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Examination paper for TPG4230 – Field Development and Operations

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Permitted examination support material: A single sheet of paper with relevant formulas and equations is permitted. Approved calculator permitted

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Informasjon om trykking av eksamensoppgave	
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Date Signature

PROBLEM 1 (9 POINTS). Production system layout

Statoil Brazil is planning to develop the gas condensate reservoir "Pao de Acucar" in block BM-C-33 (Campos Basin) offshore Brazil. The water depth is 2 900 m thus it will be developed with 4 satellite subsea wells, a subsea manifold and an FPSO. By law (Resolucao Conjunta ANP/INMETRO No. 1), the Brazilian government requires each well to be tested at least every 42 days. **The only testing method approved by the law is using a test separator.**

Task 1. (5 POINTS) Propose a simplified P&I diagram of the subsea system of Pao de Acucar. Show in your sketch the entire system from the wellhead to the separator(s) including all relevant valves, instrumentation. Indicate what is in the X-mas tree template, in the manifold template, subsea, and on the FPSO.

Task 2. (3 POINTS) Due to the water depth and low temperature of the sea, MeOH will be injected before the wing valve to avoid Hydrate formation using a SDU (Subsea distribution unit). Propose a simplified P&I system of the MeOH distribution system. You may perform your drawing on top of the one performed for task 1.

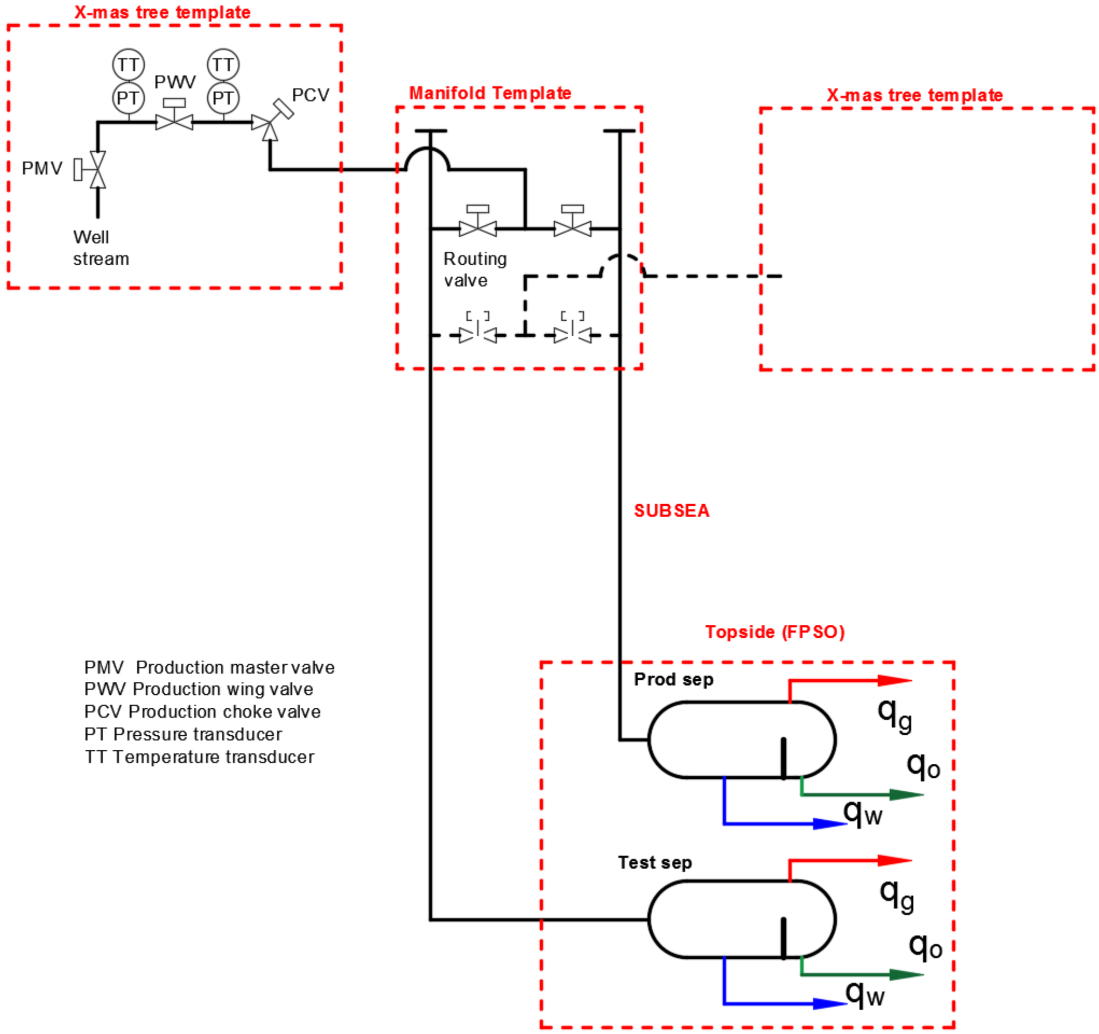
Task 3. (1 POINT) If frequent pigging is required, what modifications have to be made to the system proposed in task 1? Sketch them.

