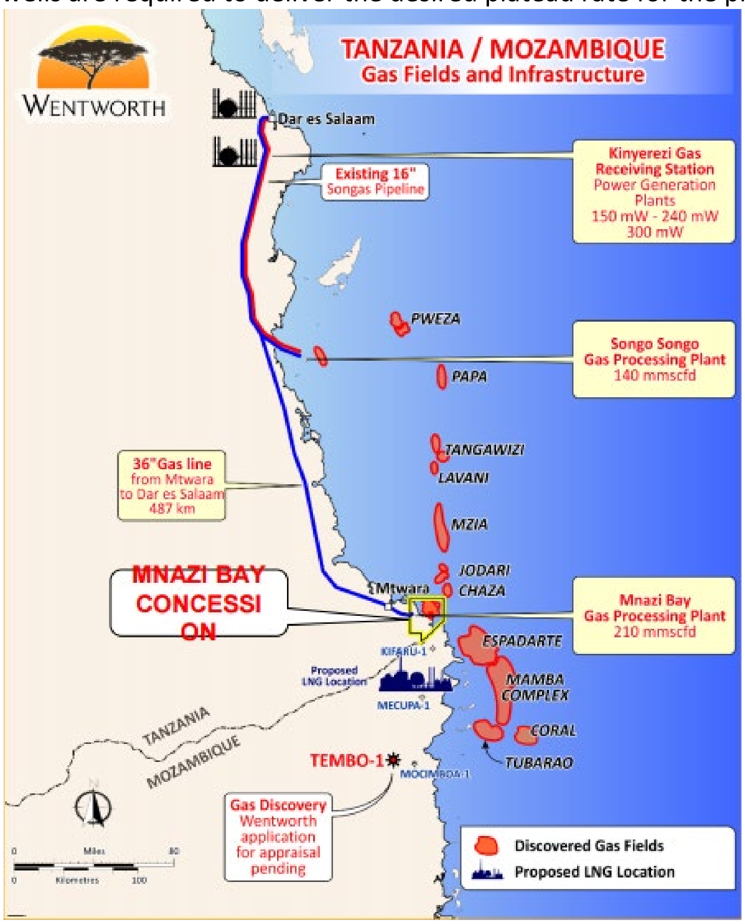
PROBLEM 1. (30 POINTS)

ANSWER THIS PROBLEM USING EXCEL AND WRITE THE PROCEDURE IN THE EXCEL FILE. NO EXCEL FILE IS GIVEN. YOU MUST CREATE YOUR OWN.

The Mnazi Bay is a gas field located in the south-eastern shores of Tanzania, estimated to have initial gas in place of Initial gas in place (G) of 12 E09 Sm3. The field will be produced with standalone vertical wells to a gas processing center for dehydration and dew point control. The gas will be sent further via pipeline to feed the main power plant in Dar es Salaam, a local power plant in Mtwara/Lind and a Urea and Cement plant. The customers require a total constant gas production of 2.5 E06 Sm^3/d for a period of 10 years, and assuming each year has a total number of 355 operational days. The reservoir engineer has estimated that 7 wells are required to deliver the desired plateau rate for the plateau time.



Assume the field can be modeled using the concept of production potential and assuming all wells are identical. The analytical expression for field production potential (in Sm^3/d) as a function of cumulative gas production of the field (G_p in Sm^3), and number of wells (N_w) is the following:

$$q_{pp} = N_w \cdot q_{ppo,well} \cdot \left(1 - 1.14 \cdot \frac{G_p}{G}\right)$$

With $q_{ppo,well}$ = 2.5 E06 Sm3/d.

Your tasks are the following:

1. **(10 POINTS)** Verify the number of wells estimated by the reservoir engineer can actually deliver the desired plateau rate and duration.
2. **(15 POINTS)** Well cost (drillex) is highly uncertain due to the remote location of the field and the drilling path. Calculate the maximum well cost allowed to still yield an economically-viable project (NPV>=0).
3. **(5 POINTS)** If it turns out the reservoir is bigger than initially anticipated (18 E09 Sm3), will this have any effect on the results of task 2? If yes, estimate the new value of well cost.

Guidelines to calculate NPV:

- In the cash flow, consider well costs and revenue income only.
- Assume that a year consists of 355 operational days.
- Assume that all wells are paid in year "0" (no need to discount the value)
- Assume production starts at the end of year 4 (beginning of year 5).
- Consider revenue during the plateau period only, and if plateau duration is equal to a fraction (e.g. 11.1 years) neglect the fraction and consider the integer part only.
- Use a discount factor of 8%.
- Use a gas price of 0.08 [USD/ Sm^3]

Additional information:

- To calculate the revenue part of NPV:

$$NPV_{rev} = \sum_{t=1}^{N} \frac{Revenue_t}{(1+i)^t}$$

Here t is year counter, N is total number of years, and "i" is discount factor (in fraction).

