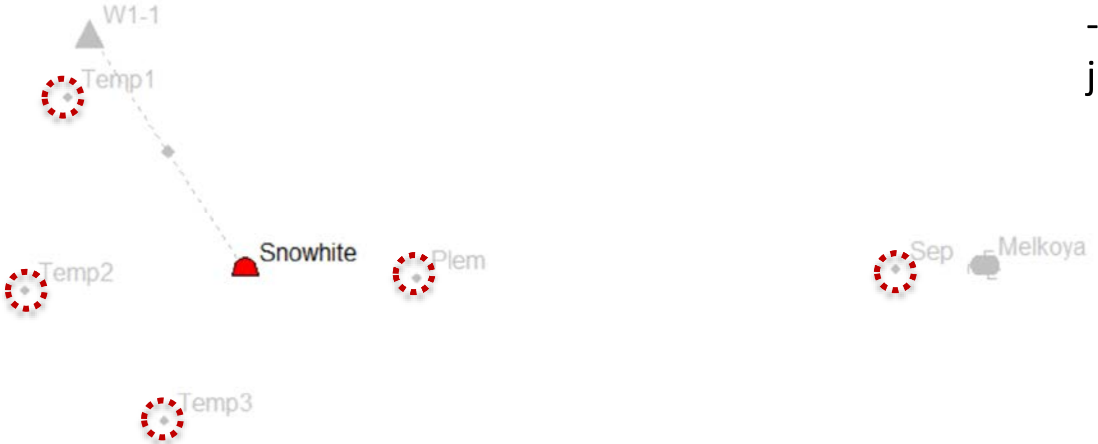
Select Type

- Production Separator
- Water Injection Manifold
- Gas Injection Manifold
- Steam Injection Manifold
- Oil Injection Manifold
- LNG Process Plant

GAP: Joint (Xtree, Manifold, etc)

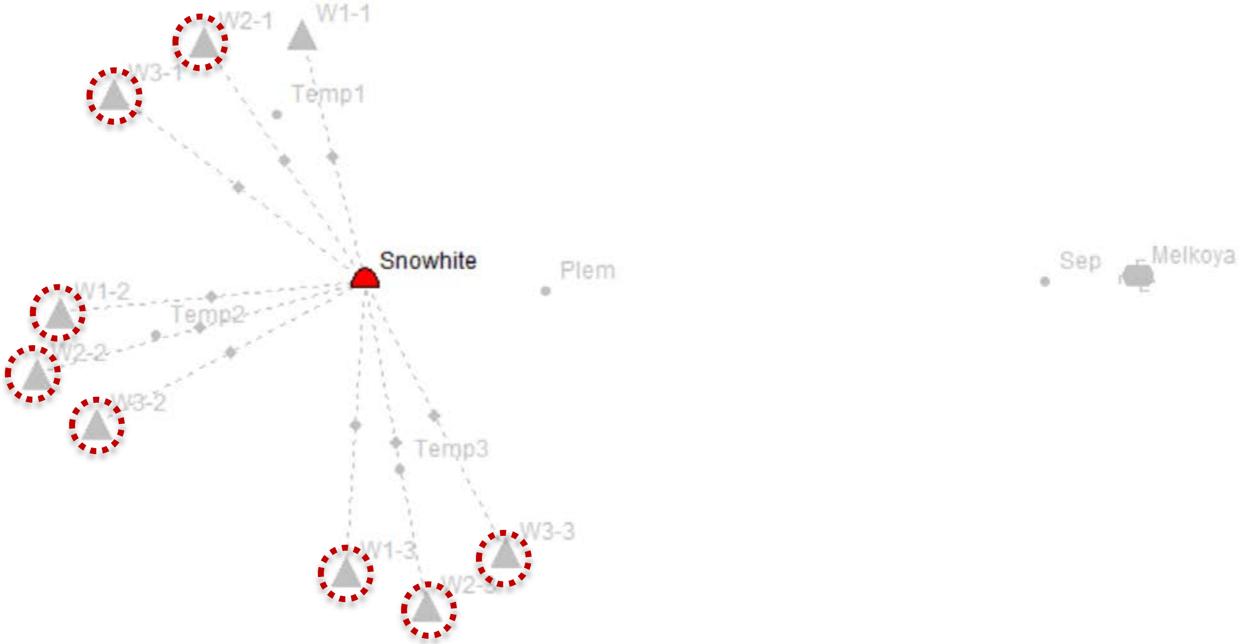


-add joint icon
-Rename the joint label
-pipeline is modelled between 2 joints

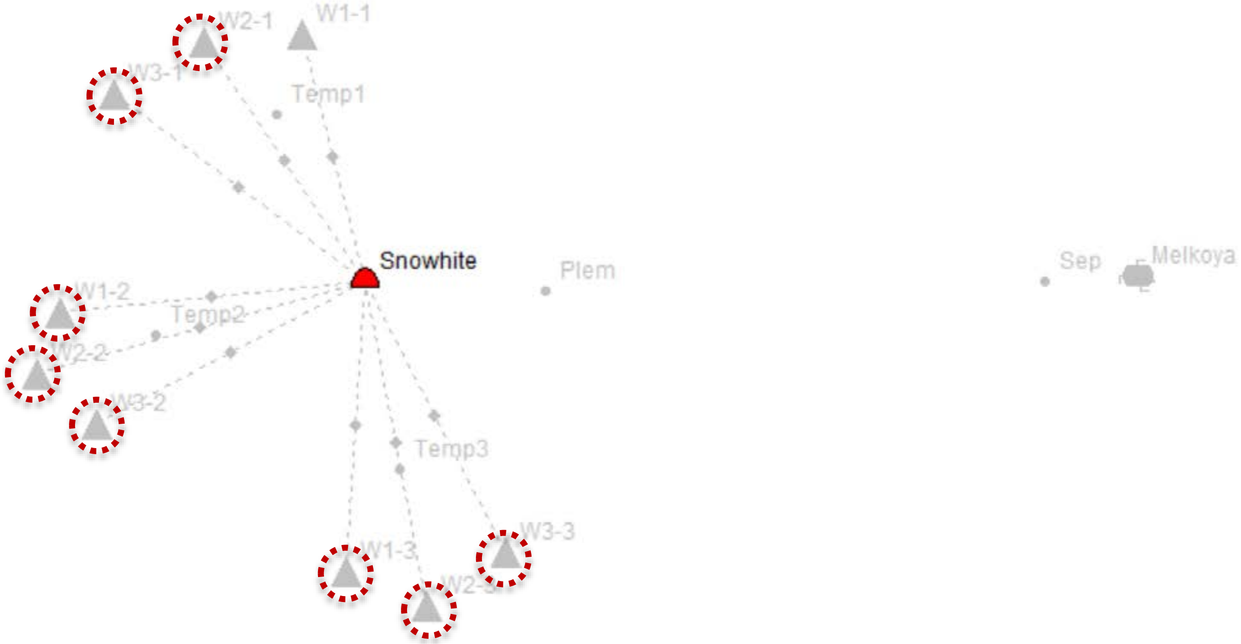


GAP: Adding more wells

-All wells are identical, thus, copy and paste wells (8 times)

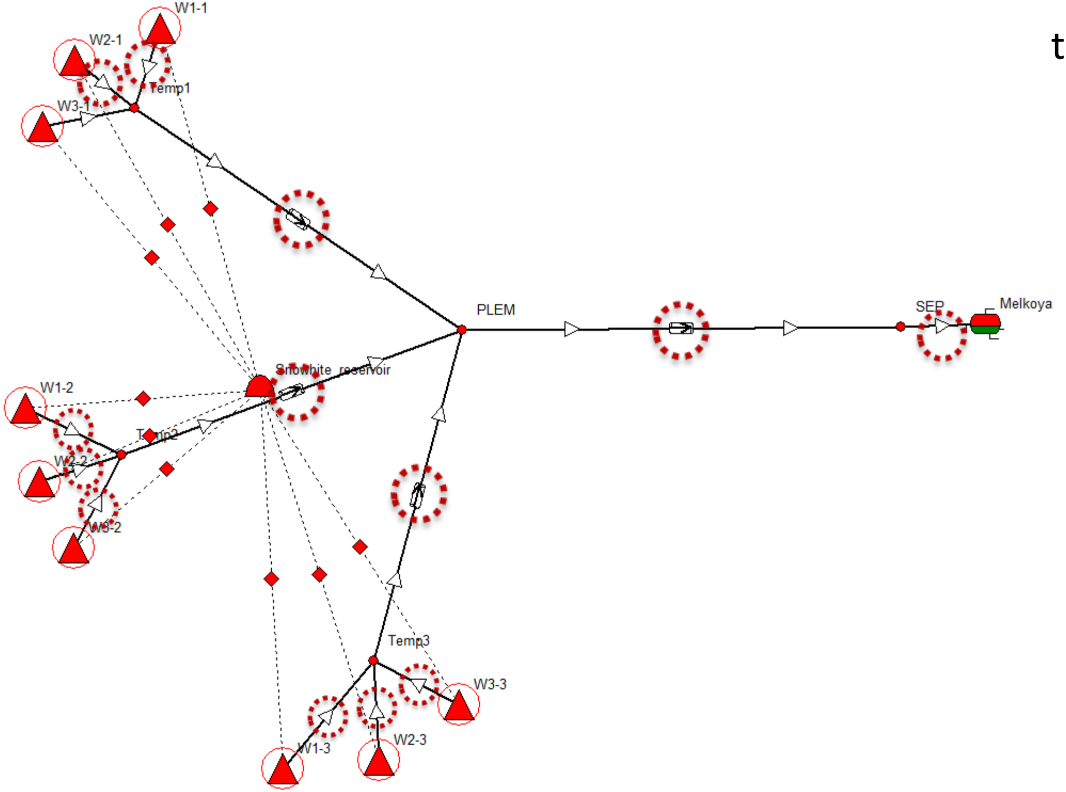


GAP: Adding more wells



-All wells are identical, thus, copy and paste wells (8 times)

