Department of Geoscience and Petroleum

Examination paper for TPG4230 Field Development and Operations

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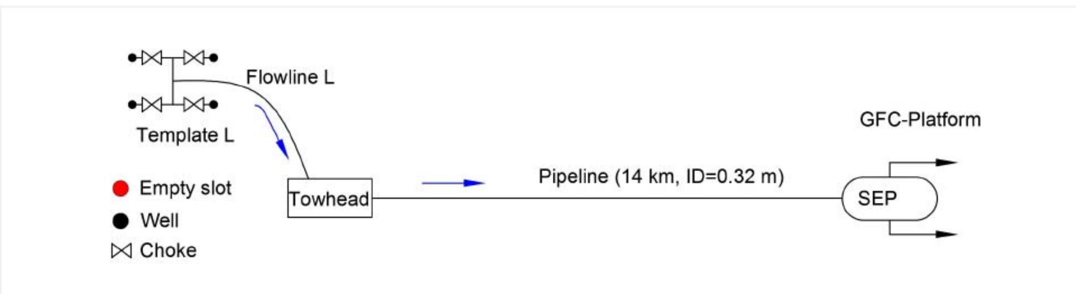
Examination date: 24.05.2018
Examination time (from-to): 15:00 – 19:00
Permitted examination support material: D: No printed or hand-written support material is allowed. A specific basic calculator is allowed.

Other information:

Language: English
Number of pages (front page excluded): 20

i Introduction text to tasks 1-6



A reservoir unit in Gullfaks South field (Block 13) has been producing oil and gas since 1999 by a subsea template with 4 wells (Template L). The production is commingled in the template and flows to another subsea template (called "Towhead") and is transported further using **a production pipeline** to the Gullfaks C platform.

Due to the depletion of the oil layer in the formations, the wells in template L have been recompleted towards the end of year 2008 to produce liquid rich gas. At the end of this year, reservoir pressure is 240 bara and Initial Gas in place, G is 54.2 E9 Sm3. From 2009, the template is produced in plateau mode with a total rate of 7.4 E6 Sm^3/d.

i **Useful information for tasks 1-6**

G, initial gas in place (start 2009)	54.2E+9	Sm3
Pi, initial reservoir pressure (start 2009)	240	bara
C, inflow	1000	Sm3/bar^2n
n, inflow	0.8	
Ct, Tubing coefficient	38152	Sm3/bar
S, tubing	0.43	
C_{FL} flowline temp to towhead	1403000	Sm3/bar
C_{PL} pipeline, towhead to plat	148200	Sm3/bar
Sep pressure	60	bara

Material balance:

$$p_R = p_i \cdot \left(1 - \frac{G_p}{G}\right)$$

Inflow equation:

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

Tubing equation:

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

Flowline Template-Towhead:

$$q_{gsc} = C_{FL} \cdot \left(p_{TEMP}^2 - p_{TH}^2\right)^{0.5}$$

Pipeline equation Towhead-platform:

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

Useful information and equations

Task 1.a

Using flow equilibrium calculations, determine the choke pressure drop (in bar) required to deliver the plateau rate of 7.4 E-6 Sm^3/d when reservoir pressure is 240 bara: ________.

Check answer

SOLUTION:

86.76

2 **Task 1.b**

Explain how you have performed task 1.a.

Fill in your answer here

SOLUTION:

1. Calculate qw = qplateu / 4 = 1.85E+6 sm3/d

2. Compute Pwf with Pr and qw as inputs. The equation is

Pwf = (Pr^2 - (qw/Cr)^(1/n))^0.5

Pwf = (240^2 - (1.85E+6/1000)^(1/*0.8))^0.5

Pwf = 213.23 bara

3. Compute Pwh with Pwf (obtained from step 2) and qw as inputs. The equation is

Pwh = ((Pwf^2/e^s)-(qw/Ct)^2)^0.5

Pwh = ((213.23^2/e^0.43)-(1.85E+6/38152)^2)^0.5

Pwh = 165 bara

4. Compute Pth with Psep and qplateau as inputs. The equation is

Pth = (Psep^2 + (qplateau/Cpl)^2)^0.5

Pth = (60^2 + (7.4E+6/148200)^2)^0.5

Pth = 78.06 bara

5. Compute Ptemp with Pth and qplateau as inputs. The equation is

Ptemp = (Pth^2 + (qplateau/Cfl)^2)^0.5

Ptemp = (78.06^2 + (7.4E+6/1403000)^2)^0.5

Ptemp = 78.24 bara

6. Compute dPchoke (assume located in template) with Pwh and Ptemp as inputs. The equation is

dPchoke = Pwh - Ptemp

dPchoke = 165 - 78.24 = 86.76 bar

3 **Task 2.a**

Using flow equilibrium calculations, determine until which reservoir pressure will it be possible to deliver the plateau rate of 7.4 E-6 Sm^3/d. ______.

SOLUTION:

158.61

4 **Task 2.b**

Explain how you have performed task 2.a.

Fill in your answer here

SOLUTION:

1. Compute Pth with Psep and qplateau as inputs. The equation is

Pth = (Psep^2 + (qplateau/Cpl)^2)^0.5

Pth = (60^2 + (7.4E+6/148200)^2)^0.5

Pth = 78.06 bara

2. Compute Ptemp with Pth and qplateau as inputs. The equation is

Ptemp = (Pth^2 + (qplateau/Cfl)^2)^0.5

Ptemp = (78.06^2 + (7.4E+6/1403000)^2)^0.5

Ptemp = 78.24 bara

3. At the end of plateau period, the choke is fully open, which implies that the Pwh = Ptemp

Pwh = 78.24 bara

4. Compute Pwf with Pwh and qw (=qplateau/4) as inputs. The equation is

Pwf = (e^s((qw/Ct)^2 + Pwh^2))^0.5

Pwf = (e^0.43((1.85E+6/38152)^2 + 78.24^2))^0.5

Pwf = 114.13 bara

5. Compute Pr with Pwh and qw as inputs. The equation is

Pr = ((qw/Cr)^(1/n)+Pwf^2)^0.5

Pr = ((1.85E+6/1000)^(1/0.8)+114.13^2)^0.5

Pr = 158.61 bara

5 **Task 3.a**

Using the material balance equation and neglecting the change in the gas deviation factor, determine which cumulative production gives you the reservoir pressure where the plateau starts declining (in Sm^3): ______. If the template produces for 328 days per year, what is the duration of the plateau? (in years): ______.

SOLUTION:

1.8380575E10 ✔ 7.57 ✔

6 **Task 3.b**

Explain how you have performed task 3.a.

Fill in your answer here

SOLUTION:

1. Determine Gp using IGIP (G), reservoir pressure at the end of plateau period (Pr), and intial reservoir pressure. The reservoir pressure at the end of plateau period is obtained in question number 3 & 4.

Gp = G *[1-Pr/Pri]

Gp = 54.2E+9 * [1 - 158.61/240]

Gp = 18.38E+9 sm3 = 18,380,575,000 sm3

2. Compute the plateu period using qplateau, uptime, and Gp

Gp = qplateau * tp (in years) * uptime

tp = Gp / (qplateau*uptime)

tp = 18.38E+9 / (7.4E+6 * 328)

tp = 7.57 years

7 **Task 4.a**

Estimate the natural equilibrium flow of the template (in Sm^3/d) for a reservoir pressure of 140 bara: ______.

SOLUTION:

5.946e6 Sm^3/d

8 **Task 4.b**

Explain how you have performed your calculations in Task 4.a.

Fill in your answer here

SOLUTION:

Basically, what is known is Pr and Psep. The unknown is qfield (or =4*qw).
Since it is in decline period, the choke is fully open, which implies that Pwh = Ptemp.
Here is the steps involved to set up equation with Pr and Psep as inputs.