Solution:

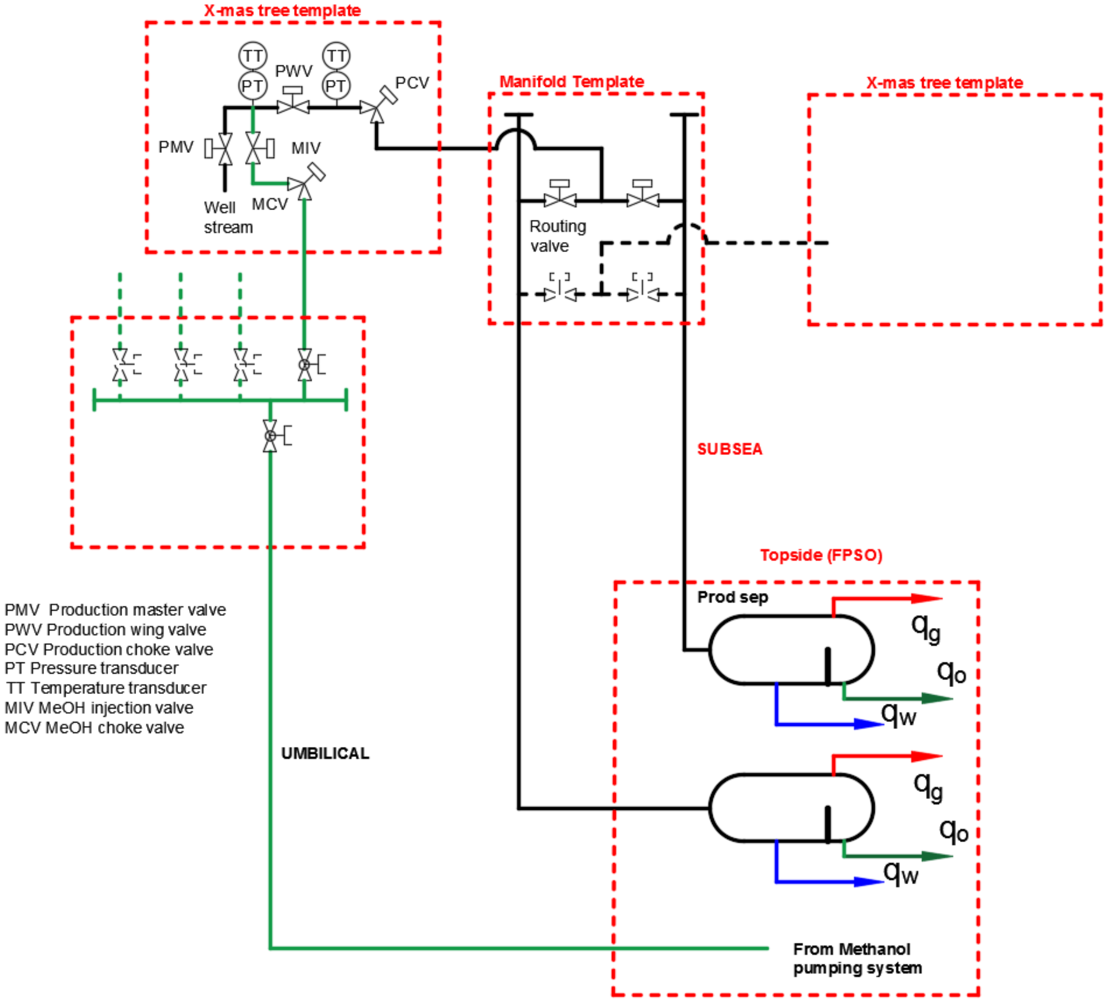
If by law you are obliged to test each well with a test separator therefore there is no other solution than to have two SEPARATE flowlines to the FPSO.

In the drawing below only one well is shown. The remaining three have an identical arrangement.

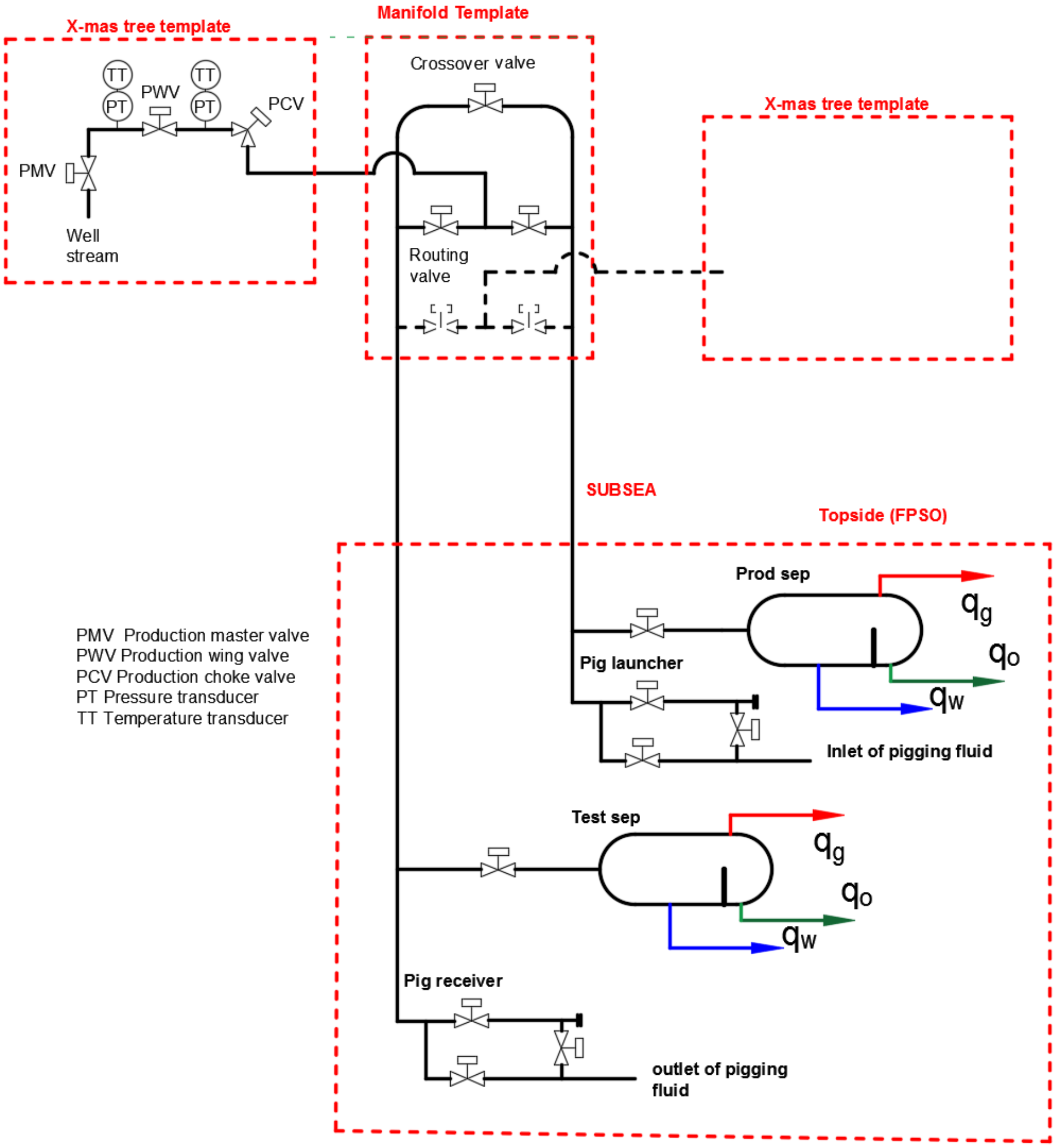
Task 1.