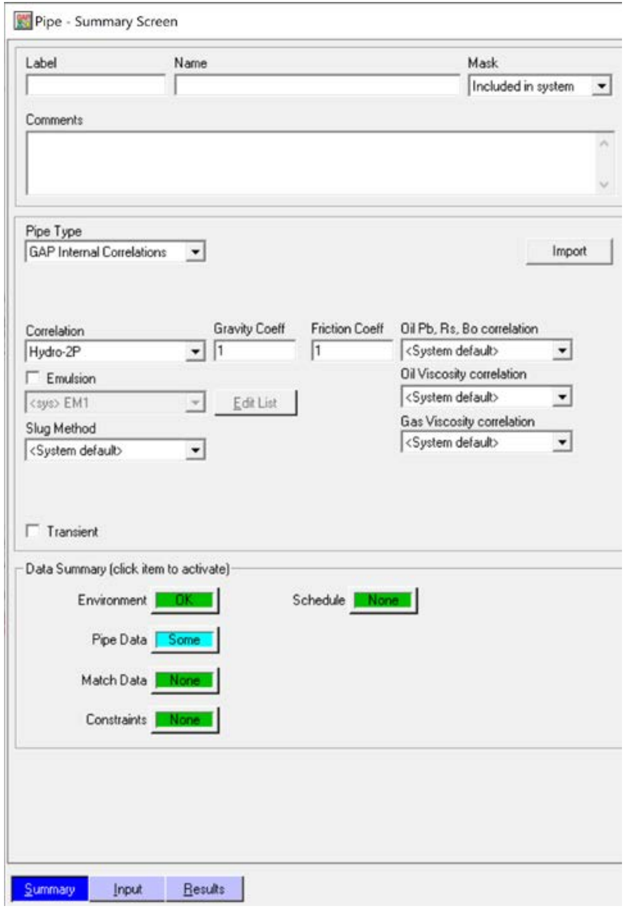
GAP: Joint (Xtree, Manifold, etc)



-connect the joints

-connect wells and separator to the joints

GAP: Pipeline: Summary tab



Pipe - Summary Screen

Label:

Name:

Mask: Included in system

Comments:

Pipe Type: GAP Internal Correlations

Correlation: Hydro-2P

Gravity Coeff: 1

Friction Coeff: 1

Oil Pb, Rs, Bo correlation: <System default>

Oil Viscosity correlation: <System default>

Gas Viscosity correlation: <System default>

☐ Emulsion: <sys> EM1

Slug Method: <System default>

☐ Transient

Data Summary (click item to activate)

Environment: OK

Pipe Data: Some

Match Data: None

Constraints: None

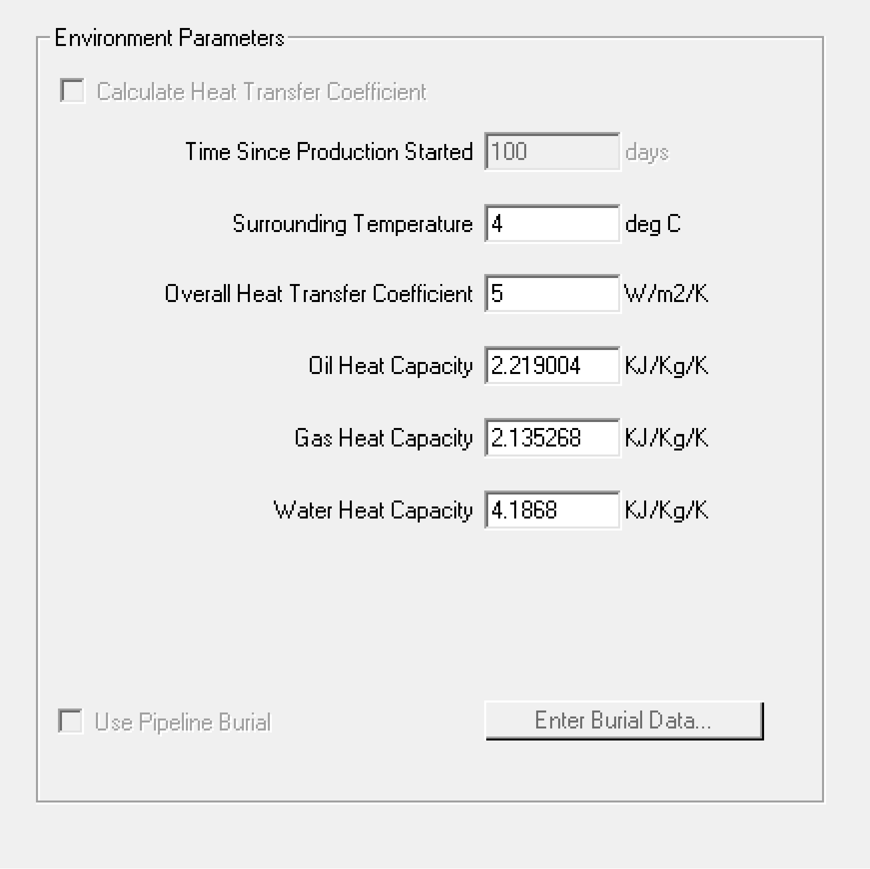
Schedule: None

-double click in the selected pipeline

-open ’summary’ tab → select PVT correlations

-leave the other things as defaults

GAP: Pipeline: Input tab



Environment Parameters

☐ Calculate Heat Transfer Coefficient

Time Since Production Started: 100 days

Surrounding Temperature: 4 deg C

Overall Heat Transfer Coefficient: 5 W/m2/K

Oil Heat Capacity: 2.219004 KJ/Kg/K

Gas Heat Capacity: 2.135268 KJ/Kg/K

Water Heat Capacity: 4.1868 KJ/Kg/K

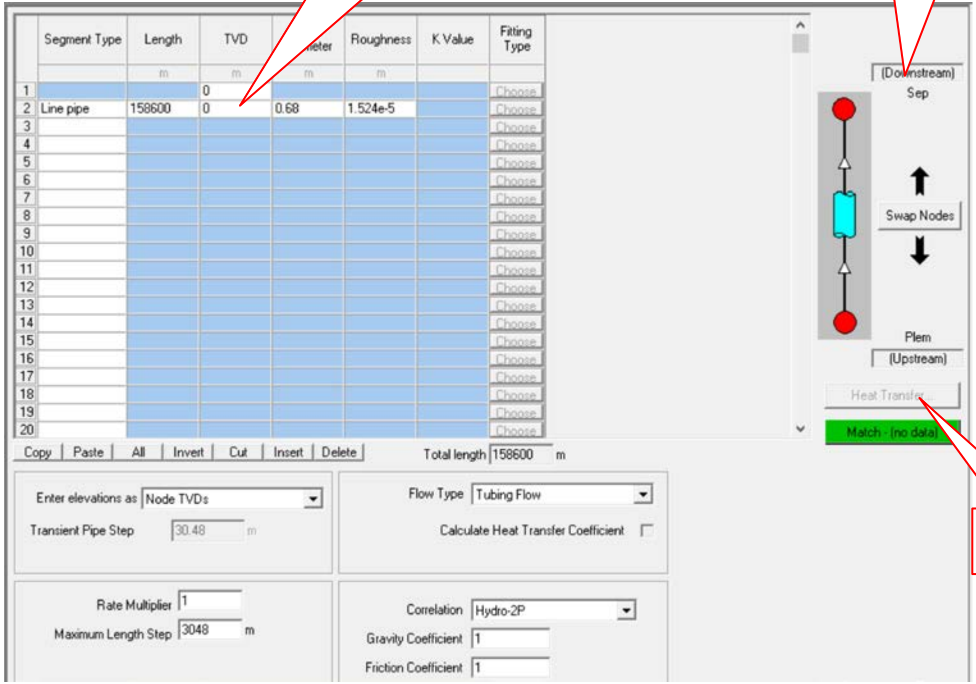
☐ Use Pipeline Burial

-open ’input’ tab → open ‘environtment’ sub-tab
-input ambient temperature (= 4 degC)
-input U (= 5 W/m2/K)

GAP: Pipeline: Input tab

Inlet TVD

outlet



	Segment Type	Length	TVD	eter	Roughness	K Value	Fitting Type
		m	m	m	m		
1			0				Choose
2	Line pipe	158600	0	0.68	1.524e-5		Choose
3							Choose
4							Choose
5							Choose
6							Choose
7							Choose
8							Choose
9							Choose
10							Choose
11							Choose
12							Choose
13							Choose
14							Choose
15							Choose
16							Choose
17							Choose
18							Choose
19							Choose
20							Choose

Total length 158600 m

Enter elevations as: Node TVDs

Transient Pipe Step: 30.48 m

Flow Type: Tubing Flow

Calculate Heat Transfer Coefficient ☐

Rate Multiplier: 1

Maximum Length Step: 3048 m

Correlation: Hydro-2P

Gravity Coefficient: 1

Friction Coefficient: 1

inlet

-open ’input’ tab → open ‘description’ sub-tab

-input pipeline properties: length:

5000 m for flowline

158600 m for pipeline

ID:

0.355 for flowline

0.68 m for pipeline

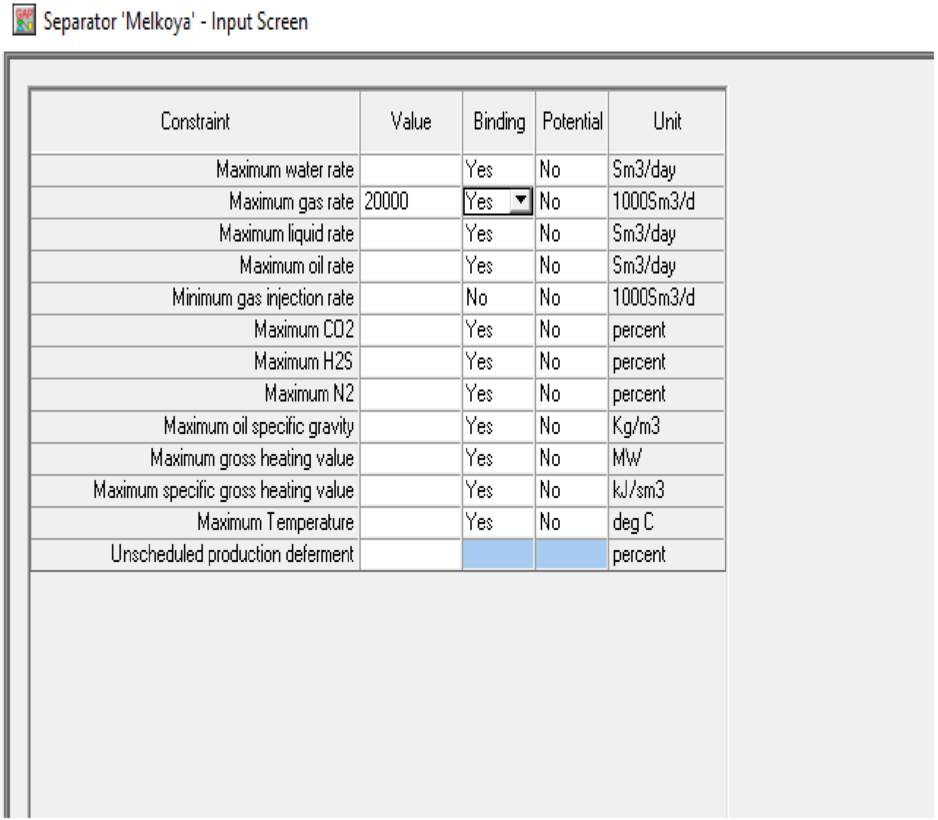
, roughness (=0.015 mm)

