PROBLEM 1 (30 POINTS): Field development and production scheduling studies for the Alta-Gohta oil field in the Barents Sea.

The offshore Alta-Gohta field (production license operated by Lundin) consists of two separate reservoirs (Alta and Gohta).

The reservoir management team of Lundin is currently developing the field. They are evaluating to produce the field with **field plateau rate** of 12 000 Sm^3/d. Each reservoir will be produced independently to the FPSO, via a separate pipeline. The oil production potential **of each individual reservoir versus its cumulative oil production and its number of wells** can be estimated with following expression (available as a VBA function in the Excel sheet provided):

$$q_{pp} = e^{-5.169 \cdot \frac{N_p}{N}} \cdot q_{ppo} \cdot N_w$$

Where the values for Alta and Gohta are summarized in the table below:

Reservoir	q_{ppo} [Sm^3/d]	N [1E06 Sm^3]	N_w
Alta	4.1 E3	80	6
Gohta	2.7 E3	25	3

Your tasks are:

1. Determine what plateau rates of Alta and Gohta should be employed to achieve maximum plateau duration. Report the field plateau duration.
2. Compute the ultimate recovery factor at abandonment.
3. Compute the NPV of the development.
4. If there was uncertainty in the initial oil in place volumes of Alta and Gohta (a log-normal distribution for each reservoir), and in the cost figures (a uniform distribution between 20% more and 20% less the base case values), **how would you quantify the resulting uncertainty on NPV using probability trees** (with tree branches per variable). Sketch the probability tree you suggest using to solve this task and indicate how do would you calculate the probability of each branch and end node. **Do not calculate anything in this task, only explain how you would solve it.**

Deliverables:

- Excel file with the solution of the exercise
- A text briefly describing the steps taken to solve this exercise
- A sketch, by hand, PowerPoint, paint, etc. with the solution of task 4.

Recommendations and suggestions

- Perform your production profile and NPV calculations on a year basis until the field rate drops below 3.5 E3 Sm3/d. Remember that at year "zero", no oil is recovered yet from the field.
- Estimate yearly oil production (e.g. of year "i") by assuming that the rate of year "i-1" is constant in the period "i-1"→"i"
- Assume a year has 355 operational days
- You can do your calculations in the Excel file provided and upload the file.

Additional information:

For estimating the economic value of the project, you must use the following simplified expression of NPV (in million USD)

$$NPV = NPV_{rev} - C$$

This equation assumes that all expenses are executed at time "zero" (start of production). The net present value of revenue is, discounted from year zero (start of production):

$$NPV_{rev} = \sum_{k=1}^{n} P_o \cdot \frac{\Delta N_{p,k}}{(1+i)^k}$$

i	Discount rate (use 0.08 1/year)
k	Counter for the number of years
n	Total number of years, unknown
$\Delta N_{p,k}$	Field oil production of year "k"
P_o	price per Sm^3 of oil, [180 USD/Sm^3]

- C is the approximated cost of the development, representing facilities and wells mainly [in million USD]. It can be assumed that the cost is a function of the field's plateau oil rate and the total number of wells in the field. It is given by the equation (available as a VBA function):

$$C = q_{plateau,field} \cdot 0.12 + 250 + N_{wells,field} \cdot 100$$

ONLY for task 4: To capture the effect of uncertainty in the cost, the cost equation can be multiplied by a factor F, uniformly distributed between 1.2 and 0.8.

$$C_{uncertain} = F \cdot \left(q_{plateau,field} \cdot 0.12 + 250 + N_{wells,field} \cdot 100\right)$$

Solution:

For each reservoir (Alta and Gohta):

1. qpp: use the given vba qpp function with Np, N, qppo and Nwells as its inputs
2. q: use Excel IF function with logical test: qplateau (C4 for Alta or C5 for Gohta) <= qpp, value if true: C4 and value if false: qpp.
3. delta Np (at year i): q (at year i-1) * (year i - year (i-1)) * 355 days/year/1E06
4. Np (at year i): Np (year i-1) + delta Np (year i)

Field

1. qfield: q Alta + q Gohta
2. delta Np: delta Np Alta + delta Np Gohta
3. Np: Np Alta + Np Gohta
4. Rf: Np/(N alta + N Gohta)
5. Discounted yearly revenue: use the given npv revenue equation and the delta Np of the field.

