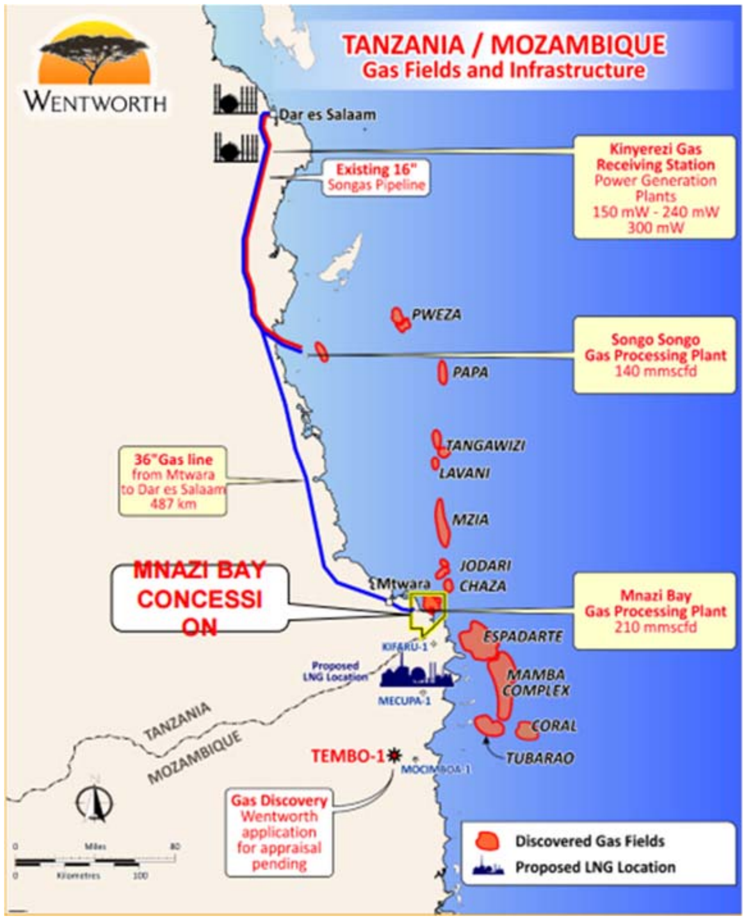
PROBLEM 1. (25 POINTS)

The Mnazi Bay is a gas field located in the south-eastern shores of Tanzania. The field will be produced with standalone vertical wells to a gas processing center (dehydration and refrigeration). 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.



1. Estimate the minimum number of wells required to produce in plateau for 10 years with a field rate of 2.5 E6 Sm^3/d. Determine the exact plateau duration (in days).
2. Using the results from question 1, and assuming that the minimum economic rate (field abandonment rate) is 0.2 E06 Sm3/d, what is the ultimate recovery factor expected from the field?
3. The values of $q_{ppo,well}$ and G are highly uncertain. Experts have estimated that they may vary within the ranges described below.

	min	max
$q_{ppo,well}$ [1E06 Sm^3/d]	2	3
G [1E09 Sm^3]	11	18

Considering these uncertainties, and using a conservative approach, determine the number of wells needed to ensure the field delivers a reservoir plateau rate of 2.5 E6 Sm3/d for at least 10 years.

4. Using the results from Task 1, compute the NPV of the project. Consider **only** the revenue from gas sales in the 10-year plateau period and the DRILLEX.

The following information is available:

- Initial gas in place (G): 12 E09 Sm3
- Assume that a year consists of 355 operational days.
- 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. This expression assumes all wells are identical.

- Assume a DRILLEX of 5 E6 USD per well. 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).
- Use a discount factor of 8%.
- Gas price: 0.11 [USD/ Sm^3]

Solution:

Task 1:

Number of wells (8 POINTS)

If the plateau lasts 10 years, The cumulative production at plateau end ${G_p}^*$ is:

$${G_p}^* = 2.5\ \mathrm{E6}\frac{\mathrm{Sm3}}{\mathrm{d}} \cdot 10 \cdot 355 = 8.88\ \mathrm{E09\ Sm3}$$

we use the expression for field production potential applied at the end of plateau:

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

Clearing out the number of wells:

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

Substituting, this gives 6.37 wells, i.e, 7 wells.