The following expression can be used (only for plateau period):

$$NPV_{rev} = q_{plateau} \cdot P_g \cdot t_{uptime} \cdot \left[\frac{e^{-i \cdot t_{ini}} - e^{-i \cdot (t_{ini} + \Delta t_p)}}{i} \right]$$

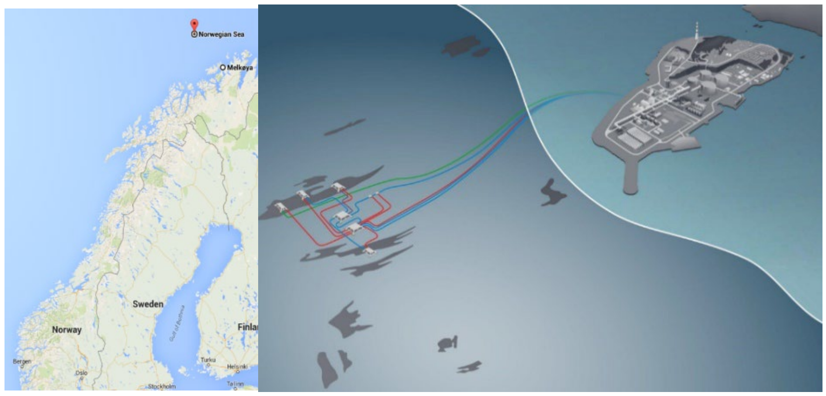
Where t_{uptime} is number of producing days in a year, P_g is gas price (in USD/Sm3), t_{ini} is startup time (in years), Δt_p is plateau duration (in years).

SOLUTION:

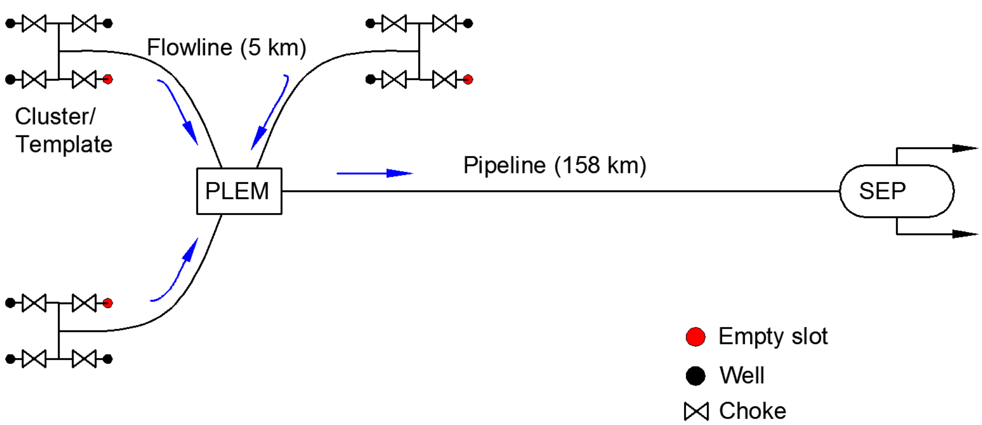
See attached Excel file

PROBLEM 2. (20 POINTS)