-done

-repeat for the other pipelines

GAP: Separator

Setting up constraint



Separator 'Melkoya' - Input Screen

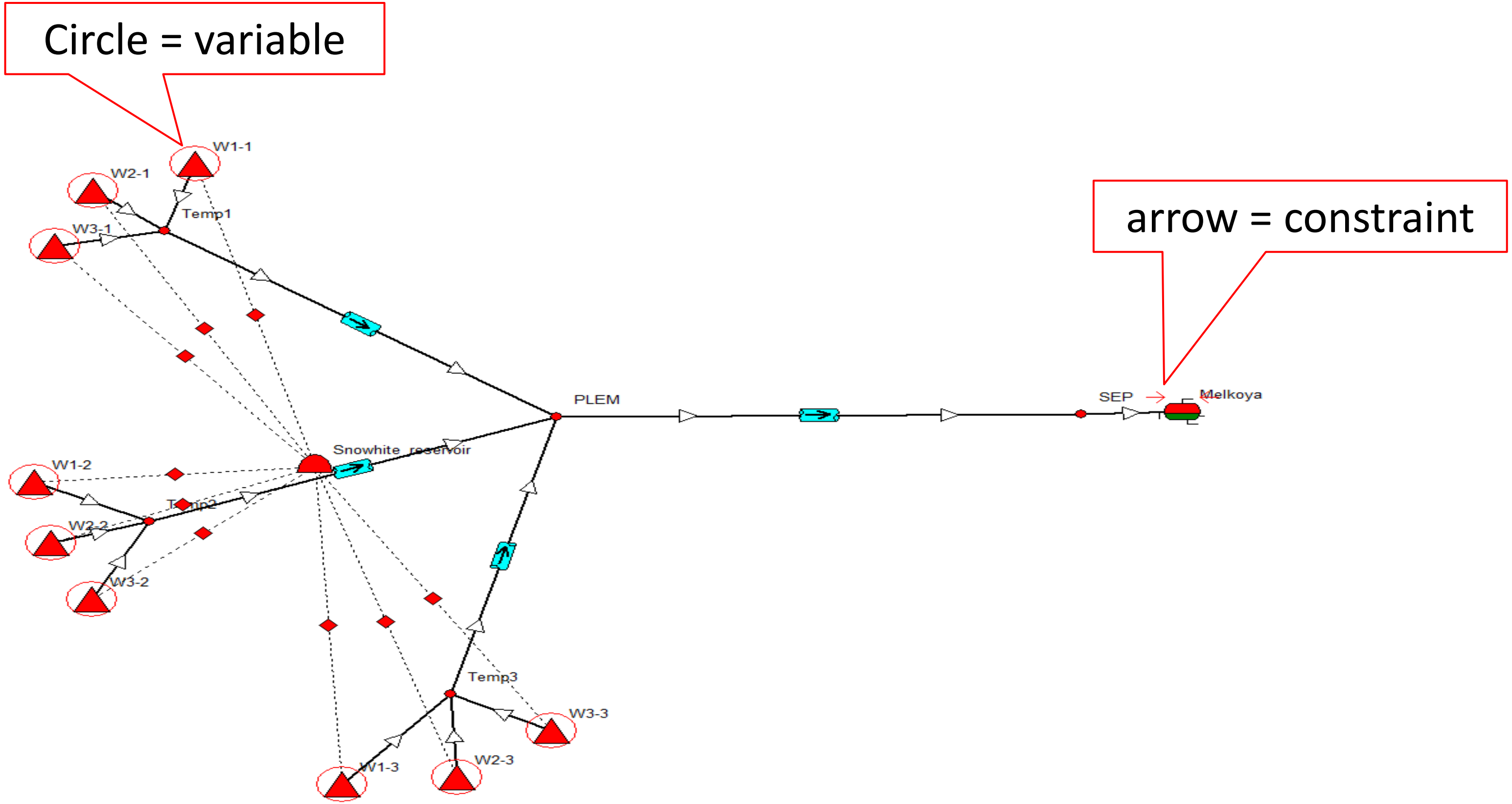
Constraint	Value	Binding	Potential	Unit
Maximum water rate		Yes	No	Sm3/day
Maximum gas rate	20000	Yes	No	1000Sm3/d
Maximum liquid rate		Yes	No	Sm3/day
Maximum oil rate		Yes	No	Sm3/day
Minimum gas injection rate		No	No	1000Sm3/d
Maximum CO2		Yes	No	percent
Maximum H2S		Yes	No	percent
Maximum N2		Yes	No	percent
Maximum oil specific gravity		Yes	No	Kg/m3
Maximum gross heating value		Yes	No	MW
Maximum specific gross heating value		Yes	No	kJ/sm3
Maximum Temperature		Yes	No	deg C
Unscheduled production deferment				percent

-double click on the separator icon

-open ‘input’ tab → open ‘constraints’ tab

-input the gas plateau rate

GAP: All System



Circle = variable

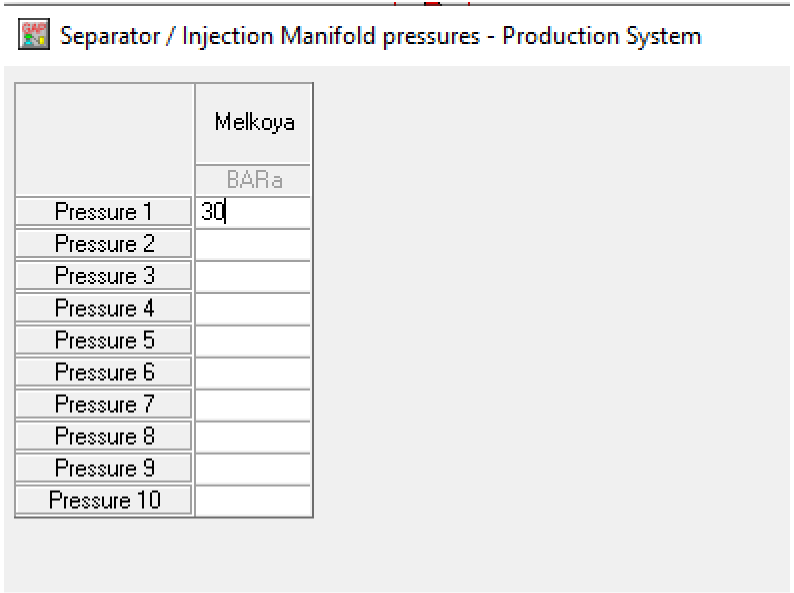
arrow = constraint

Outline

- Licensing
- PROSPER
- MBAL
- GAP: Set up Production Network
- GAP: Solve Production Network

GAP: Solve Network

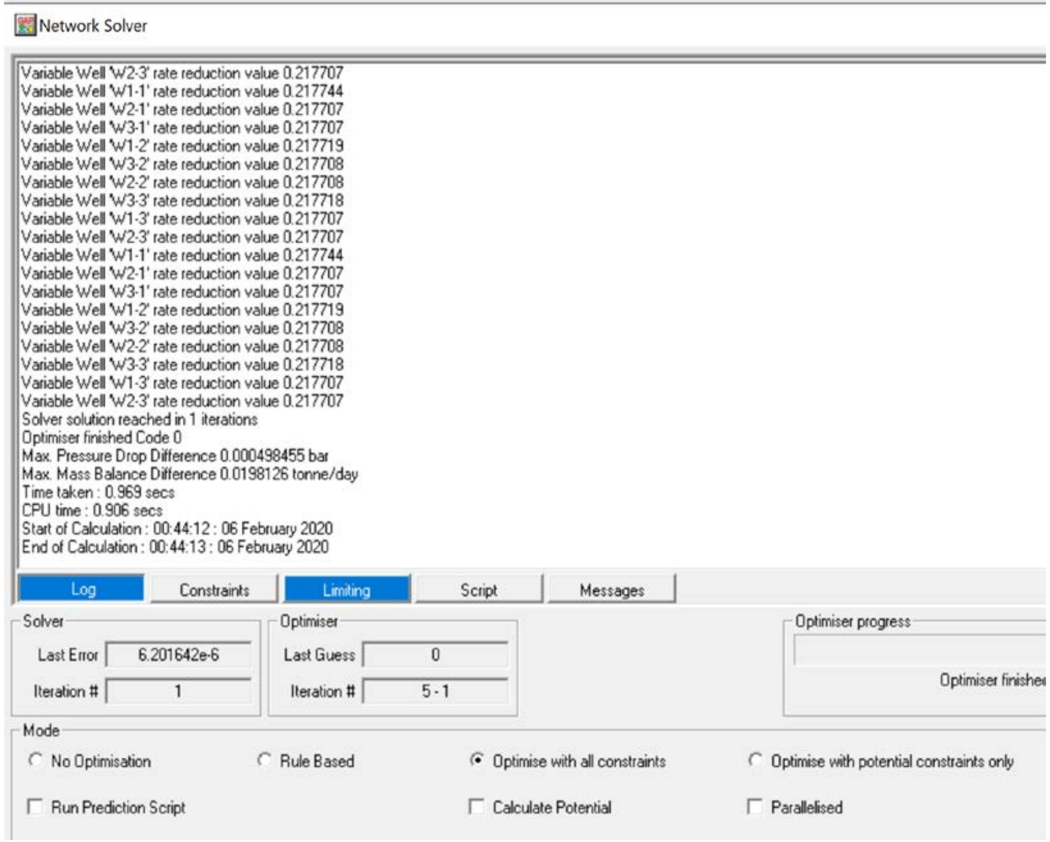
- open 'solve network' to solve the production network at t = 0
- run network solver
- input separator pressure