X-mas tree template
TT
PT
PWV
TT
PT
PCV
PMV
Well
stream
Manifold Template
Routing
valve
X-mas tree template
SUBSEA
Topside (FPSO)
Prod sep
q_g
q_o
q_w
Test sep
q_g
q_o
q_w
PMV Production master valve
PWV Production wing valve
PCV Production choke valve
PT Pressure transducer
TT Temperature transducer

Task 2

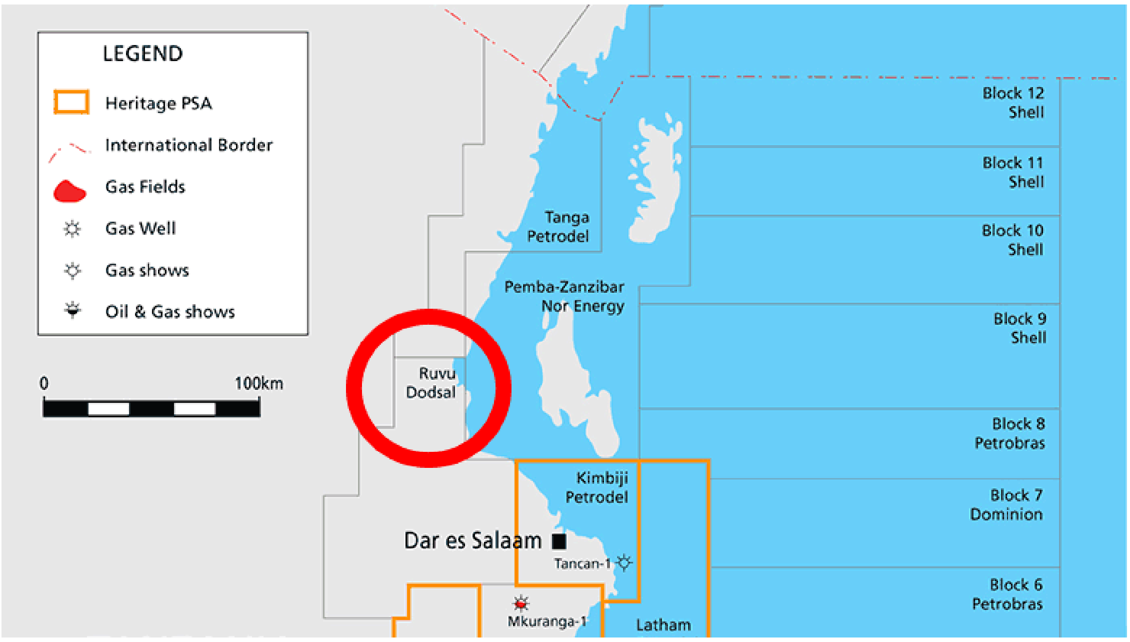


Task 3. Adding a crossover valve (or pigging valve) in the subsea manifold and a pig launcher and receiver in the FPSO



PROBLEM 2 (18 POINTS). Field planning using production potential curves.

The Tanzanian Petroleum Development Corporation (TPDC) is planning to develop the Ruvu field located in the coast region close to Dar es Salaam.



The field has two main reservoirs, Tanga and Latham that will be produced simultaneously using standalone vertical wells. The field plateau rate has been set to 15 E6 Sm^3/d from which 10 E6 Sm^3/d will be produced from Tanga and 5 E6 Sm^3/d from Latham.

Task 1. (9 POINTS) Using the production potential curve of each reservoir estimate the number of wells required in each reservoir if the **field plateau length required** is 30 years.

Consider the following:

- Assume that a year consists of 355 operational days.
- **For each reservoir,** there is an analytical expression for **single gas well** production potential (in **Sm^3/d**) as a function of cumulative gas production of the reservoir (G_p in **Sm^3**):

$$q_{pp} = q_{pp0} - m \cdot G_p$$

Assume that all wells are identical and that their production potential depends on the reservoir cumulative production. This yields that the field production potential of the reservoir can be expressed as:

$$q_{pp\_reservoir} = N \cdot \left(q_{pp0} - m \cdot G_p\right)$$

Where N is the number of wells drilled in the reservoir.

The constants for each reservoir are given in the table below:

Reservoir name	**q_{ppo} [Sm^3/d]**	**m [1/d]**
Tanga	4.0 E6	2.4 E-5

Latham	2.5 E6	1.5 E-5

Task 2. (2 POINTS) Determine the exact plateau end for both reservoirs (in years).

Task 3. (4 POINTS) Determine the field rate at year 33. For this task, assume that the post plateau period of each reservoir can be described using the following exponential expression:

$$q_{reservoir}(t) = q_{plateau} \cdot e^{-m \cdot N \cdot (t - t_{plateau})}$$

Where t is in days.