Inflow equation with Pr and qw as inputs:
$$Pwf^2 = Pr^2 - (qw/Cr)^{(1/n)} \quad (1)$$

Tubing equation with Pwf and qw as inputs:
$$Pwh^2 = (Pwf^2/e^s)-(qw/Ct)^2 \quad (2)$$

combine eq (1) and (2)
$$Pwh^2 = ((Pr^2 - (qw/Cr)^{(1/n)})/e^s)-(qw/Ct)^2 \quad (3)$$

$$Ptemp = Pwh \quad (4)$$
Combine eq (3) and (4)
$$Ptemp^2 = ((Pr^2 - (qw/Cr)^{(1/n)})/e^s)-(qw/Ct)^2 \quad (5)$$

Flowline equation with Ptemp and qfield (=4*qw) as inputs:
$$Pth^2 = Ptemp^2 - (4*qw/Cfl)^2 \quad (6)$$
Combine eq (5) and (6)
$$Pth^2 = ((Pr^2 - (qw/Cr)^{(1/n)})/e^s)-(qw/Ct)^2 - (4*qw/Cfl)^2 \quad (7)$$

Pipeline equation with Pth and qfield (=4*qw) as inputs:
$$Psep^2 = Pth^2 - (4*qw/Cpl)^2 \quad (8)$$
Combine eq (7) and (8)
$$Psep^2 = ((Pr^2 - (qw/Cr)^{(1/n)})/e^s) - (qw/Ct)^2 - (4*qw/Cfl)^2 - (4*qw/Cpl)^2 \quad (9)$$

In equation (9), the inputs consist of Psep, Pr, and qw. As Pr and Psep are known, the only unknown is qw. qw can be found by solving eq (9). Since eq (9) is not a quadratic equation, iterative approach is used to solve the equation. First, qw is assumed, then Psep is computed. If the Psep is not equals to 60 bara, the qw is changed such that the computation results Psep of 60 bara.

qw (sm3/d)	Psep (bara)
1E+6	87.56
1.2E+6	78.14
1.4E+6	66.25
1.5E+6	58.94 (close to 60)

By doing the approach, it is found
qw = 1.5E+6 sm3/d
qtemp = qfield = 4 * qw = 6E+6 sm3/d

9 **Task 5.a**

When reservoir pressure is 140 bara, If one wishes to produce 7.4 E06 Sm^3/d from the template by installing a compressor at the towhead, estimate the pressure boost required from the compressor (in bar) ______, the pressure ratio ______ and the outlet temperature (in celsius) ______, assuming that the inlet temperature is 70 C and the polytropic exponent is 1.4 (use the expression provided below) : .

$$\frac{T_{out}}{T_{in}} = \left(\frac{p_{out}}{p_{in}}\right)^{\frac{n-1}{n}}$$

SOLUTION:

28.28 ✔ 1.57 ✔ 117.07 ✔

10 **Task 5.b**

Explain how you have performed task 5.a.

Fill in your answer here

SOLUTION:

1. Compute the required Pth to produce plateau rate of 7.4E+6 sm3/d. The inputs for pipeline equation are Psep and qplateau. The equation is

Pth = (Psep^2 + (qplateau/Cpl)^2)^0.5

Pth = (60^2 + (7.4E+6/148200)^2)^0.5

Pth = 78.06 bara (required)

2. Now compute the available Pth. It begins with the inflow equation to determine Pwf with Pr = 140 bara and qw (=qplateu/4) as inputs. The equation is

Pwf = (Pr^2 - (qw/Cr)^(1/n))^0.5

Pwf = (140^2 - (1.85E+6/1000)^(1/*0.8))^0.5

Pwf = 86.41 bara

3. Then compute Pwh with Pwf (obtained from step 2) and qw as inputs. The equation is

Pwh = ((Pwf^2/e^s)-(qw/Ct)^2)^0.5

Pwh = ((86.41^2/e^0.43)-(1.85E+6/38152)^2)^0.5

Pwh = 50.06 bara

4. Since the choke at wellhead is fully open, Pwh = Ptemp

Ptemp = 50.06 bara

5. Compure the available Pth using flowline equation with Ptemp (obtained from step 4) and qplateau as inputs. The equation is