Separator / Injection Manifold pressures - Production System

	Melkoya
	BARa
Pressure 1	30
Pressure 2	
Pressure 3	
Pressure 4	
Pressure 5	
Pressure 6	
Pressure 7	
Pressure 8	
Pressure 9	
Pressure 10	

GAP: Solve Network



```
Variable Well 'W2-3' rate reduction value 0.217707
Variable Well 'W1-1' rate reduction value 0.217744
Variable Well 'W2-1' rate reduction value 0.217707
Variable Well 'W3-1' rate reduction value 0.217707
Variable Well 'W1-2' rate reduction value 0.217719
Variable Well 'W3-2' rate reduction value 0.217708
Variable Well 'W2-2' rate reduction value 0.217708
Variable Well 'W3-3' rate reduction value 0.217718
Variable Well 'W1-3' rate reduction value 0.217707
Variable Well 'W2-3' rate reduction value 0.217707
Variable Well 'W1-1' rate reduction value 0.217744
Variable Well 'W2-1' rate reduction value 0.217707
Variable Well 'W3-1' rate reduction value 0.217707
Variable Well 'W1-2' rate reduction value 0.217719
Variable Well 'W3-2' rate reduction value 0.217708
Variable Well 'W2-2' rate reduction value 0.217708
Variable Well 'W3-3' rate reduction value 0.217718
Variable Well 'W1-3' rate reduction value 0.217707
Variable Well 'W2-3' rate reduction value 0.217707
Solver solution reached in 1 iterations
Optimiser finished Code 0
Max. Pressure Drop Difference 0.000498455 bar
Max. Mass Balance Difference 0.0198126 tonne/day
Time taken : 0.969 secs
CPU time : 0.906 secs
Start of Calculation : 00:44:12 : 06 February 2020
End of Calculation : 00:44:13 : 06 February 2020
```

Solver
Last Error 6.201642e-6
Iteration # 1

Optimiser
Last Guess 0
Iteration # 5 - 1

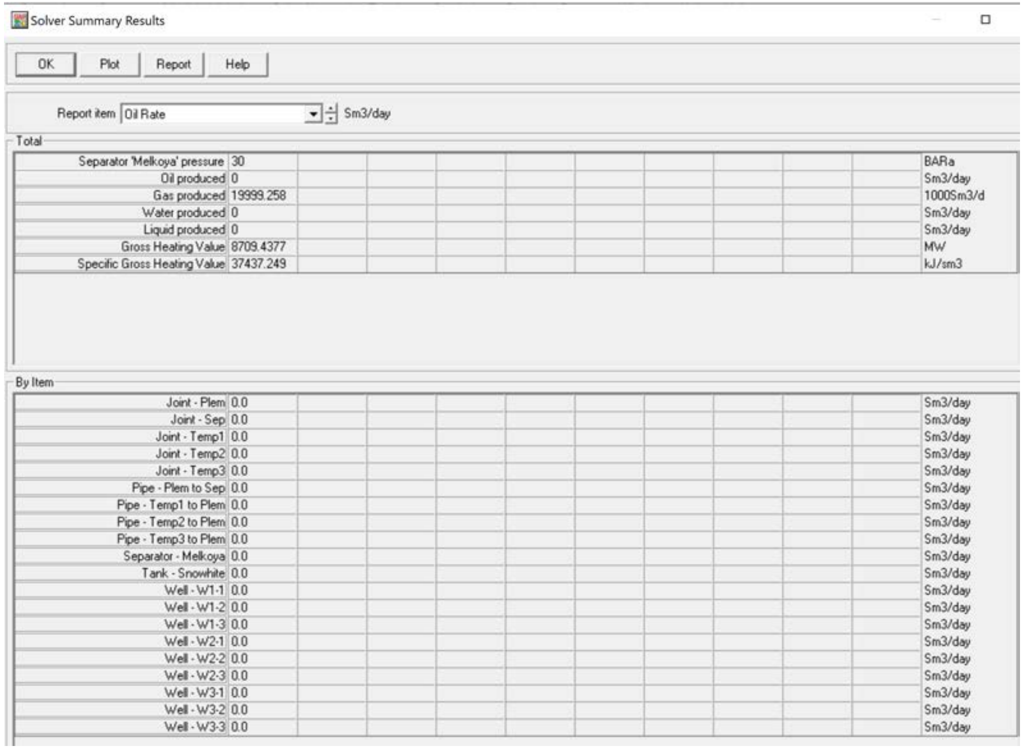
Optimiser progress
Optimiser finishe

Mode
○ No Optimisation ○ Rule Based ● Optimise with all constraints ○ Optimise with potential constraints only
☐ Run Prediction Script ☐ Calculate Potential ☐ Parallelised

-since we have a constraint to be satisfy, choose ‘optimise with all constraints’ mode
-calculate

GAP: Solve Network

-to see the results, open ‘results’ tab → ‘summary’ → ‘all items’



Report item: Oil Rate Sm3/day

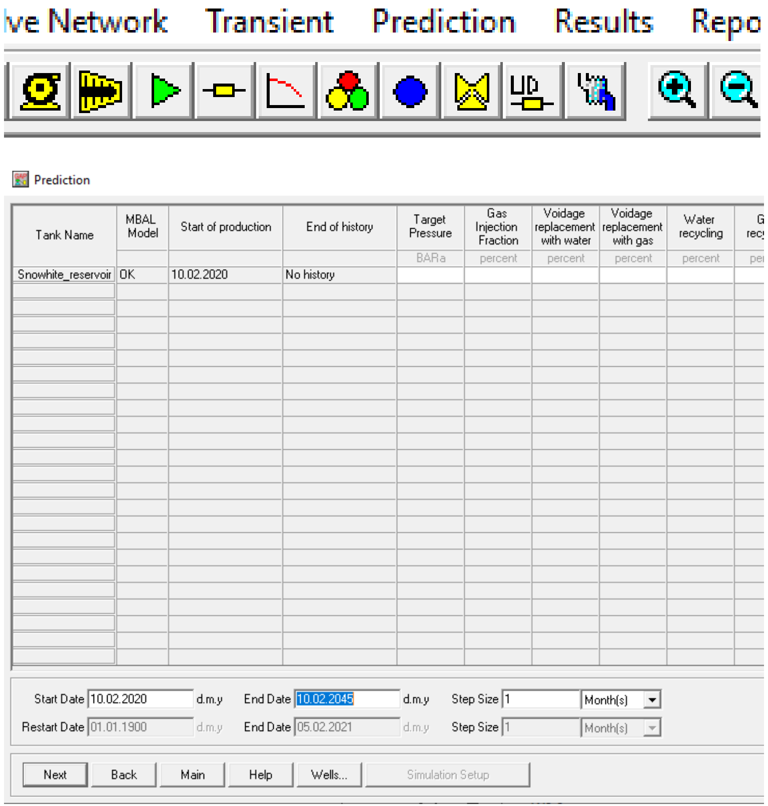
Total

Separator 'Melkoya' pressure	30	BARa
Oil produced	0	Sm3/day
Gas produced	19999.258	1000Sm3/d
Water produced	0	Sm3/day
Liquid produced	0	Sm3/day
Gross Heating Value	8709.4377	MW
Specific Gross Heating Value	37437.249	kJ/sm3

By Item

Joint - Plem	0.0	Sm3/day
Joint - Sep	0.0	Sm3/day
Joint - Temp1	0.0	Sm3/day
Joint - Temp2	0.0	Sm3/day
Joint - Temp3	0.0	Sm3/day
Pipe - Plem to Sep	0.0	Sm3/day
Pipe - Temp1 to Plem	0.0	Sm3/day
Pipe - Temp2 to Plem	0.0	Sm3/day
Pipe - Temp3 to Plem	0.0	Sm3/day
Separator - Melkoya	0.0	Sm3/day
Tank - Snowhite	0.0	Sm3/day
Well - W1-1	0.0	Sm3/day
Well - W1-2	0.0	Sm3/day
Well - W1-3	0.0	Sm3/day
Well - W2-1	0.0	Sm3/day
Well - W2-2	0.0	Sm3/day
Well - W2-3	0.0	Sm3/day
Well - W3-1	0.0	Sm3/day
Well - W3-2	0.0	Sm3/day
Well - W3-3	0.0	Sm3/day

GAP: Prediction



Prediction

Tank Name	MBAL Model	Start of production	End of history	Target Pressure	Gas Injection Fraction	Voidage replacement with water	Voidage replacement with gas	Water recycling	G recy
				BARa	percent	percent	percent	percent	pe
Snowhite_reservoir	OK	10.02.2020	No history						

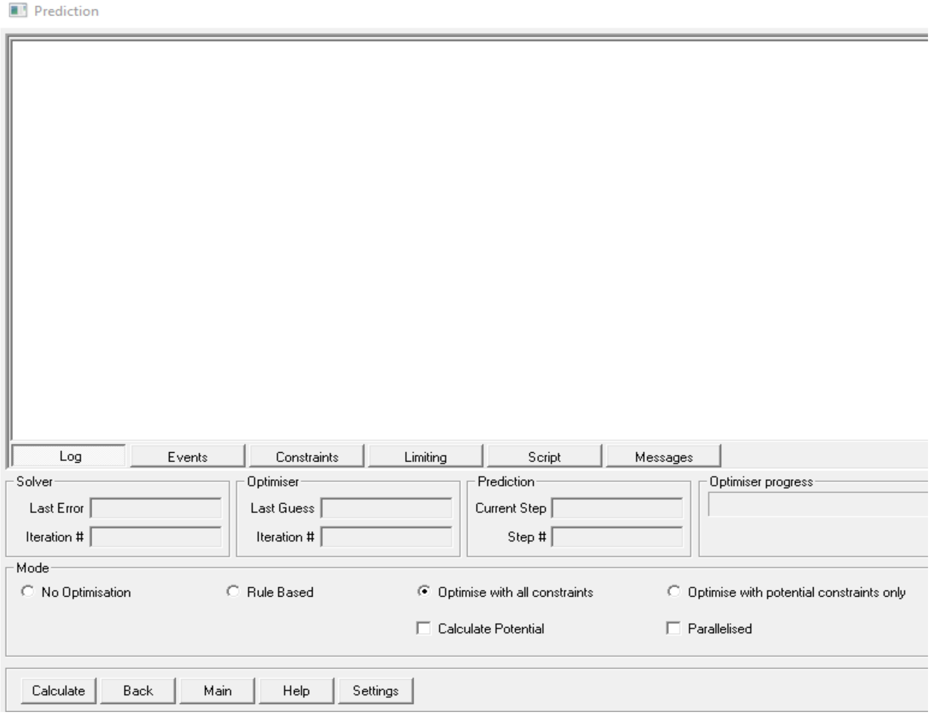
Start Date 10.02.2020 d.m.y End Date 10.02.2045 d.m.y Step Size 1 Month(s)