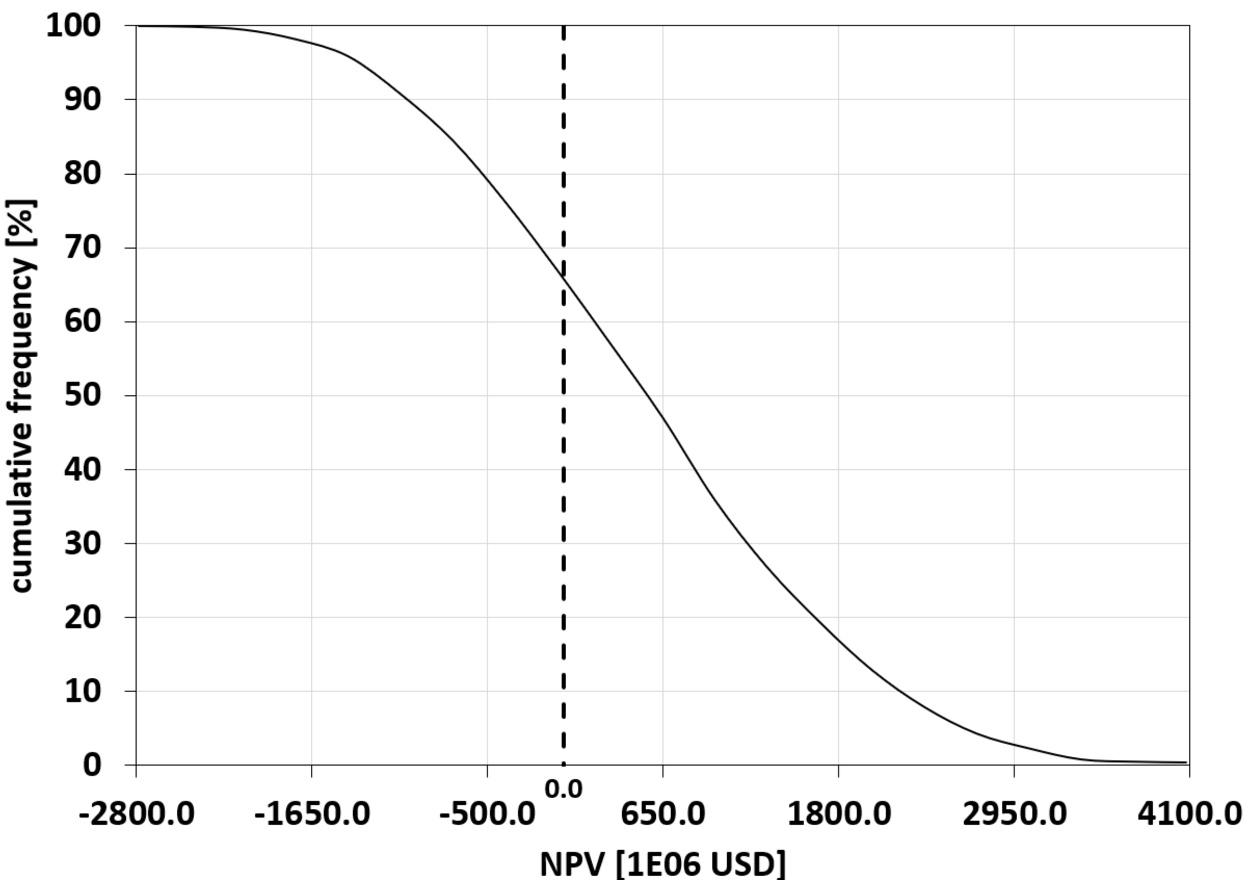
Snøhvit is an offshore gas field located in the Barents Sea, 158 km from Hammerfest. The field will be developed with the “subsea to beach” concept. The gas production will be processed in a LNG plant on Melkøya (an island nearby the city of Hammerfest) and transported further in LNG carrier to customers in US and Spain. The field will be produced in plateau mode, with a field rate of 20 E06 Sm3/d for a period of 20 years and later for 10 years in decline.



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. Typically, only three wells are completed in each template (there is one slot for redundancy). Well rate is controlled with wellhead chokes. The templates will be symmetrically positioned 5 km away from the subsea Pipeline Entry Module (PLEM). Each template is connected by flowline 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. At this stage, it is assumed all wells are identical.



A Monte Carlo simulation was performed to evaluate the effect of uncertainties (cost, well productivity, initial gas in place, production startup and gas price) on NPV. The results are presented in the figure below (in this figure, the minimum and maximum NPV values are -2800 and 4100 1E06 USD respectively).