Pth = (Ptemp^2 - (qplateau/Cfl)^2)^0.5

Pth = (50.06^2 - (7.4E+6/1403000)^2)^0.5

Pth = 49.78 bara (available)

6. Compute dPcomp

Psuc = Pth available = 49.78 bara

Pdis = Pth required = 78.06 bara

dPcomp = Pdis - Psuc

dPcomp = 28.28 bar

7. Compute the pressure ratio of the compressor

rp = Pdis/Psuc = 1.57

8. Compute Tout

Tout = Tin * rp ^ ((n-1)/n)

Tout = (70 + 273.15) * (78.06/49.78)^((1.4-1)/1.4)

Tout = 390.2 K = 117.07 deg C

11 **Task 6**

What are the typical production modes to operate a field?. Explain in which situation do you use each. How does plateau height affect plateau duration?

Fill in your answer here

SOLUTION:

1. Mode A / Plateau / Constant Rate

In this production mode, production potential of the field is higher than the plateau rate. Therefore, choke is employed to control the production rate (reduce the available pressure).

This production mode is applied for:

-Standalone development with independent processing facilities and offshore structure

-New field with no neighboring fields with space processing capacity

-When there is an agreed production contract

2. Mode B / Decline / Constant Pressure

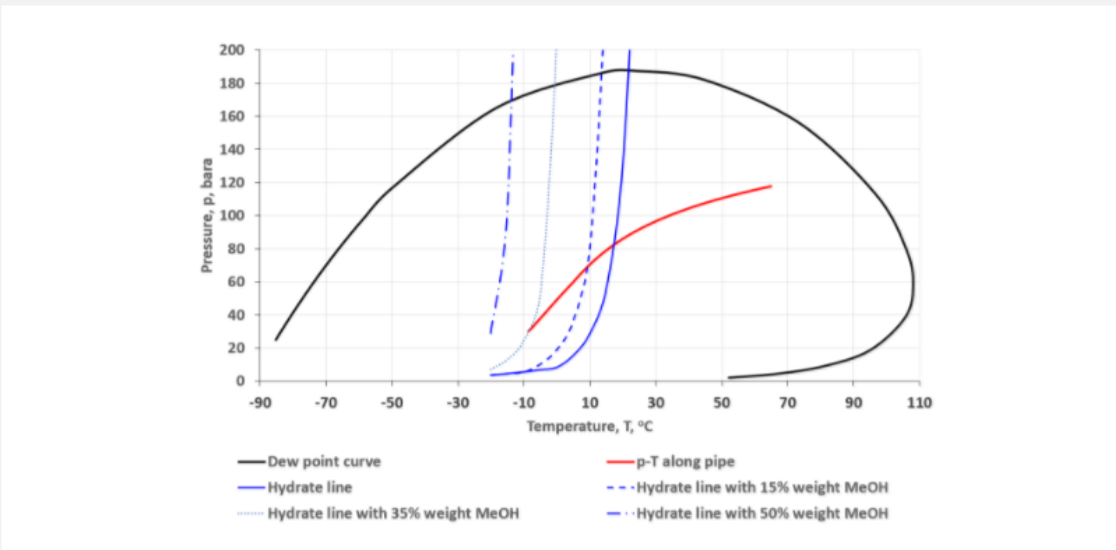
In this mode, field is produced against constant separator pressure. The choke is fully open. Since the reservoir pressure depletes with production, the field rate also declines.