Restart Date 01.01.1900 d.m.y End Date 05.02.2021 d.m.y Step Size 1 Month(s)

-to generate the production profile, go to 'prediction' → 'Run prediction'

-set prediction timespan & timestep size (in this exercise, you can use dt = 1 year)

GAP: Prediction



Solver
Last Error
Iteration #

Optimiser
Last Guess
Iteration #

Prediction
Current Step
Step #

Optimiser progress

Mode
○ No Optimisation
○ Rule Based
● Optimise with all constraints
○ Optimise with potential constraints only
☐ Calculate Potential
☐ Parallelised

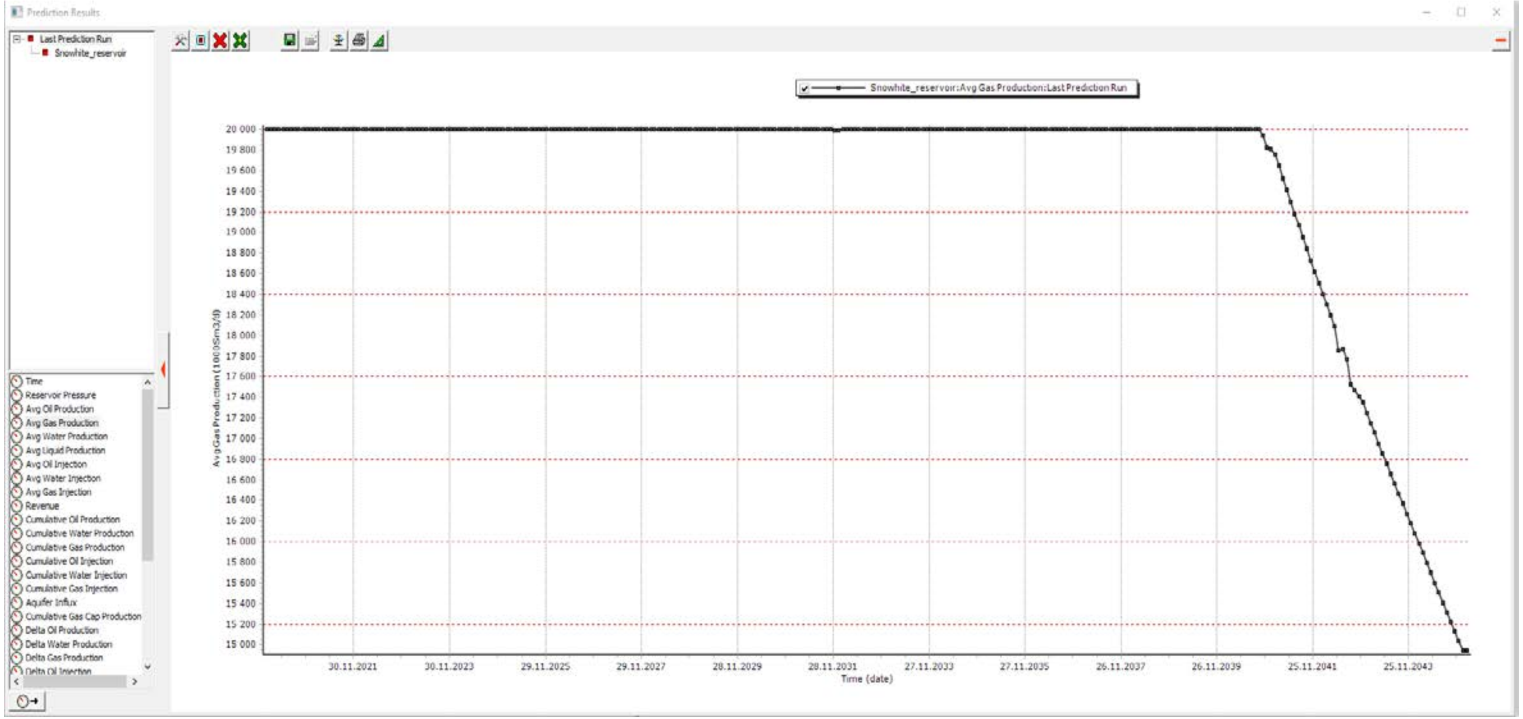
-input separator pressure

-since we have a constraint to be satisfy, choose ‘optimise with all constraints’ mode

-calculate

GAP: Prediction

-to see the results, open ‘prediction’ → ‘plot nodes prediction results’ → select all equipment types → plot



Questions

1. Snøhvit subsea gas well modeling in Prosper

Fluid information:

Use the black oil model for your PVT behavior.

WGR = 0 Sm^3/Sm^3
CGR = 0 Sm^3/Sm^3
Condensate density = 751 Kg/m^3
Gas gravity = 0.55
Formation Water salinity = 0 ppm
No H2S, CO2, N2.

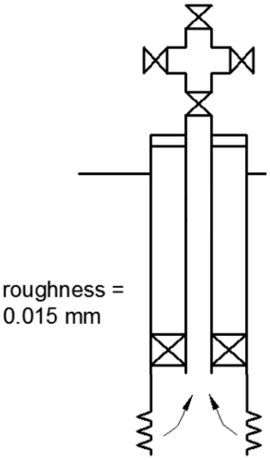
Well layout:

Deviation survey

MD [m]	TVD [m]
0	0
2100	2100

Geothermal gradient

MD [m]	T [C]
0	4
2100	92



Flow in tubing, tubing diameter 0.15 m

Overall wellbore heat transfer coefficient = 45 W/m^2 K

Reservoir info:

Producing from a single layer
Reservoir pressure = 276 bara
Reservoir temperature = 92 C
Backpressure coefficient = 1000 $Sm^3/d/bara$
Backpressure exponent = 1

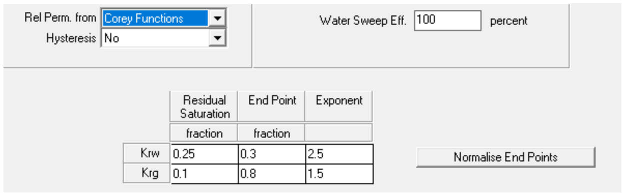
Tasks:

- Create a Prosper model of a Snøhvit subsea gas well.
- Estimate the producing rate using flow equilibrium assuming that the well is producing against a constant wellhead pressure of 100 bara
  - Compare the resulting TPR curve (curve of required flowing bottomhole pressure versus gas rate, for a constant wellhead pressure of 100 bara) against the curve used in Excel (with the CT and S). If necessary, adjust the CT and S in Excel to match the results from Prosper.
- Generate and export lift curves to be used in GAP (in the following exercise). p_{wh} range: 30-276 bara

2. Creating MBAL file of the Snøhvit reservoir

Fluid information:

Use the black oil model to represent your PVT behavior.
Gas gravity = 0.55
Condensate gravity = 751 Kg/m^3
At initial conditions no water.
Formation Water salinity = 0 ppm
No H2S, CO2, N2.
Temperature: 92 C
Initial pressure: 276 bara
Porosity: 0.15
Connate water saturation: 0.25
Original oil in place: 270 000 E6 Sm^3
Start of production: 05.04.2022
Water influx: No aquifer
Rel Perm: Corey Functions



Rel Perm. from: Corey Functions
Hysteresis: No
Water Sweep Eff. 100 percent

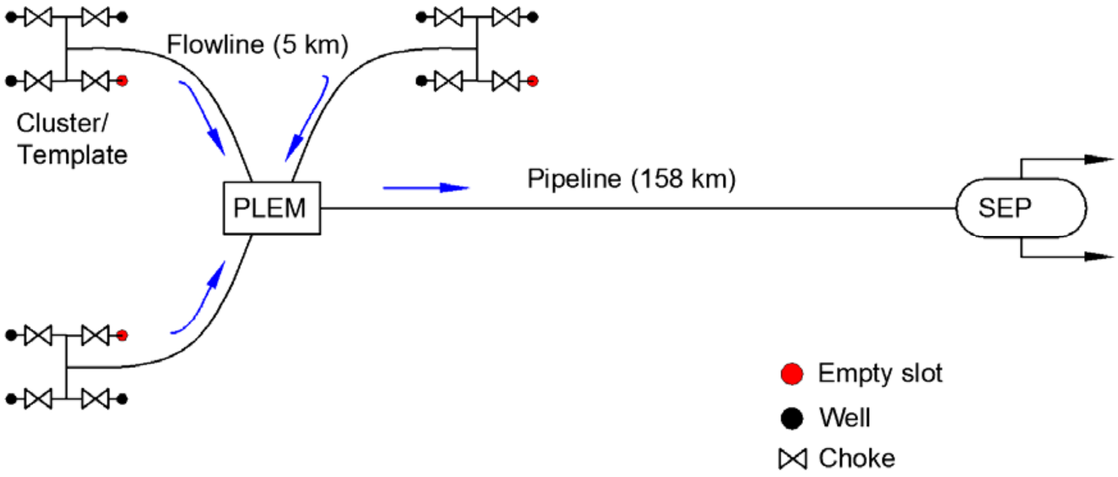
	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.25	0.3	2.5
Krg	0.1	0.8	1.5

Tasks:

- Set up a MBAL model of the Snøhvit dry gas reservoir.