Task 4. (3 POINTS) How was the exponential expression given in Task 3 derived? What are the limitations of the production potential method used in this exercise?

Solution

A plateau of 30 years is desired. This means that both reservoirs should have a plateau length of at least 30 years. First we calculate the cumulative productions of reservoirs Tanga and Latham at 30 years

$G_p{}^T{}_{@30y}$=30*355*10E6 = 1.065E11 Sm^3
$G_p{}^L{}_{@30y}$=30*355*5E6 = 5.325E10 Sm^3

Then we substitute these values in the expression for the production potential of each field

$$q_{ppfield} = N \cdot (q_{pp0} - m \cdot G_p) = 10E6 = N_T (4.0E6 - 2.4E - 5 \cdot 1.065E11)$$

This gives a total number of wells for Tanga of: 7 (You should always round up to be sure the plateau will be fulfilled)
For Latham

$$q_{ppfield} = N \cdot (q_{pp0} - m \cdot G_p) = 5E6 = N_L (2.5E6 - 1.5E - 5 \cdot 5.325E10)$$

This gives a total number of wells for Latham of: 3

The actual plateau duration is

$$10E6 = 7(4.0E6 - 2.4E - 5 \cdot 10E6 \cdot 355 \cdot t)$$
$$t_T = 30.18 years$$
$$5E6 = 3(2.5E6 - 1.5E - 5 \cdot 5E6 \cdot 355 \cdot t)$$
$$t_L = 31.29 \ years$$

Production at year 33 is (This expression is valid because both fields are in the declining phase)

$$q_{field}(t) = q_{plateau\_Tanga} \cdot e^{-m_{tanga} \cdot N_{wells\_tanga} \cdot (t - t_{plateautanga})} +$$

$$q_{plateau\_Latham} \cdot e^{-m_{Latham} \cdot N_{wells\_tanga} \cdot (t - t_{plateautLtham})}$$

$$q_{field}(t) = 10E6 \cdot \exp(-2.4E-5 \cdot 7 \cdot 355 \cdot (33 - 30.18)) +$$

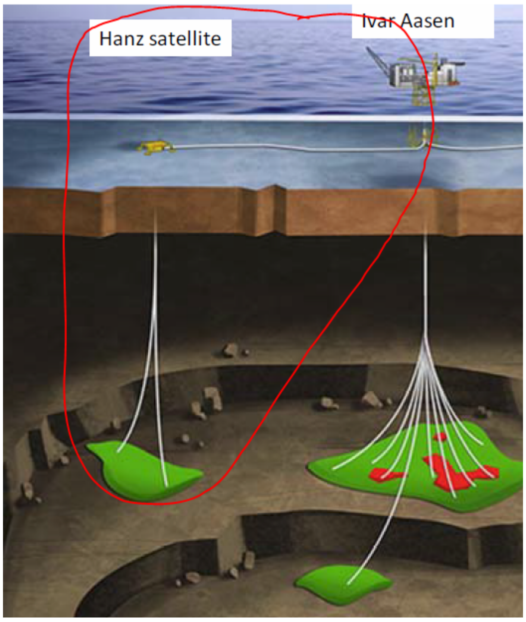
$$5E6 \cdot \exp(-1.5E-5 \cdot 3 \cdot 355 \cdot (33 - 31.29))$$

$$qfield(33) = 13.32E6\ Sm\text{^}3/d$$

Task 3. This expression was found assuming that the field is producing always at production potential and that the production potential curve is linear versus cumulative production. The production potential curve is inserted in the cumulative production definition and the rate is calculating by deriving and integrating the equation.

PROBLEM 3 (15 POINTS). Estimating the production profile of the field using flow equilibrium.

Hanz is a small undersaturated oil reservoir satellite to the Ivar Aasen platform. The initial reservoir pressure of Hanz is 250 bara. The reservoir will be developed using one single producer and a flowline connected to the platform. The flowline from the Xmas tree to the platform exhibits a very low pressure drop, thus, as a first approximation, the wellhead pressure can be safely assumed to have a constant value of 50 bara.
The well will be produced in production mode “B”, i.e., with open choke. The well doesn’t produce any water.