Task 1, a sensitivity study is performed to estimate the plateau rates of each reservoir which gives the maximum plateau duration. Around **9000 Sm3/d for Alta and 3000 Sm3/d for Gohta gives around 4 years of plateau duration.**

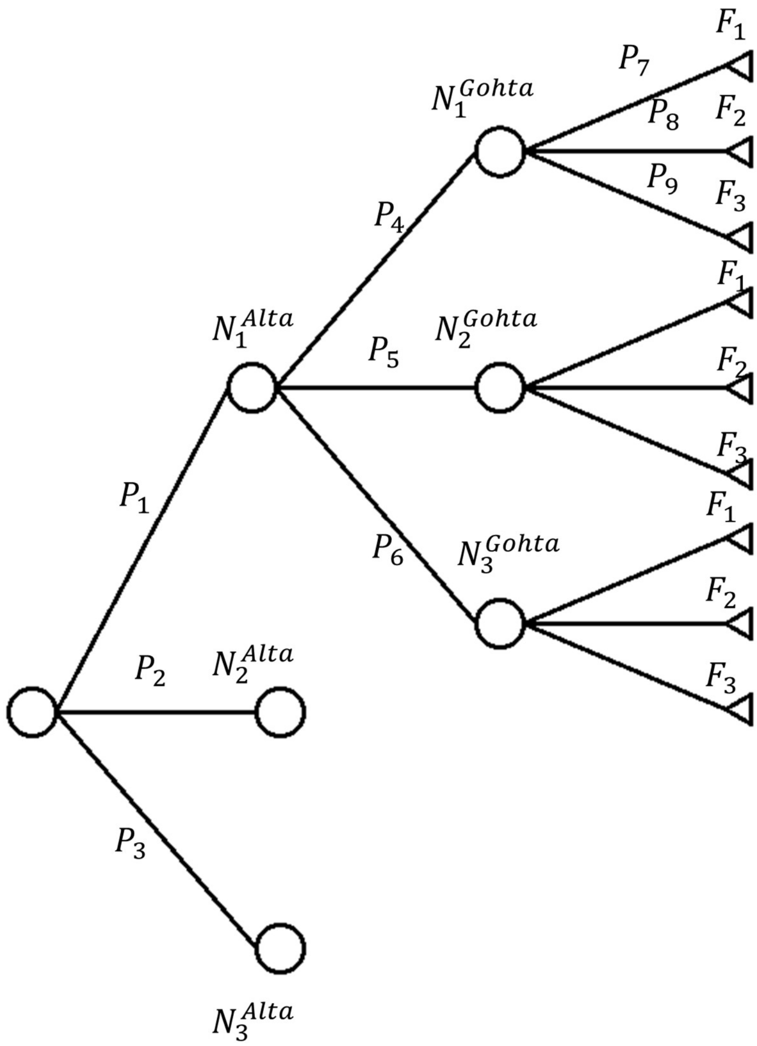
Task 2, as the field rate reach below 3.5E3 Sm3/d, the field needs to be abandoned (erase all rows after year 16).

Task 3, The NPVrev is the total NPVrev from year 0-16. Cost is calculated using the given cost function with qplateau field (12000 Sm3/d) and the total number of wells (9 wells) as input.

Task 4.