Plateau duration (2 POINTS)

Using the expression for field production potential applied at the end of plateau, inputting Nw, clearing out Gp*

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

This gives:

$${G_p}^* = 9.02\ E09\ Sm3$$

The plateau duration (in days) is:

$t_{plateau} = \frac{{G_p}^*}{q_{pp}}$ =3609 d

Task 2 (5 POINTS):

In decline, the field is producing at potential, therefore, we use the expression for field production potential

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

Or, equivalently:

$$q_{pp} = N_w \cdot q_{ppo,well} \cdot (1 - 1.14 \cdot R_f)$$

Clearing out the recovery factor:

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

Substituting q_{pp} = 0.2 E06 Sm3/d, Nw = 7 gives $R_f = 0.867$

Task 3 (5 POINTS):

Using the conservative case, the worst-case scenario is a small reservoir, and a well with poor productivity, i.e.:

$q_{ppo,well} = 2E06\ Sm3/d$

G= 10 E09 Sm3

Using the same procedure as for Q1 gives: 16 wells

Task 4 (5 POINTS):

$$NPV = -CAPEX - DRILLEX + NPV_{rev}$$

Gas price	[USD/Sm3]	0.11
discount rate	[-]	0.08
DRILLEX per well	[USD/well]	5.00E+06
DRILLEX TOTAL	[USD]	3.50E+07
	NPV [USD]	4.46E+08
end of year	**yearly cum prod**	**DCF (revenue)**
	[Sm3]	**[USD]**
5	8.88E+08	6.64E+07
6	8.88E+08	6.15E+07
7	8.88E+08	5.70E+07
8	8.88E+08	5.27E+07
9	8.88E+08	4.88E+07
10	8.88E+08	4.52E+07
11	8.88E+08	4.19E+07
12	8.88E+08	3.88E+07
13	8.88E+08	3.59E+07
14	8.88E+08	3.32E+07

PROBLEM 2 (5 POINTS)

As a follow-up to problem 1, explain the reason why adding more wells gives a longer plateau?

Solution:

In a field with vertical dry gas wells and production controlled by choke, by adding more wells the rate per well is lower, therefore the available pressure upstream the choke is higher for the same reservoir pressure. The plateau ends because the deltap at the choke becomes zero. When more wells are used, this will occur at a lower reservoir pressure (higher cumulative production).

PROBLEM 3 (2 POINTS)

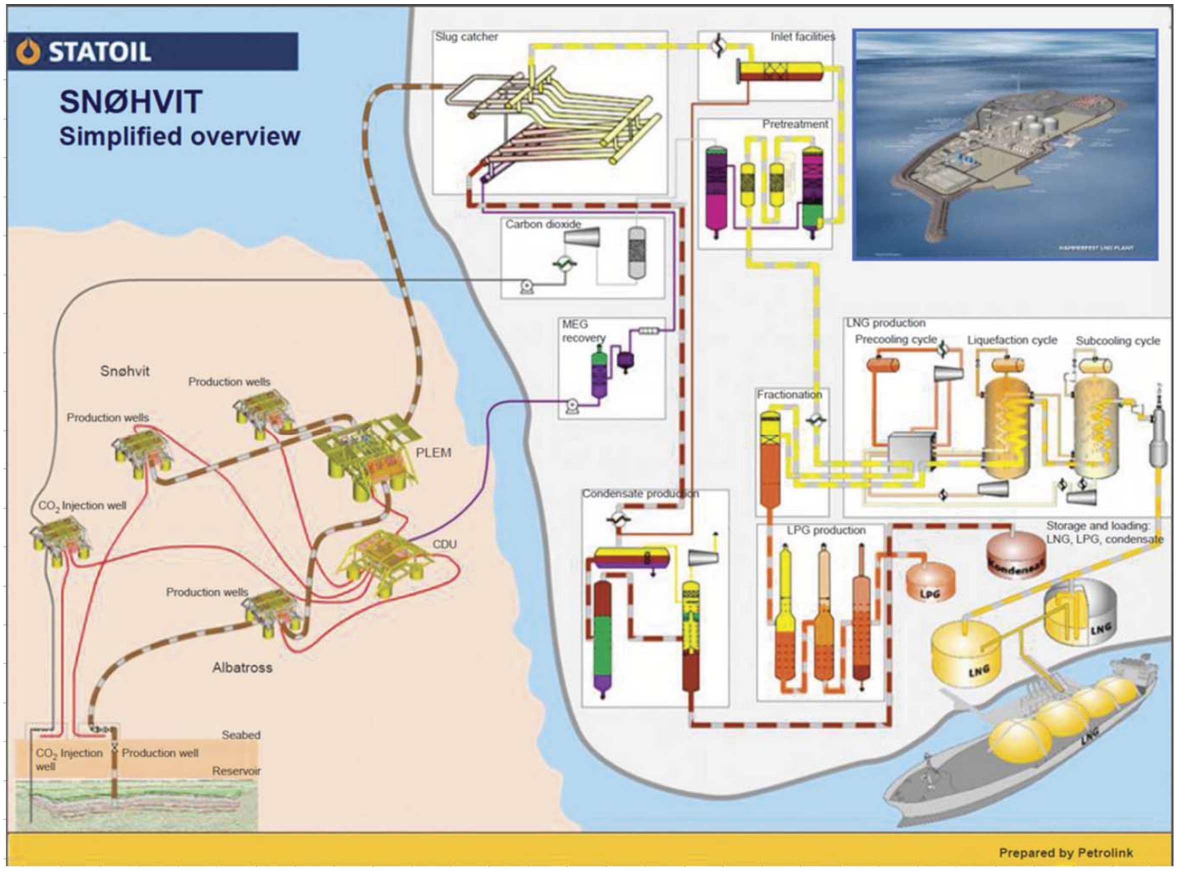
As a follow-up question to Problem 1, explain what is the relationship between plateau duration and rate? What is the reason for this?