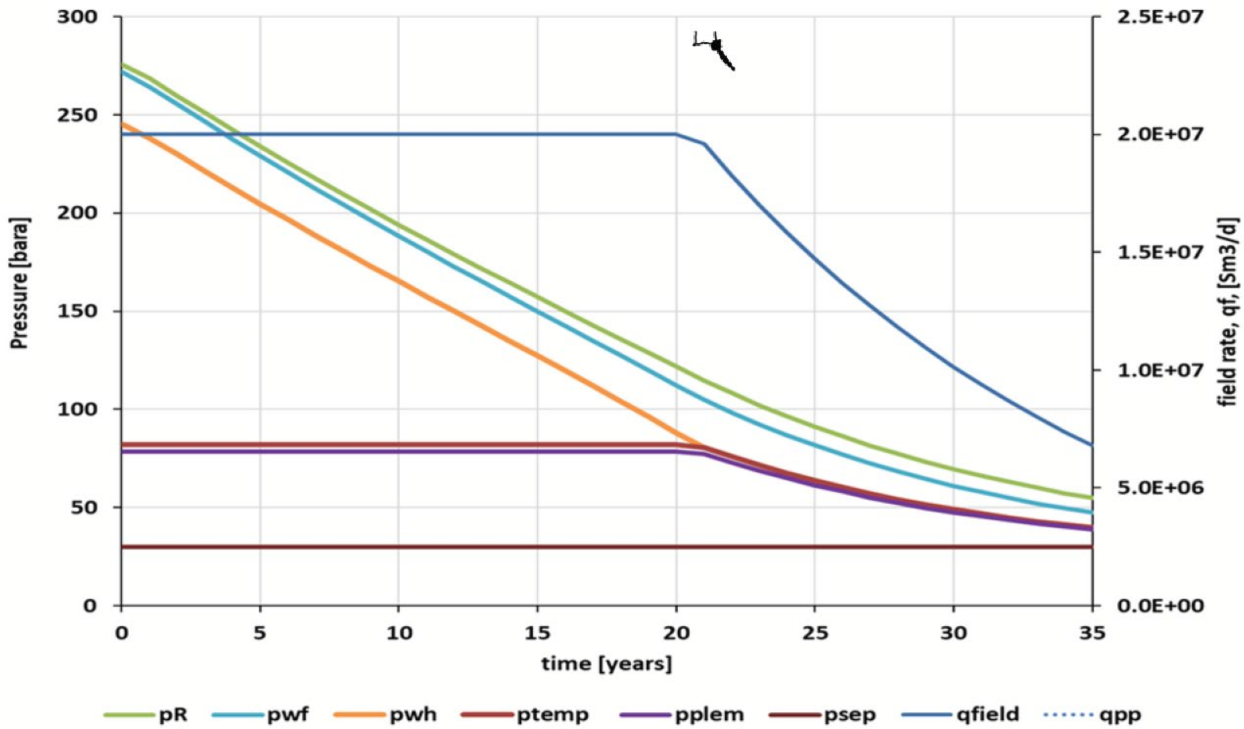
Answer the following questions:

- **Task 1. (10 POINTS)** Make a plot of variation of pressure versus time for important locations of the production system (reservoir, bottom-hole, wellhead, template, PLEM and separator). From production start until abandonment.
    - Explain why plateau ends.
    - Explain how does one calculate the variations of these pressures in time.
    - Consider one drills 3 additional wells (one per template). Explain if (and why) this yields a longer (or shorter) plateau.

- **Task 2 (10 POINTS) .** Regarding the results of the Monte Carlo simulation:
    - Explain how does one perform a Monte Carlo simulation
    - Provide the probability of the project having a negative NPV.
    - Provide the P90, P50 and P10 values of the NPV distribution, and explain what do they mean.

SOLUTION:

Task 1.



Plateau ends because the available pressure at the wellhead is going down in time since reservoir pressure is going down in time due to offtake. At some time it becomes smaller than required template pressure to flow against separator, then choke is fully open and the rate must decline to make template pressure and wellhead pressure equal.

Psep is constant.

Pplem is calculated by using the pipeline flow equation with given plateau rate and downstream pressure (separator pressure)

Ptemp is calculated by using the flowline equation with template rate and downstream pressure (pplem)

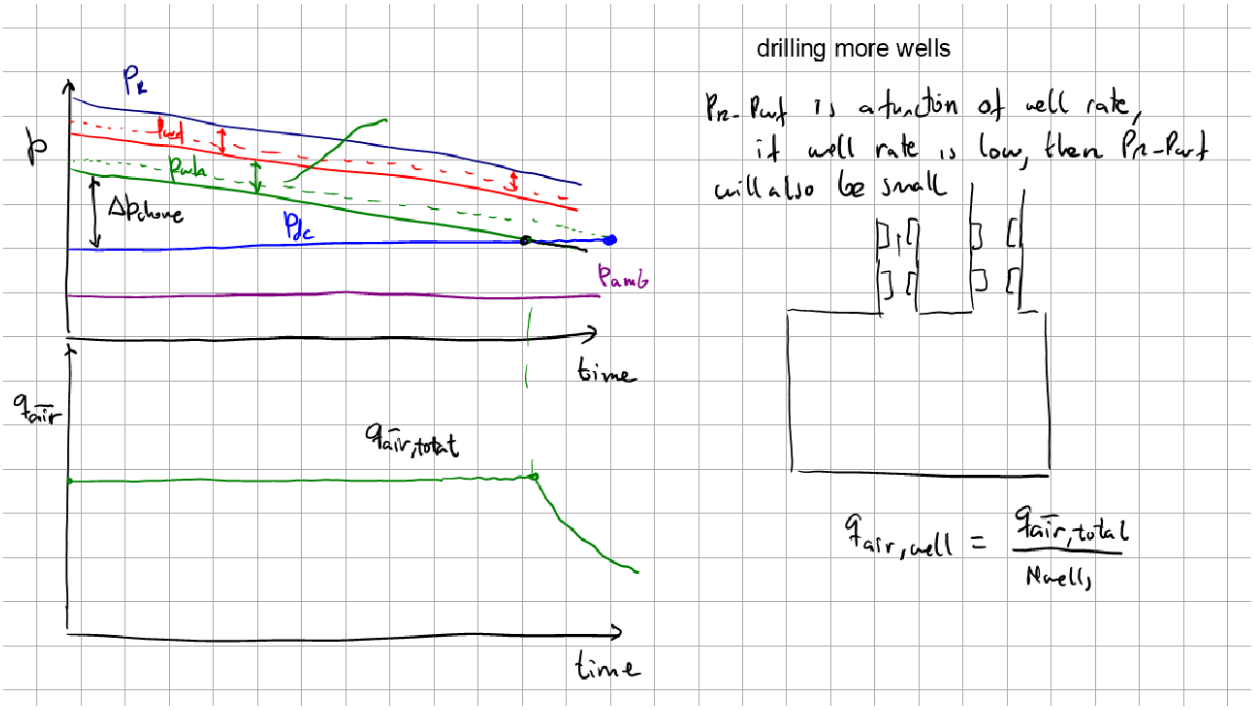
Pres is calculated with the material balance equation, using initial reservoir pressure, initial gas in place and cumulative production.