3. Modeling of the Snøhvit subsea network with nine gas wells in GAP

The layout of the production network layout is shown below.



All wells are identical
Pipeline and flowline heat transfer coefficient: 5 W/m^2 K
Pipeline ID: 0.680 m, roughness 1.5e-5 m
Flowline ID: 0.355 m, roughness 1.5e-5 m

Tasks:

1. Build the GAP model of Snøhvit subsea wells producing to the LNG plan in Melkøya.
2. Run a network simulation (Solve Network) for initial time. Try the following options:
   a. Set DP choke control in wells to "fixed value" equal to zero bar. Report well and field rate.
   b. Set DP choke control in wells to "fixed value" equal to 30 bar. Report well and field rate.
   c. Set DP choke control in wells to "Calculated". Add a constraint to the separator for the maximum allowed gas rate to be equal to 20 E06 Sm3/d. Solve the network with "optimization". Report well rates. Plot the evolution of pressure and temperature along the long pipeline.
3. Estimate and plot production profiles[1] for the cases shown below. Do your computations until field rate goes below 5 E06 Sm3/d.
   - Gas plateau rates of 15, 20, 30, 40 E06 Sm3/d
4. For the case of plateau rate equal to 20E06 Sm3/d:
   a. Add the real elevation profile of the pipeline (see the image attached). Repeat your calculations and compare the production profile agains the one obtained in task 3.
   b. Modify the backpressure coefficient of all wells in the same template (e.g. to C = 800 Sm^3/d/bara). Predict production profiles and compare against the results of task 3.

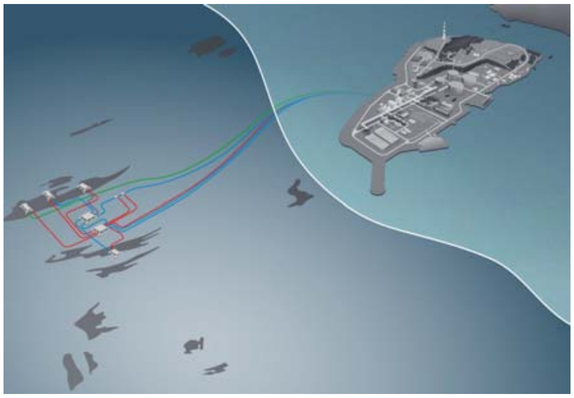
---

[1] Set DP choke control in wells to "Calculated". Add a constraint to the separator for the maximum allowed gas rate to be equal to the plateau rate. Then make a run using prediction mode, selecting the option of optimization with constraint.

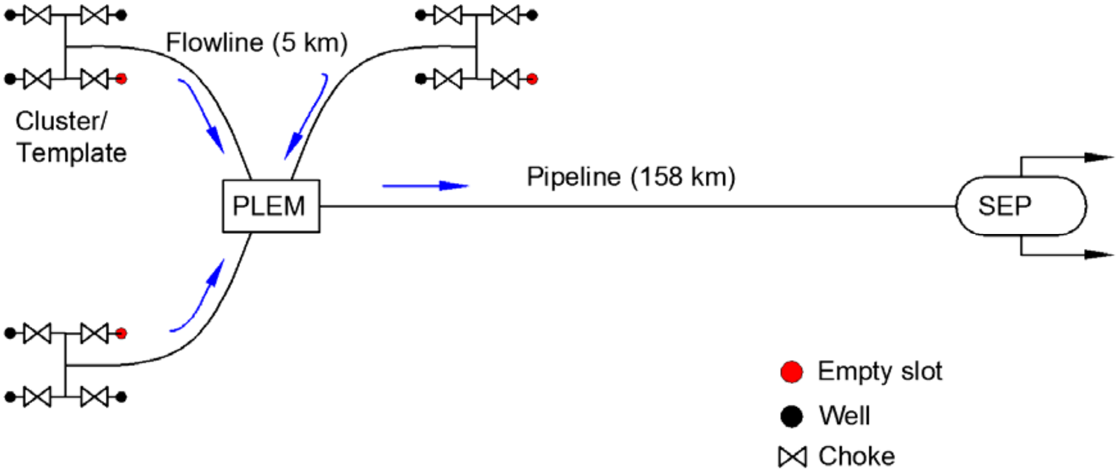
Calculate and plot the production share from that template versus time (qtemplate*100/qfield)

Flow assurance analysis of the Snøhvit pipeline using Hysys

Snøhvit is an offshore gas field located in the Barents Sea 158 km from Hammerfest currently under development. The field will be developed with the "subsea to beach" concept. The gas production will be taken by a LNG plant and transported further in LNG carrier to customers in US and Spain. The plateau rate of the field has been set to 20 E6 Sm^3/d and Equinor plans to maintain it until year 2032.



According to the base case Scenario (BCS) selected for the study, the field is completed subsea with three subsea templates, each with 3 wells.



You are asked to perform a steady-state, 1D simulation using the simulator Hysys to compute pressure and temperature drop along the main transportation pipeline from the PLEM to the slug catcher. The main goal is to assess hydrate formation. You have to perform your calculations for the plateau phase.

Tasks:

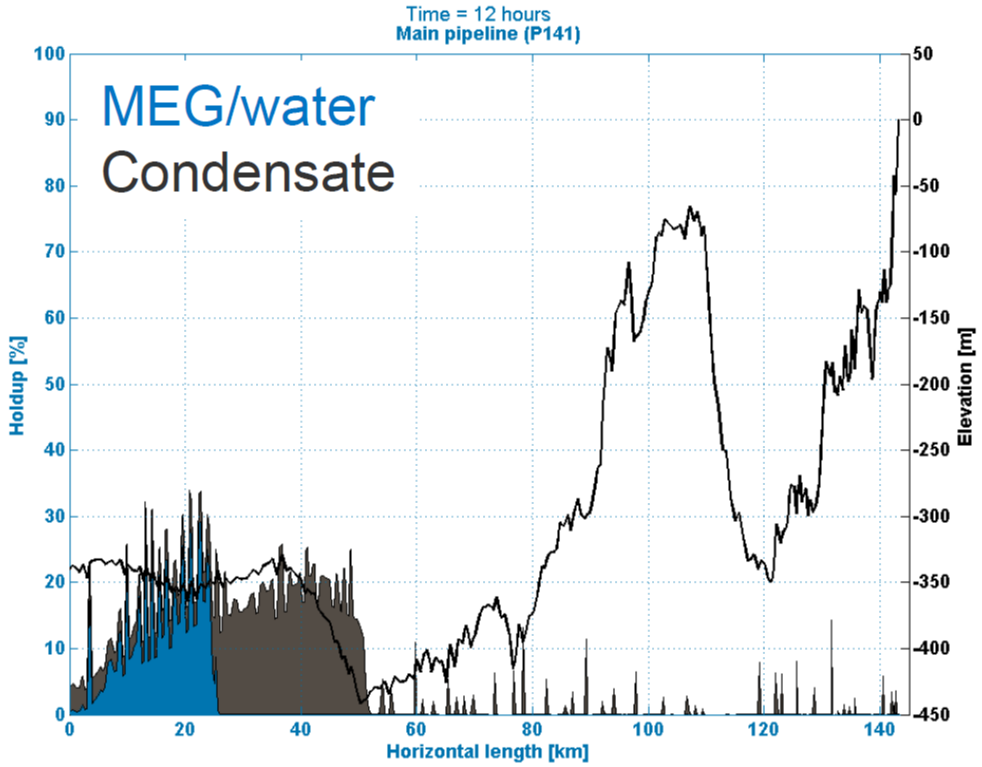
- Tabulate and plot pressure, temperature and liquid holdup along the pipeline. Compute the total amount of liquid in the pipeline.
- Plot the phase envelope (P-T diagram) of the gas mixture illustrating the saturation lines (bubble and dew point lines) and the quality lines inside the two-phase region (0.01, 0.02, 0.03, 0.04, 0.05, 0.1, 0.2). Plot also the hydrate line provided. Indicate in your plot the following:
    - Cricondenbar and Cricondentherm points
    - Plot the p-T along the pipeline on top of the P-T diagram. Detect if there is any condensate retrograde behavior. In this context condensate retrograde behavior is when the liquid stops condensing in the pipeline and it starts evaporating (the quality, mliquid/mtotal, starts to diminish)
    - Will hydrates form in the pipeline?

Solving suggestions

- Remember that Hysys performs its calculations co-current. This means that you provide a pwh pressure, Twh temperature, and a molar rate at the inlet of the pipe, and Hysys calculates the gas flow rates at the exit of the separator and the separator pressure. However, separator pressure has to be 30 bara. In order to force Hysys to reach this value, it is necessary to use an ADJUST.
- Water should be included in your calculations. The well stream is saturated with water at reservoir pressure and temperature (92 ºC)
- There might be a mismatch between the pressure drop calculations in Hysys and the ones performed previously with Excel. Hysys considers the effect of liquid on the pipe and the variation of density and viscosity of the fluids.
- Use increments of 1 km for your calculations.

Available information

- Pipeline profile. Use the program webplotdigitizer (https://automeris.io/WebPlotDigitizer/) to “steal” the poins from the chart below. Use at least 10 points.



