Problem 1 (10 POINTS). In the context of field development, what is bottlenecking and how can it affect the current and planned production rates of the field?

Answer: Bottlenecking is a situation that occurs in an oil and gas field when there is a constraint which is hindering from producing more hydrocarbons. For example, processing facilities usually have maximum processing capacities of gas and water, so if water or gas production is excessive, then wells must often be choked back to ensure production is at or below capacity, and this usually entails reducing oil or gas production also. Bottlenecking can be caused e.g. processing equipment (separators, pumps, compressors), issues in injectors, excessive sand production, among many others.

The field and its processing capacities are usually designed using best estimates for production profiles of oil, gas and water. If it turns out that the rates are higher than what was originally anticipated, this could cause bottlenecking and deviation from the predicted profiles, which impacts negatively the project's economy.

Problem 2. (20 POINTS)

Consider that you work in a field producing in plateau mode an oil ($q_{\bar{o}}$) plateau rate of 37 000 Sm^3/d, a gas-oil ratio (GOR = $\frac{q_{\bar{g}}}{q_{\bar{o}}}$) of 120 and water cut of 20% (water cut is $\frac{q_{\bar{w}}}{q_{\bar{w}}+q_{\bar{o}}}$). The field has a gas processing capacity of 8 E06 Sm^3/d, a water processing capacity of 22 000 Sm^3/d and a liquid (oil+water) processing capacity of 51 000 Sm^3/d.

Your supervisor is concerned about an increasing trend in producing GOR and water cut. It is continues increasing, he fears the field might become bottlenecked and it will be necessary to reduce the oil field rate.

Your tasks are to estimate the critical GOR and water cut where bottlenecking will occur. Your values will be used as input in production forecasting calculations to determine when will bottlenecking occurs.

Answer:

To find the critical GOR where bottlenecking occurs during plateau, we make the gas processing capacity equal to the maximum GOR allowed times the oil plateau rate:

$$q_{\bar{g},capacity} = GOR_{max} \cdot q_{\bar{o},plateau}$$

Clearing out from this expression the GOR_{max} gives: 8 E06 /37000 = 216

Similar to the gas case, To find the critical water cut where bottlenecking occurs during plateau due to excessive water production, we consider the water processing capacity:

$$W_{c,max} = \frac{q_{\bar{w},capacity}}{q_{\bar{w},capacity} + q_{\bar{o},plateau}} = 0.37 \rightarrow 37\%$$

Lastly, to find the critical water cut where bottlenecking occurs during plateau due to excessive liquid production, we use:

$$q_{\bar{l},capacity} = q_{\bar{w},max} + q_{\bar{o},plateau} = 51000$$

$$q_{\bar{w},max} = 14000$$

$$W_{c,max} = \frac{q_{\overline{w},max}}{q_{\overline{w},max} + q_{\overline{o},plateau}} = 0.27 \rightarrow 27\%$$

Problem 3. (10 POINTS). What is the production manifold and what are its functions?

Answer:

The production manifold is a piping arrangement that includes on-off valves, check valves, headers, sensors, meters. Its functions are to commingle production from several wells into a single output and to redirect/isolate production selectively to e.g. specific separators and for metering (e.g. in a test separator or a multiphase flow meter). The manifold might also include a cross over valve between two headers (e.g. production and test) to perform pigging.

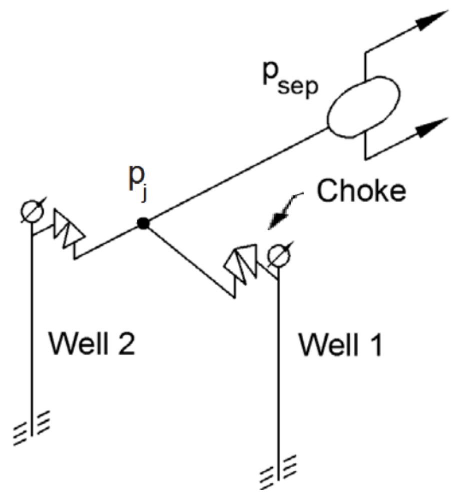
Problem 4. (10 POINTS). When dealing with flow assurance, many of the preventive and corrective measures involve the continuous or on-demand injection of chemicals (for example when dealing hydrate formation, hydrate inhibitors are injected at the wellhead). Explain how the chemical injection strategy impacts the design of the field.