Pwf is calculated with the ipr equation, using well rate and upstream pressure (reservoir pressure)

Pwh is calculated with the tubing equation, using wellrate and upstream pressure (pwf)

Dp choke is pwh-ptemp

Drilling more wells gives longer plateau, see the figure below, the distance between pR and pwf and pwf and pwh is smaller thus zero choke dp occurs at a later point in time.



Task 2.

To perform a Monte carlo simulation one:

1. Defines pdf and cdf of uncertain variables
2. Samples randomly a single value of each uncertain variable (usually using the cdf, by using a random value between 0 and 1).
3. Run the simulation using the random samples of the uncertain variables
4. Record the output (e.g. NPV)
5. Repeat septs 2-4 for many iterations
6. Perform a frequency analysis on the recorded outputs and calculate their pdf and cdf.

The probability of having a negative NPV is the probability of the project having an NPV equal to 0 or less. The figure presented gives that there is a 65% probability of the project having an NPV equal to zero or higher. Therefore, there is a 35% probability of the project having an NPV equal to zero or lower.

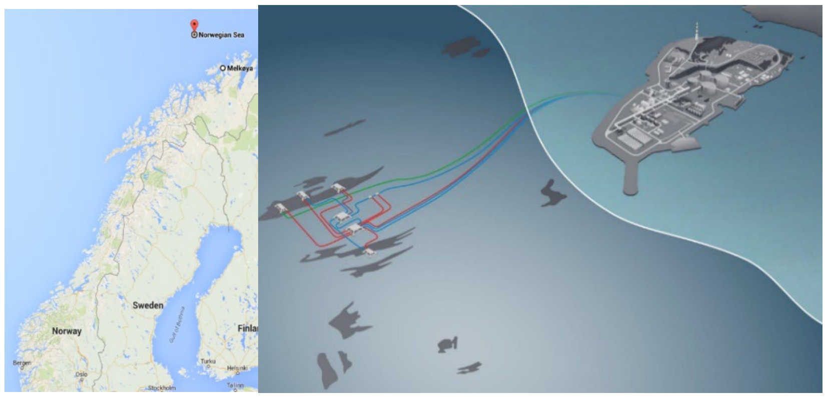
P90 = -1050 E06 USD. There is a 90% probability that the NPV value of the project is equal to this number or higher.

P50 = 550 E06 USD There is a 50% probability that the NPV value of the project is equal to this number or higher.

