<u>Problem 1:</u> Selection of Inflow performance relationship equation for the "Borthne" saturated oil field

A small, saturated volatile oil reservoir will be produced using an unmanned platform with 4 well slots. The X-mas trees are on the platform. The platform has a separator with a constant pressure of 30 bar. Wells are equipped with wellhead chokes to regulate production. The separator is very close to the wellhead.

In this exercise, we will focus on well A01.

The reservoir engineering department has performed some preliminary studies and has provided well production profiles of oil, gas, reservoir pressure and flowing-bottomhole pressure (given in the Excel sheet attached). Unfortunately, after this, the reservoir engineer went on holidays (to the Bahamas) and is not available to help you.

Assume that all production comes from the oil layer (there is no coning from the gas cap)

<u>Task 1:</u>

For your production engineering calculations, you would like to find a suitable expression for IPR to represent the inflow. You are considering using an IPR of the form:

$$q_o = q_{o,max}\left[1 - V \cdot \frac{p_{wf}}{p_R} - (1 - V) \cdot \left(\frac{p_{wf}}{p_R}\right)^2\right]$$

From your lectures of TPG4245, you remember that V can usually be considered constant with depletion, but $q_{\bar{o},max}$ will vary.

Your main task is to find the behavior of $q_{\bar{o},max}$ versus reservoir pressure with the data provided by the reservoir engineering department. Consider several values of V, ranging from 0 (Fetkovich) to 1 (Linear PI).

Provide observations about your results.

Task 2:

Well A01 will be produced in plateau mode, this means at a constant rate and then it eventually enters in decline. In the forecast calculated earlier by the reservoir engineering department, the plateau rate of the well is 225 Sm3/d. The plateau period ends between year 3 and year 3.5.

Your manager wishes to extend the plateau period by gas-lifting the well. Therefore, he would like you to conduct a study at year 3.5 to determine what flowing bottom-hole pressure value you need to maintain the rate of 225 Sm3/d. He will later use this information to determine if it is possible to achieve this pressure with gas-lift.
However, you are yet now sure about what IPR to use in this well. Using all possible IPRs calculated in task 1 for year 3.5, provide your manager a range of flowing bottom-hole pressures needed to provide the required rate.

Task 3:

In task 1 you realized that you need more information to select a proper IPR model. Luckily, the reservoir engineer is back from his holidays and is in a good mood to help you. You asked him to perform a numerical multirate test at 0.5 years and at 10 years. The results are given in the excel sheet attached.
Use this information to decide which values of V and $q_{\bar{o},max}$ to use. Assume that V remains constant during depletion, but that $q_{\bar{o},max}$ changes.

TIP: use the excel solver to find values of V and $q_{\bar{o},max}$ that best fit the data provided.

Task 4:

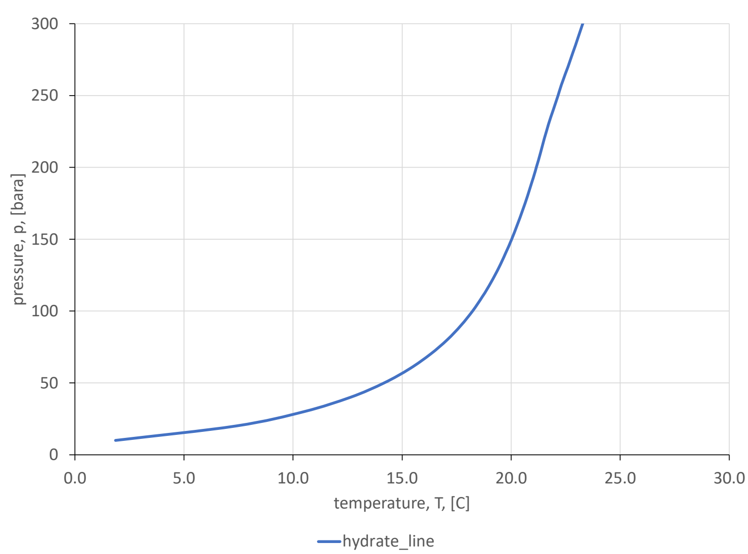
In case the well exhibits high velocity flow, how could this affect your results? Discuss.

<u>Problem 2:</u> Temperature calculations for well A01.

Your manager is concerned about possible formation of hydrates in the choke of well A01 during the plateau period (when the choke is partially closed) due to cooling induced by choking. Hydrates are ice-like solids (see the image below) that form with water and small hydrocarbon molecules such as methane, ethane, propane. This can plug the choke and cause it to get stuck. If there is a risk of this happening, a hydrate inhibitor must be injected upstream the choke.

The injection system and the inhibitor purchase and storage have some extra costs, thus threaten the economy of this marginal development.