This production mode is applied for:

-Satellite field development that is produced via existing processing facilities (in the neighboring field) with spare capacity

The higher the plateau, the shorter the plateau duration is. This is because a higher production will make reservoir pressure to decline much faster. The lower plateau height is, the longer the plateau duration is.

i Introductory text to tasks 7, 8 and 9



The 158 km, 678 mm ID subsea pipeline that takes reservoir fluids (gas+water+condensate) from the Snowhite field to shore (Melkøya LNG plant) has been modeled in Hysys (Total gas flow: 20 E6 Sm^3/d, total mass flow rate 80 000 kg/hr). The analysis is steady-state. The results are shown on the plot above showing the phase envelope of the fluid stream, the evolution of pressure and temperature along the pipeline and the hydrate line for different values of methanol concentration.

12 Task 7

Explain what is the general workflow to estimate manually pressure drop along a pipe with multiphase flow.

Fill in your answer here

SOLUTION:

Computing pressure drop along a pipe with multiphase flow is done in step wise manner. The general steps are written below:

1. Dicretize the flow conduit into 'N' number of segments
2. Begin the calculation with the point with known P,T
3. Assume a flow rate in surface condition. For example qo,sc. Then compute the gas and water flow rates at surface condition with GOR and WC, respectively.
4. Determine fluid properties at P,T. This can be done by involving Black-Oil method for example.
5. Compute local flowrates at P,T (using the fluid properties obtained is previous step)
6. Compute superficial velocity of the fluid.

vsg = qg_local / A_pipe

7. Calculate dP/dx for multiphase flow. This can be done by using correlation, mechanistic model, or homogeneous model.
8. Intergrate and find P_i+1 using implicit or explicit method
9. Repeat step 4 until pressure in all grid blocks are computed.

Note: if the temperature profile is not defined, the workflow should include the computation of temperature simultaneously.

13 Task 8

What are the necessary conditions for hydrate formation?. Will there be a hydrate problem in the pipeline? If yes, indicate 3 measures to avoid the formation of hydrates.

Fill in your answer here

SOLUTION:

Hydrates form only if **ALL** following ingredients are present:

- Free water (in liquid phase)
- Small hydrocarbon molecules
- Particular range of pressure and temperature.

(usually high pressures and low temperatures).

There will be a hydrate problem in the pipeline because the pressure and temperature along the pipeline cross and move inside the hydrate formation region.

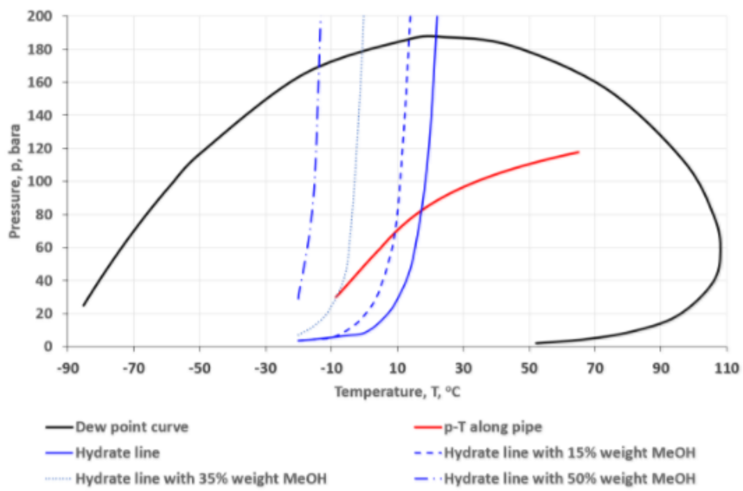
Measures to avoid hydrate formation:

-Insulation (mechanism: keep the fluid temperature outside the hydrate formation region)

-Heat tracing (mechanism: keep the fluid temperature outside the hydrate formation region)

-Chemical inhibitor, such as MEOH, MEG (mechanism: shift the hydrate formation region to the left)

14 **Task 9**



The figure above shows how the hydrate line is modified when one adds a hydrate inhibitor (Methanol, MeOH) to the fluid stream in different proportions (mass of MeOH divided by mass of methanol+water). If the Water Gas Ratio of the Snowhite field is 6E-6 Sm^3/Sm^3, estimate how much methanol (in kg/d) will it be necessary to inject to avoid the formation of hydrates (assume density of water = 1000 kg/m^3 and neglecting the evaporation of methanol in the gas): ______.