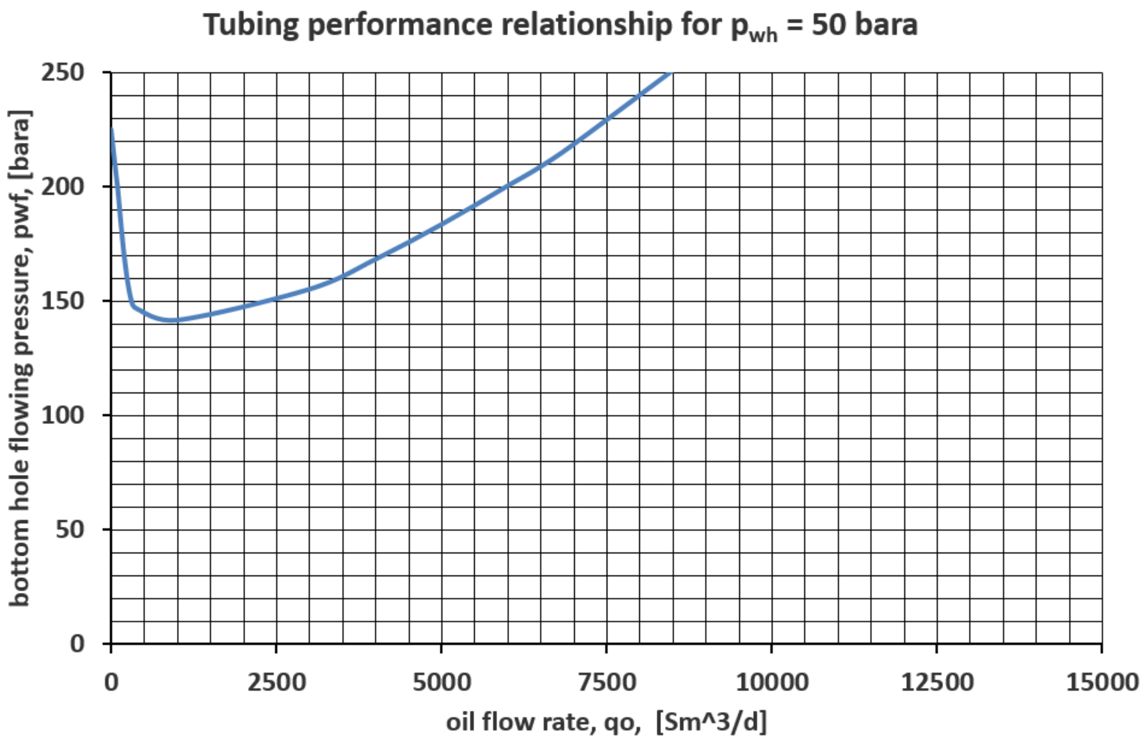


The IPR of the well is provided:

$q_{\bar{o}} = J \cdot (p_R - p_{wf})$

J = 60 Sm^3/d/bar

The tubing performance relationship (required flowing bottom-hole pressure at constant wellhead pressure of 50 bara) is provided in the figure below.



Task. 1. (10 POINTS) You are asked to determine the production profile of the reservoir **for the first three years of production (until end of year 3/beginning of year 4).** Perform your calculations in a yearly basis starting from the end of year "0". Assume that there are 360 operational days in a year. Plot the IPR (Inflow performance relationship) of the well for all years in the TPR plot.

The following expression is provided to compute reservoir pressure as a function of cumulative oil production.

$$p_R = 250\,bara - 1.4E-5\,\frac{bara}{Sm^3}\,N_P$$

Use the rectangle integration method to estimate oil cumulative production.

Task 2. (1 POINT) Is it correct to assume that the TPR curve won't change much during the first four years of production?. Explain your answer.

Task 3. (4 POINTS) If during your calculations, the oil rate drops below 3000 Sm^3/d, The company is evaluating installing an ESP in the well (very close to the bottom-hole) to increase production. Please estimate the power required to pump the desired rate. Use the expression below.

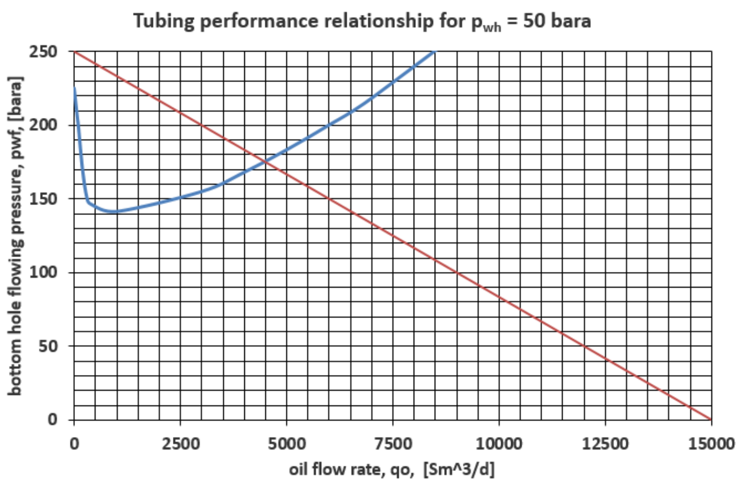
The pump power [in watts, W] can be estimated with:

$$Power = \frac{q \cdot \Delta p \cdot 1E5}{\eta \cdot 24 \cdot 3600}$$

Where Δp [bara], q in [m^3/d]. Assume a constant pump efficiency (η) of 0.6. Assume an oil formation volume factor (Bo) at the pump suction of 1.2 m^3/Sm^3.

Solution

Plot the IPR on top of the TPR at year 0 to find out the initial well rate (flow equilibrium at the well bottom-hole).The choke is fully open thus the wellhead pressure should be always constant and equal to 50 bara, in consequence the TPR doesn't change.
A practical way to do this is to estimate the absolute open flow (when pwf = 0 bara). For pR=250 bara, qo = 15 000 Sm^3/d. Remember, the IPR equation provided is linear (undersaturated fluids) so you just need two points
Please note that the IPR wont probably be linear all the way down to 0 bara, because it will reach the bubble point pressure before and the IPR will start having a curvature. We are neglecting this complexity in the exercise



The well rate is 4500 Sm^3/d.

Calculating the cumulative production for year 1 Np = 1 * 360 * 4500 Sm^3/d = 1.62 E6 Sm^3.

Using the material balance equation, to calculate reservoir pressure at the end of year 1:

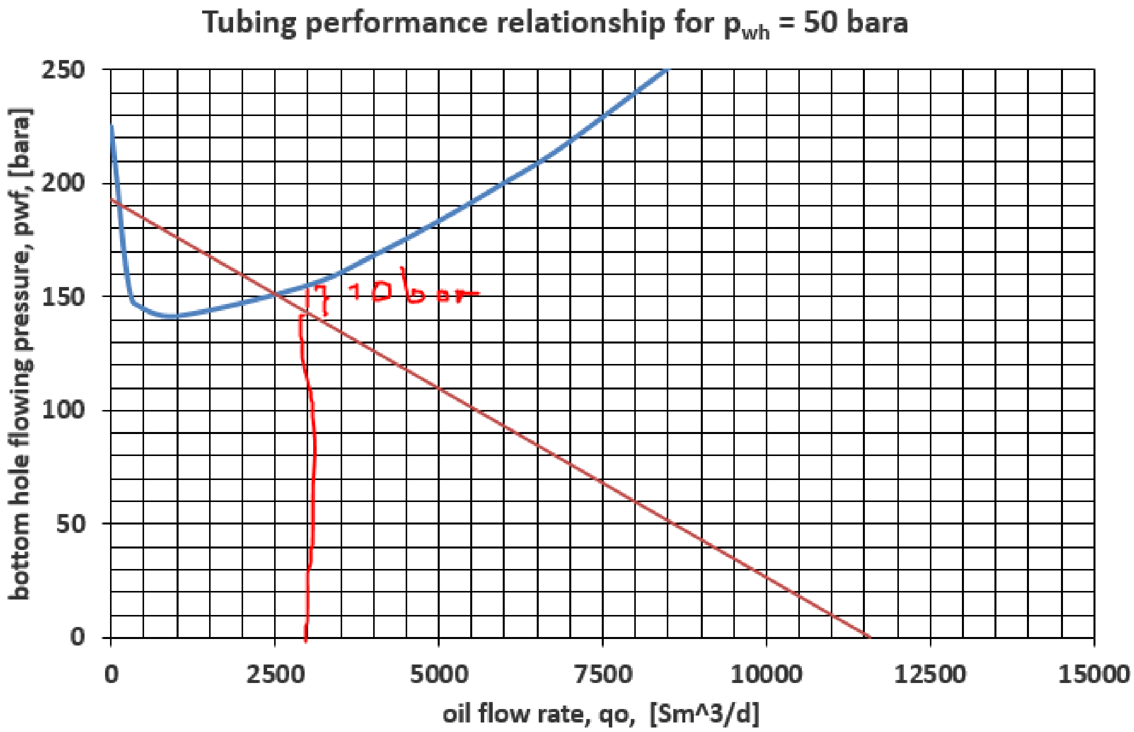
$$p_R = 250\,bara - 1.4E-5\,\frac{Sm^3}{bara} 1.62E6 Sm\hat{}3$$

The process is repeated until the end of year 3 (beginning of year 4). The results are:

time	qo	Np	pR
[year]	[Sm^3/d]	[Sm^3]	[bara]
0	4500	0.00E+00	250
1	3750	1.62E+06	227
2	3125	2.97E+06	208
3	2500	4.10E+06	193

The TPR won't change if the GOR, WC and pwh don't change. Also if the geometry doesn't change (e.g. tubing diameter and length). However, eventually the bottomhole pressure will reach a value below the bubblepoint and the GOR will change. Also there might be water coning and the WC will also change.

For end of year 3, the rate has dropped to 2500 Sm^3/d. If the rate is to be maintained at 3000, then, the pump has to bridge a DP = 10 bar.



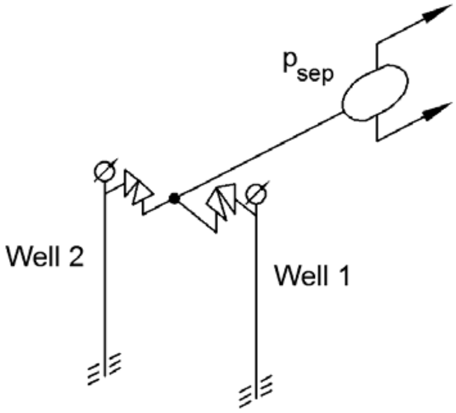
The required power is then

$$Power = \frac{3000 * 1.2 \cdot 10 \cdot 1E5}{0.6 \cdot 24 \cdot 3600} = 69.4kW$$

Please note that for some years there might be two intersections of the required and available pressure curves. We always take the intersection on the right, for reasons explained in class, page 102.

PROBLEM 4 (18 POINTS). Network solving.

Consider the gas field with two wells, a manifold a pipeline and a separator shown in the figure below. The wellhead of the wells are very close to the junction so it can be safely assumed that the wellhead pressure and junction pressure are equal when the choke is open.



Each well has a different H2S concentration as provided in the table below:

Well name	H2S concentration [mg/Sm^3]
Well 1	2.6
Well 2	10.0

The wellhead performance relationship (WPR, available pressure at the wellhead) of each well can be expressed with the following equation:

$$q = C_{wh} \cdot \left(p_{whs}^{\ 2} - p_{wh}^{\ 2}\right)$$

Where p_{whs} is the static wellhead pressure recorded when the well is shut-in. The values for both wells are provided in the table below:

Well Name	C_{wh} [Sm^3/d/bara^2]	P_{whs} [bara]
Well 1	60	150
Well 2	100	135

The pipeline performance relationship (PPR, required pressure at the junction) can be expressed with the following equation:

$$q = C_{pl} \cdot \left(p_j^{\ 2} - p_{sep}^{\ 2}\right)^{0.5}$$

Where
C_{pl} = 45 000 [Sm^3/d/bar^2]
p_{sep} = 30 [bara]