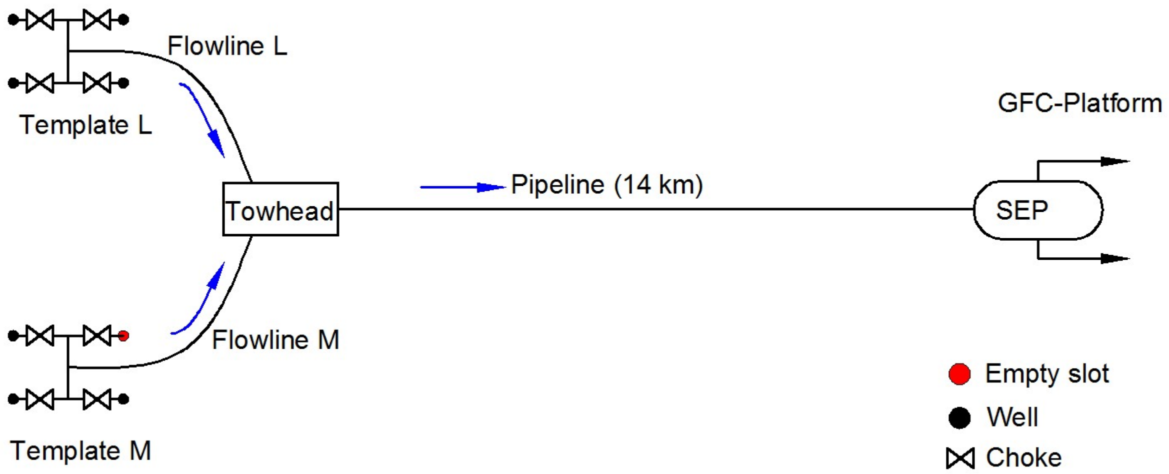
The log-normal distributions of oil in place volume of Alta and Gohta must be discretized with three values each. The F factor (uniformly distributed between 0.8-1.2) must also be discretized with three values. To discretize one can use many methods, but one method is the equal area method, where one defines intervals in the cdf (the length of the interval is the probability of the discrete value) and then finds the values of the variables within the interval that yield similar areas both to the right or to the left. Another method is to pick three values of the variable and read from the pdf the probability and then normalize with the sum to find the probability of the discrete values. Other methods are also valid.

A probability three is then made with three layers, one for the IOIP of Alta, one with IOIP of Gohta and one with the cost factor F. Each branch will have a probability associated. Each end node has a total probability computed by multiplying the probability of each branch. One can calculate the NPV of each end node and its associated probability. This is an approximation to quantify the uncertainty in the project.


F_1
P_7
N_1^{Gohta}
P_8
F_2
P_9
F_3
P_4
F_1
N_1^{Alta}
P_5
N_2^{Gohta}
F_2
F_3
P_1
F_1
P_6
N_3^{Gohta}
F_2
P_2
N_2^{Alta}
F_3
P_3
N_3^{Alta}

PROBLEM 2 (20 POINTS). Network and subsea compression calculations for the Gullfaks South field.

The Gullfaks South field has two subsea templates, L and M. Template L has 4 wells and template M has 3 wells. For the purpose of this exercise, consider that all wells **in each** template are identical. The production of all wells in a template is comingled in the template manifold and transported via a flowline to a towhead (junction), where the production of the two templates is commingled. The total gas production is then transported further with a pipeline to the platform of Gullfaks C.



Tasks.

1. Is it possible to produce a template gas rate of 6 E06 Sm3/d from template L and a template gas rate of 3 E06 Sm3/d from template M? if it is, calculate the wellhead choke pressure drops required to apply on each well to achieve the desired rates.
2. What is the equilibrium rate of template L and M with fully open wellhead chokes?
3. If a subsea compressor is installed at the towhead (at the inlet of the pipeline, after the gas from both templates is commingled) estimate the following variables:
   - Compressor pressure increase,
   - Compressor pressure ratio
   - Required compression power
   - Outlet temperature of the compressor

   when the compressor delivers a total gas rate of 19 E6 Sm^3/d split in 15 E06 Sm3/d from template L and 4 E06 Sm3/d from template M. Assume an inlet temperature of 70 C and a polytropic compression exponent (n_p) of 1.43 (polytropic efficiency of 0.73). Is it necessary to use wellhead chokes in this configuration?