SOLUTION:

Water Gas ratio of 6 E-6 Sm_3/Sm_3. The plateau production of the field is 20 MSm_3/d, thus it produces around 120 Sm_3/d of water, or, equivalently, 120 000 kg/d of water. If we assume that the inhibitor concentration used is 35 in weight %, then this gives 64615.4 kg/d of MEG that must be continuously injected on the field.

i **Text to support task 10**

In tree analysis, we usually make a discrete approximation by setting up nonoverlapping (mutually exclusive) ranges that encompass all possible values (collectively exhaustive), by finding the probabilities that the values fall in these ranges, and by then choosing a value to represent that range. (This is the approximation.) By doing this, we have converted a continuous variable to a discrete variable and a probability density function to a probability mass function.

Given a continuous probability distribution such as the one shown in Figure 2–14, how does one perform this approximation? One widely used technique is to select the number of outcomes and the values of the probabilities you want and then draw a horizontal line at these probabilities. In Figure 2–15, we have chosen the number of outcomes to be three. We have also chosen the probabilities .25 for the lower range (line at .25), .5 for the

Figure 2–14

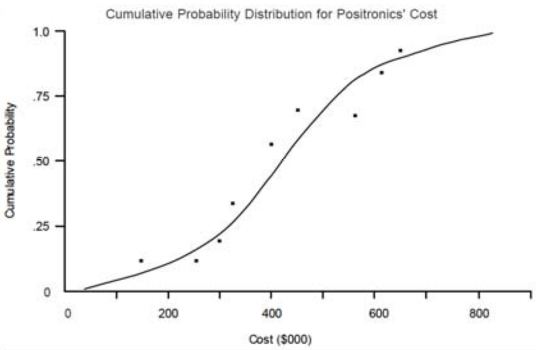
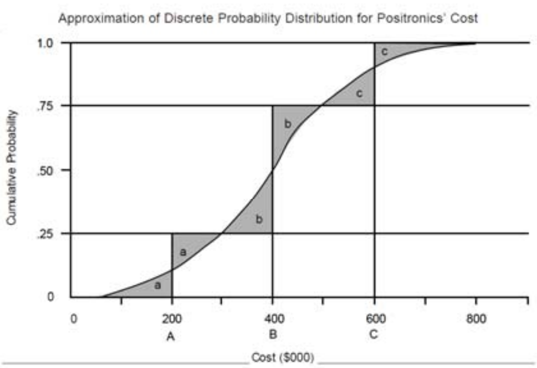


Figure 2–15



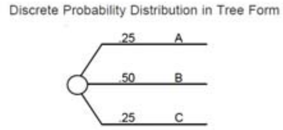
middle range (line at .25 + .50 = .75), and .25 for the top range (line at .25 + .5 + .25 = 1).

Next, we draw a vertical line at A, choosing point A so that the shaded area to the left of the vertical line is equal to the shaded area to the right. (The eye is surprisingly good at doing this.) These two areas are marked by the letter "a." Then we pick a point, B, at which to draw a vertical line with the shaded area to the right being equal to the shaded area to the left. Finally, we pick the third point, C, at which to draw the vertical line balancing the two shaded areas.

The procedure sounds much more complicated than it is in practice. The result is that we now have approximated the continuous probability distribution; the discrete probability distribution is shown in tree form in Figure 2–16. The actual values are A = 200, B = 400, and C = 600. These values are used for Positronics' cost in this chapter. In general, the values for A, B, and C will not come out evenly spaced.