Solution:

The higher the plateau rate, the shorter the plateau. The lower the plateau rate, the longer the plateau. Considering the number of wells is constant, a high plateau rate reduces the reservoir pressure quicker and the point where deltap choke equals zero occurs earlier (also available pressure upstream the choke is lower than the low plateau rate case). A low plateau rate reduces the reservoir pressure slower and the point where deltap choke equal zero occurs later.

PROBLEM 4 (15 POINTS)

The excel sheet provided, in the sheet "p_T_pipeline", contains the steady-state pressure and temperature profile along the pipeline that goes from the Snøhvit field to the LNG plan in Hammerfest. The sheet "Hydrate line" contains the p-T points of the hydrate line with no inhibitor and it allows to compute a new hydrate line when Mono ethylene glycol (MEG) is added (using the Hammerschmidt equation).

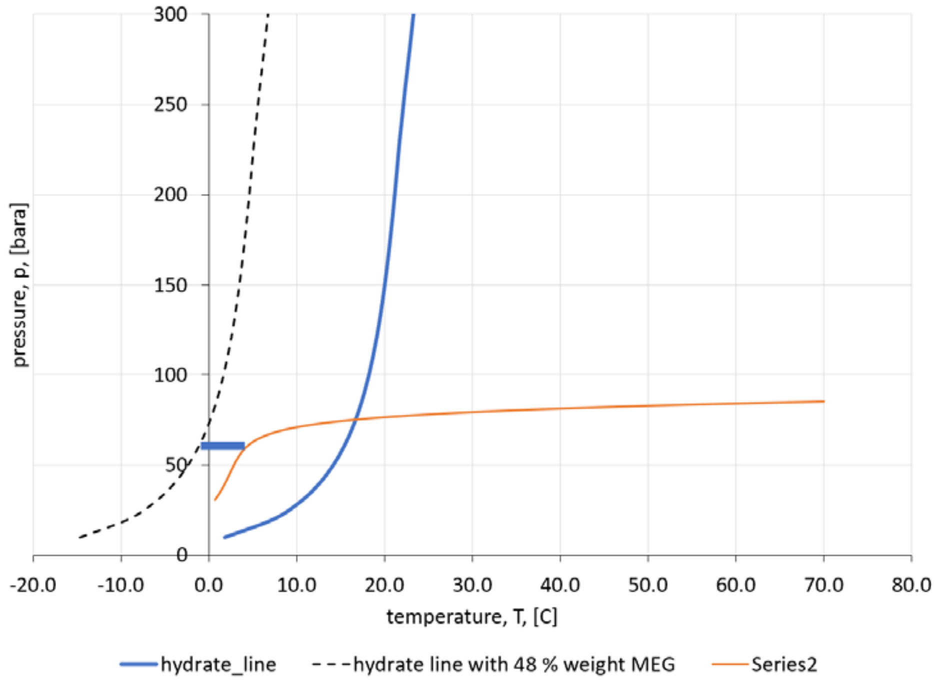


Address the following questions

1. What is the minimum weight percent MEG is required to avoid the formation of hydrate on the pipe? **Include a 5 °C "safety factor"** (the minimum delta temperature between the hydrate equilibrium curve and the curve of pressure-temperature along the pipe should be equal to 5 °C)
2. As a follow-up to question 1, assume that the free water comes only from condensation from the gas. Using the weight % found in task 1, how much MEG (in kg/d) is necessary to inject to avoid hydrate formation in the pipeline, assuming that gas production is 20 E06 Sm3/d? **Additional information:** Neglect the presence of condensate, assume the free liquid is made up of water and MEG only. Reservoir gas is saturated with water at a reservoir pressure and temperature of 276 bara and 92 °C respectively. Use the Excel calculator "Water_solubility.xls" provided (this calculator gives how much water is dissolved in the gas at a given pressure and temperature, in kg of water/1E06 Sm3 of gas).