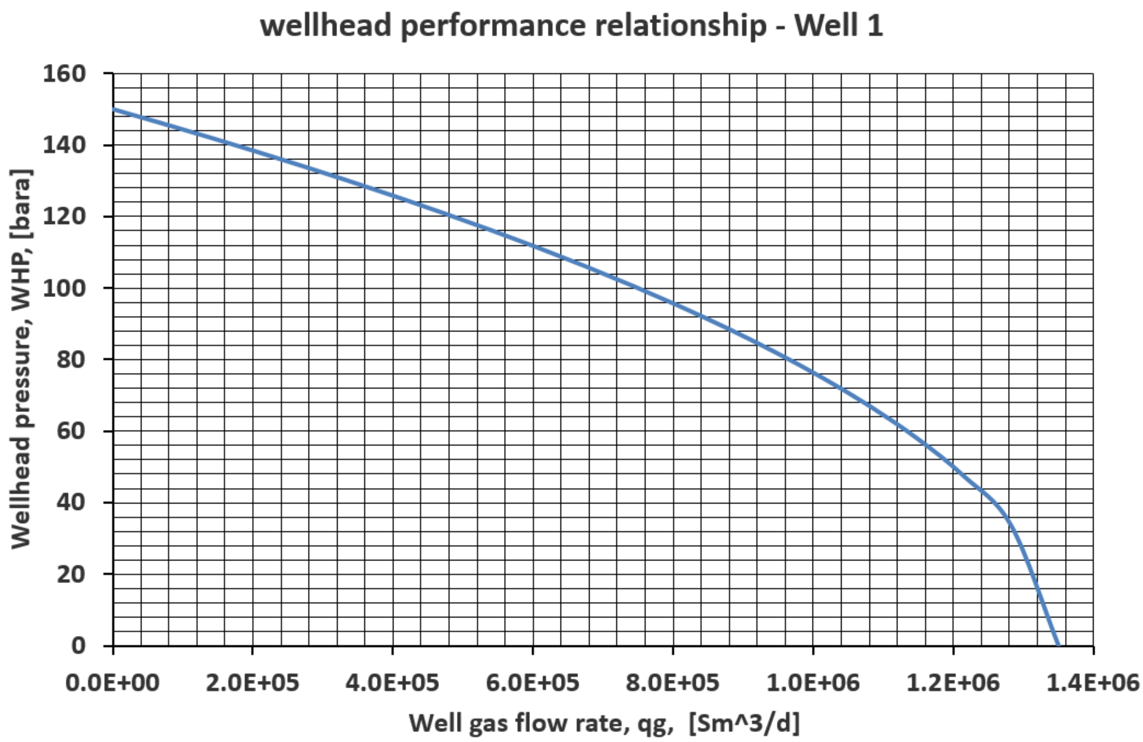
You can also solve this problem graphically, the available and required pressure curves are provided at the end of the exercise.

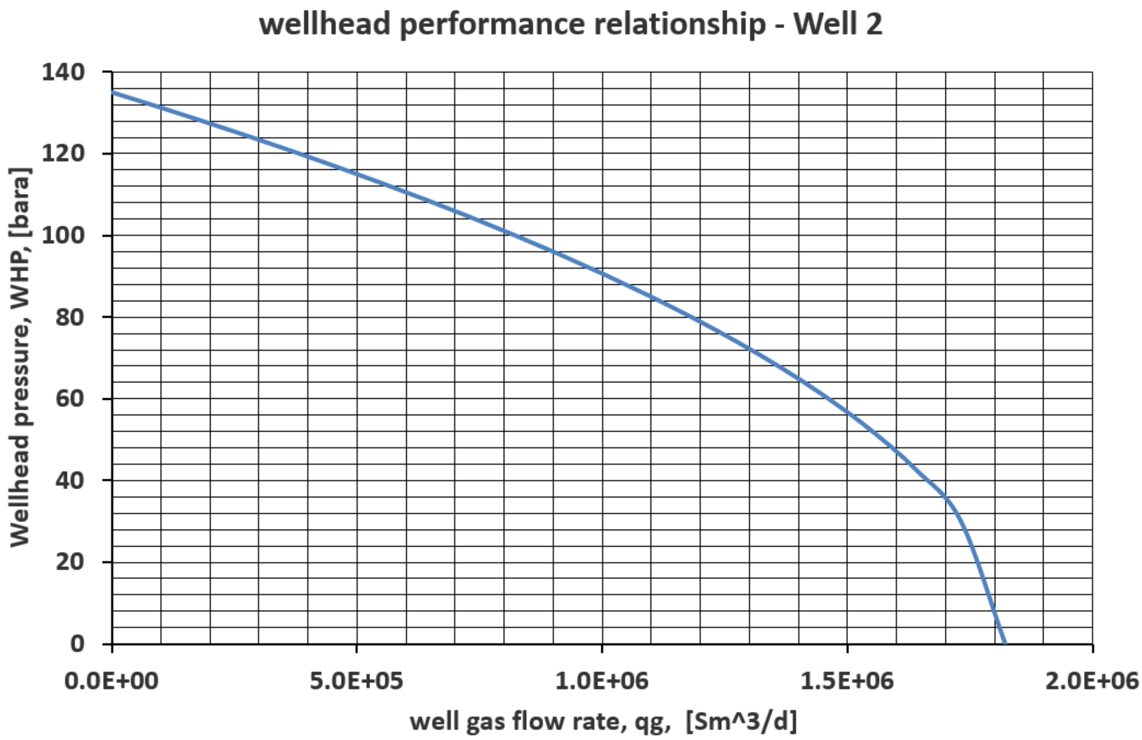
You tasks are:

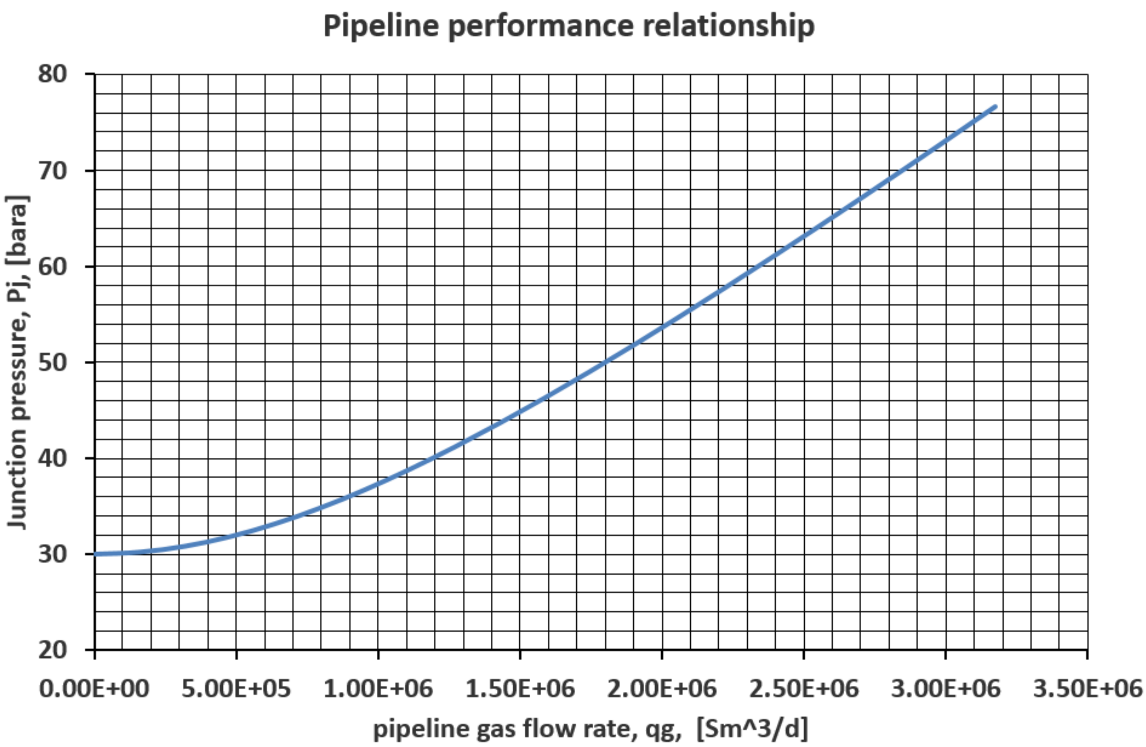
Task 1 (9 POINTS). Calculate the operating flow rates when the chokes are fully open. Verify if the H2S concentration of the field is higher than the maximum value allowed (5.7 mg/Sm^3)

Task 2. (6 POINTS) If the H2S constraint is violated, please find an operational point that does not violate the H2S constraint (by choking one or two wells). Hint: Fix the rate on both wells. Report the pressure drop across the chokes.

Task 3. (3 POINTS) Will it be worth to apply model-based optimization to this problem?. Explain your answer. If yes, please explain how will you set up the optimization problem, what is the objective, what variables will you change and what are the constraints (In excel). Please specify where will you locate the input, output and in which cells are the objective, constraints and variables.







Solution

Assume pj = 64 bara.
From WPR1 q1 = 1.1 E6 Sm^3/d

From WPR2 q2 = 1.45 E6 Sm^3/d

From PPR q = 2.55 E6 Sm^3/d

q1+q2 is approximately equal to q, thus this is the flow equilibrium point. We got lucky on the first try!

The H2S concentration of the field production is calculated by

$$cont.H_2S = \frac{cont.H_2S^1 \cdot q_1 + cont.H_2S^2 \cdot q_2}{q} = 6.8\ mg/Sm\text{^}3$$

This violates the requirement!

Task 2. I have to choke well 2 to reduce the H_2S concentration in the field production. I assume that I will produce the same from well 1 (the GOOD well with low H2S), but I use the equation above to estimate how much I have to produce from well 2 to meet the requirement.
OBS: You can use this approach or any other approach. The main idea is that the rate that you have to fix in well 1 is lower than the natural equilibrium rate!.
q1 = 1.1 E6 Sm^3/d

$$\frac{2.6\ mg/Sm\text{^}3 \cdot 1.1E6\ Sm\text{^}3/d + 10\ mg/Sm\text{^}3 \cdot q_2}{q} = 5.7\ mg/Sm\text{^}3 \quad (1)$$

And additionally

q1+q2 = q thus

1.1E6 Sm^3/d + q2 = q (2)

A system of equations with 2 unknowns

Solving the system

From eq (2) clear q2
q2 = q-1.1E6 Sm^3/d (3)

rearrange eq. (1)
$$2.86\ E6mg/d + 10\ mg/Sm\text{^}3 \cdot q_2 = 5.7\ mg/Sm\text{^}3 \cdot q \quad (4)$$

Substitute eq. (4) in eq. (3)
$$2.86\ E6mg/d + 10\ mg/Sm\text{^}3 \cdot (q - 1.1E6\ Sm\text{^}3/d) = 5.7\ mg/Sm\text{^}3 \cdot q$$
$$-8.14\ E6mg/d = -4.3\ mg/Sm\text{^}3 \cdot q$$
$$q = 1.89E6\ Sm\text{^}3/d$$

q2 = 0.79E6 Sm^3/d

checking if the operational point is feasible

from WPR1, pwh1 = 64 bara

from WPR2, pwh 2 = 101 bara
from PPR pj = 52 bara

thus, it is a feasible operational point. DP1 = 12 bar, DP2 = 49 bar.

Task 3. It is definitively worth to perform model-based optimization in this problem. The formulation will be to find choke opening such that the gas production of the field is maximized, and fulfilling the constraint that the H_2S concentration is below than 5.7 mg/Sm^3 .
The layout of the excel sheet will be very similar to the one discussed in page 129 of class notes but including a column for choke opening. The solver will find choke opening and pwhs of the wells such as qg_field is maximized, the concentration constraint is satisfied and the junction pressure error is equal to zero (or a tolerance).

TPG4230, Milan Stanko, 20170228														
Separator pressure, psep	60		bara											
	Nwells	pR [bara]	pwf [bara]	C [Sm^3/bar^2n]	n	qg [Sm^3/d]	Ct [Sm^3/bar]	S	pwh [bara]	qtemp [Sm^3/d]	Cfl [Sm^3/bar]	ptowhead[bara]	error [bara^2]	
Template L	4	145	99.6	1000	0.8	1.72E+06	38152	0.43	66.6	6.89E+06	1403054	66.5	0.0	
Template M	3	102	80.4	700	0.8	5.27E+05	41163	0.34	66.5	1.58E+06	1397663	66.5	0.0	
Pipeline									qfield [Sm^3/d]=	8.47E+06	296439	66.5	0.0	
											average p, [bara]=	66.5	0.0	=Error