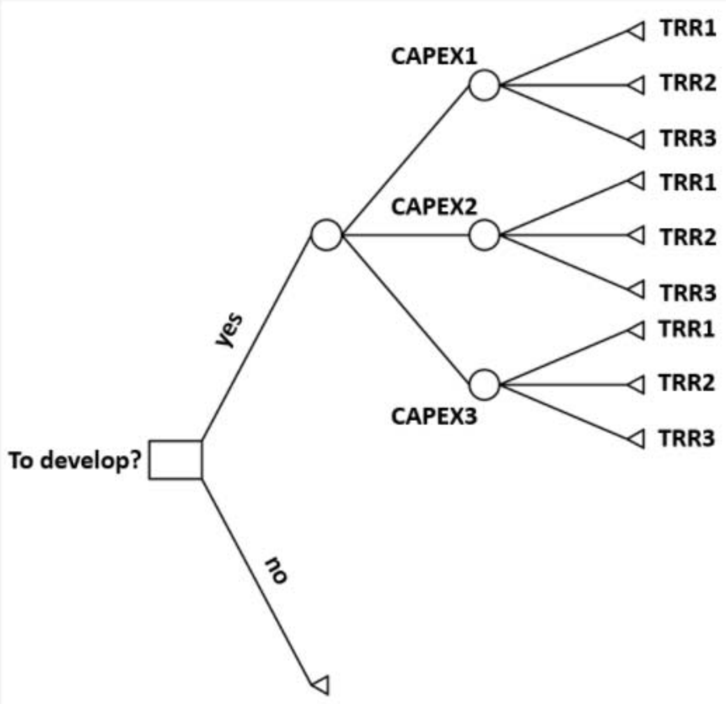
The reason the procedure works is that we divided the continuous probability distribution into ranges with associated probability when we drew the horizontal lines. In Figure 2–17, we see that the first range was from negative infinity to x and had probability .25. The second range was from x to y and had a probability of .5. The third range was from y to infinity and had a probability of .25. (For this example, x = 300 and y = 500, corresponding to the ranges in Figure 2–4.) Picking point A in such a way that the shaded areas are equal is a visual way of finding the expected value, given that you are in the lowest range. (Proving that the expected value makes the shaded areas equal is a nice exercise in calculus in problem 2.15.) Choosing the expected value to represent the range is a natural approximation and is commonly used. There are, however, other possible choices.

Figure 2–16

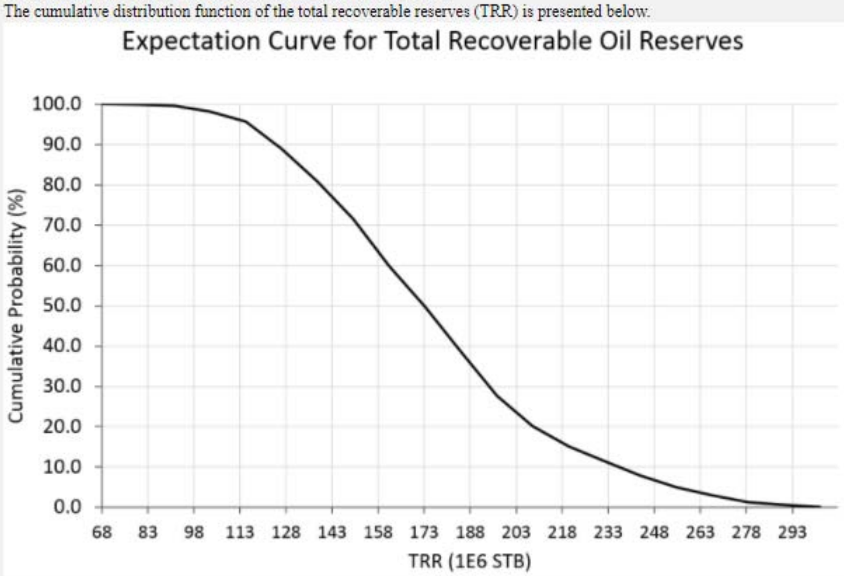


15 **Task 10**

Your company is deciding whether to develop a reservoir or not in the Barents Sea region. To help them take the decision, you have proposed to use a decision tree just like the one presented in the figure below.



The capex values have already been discretized and are given next with their respective probability: CAPEX1: 0.7 E9 USD, P1: 0.3, CAPEX2: 1.1 E9 USD, P2: 0.4, CAPEX3: 1.5E9, P3: 0.3.
The cumulative distribution function of the total recoverable reserves (TRR) is presented below.