Pout (Slug catcher pressure)	**[bara]**	30
Tseabed	**[C]**	6

Component	**Mole %**
Nitrogen	2.525
Carbondioxide	5.262
Methane	81.006
Ethane	5.027
Propane	2.534
i-Butane	0.4
n-Butane	0.83
i-Pentane	0.281
n-Pentane	0.308
Hexanes	0.352
Heptanes	0.469
Octanes	0.407
Nonanes	0.203
Decanes+	0.397

Density of Decane+: 814 kg/m^3
MW of Decane+: 172 kg/kmol

The overall heat transfer coefficient of the pipeline assuming that the pipe is "naked" is: 10 W/m2 K

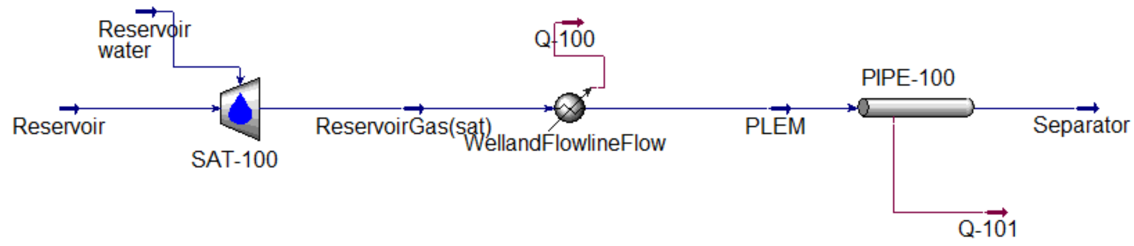
Use the following information:

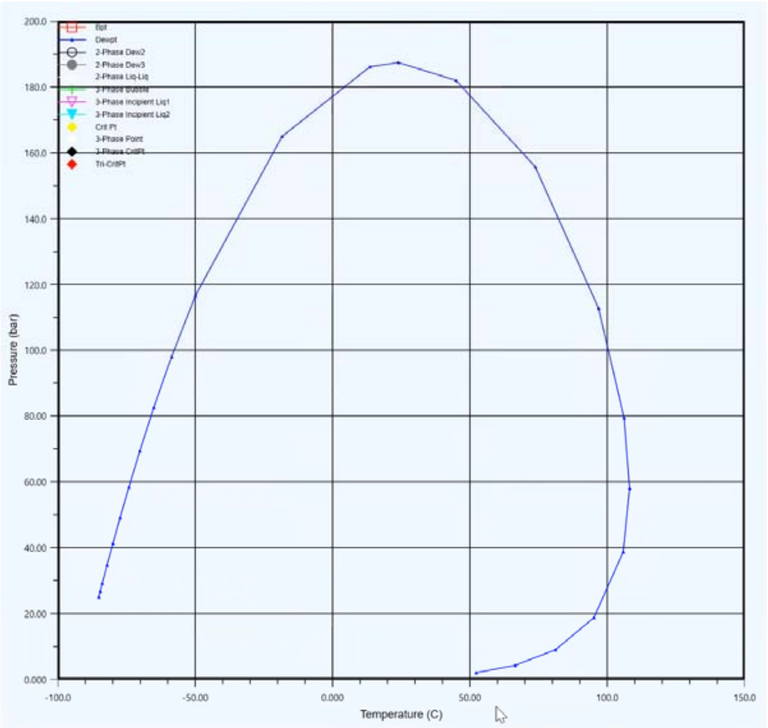
Inner diameter of the steel pipe ID, [mm]	**678.2**
Outer diameter of the steel pipe OD [mm]	**711.2**

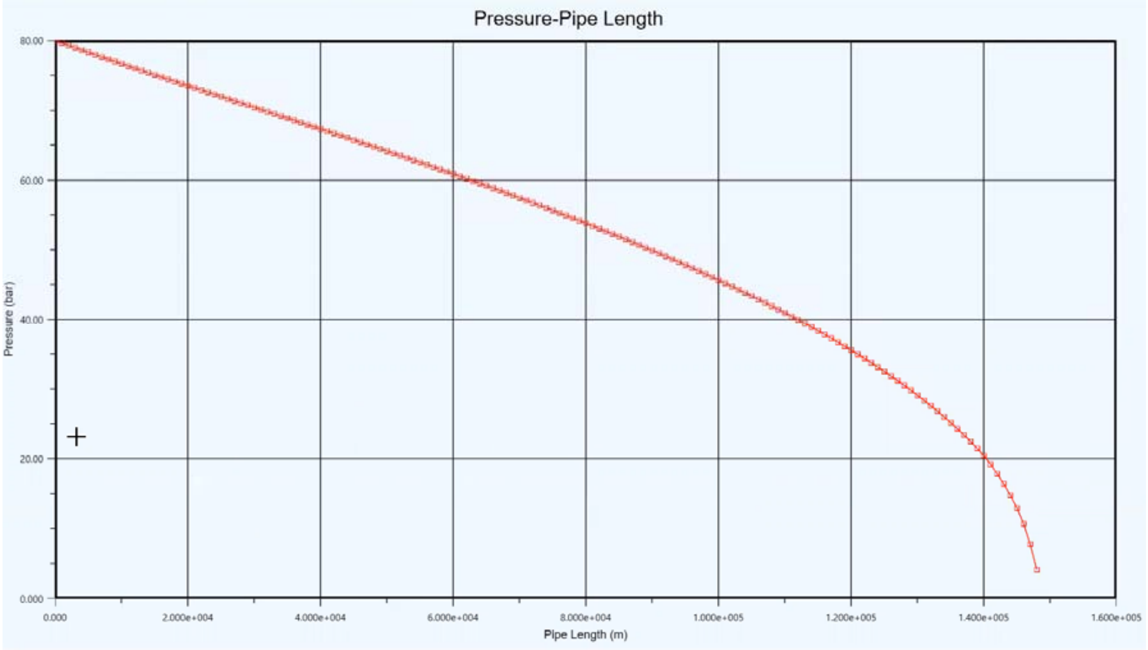
Some help with Hysys:

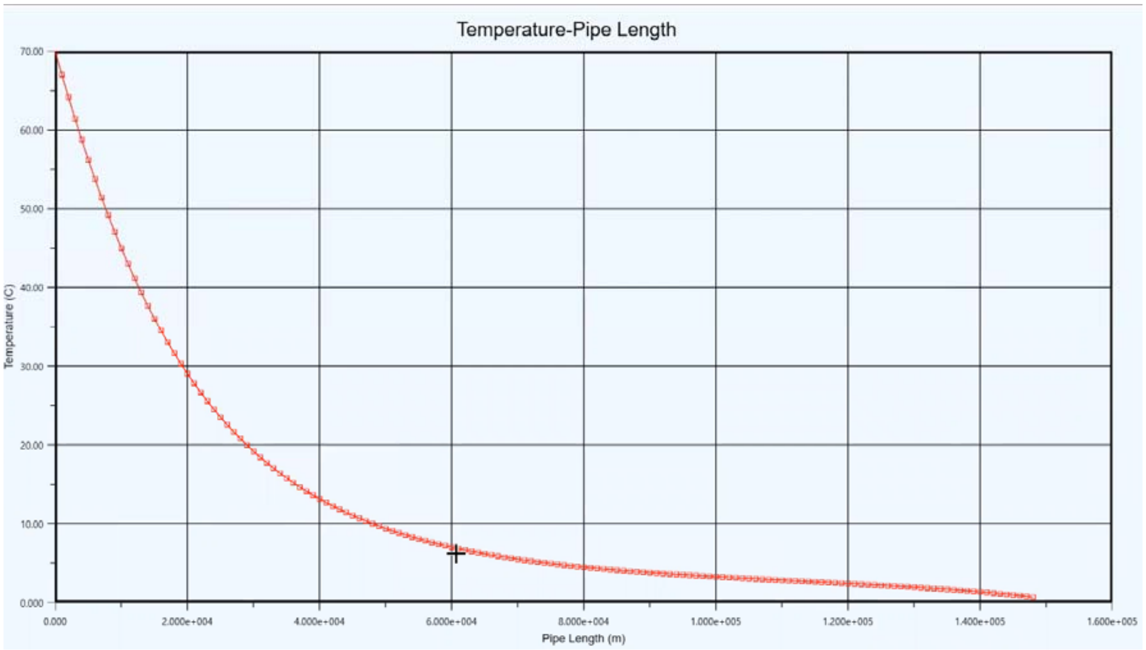
You can run Hysys remotely from your computer using
https://farm.ntnu.no
Alternatively, Hysys is installed in some computers in the computer lab on the 3rd floor.
If you need some help getting started with Hysys, watch the introductory video:
https://www.youtube.com/watch?v=3h6i_K_3yq0

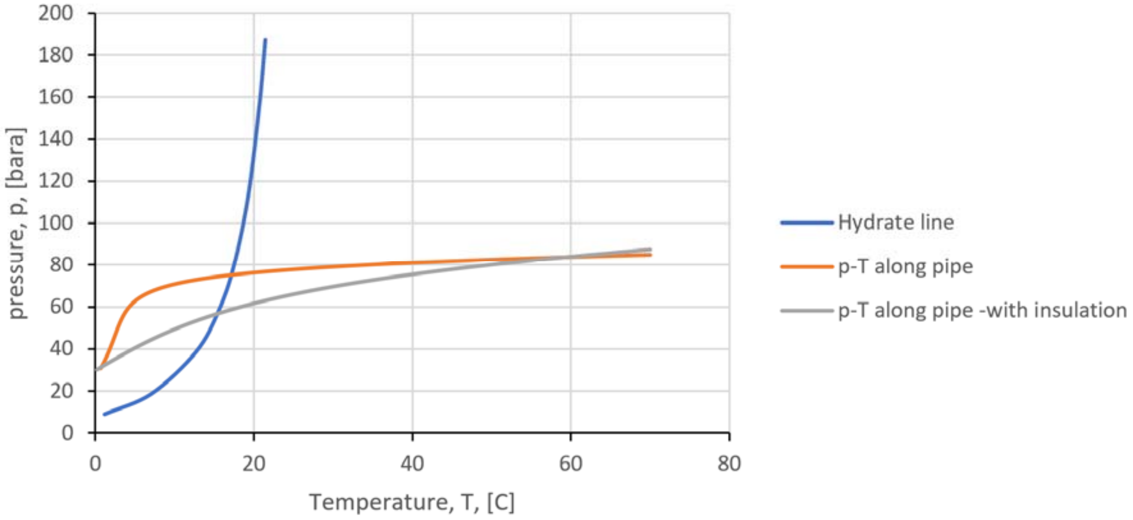
Solution (worked out in class):








Temperature-Pipe Length
Temperature (C)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.000
0.000
2.000e+004
4.000e+004
6.000e+004
8.000e+004
1.000e+005
1.200e+005
1.400e+005
1.600e+005
Pipe Length (m)


pressure, p, [bara]
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
Temperature, T, [C]
Hydrate line
p-T along pipe
p-T along pipe -with insulation

20220426

PENSUM:

- Field development workflow.
  - Lifecycle of a hydrocarbon field
  - Overview – The field development process
  - Production modes
  - Discounting
  - Relationship between plateau height and length
  - Rule of thumb between plateau height and TRR
  - Bottlenecking and processing capacity (separation capacity)
  - Onshore vs offshore
  - Oil vs gas
- Excel VBA, functions and routines.
- Field production performance
  - Estimation of production profiles
  - Dry gas production system: material balance, IPR, TPR, FPR, choke, flow equilibrium.
  - Dry gas production system: production scheduling
  - Measures to prolong the plateau.
  - Production potential
  - Boosting
  - Dry gas networks.
- Value chain model, cost estimation and NPV calculations
- Introduction to Python, Jupyter Notebook
- Dealing with uncertain parameters in FD
  - Probabilistic reserve estimation
    - Monte Carlo
  - Decision and probability tree analysis
- Presentation by Inflow Control
- Offshore structures
  - Overview
  - Layout of production systems
  - Marine loads on offshore structures
- Presentation and group work for Exercise set 1
- Flow assurance considerations
  - General overview
  - Inhibitor subsea system. Disposal.
  - Simulation of pipeline using commercial software (Hysys)
- Field production performance using commercial software (GAP and PROSPER)
- Presentation by Prof. Bahman Tohidi (HW) on Cold Flow

Home exercises
Class exercises
Quizzes

Lecture material :

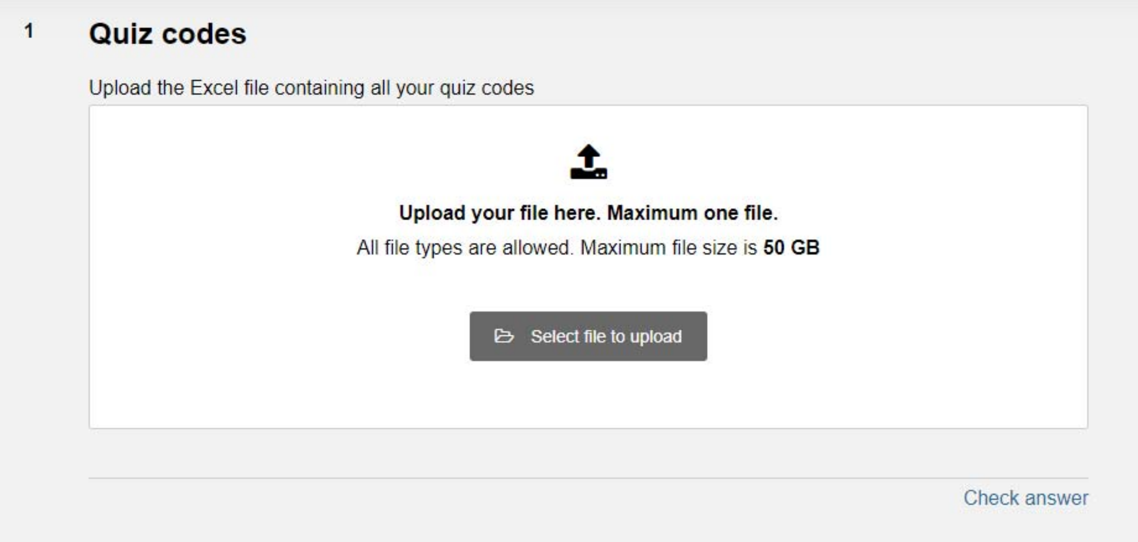
- Live lectures
- Youtube videos
- Reading material

- Video recording of presentation about Aasta Hansteen development

Delivery of work (40%)

The delivery of the quiz completion codes and Exercise set 1 is set for the 06.05, at 23:59, in Inspera. You can deliver anytime from now until that date. You should have already received an email from Inspera informing you about this. **The delivery is individual.**
The form in Inspera has two questions, one for the quiz codes, one for Exercise set 1.

For the quiz codes, the question looks like this:



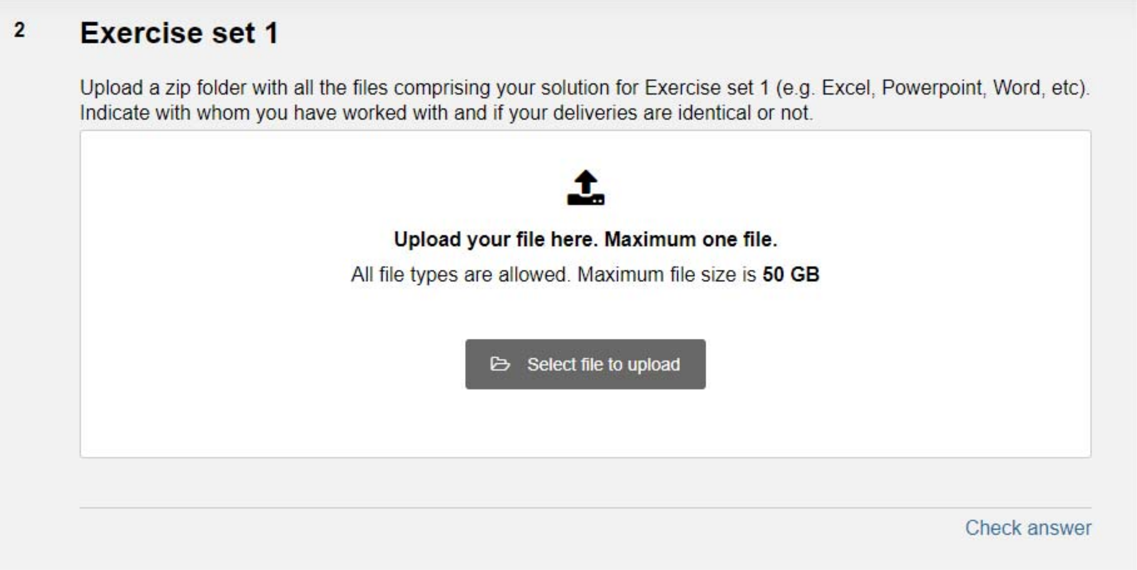
1 **Quiz codes**

Upload the Excel file containing all your quiz codes

Upload your file here. Maximum one file.

All file types are allowed. Maximum file size is **50 GB**

For Exercise set 1, the question looks like this:



2 **Exercise set 1**

Upload a zip folder with all the files comprising your solution for Exercise set 1 (e.g. Excel, Powerpoint, Word, etc). Indicate with whom you have worked with and if your deliveries are identical or not.

Upload your file here. Maximum one file.

All file types are allowed. Maximum file size is **50 GB**

For this item, upload a zip folder with all the files comprising your solution for Exercise set 1 (e.g. Excel, Powerpoint, Word, etc). Indicate with whom you have worked with and if your deliveries are identical or not.

I will try my best to correct these deliveries and give you the grades before the exam.

The quizzes will account for 20/100 points. Remember you have to deliver the approval code for all quizzes to gain access to the exam. There are a total of 14 quizzes. There is no half grade, If you deliver codes for all quizzes you will get 20 points.

The exercise set 1 accounts for 20/100 points

QCing your quiz codes

I have made a "quiz code checker", available in the following website: http://www.ipt.ntnu.no/~stanko/files/Courses/TPG4230/2022/Quizzes/Quiz_code_checker.html. This utility allows you to check the status of quiz completion codes, i.e., if they are valid and to which quiz they correspond to.

Last meeting of reference group

I will ask the reference group to meet one last time (probably next week) to summarize their findings and prepare the final report. Please convey your comments (of things that worked well, or for improvement) to them. I might send a survey for you to fill. Remember that your feedback is important, especially for future courses.

Additional Q&A sessions

If you have questions from now until the date of the exam, I suggest the following alternatives:

-Use the Blackboard forum

-Send an email to Nabeel or to me

We can arrange general Q&A Zoom sessions for several people with Nabeel or me, or both, if this is necessary. Please, send an email to Nabeel or to me to make this request.

Final exam

-Date: 09 Jun, 2022, 9:00-12:00

-The exam accounts for 60/100 points, and it will be conducted in Inspera. The exam questions will add up to 100 points that will then be converted to 60.

-You can see examples of previous exams in the side menu of Blackboard, under the point "Previous exams"

-The exam covers all the materials provided during the course, but emphasis is made on the material covered in the quizzes, homework and lectures.

-There will be no Python, HYSYS nor GAP/PROSPER/MBAL (IPM) for the exam.

-The guest presentations (inflow control, Prof. Tohidi) will not be covered in the exam.

-The value of each exam task will be provided in Inspera.

-The exam hasn't been prepared yet, but it could be a combination of long answer questions, value-fill questions in Inspera, and questions using Excel (where the problem must be solved in Excel and the Excel file is delivered). The exam is usually structured in the following way:

- Question text (indicating the number of points that the problem is worth)
- Data
- Link to download an Excel file (if any). The Excel file contains, in most cases, the problem's data, a suggested structure layout to solve the problem and some useful VBA functions.

- A long answer field, to provide a brief explanation about how you solved the problem
- A link to upload the Excel file containing your solution (if any)
- A link to upload additional files, e.g. images, sketches, word document, pdf, etc. (if any).

-When solving the exam, make sure that you make clear the procedure used to solve it, either by adding text to the Excel file, or by filling the text box.

-The digital exam department recommends you use Excel available on your computer. Therefore, make sure that Excel works properly on your computer, that you have access to the VBA module, and that the Excel Solver is installed and working properly.

-During the exam, when working with Excel, remember to save often.

-When you first download and open the Excel file, make sure to enable macros and make it a trusted document, otherwise you will have issues using the VBA functions. You can also save it with a different name so your computer recognizes it as its own.

-If you encounter technical problems during the exam, in the cover page there will be a telephone number of Oracle to get assistance.

-If the Excel on your machine encounters problems, you can also run it on the exam farm of NTNU (examfarm.ntnu.no. See instructions about how to connect here: https://innsida.ntnu.no/wiki/-/wiki/English/Home%20Exam%20with%20third%20party%20software). It seems that when connecting to examfarm.ntnu.no it opens a virtual desktop where you can run Excel in.

-Other relevant information:

- https://innsida.ntnu.no/wiki/-/wiki/English/Digital+home+exam+-+for+students
- https://innsida.ntnu.no/wiki/-/wiki/English/Home%20Exam%20with%20hand%20drawings
- https://innsida.ntnu.no/wiki/-/wiki/English/Pack+and+unpack+zip+files

Evaluation

-The course will be evaluated using percentage points, later converted to letters. The following limits will be used: https://innsida.ntnu.no/wiki/-/wiki/English/Grading+scale+using+percentage+points