Deliverables:

- Excel file with the solution of the exercise
- A text briefly describing the steps taken to solve this exercise

Useful information:

- **Neglect the pressure drop in the flowline from template to towhead**

Inflow equation (programmed in VBA):

$$q_g = C_R \cdot \left(p_R^2 - p_{wf}^2\right)^n$$

With:
Template L
C_R= 1000 $Sm^3/d/bar^{2n}$
n= 0.8
p_R= 240 bara
Template M
C_R= 700 $Sm^3/d/bar^{2n}$
n= 0.75
p_R= 210 bara

Tubing equation (programmed in VBA):

$$q_{gsc} = C_T \cdot \left(\frac{p_{wf}^2}{e^S} - p_{wh}^2\right)^{0.5}$$

Template M
C_T = 3.8 E4 $Sm^3/d/bar$
S = 0.43
Template L
C_T = 4.1 E4 $Sm^3/d/bar$
S = 0.34

Pipeline equation towhead to platform (programmed in VBA):

$$q_{gsc} = C_{PL} \cdot \left(p_{towhead}^2 - p_{SEP}^2\right)^{0.5}$$

C_{FL} = 1.4 E5 $Sm^3/d/bar$
p_{sep} = 60 bara

- Polytropic expansion (available as a VBA function, Tout), 1 inlet, 2 outlet:

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

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

$$P = (T_{dis} - T_{suc}) \cdot Z_{av} \cdot R \cdot \frac{k}{k-1} \cdot \frac{\dot{m}}{\eta_m}$$

with

T_{dis}	Discharge compressor temperature [K]
T_{suc}	suction compressor temperature [K]
Z_{av}	Average gas deviation factor between compressor discharge and suction. Assume equal to 1.
R	Specific gas constant [J/kg K], universal gas constant (8314.462 J/kmol K) divided by molecular weight of gas
$\dot{m}$	Mass flow [kg/s]
η_m	Mechanical efficiency (assume equal to 0.98)
k	Heat capacity ratio, assume equal to 1.3

Density of gas at standard conditions = 0.67 kg/m^3
Molecular weight of gas: 16 kg/kmol

Solution:

Task 1

Fill each cell with its corresponding value/function.

1. Fill qtemp provided in column O. Calculate the sum in the cell below.
2. Compute qwell in column K by dividing qtemp by Nwells
3. pwf: use the given vba IPRpwf function with p_r, C, n and qwell as inputs
4. pwh: use the given vba Tubingp2 function with S, Ct, pwf and qwell as its inputs
5. ptowhead: use the given vba Linep1 function with Cfl, psep and sum of both qtemp(s) as inputs
6. pdownstreamchoke: **equal to ptowhead** as the pressure drop in the flowline from template to towhead can be neglected.
7. Compute dpchoke: pwh - pdownstreamchoke

The solution is that **both templates can produce the desired flowrate**

Task 2

Fill each cell with its corresponding value/function.

1. Guess bottomhole pressure pwf:
2. qwell: use the given vba IPRqg function with p_r, C, n and pwf as inputs
3. pwh: use the given vba tubingp2 function with S, Ct, pwf and qwell as inputs
4. Set deltapchoke equal to zero and compute pdownstreamchoke as pwh - dpchoke

5. Compute qtemp in column O by multiplying qw by Nwells. Compute total gas production
6. ptowhead: use the given vba Linep1 function with Cfl, psep and sum of both qtemp(s) as its inputs
7. average= (cell P10): use excel built-in AVERAGE function from cell N7,N8 and P9
8. error: ((N7 - P10)^2 and so forth for N8 and P9. The error sum will the objective value in the solver.