Answer:

When it is necessary to have chemical injection, the main repercussions on the field design are:

- Including and designing chemical distribution and injection systems. For subsea systems, this involves umbilicals, subsea distribution units, additional piping in the well template, choke valves, etc.
- Adding processing units to reclaim chemicals topside (for example to recover MEG).
- It is important to map chemicals, their category (black, red, yellow or green) and were they will end up (produced water, oil or gas). For example it is desirable to reduce/eliminate the disposal to the environment (sea and air) of yellow, red and black chemicals. One should try to substitute yellow, red and black chemicals by green ones.
- It affects the project economy since it

Problem 5. (25 POINTS). Consider the gas field with two wells, a manifold, a pipeline and a separator shown in the figure below.



Calculate the wells and field rates when deltapchoke for wells 1 and 2 are 40 and 60 bar respectively. Use the Excel file provided (it has user defined VBA functions to perform calculations in inflow, tubing, and pipeline/flowline, and all the data you need to perform your calculations). **Write an explanation in the excel file about how you have solved the problem**. You must include in your calculations the pressure drop in the flowlines that goes from the choke discharge to the junction.

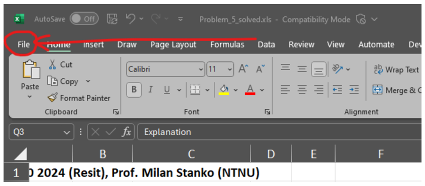
Additional information:

- Dry gas flow equations programmed in VBA

Inflow equation: $q_{\bar{g}} = C_R \cdot \left(p_R^2 - p_{wf}^2\right)^n$	C_R Inflow backpressure coefficient n, inflow backpressure exponent p_R reservoir pressure , bara p_{wf} flowing bottomhole pressure , bara
Tubing equation: $q_{\bar{g}} = C_T \cdot \left(\dfrac{p_{wf}^2}{e^S} - p_{wh}^2\right)^{0.5}$	C_T, tubing coefficient, Sm^3/bar S, tubing elevation coefficient, [-] p_{wh}, wellhead pressure , bara
Flowlines/pipelines $q_{\bar{g}} = C_{FL} \cdot \left(p_1^2 - p_2^2\right)^{0.5}$	p_1, upstream pressure, bara p_2, downstream pressure, bara C_{FL}, flowline coefficient, Sm^3/bar

Activating the solver in Excel:

- Step 1: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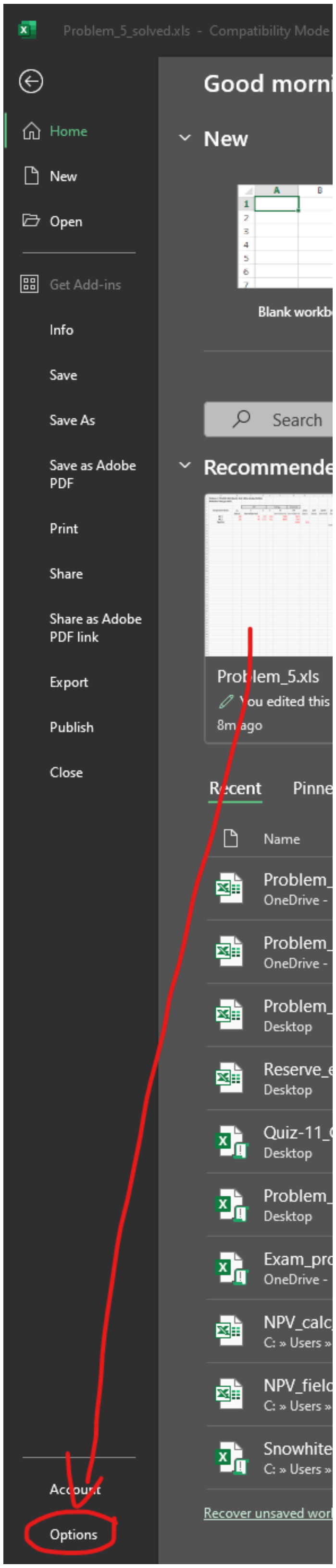
2024 (Resit), Prof. Milan Stanko (NTNU)