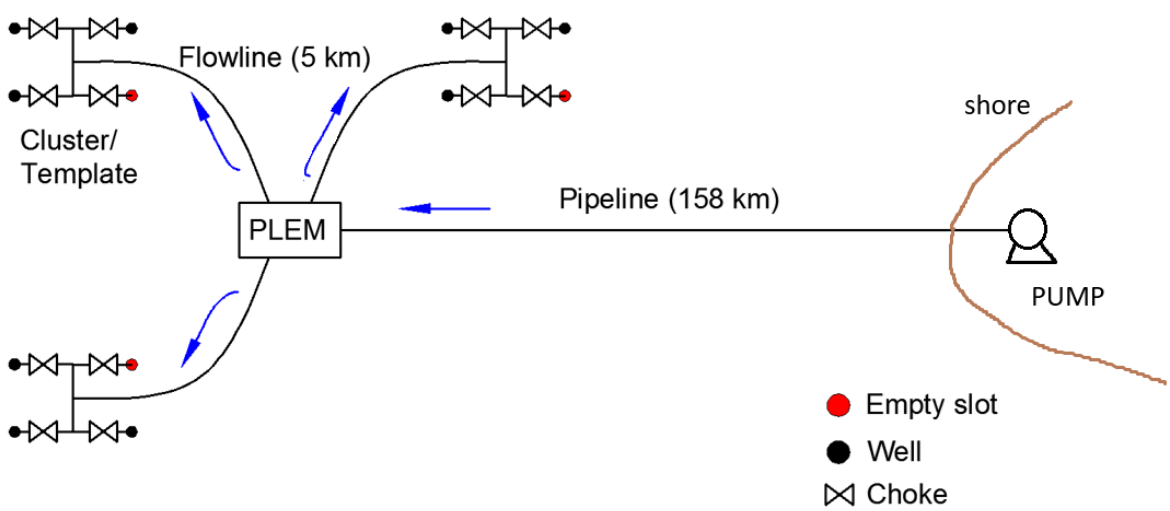
P10 = 2100 E06 USD There is a 10% probability that the NPV value of the project is equal to this number or higher.

PROBLEM 3. (15 POINTS)

The Snøhvit CO_2 is a fictitious CO_2 injection field. The field is located in the Barents Sea, 158 km from Hammerfest, at a water depth of 300 m. The field will be developed with the "beach to subsea" concept. The CO_2 captured in Melkøya (an island nearby the city of Hammerfest) is compressed to a "supercritical" state (with water-like density, 900 kg/m^3 and low viscosity) and sent through a pipeline and distributed to 9 subsea wells. The field will be operated in a constant injection mode, with an injection rate of 37 000 t/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. At this stage, it is assumed all wells are identical. There are wellhead chokes in use to ensure the same rate is injected in all wells. Typically, only three wells are completed in each template (there is one slot for redundancy). The templates will be symmetrically positioned 5 km away from the subsea Pipeline Exit Module (PLEM), that distributes CO_2 to all templates. The PLEM is on the seabed approximately 158 km from shore and is connected by the main field injection pipeline to the delivery pump on shore. The pump provides a constant discharge pressure of 200 bara.



The reservoir is a saline aquifer located 1500 m below the seafloor. The pressure of the reservoir will increase with time, as CO_2 gets injected, displaces water and dissolves in it. Initial reservoir pressure is 300 bara. The fracture pressure of the reservoir is 390 bara (including a safety factor).

Answer the following questions:

- **Task 1.** Make a plot of variation of pressure versus time for important locations of the production system (reservoir, bottom-hole, wellhead, template, PLEM and pump discharge). From injection start until plateau end. Explain why plateau ends, and how does one calculate the variations of these pressures in time.

Use different colors for each pressure trace.