Solution:

Task 1 (7 POINTS):



Task 2 (8 POINTS):

Gas MW	16	[Kg/Kmol]			
Gas gravity	0.552				
Water salinity	0.0	[ppm]			
			qgfield	[1E06 Sm3/d]	20
p	**T**	**rsw**	min rsw in pipeline	[kg/1E06 Sm3]	174.2
[bara]	[C]	[Sm^3/1E06 Sm^3]	max mass flow of free water in pipeline	kg/d	68963.6
85	70	3622.3	weight % of MEG		48
84.7	67.0507	3220.3	MEG required	kg/d	63658.7
84.4	64.2	2869.0			
84.0	61.5	2561.9			
83.7	58.8	2293.5			
83.4	56.3	2058.7			

PROBLEM 5 (2 POINTS)

How does the water salinity affect the hydrate equilibrium (pressure-Temperature) curve?

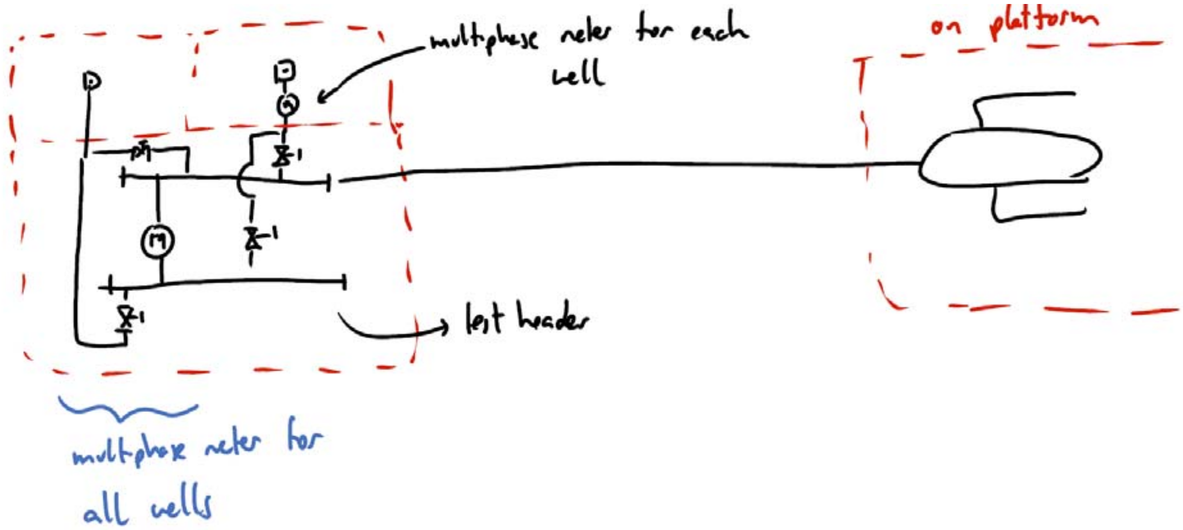
Solution

Salt acts as an inhibitor, i.e. it shrinks the hydrate formation region, it moves the curve to the left (lower temperatures are required for hydrate to form)

PROBLEM 6 (8 POINTS)

As a follow-up to problem 4, make a sketch of a 4 well subsea template of the Snohvit field. The 4 well subsea template has 4 gas wells (4 X-mas tree modules), a manifold module consisting of the wells' routing valves, two headers and a multiphase meter. One of the headers is connected to a flowline that takes the production to the PLEM (pipeline entry module).