- Step 2: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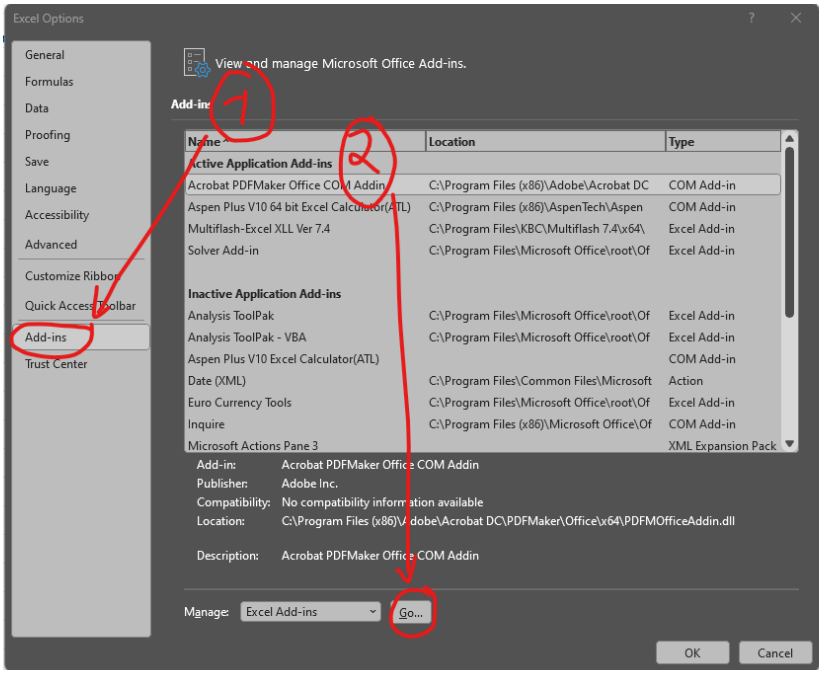
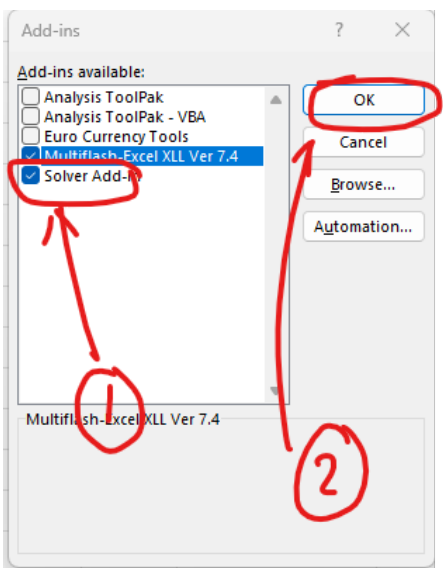
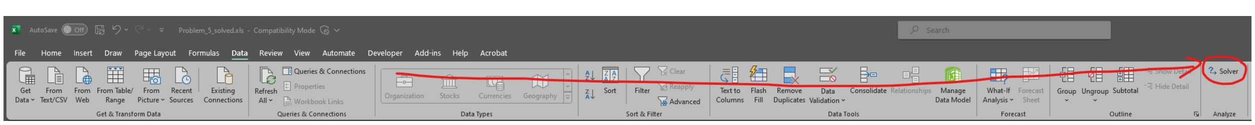
- Step 3:



- Step 4:

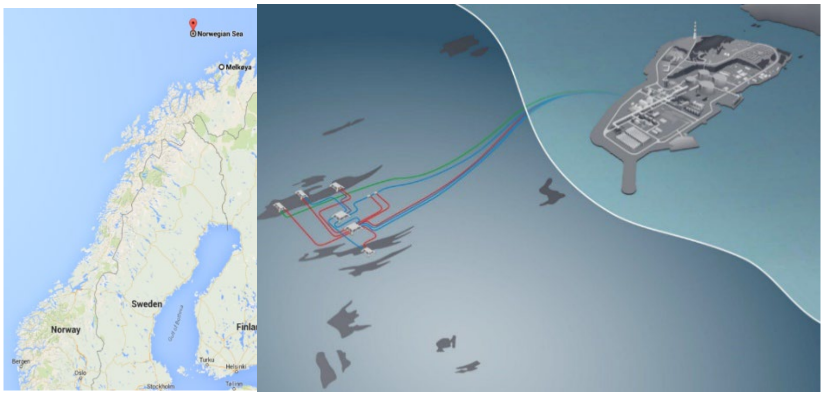


- Step 5:

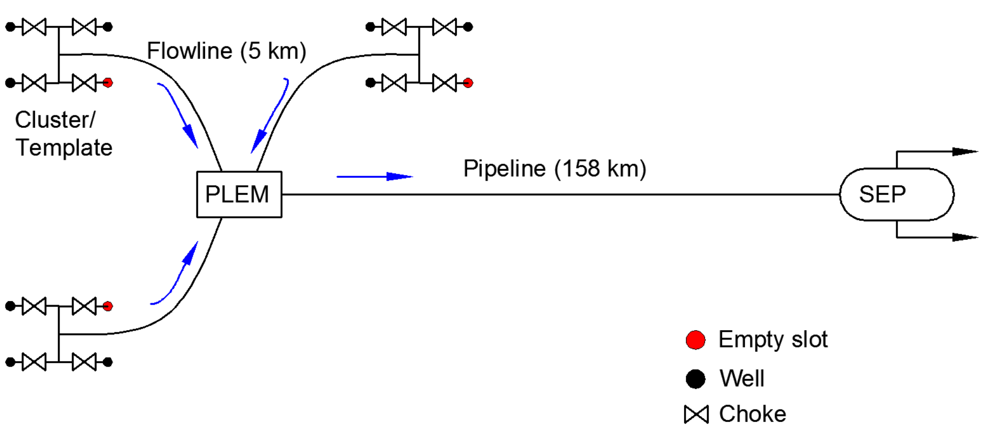


Problem 6. (25 POINTS).

Snøhvit is an offshore gas field located in the Barents Sea, 158 km from Hammerfest. The field will be developed with the “subsea to beach” concept. The gas production will be processed in a LNG plant on Melkøya (an island nearby the city of Hammerfest) and transported further in LNG carrier to customers in US and Spain. The field will be produced in plateau mode, with a field rate of 20 E06 Sm3/d.



According to the base case Scenario (BCS) selected for the study, the field is completed subsea with 3 subsea templates, each with 4-well slots. Each template is connected by flow line to the PLEM where the production streams of all the templates are commingled (combined and mixed). The PLEM is on the seabed approximately 158 km from shore and is connected by the main field export pipeline to the slug catcher (separator) on shore.



Task. The field is currently in the project planning phase, specifically under the stage of concept planning (DG2-DG3). You are part of the engineering team that is evaluating the economical feasibility of the proposed concept. **Your task is to calculate the probability of the project having a negative NPV considering uncertainties in the size of reservoir (initial gas in place) and time of production startup. Write an explanation in the excel file about how you have solved the problem.**

To perform your NPV calculations, a senior engineer in the company has provided you the following approximate analytical expression:

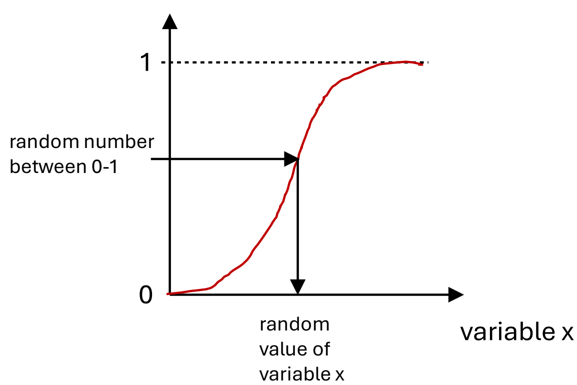
$$NPV = q_{p,f} \cdot P_g \cdot t_{uptime} \cdot \left[\frac{e^{-i \cdot t_{ini}} - e^{-i \cdot (t_{ini} + \Delta t_p)}}{i} + \frac{e^{-i \cdot (t_{ini} + \Delta t_p)} - e^{-(m+i) \cdot t_{end} + m \cdot (\Delta t_p + t_{ini})}}{(m+i)} \right] - N_w \cdot 100\ E06\ USD - 500\ E06\ USD - 200 \cdot q_{p,f} - 200\ E06\ USD \cdot \frac{\left(e^{-i \cdot t_{ini}} - e^{-i \cdot t_{end}}\right)}{i}$$

This expression outputs a value in USD. The first term in the right-hand side is the discounted revenue, the second term is the DRILLEX, the third and fourth term are CAPEX and the last term is the OPEX. A detailed explanation of all the terms and their values to assume follow.

For your convenience, the equation above has been programmed in Excel VBA and is available in the excel sheet provided with the name "NPV_Snowhite".

<u>Data:</u>

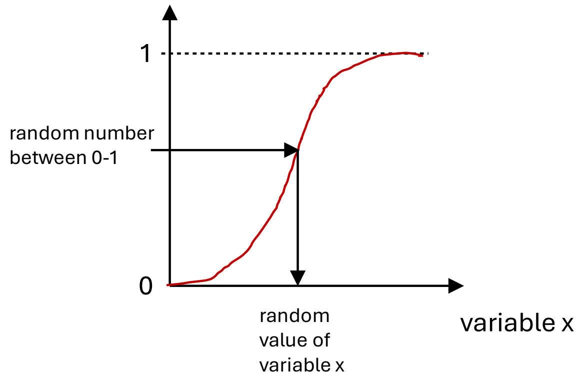
- $q_{p,f}$, Field plateau rate, in Sm^3/d, must be lower than $N_w \cdot q_{ppo,w}$
- P_g, Gas price, 0.1 $\frac{USD}{Sm^3}$
- t_{uptime}, Number of operational days in a year, 360 days/year
- i, discount rate, 0.05.
- t_{ini}, time to production start, years. This parameter exhibits a triangular distribution with minimum 3 years, mode 5 years and maximum 7 years. **The VBA function "x_Triangular" is provided to generate a random sample (value of the variable) using a random number between 0-1 and the cumulative distribution function (cdf) of the triangular distribution (see figure below)**.



- Δt_p, plateau duration (in years):

$$\Delta t_p = \frac{G}{1.14 \cdot t_{uptime}} \cdot \left(\frac{1}{q_{p,f}} - \frac{1}{N_w \cdot q_{ppo,w}} \right)$$

- $q_{ppo,w}$, Maximum gas production of a single well at initial reservoir pressure with open choke, $5.7e6$, in Sm^3/d
- Number of wells, N_w, equal to 9.
- G, initial gas in place. This variable is normally distributed with mean 270 E09 Sm^3 and standard deviation 20e9 Sm^3**. The VBA function X_normal is provided to generate a random sample (value of the variable) using a random number between 0-1 and the cumulative distribution function (cdf) of the normal distribution (see figure below)**.



- m is a constant:

$$m = \frac{1.14 \cdot N_w \cdot q_{ppo,w} \cdot t_{uptime}}{G}$$

- t_{end}, abandonment time, 31 years.

<u>Additional information:</u>

- To perform a frequency analysis, remember you can use Excel's built in function FREQUENCY(data_array, bins_array). "data_array" is a set of values for which you want to count frequencies, "bins_array" is intervals into which you want to group the values in "data_array". To use the function you must first select the cell range where you want to place the output (usually cells next to the "bins_array"), call the function and then use ctrl+shift+Enter to execute the function.
- Regarding bins_array, it recommended to use at least 15.
- If you need to perform a MonteCarlo simulation, use at least 500 iterations.