Your tasks are:

1. Provide P10: ______ ., P50 ______ and P90: ______ of the TRR (in stb).

2. Use these values of TRR in the decision tree, i.e. TRR1=P10, TRR2 = P50 and TRR3 = P90. Find the associated probabilities from the cumulative distribution function of the TRR: (in fraction) P1: ______ P2: ______ and P3: ______.

3. What is the mean expected value of the development in USD?: ______. To estimate the monetary value of each combination use the expression MV = TRR*60*0.4-CAPEX.

4. Do you advice to develop the field (1 for yes, 0 for no): ______

SOLUTION:

2.362E8 ✓ 1.73E8 ✓ 1.248E8 ✓

0.25 ✓ 0.5 ✓ 0.25 ✓

3.13E9

1.0 ✓

OPTION	CAPEX	P_capex	TRR	P_TRR	MV = TRR*60*0.4-CAPEX	P=P_capex*P_TRR	MV*P	
1	7.00E+08	0.3	1.24E+08	0.23	2.28E+09	0.069	1.57E+08	
2	7.00E+08	0.3	1.73E+08	0.54	3.45E+09	0.162	5.59E+08	
3	7.00E+08	0.3	2.36E+08	0.23	4.96E+09	0.069	3.43E+08	
4	1.10E+09	0.4	1.24E+08	0.23	1.88E+09	0.092	1.73E+08	
5	1.10E+09	0.4	1.73E+08	0.54	3.05E+09	0.216	6.59E+08	
6	1.10E+09	0.4	2.36E+08	0.23	4.56E+09	0.092	4.20E+08	
7	1.50E+09	0.3	1.24E+08	0.23	1.48E+09	0.069	1.02E+08	
8	1.50E+09	0.3	1.73E+08	0.54	2.65E+09	0.162	4.30E+08	
9	1.50E+09	0.3	2.36E+08	0.23	4.16E+09	0.069	2.87E+08	
						1	3.13E+09	**EMV**

Task 11

The Peregrino field has platform wells lifted with Electric submersible pumps and operating with open choke and constant wellhead pressure of 7 bara.

If reservoir pressure declines with time, but all other parameters remain constant (water cut, GOR, well productivity, etc). What adjustment does one have to make to the system to maintain the same production rate?. Explain your answer.

Fill in your answer here

SOLUTION:

It is assumed that GOR, water cut, Pwh and location of ESP are constant parameters. Because of the assumption, it can be said that the discharge pressure of the ESP will remain constant for delivering the same fluid rates (pressure drop in the tubing doesn't change since the composition of flowing fluid doesn't change).

As the reservoir pressure declines, lower Pwf is required to produce the same fluid rate (it is also assumed that the productivity doesn't change). As consequence, lower pressure is available at the ESP suction.

Since the discharge pressure remains constant while the suction pressure decreases, the dPesp (=Psuc-Pdic) will increase as the reservoir pressure drops. In the following table, the consequence of decreasing reservoir pressure and its potential adjusment on the ESP are described:

Parameters affected by decreasing Pr	**Operational constrain of the ESP**	**Adjustment to the ESP**
Increasing dPesp	Increasing required pump power	Change the ESP motor with the higher power availability
Increasing dPesp	The operating point moves upward of the operational maps	Increase the operating frequency of the ESP (if the operating point is inside the operational map) or add more stages (if the operating point is outside the operational map)
Decreasing Psuc	Psuc < Pb	Lower the ESP location, closer to the perforation

The adjusments mentioned above are related to ESP. Other adjusment also can be made to the system (other than ESP), such as:

-Increase the tubing diameter, decrease pipe roughness, or apply gas lift method. This adjusment will decrease the pressure drop in the tubing thus lowering the dPesp.

-Maintain reservoir pressure by water or gas injection so the Psuc and dPesp can be maintained.