Solution

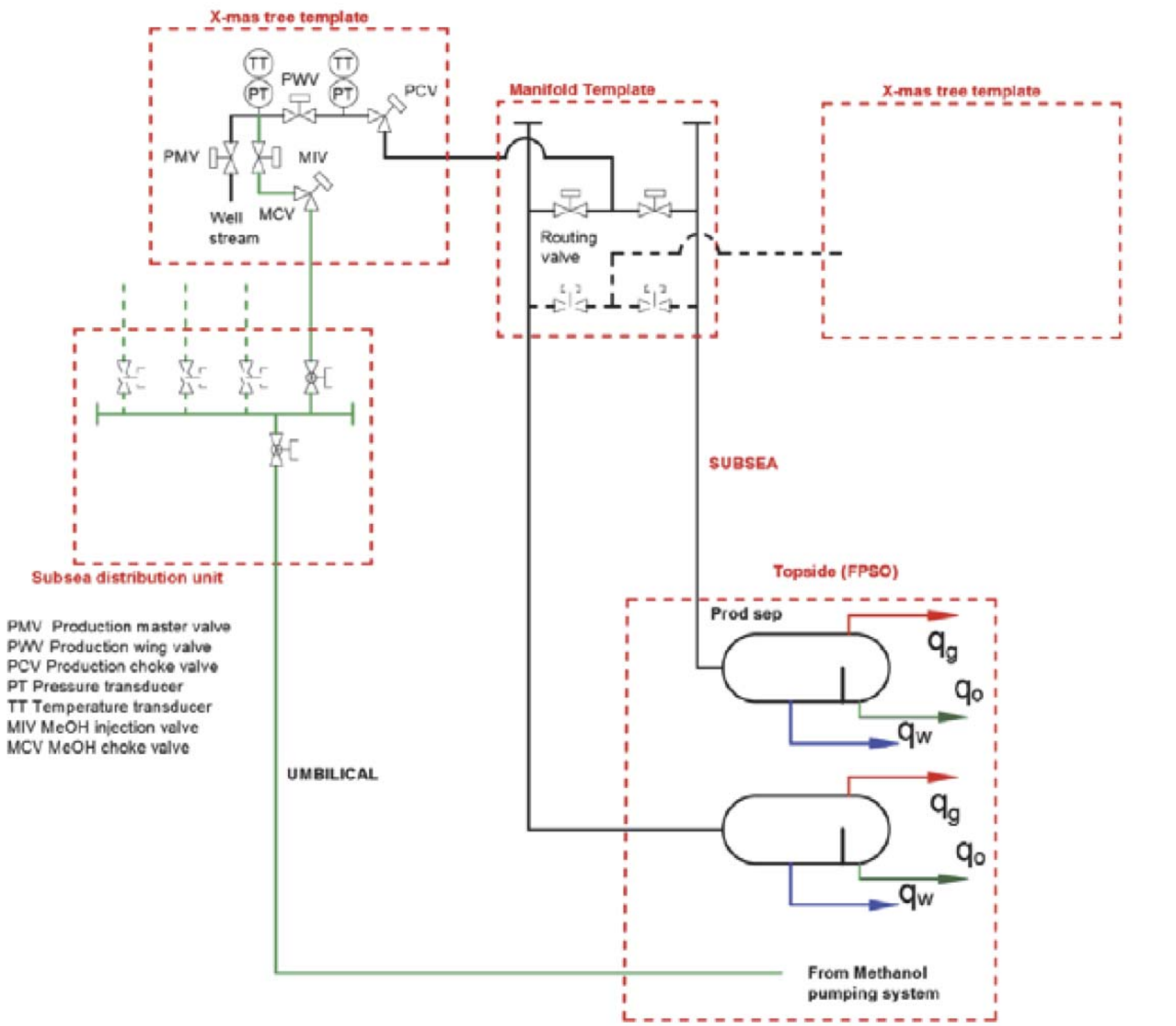


PROBLEM 7 (3 POINTS)

As a follow-up to problem 6, explain how and where is the MEG injected into the system.

Solution

MEG is typically injected with an umbilical from topside. The umbilical goes to a subsea distribution unit, and then it is distributed to the wells (or to the subsea template first and then the wells). The MEG is typically injected in the X-mas tree, upstream the production wing valve.


X-mas tree template
TT
PT
PWV
TT
PT
PCV
PMV
MIV
Well stream
MCV
Manifold Template
Routing valve
X-mas tree template
Subsea distribution unit
SUBSEA
Topside (FPSO)
Prod sep
qg
qo
qw
qg
qo
qw
PMV Production master valve
PWV Production wing valve
PCV Production choke valve
PT Pressure transducer
TT Temperature transducer
MIV MeOH injection valve
MCV MeOH choke valve
UMBILICAL
From Methanol pumping system