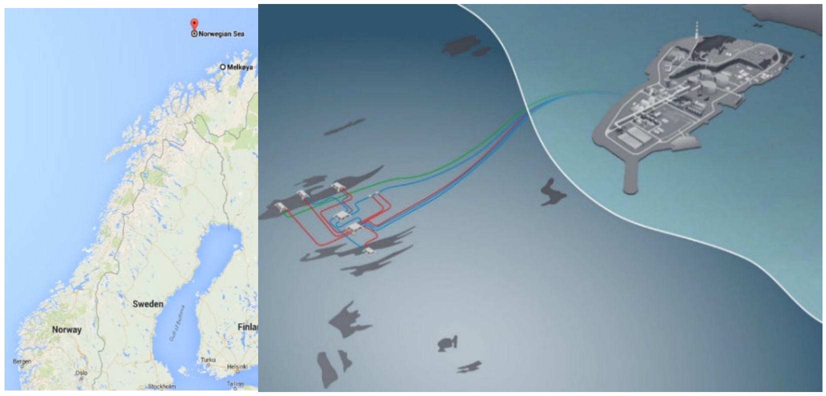
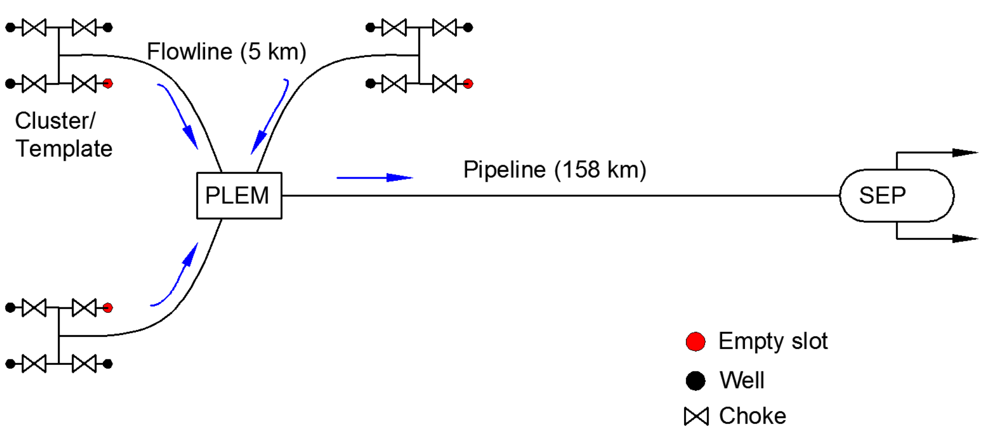
**<u>Exam problem (100 points)</u>**

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. Typically, only three wells are completed in each template (there is one slot is for redundancy). The templates will be symmetrically positioned at 5 km away from the subsea Pipeline Entry Module (PLEM). 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.



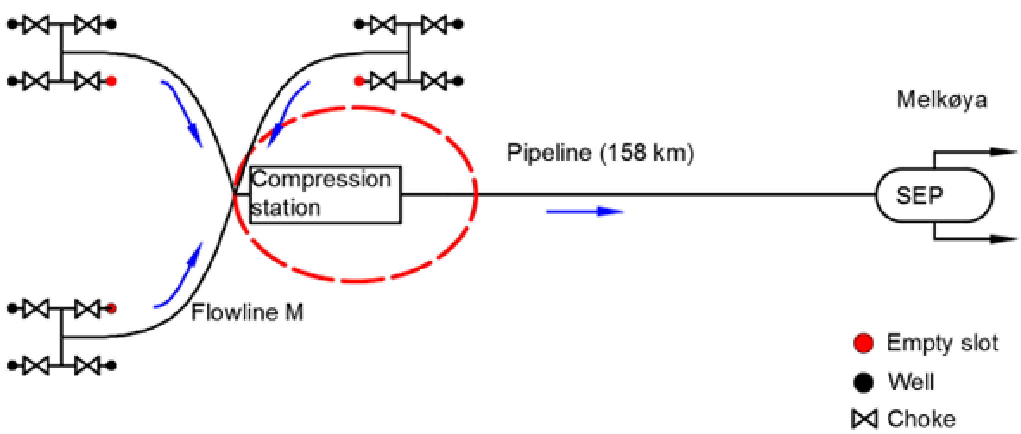

Assume all the wells are identical (in completion, depth and productivity and all other design and operation parameters) and produce from the same reservoir (tank model).

**Perform the following tasks:**

- **Task 1. Natural flow**
    1. **(30 POINTS).** Perform production profile calculations. Do your calculations on a yearly basis. After plateau ends, calculate field rate **for 5 years afterwards**. The Excel sheet should still work even if the timestep is changed (e.g. from 1 year to 0.5 year).

2. **(15 POINTS).** Estimate the net present value (NPV) of the project using the production profile calculated in the previous point.