Use the solver, set Q10 as objective to be **minimized.** The constraint is that the pwf must be lower or equal to the p_r.

Task 3

The solution is similar to the solution of task 1, the only difference is that the *pdownstreamchoke* cells must be filled with the smallest of the two wellhead pressures (*pwh, computed with Tubingp2*). This well will have fully open choke while the other must be choked because it can produce more than the amount requested.

1. Deltap compressor: the subtraction product between discharge pressure (ptowhead) and suction pressure (pdownstreamchoke).
2. rp: the ratio between pdis and psuc.
3. Tdischarge: use the given Tout function with np, Tsuc and rp as its inputs.
4. mass flow: total flow rate * density / (24*3600), time conversion.
5. Compression power: use the given Power_c function with mass flow, Mech effc, Tdischarge, Tsuc, Zav, MW and k as its inputs.

PROBLEM 3 (10 POINTS). Production optimization of a system with two gas-lifted wells.

In a small land-based field there are two gas-lifted wells with no wellhead chokes producing to a small separator with constant pressure. Wells operate independent from each other and the gas lift performance curve (produced reservoir oil versus gas-lift injected) is readily available. Your task is:

- The owner wants you to determine the gas rate to inject in each well to maximize total oil production. Estimate the amounts of gas injected per well and oil produced for the following cases:
  1. No constraints
  2. Constraint in the total amount of gas available to inject, maximum 130 E03 Sm^3/d
  3. Constraint in the total amount of gas available to inject (130 E03 Sm^3/d) and on the total gas handling capacity of the common separator (150 E03 Sm^3/d).

Solve this problem using the Excel file provided

Deliverables:

- Excel file with the solution of the exercise
- A text briefly describing the steps taken to solve this exercise

Available information:

- It is recommended to use Excel solver to solve the optimization.
- The formation (reservoir) gas-oil ratio (GOR) of well 1 is 100 Sm^3/Sm^3 and well 2 is 200 Sm^3/Sm^3
- Each well was simulated in PROSPER and the gas-lift performance curve (reservoir oil versus gas lift injected) was computed. The curves were fitted to a 4th order polynomial (available as VBA function qo_R):

$$q_{\bar{o}R} = a \cdot q_{\bar{g},inj}{}^4 + b \cdot q_{\bar{g},inj}{}^3 + c \cdot q_{\bar{g},inj}{}^2 + d \cdot q_{\bar{g},inj} + e$$

Where $q_{\bar{o}R}$ is output in Sm^3/d and $q_{\bar{g},inj}$ is input in [1E03 Sm^3/d] with the following coefficients for wells 1 and 2:

	a	b	c	d	e
	[(1/Sm^3/d)^3]	[(1/Sm^3/d)^2]	[1/Sm^3/d]		[Sm^3/d]
Well 1	-3.90E-07	2.10E-04	-0.043	3.7	12
Well 2	-1.30E-07	1.00E-04	-0.028	3.1	-17

Solution:

First define each cell with their appropriate value/function.

1. **qg_inj :** guess the injection gas rate for each well.
2. **qo :** use the qo vba function provided by inserting the variables (a,b,c,d and e) and qg_inj for each well

3. **qg_total :** the total gas flow rate produced (in 1E03 Sm3/d) is the sum of qg_inj and qo*GOR/1000
4. In the row TOTAL, sum the total gas injected, oil produced, and total gas produced

Then, use solver on excel to solve each task.

1. No constraints : The objective is to maximize qo total in cell **H6** by changing cells G4:G5.
2. Gas injection constraint: Same as before, but adding a constraint which is total qg_inj in cell G6 must be lower than or equal to the constraint in cell C8.
3. Both gas injection and produced constraints: Same as number 2, but adding one other constraint which is total qg_total in cell J6 must be lower than or equal to the constraint in cell C9.