Hydrates form at specific conditions of temperature at pressure. The figure below shows the hydrate equilibrium line for the fluids of the Borthne field. If the operating conditions fall to the left of the line, there is risk of formation of hydrates. On the right is the safe operation region.



You will perform your evaluation at the beginning of the plateau period, for the conditions:

$q_o = 225$ Sm3/d
$q_g = 65350$ Sm3/d
$p_{wf} = 285.3$ bara
$p_{wh} = 258.3$ bara

p_{sep} = 30.0 bara
γ_o = 0.83
γ_g = 0.75

The composition of the produced fluid at initial time is provided in the Excel sheet attached[1]. To perform this evaluation, you have to conduct the following tasks:

Task 1.

Calculate the wellhead temperature with the Excel sheet provided. Consider the following steps to reach this goal:

- With the composition provided, generate in Hysys[2] a table of enthalpy of mixture (mass enthalpy of the mixture) versus pressure and temperature. Use the Peng Robinson equation of state. Generate the table with the utility "Case Studies", located under home, inputting a range of pressures and temperatures and a number of points. Do not use too many points because this make it time consuming to interpolate
- Paste the enthalpy table in the sheet "PVT" of the Excel file.
- In the Excel file, in column B assume a linear pressure distribution between flowing bottom-hole pressure and wellhead pressure (TIP: use the same approach that is used for column E)
- Column C, from rows 12-23, these are assumed temperature values. Assume temperature increases with depth and it is always below formation temperature.
- With the temperature and the pressure, in column D calculate the enthalpy by interpolating in the PVT table (using the VBA function "TwoDimInterpol")
- Estimate the heat loss to the formation in every interval in the wellbore, starting from the bottom-hole. The heat transfer is computed using the temperature difference between the temperature at the inlet of the interval (T_{in}) and the undisturbed geothermal temperature (T_f, taken at the inlet of the section also), the overall heat transfer coefficient (U), the pipe inner diameter (ϕ) and the length of the interval (L):
$$\dot{Q} = \left(T_{in} - T_f\right) \cdot U \cdot \pi \cdot \phi \cdot L$$
- Assume the overall heat transfer coefficient is 10 W/m2 K, and that it is given with respect with the tubing inner diameter.
- The enthalpy at the exit of the interval (column G) can be computed using the following equation[3]:
$$h_{out} = h_{in} + (z_{in} - z_{out}) \cdot g - \frac{\dot{Q}}{\dot{m}}$$

For applying this equation, you can use the VBA function "enthalpy_out" in column G.

- The specific enthalpy at the outlet of the section is now calculated. However, this enthalpy will be different to the enthalpy in column D, that was calculated based on

[1] This is a simplified composition to make your analysis easier. The heavier and pseudo-components have been removed.
[2] The easiest way to access Hysys is through farm.ntnu.no. Log in with your NTNU username and password, go to the folder "Scientific" and click and run "Aspen HYSYS V11".
[3] ($z_{out} - z_{in}$) must be a negative number

assumed values of temperature. Both should be equal. To make them equal, do the following:

- Calculate, at each measured depth, the difference squared between columns G and D.
- Sum all errors in cell H8.
- Use the Excel solver (or Goalseek) to drive the error to zero.

Task 2.

It is now a few years later and the field is already developed and wells just entered production. The field operators report the flowing wellhead temperature to be of 70 C, a value different than the one you computed in task 1.
The reason for the deviation is most likely the overall heat transfer coefficient. The value assumed is most likely not correct and it is not constant along the wellbore.
Adjust the heat transfer coefficient until the model wellhead temperature is equal to the measured wellhead temperature.

Task 3.

In Hysys, perform an isenthalpic expansion from wellhead pressure and temperature (calculated in task 1) to separator pressure (using a valve).

Report the choke outlet temperature and evaluate if it is necessary to inject a hydrate inhibitor or not.

Task 4:

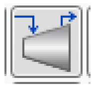
A startup consisting of NTNU students has developed a wellhead turbine to drop pressure and convert it to electricity. They are suggesting testing it in the Borthne field, in well A1. The students say that the turbine has a high isentropic efficiency ($\eta_{isentropic}$) and recommend using a value of 0.7 (70%).

Your manager wants to know how much energy can be extracted from such a device, to see if it will be worthwhile or not to install it.

To calculate the potential power output by the wellhead turbine the following equation can be used (derived from the first law of thermodynamics for open systems):

$$\dot{W} = \dot{m} \cdot \frac{(h_{in} - h_{out,s})}{\eta_{isentropic}}$$

$h_{out,s}$ is the enthalpy at separator pressure (30 bar), that has a mass entropy equal to the mass entropy of the inlet. To make an isentropic expansion, you can use the expander component in Hysys:



Evaluate if there is risk of hydrate formation when using the wellhead turbine instead of the choke.