- **Task 2. Plateau extension.**
  1. **(15 POINTS).** List 3 measures that can be used to extend plateau duration. Explain why do they work, why do they extend plateau duration?
  2. **(15 POINTS).** From the measures listed in the previous point, pick one and compute the new plateau duration (in fraction of year). The measure you pick cannot be subsea compression, as you will study that in the next question.
  3. **(25 POINTS).** Consider that a compression station will be installed at the PLEM, with a total power of 22 MW. Determine the compression power required by the compressor to maintain the plateau rate for 5 years after natural plateau ends. The compressor requires a minimum suction pressure of 15 bara.




**Additional information**

- Use the Excel sheet provided to solve this problem. The Excel sheet contains VBA functions. It is recommended that you solve the first task in the tab “Data”, then copy the tab for the subsequent tasks. To copy the tab, right click on the tab and select “Move or copy”. In the screen that pops up **remember to tick the option: “create a copy”**.
- Add text to the Excel file to explain your procedure.
- Use the trapezoidal rule to calculate yearly gas production $((q_{field,i} + q_{field,i-1}) \bullet (t_i - t_{i-1}) \bullet uptime \bullet 0.5)$
- The gas deviation factor can be calculated with the VBA function “ZfacStanding()”
- Use the following equations (programmed in VBA):

| | |
|---|---|
| **Material balance:** $$p_R = p_i \left(\frac{z_R}{z_i}\right)\left(1 - \frac{Gp}{G}\right)$$ | With G = 270 E09 $Sm^3$ <br> Use 360 operational days per year when calculating $G_p$ <br> $P_{Ri}$, initial reservoir pressure is 276 bara. |
| **Inflow equation:** $$q_g = C_R \cdot \left(p_R^2 - p_{wf}^2\right)^n$$ | $C_R$ Inflow backpressure coefficient, 1000 $Sm^3/bar^{2n}$ <br> n, inflow backpressure exponent, 1 |

| | |
|---|---|
| **Tubing equation**: $q_{gsc} = C_T \cdot \left( \frac{p_{wf}^2}{e^S} - p_{wh}^2 \right)^{0.5}$ | $C_T$, tubing coefficient, 40288.2 Sm³/bar<br>S, tubing elevation coefficient, 0.155 |
| **Flowline Template-PLEM:** $q_{gsc} = C_{FL} \cdot \left( p_{TEMP}^2 - p_{PLEM}^2 \right)^{0.5}$ | $C_{FL}$, flowline coefficient, 2.8 E05 Sm³/bar |
| **Pipeline equation PLEM-shore:** $q_{gsc} = C_{PL} \cdot \left( p_{PLEM}^2 - p_{sep}^2 \right)^{0.5}$ | $C_{PL}$, pipeline coefficient, 2.75 E05 Sm³/bar<br>$p_{sep}$, separator pressure, 30 bara. |

- Compression power (available as a VBA function, Power_c):

$$Power = \left( \left( \frac{p_{dis}}{p_{suc}} \right)^{\frac{n-1}{n}} - 1 \right) \cdot T_{suc} \cdot Z_{av} \cdot R \cdot \frac{n}{n-1} \cdot \frac{\dot{m}}{\eta_p}$$

with

| | |
|---|---|
| $p_{dis}$ | Discharge compressor pressure [bara] |
| $p_{suc}$ | Suction compressor pressure [bara] |
| n | Polytropic exponent. Calculated with the following equation: $n = \frac{k \cdot \eta_p}{k \cdot \eta_p - k - 1}$ |
| $T_{suc}$ | suction compressor temperature [K]. Calculated with the following equation: $T_{dis} = \left( \left( \frac{p_{dis}}{p_{suc}} \right)^{\frac{n-1}{n}} \right) \cdot T_{suc}$ |
| $Z_{av}$ | Average gas deviation factor between compressor discharge and suction. |
| $R$ | Specific gas constant [J/kg K], universal gas constant (8314.462 J/kmol K) divided by molecular weight of gas (16 kg/kmol). |
| $\dot{m}$ | Mass flow [kg/s]. |
| k | Adiabatic constant (Heat capacity ratio), |
| $\eta_p$ | Polytropic efficiency (in fraction) |

For estimating the NPV of the revenue use the following equation:

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} = \sum_{t=1}^{n} \frac{Revenue_t - Expenses_t}{(1+i)^t}$$

| | |
|---|---|
| $i$ | Discount rate (use 0.05 1/year) |
| $t$ | Counter for the number of years |

| | |
|---|---|
| $n$ | Total number of years to consider |
| $Revenue_t$ | Revenue of year t, equal to $\Delta G_{p,j} \cdot P_g$ |
| $\Delta G_{p,j}$ | Field gas production of year "j" |
| $P_g$ | price per $Sm^3$ of gas, [0.1 USD/$Sm^3$] |
| $Expenses_t$ | Expenses of year t, considers drillex, capex and opex: |

- Drillex: Each well has a cost of 100 E06 USD and a maximum of 4 wells can be drilled during a year. Drilling starts at end of year "0" (in year 1)
- CAPEX: capex includes 1) cost of the LNG plan, 2) cost of the LNG vessels and 3) cost of the pipeline and umbilicals. All CAPEX is executed during the first two years.
- OPEX: opex consists of a constant value of 200 e06 USD and it must be paid whenever hydrocarbons are produced