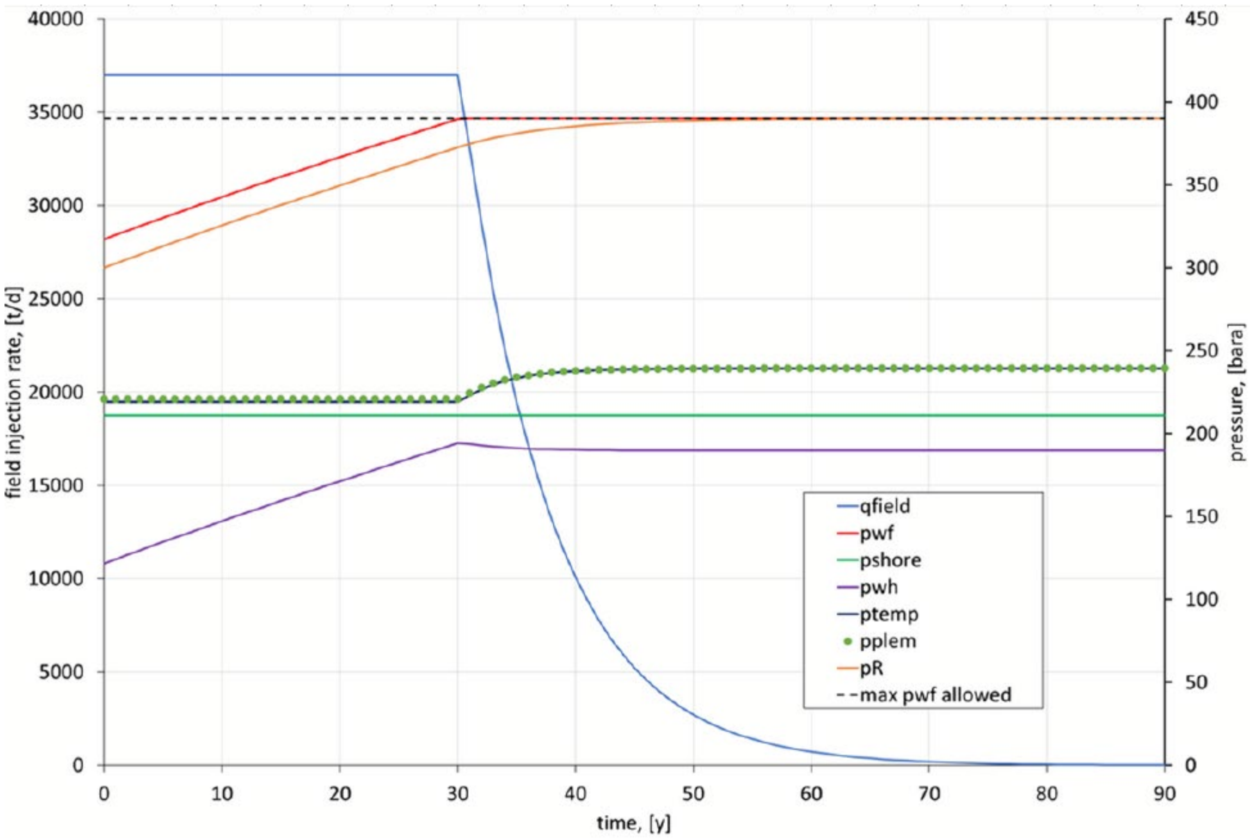
Additional information:

- When considering the flow of CO_2 in pipes, wells, consider the hydrostatic pressure drop only. Assume the frictional pressure drop is negligible.
- The inflow performance relationship of the well can be represented with the following equation, $\dot{m}_{CO2} = J \cdot \left(p_{wf} - p_R\right)$, with J = 240 t/d/bar

SOLUTION:

Problem 3

Task 1



Plateau end could occur due to two reasons:

The bottom-hole pressure reaches the fracture pressure of the formation

The choke deltap (ptemp-pwh) becomes zero.

One calculates

pR with the material balance equation, initial reservoir pressure and cumulative injection

pwf with the IPR equation, using the provided well rate, and the downstream pressure (pR)

pwh with the tubing equation, using the provided well rate and the downstream pressure (pwf). Since in this case friction can be neglected,the pressure drop in the tubing is the density times well depth times gravitational acceleration

pplem is calculated by using the pipeline equation, using the provided field rate and the upstream pressure (pump discharge) Since in this case friction can be neglected,the pressure drop in the pipeline is the density times seabed depth times gravitational acceleration ptemp is calculated by using the flowline equation, using the provided template rate and upstream pressure (pplem). Since in this case friction can be neglected, and pplem and template are at the same depth, then both pressures are equal.

PROBLEM 4. (25 POINTS)

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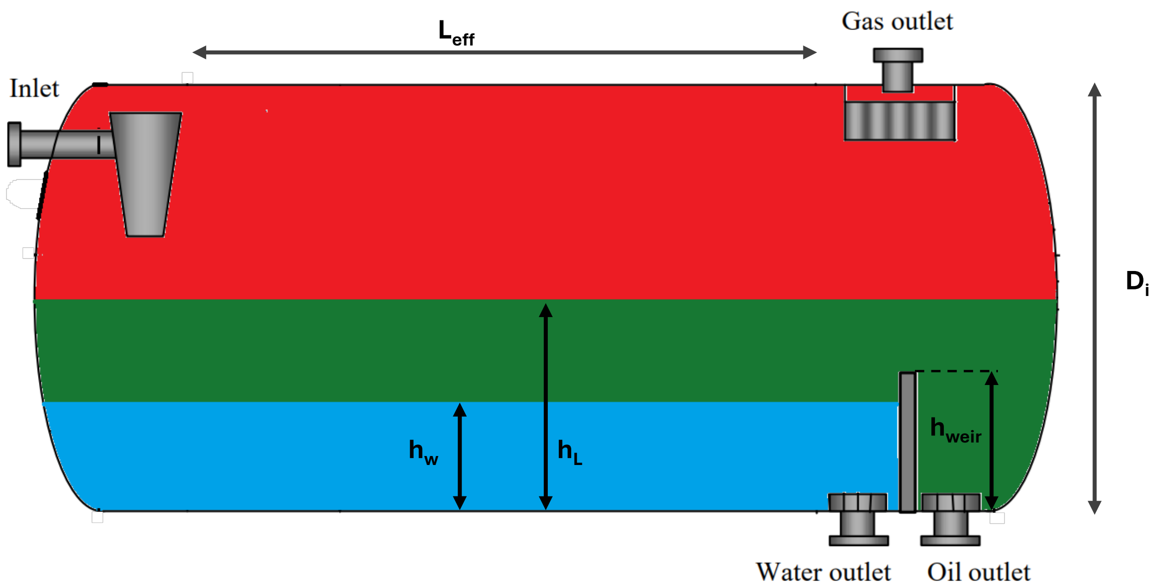
Consider that you work in a field producing in plateau mode an oil ($q_{\bar{o}}$) plateau rate of 37 000 Sm^3/d, a gas-oil ratio (GOR = $\frac{q_{\bar{g}}}{q_{\bar{o}}}$) of 120 and water cut of 20% (water cut is $\frac{q_{\bar{w}}}{q_{\bar{w}}+q_{\bar{o}}}$). All field production goes to a big primary three phase horizontal separator like the one shown in the figure below:



With inner diameter (D_i) 4 m, effective length (L_{eff}) 12 m, water level (h_w) at 1 m, liquid level (h_L) at 2 m. The position of the weirplate (h_{weir}) is 1.3 m.

Initially, before field startup, it was determined through bottle tests that the water needs a residence time of at least 120 s to ensure oil-water separation. But recently, the company started using a new environmentally-friendly corrosion inhibitor that caused oil-water emulsification and consequently an increase in the water residence time from 120 s to 240 s.

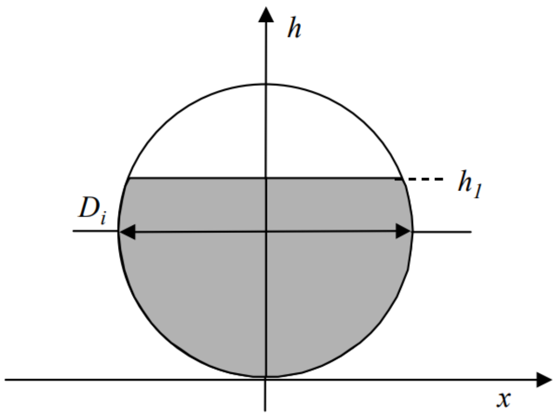
Your supervisor is concerned about an increasing trend in producing water cut. If it continues to increase, he fears the field might become bottlenecked and it will be necessary to reduce the oil field rate and consequently drop off plateau earlier than anticipated.

Your tasks are:

1. (15 POINTS) To estimate the critical water cut where bottlenecking will occur due to oil-water separation in the primary separator considering the original residence time and the new, increased residence time. Your values will be used as input in production forecasting calculations to determine when will bottlenecking occurs.
2. (10 POINTS) An option to avoid issues is to raise the oil-water contact to 1.2 m (0.1 m below the top of the weir plate). This will give a lower residence time for the oil, but the experts have determined it will still be enough to ensure proper separation. Determine if this change could provide a potential improvement.

Additional information:

- Equation to find the cross section area of the water layer (here $h_1 = h_w$):



$$A = \left(h_1 - \frac{D_i}{2}\right)\sqrt{D_i h_1 - h_1^2} + \frac{D_i^{\,2}}{4}\sin^{-1}\left(\frac{2h_1}{D_i} - 1\right) + \frac{\pi D_i^{\,2}}{8}$$

- Assume the standard conditions water rate ($q_{\bar{w}}$) is equal to the local conditions water rate q_w.

SOLUTION:

See the Excel file attached

PROBLEM 5. (10 POINTS)

Consider an offshore field that consists of an undersaturated oil reservoir with a bottom-aquifer. Reservoir pressure is kept constant by injecting large amounts of sea and produced water into the aquifer and the outskirts of the reservoir.

The reservoir is produced in plateau mode with a steel platform with 10 wells (dry X-mas trees). Assume wells are identical, are producing separately to the same separator, and the rate is kept constant using wellhead chokes.

Will this field ever drop off plateau? Explain your answer.

SOLUTION:

Yes, plateau could still end. Due to water injection, water will eventually reach the producers thus the total production liquid rate qo+qw must increase to maintain a constant qo. In this situation, plateau could end due to two reasons:

- The available pressure at wellhead will be lower than the required (separator pressure) because the flow in the tubing has more water, fluid density increases, and consequently the pressure drop increases.
- The processing facilities cannot process the higher amounts of liquid and water, and become bottlenecked.