Problem 1 (20 points)

You are part of the field development team for a recently discovered reservoir. You are considering to re-use equipment from an existing platform that will be dismantled soon.

Consider a horizontal gas oil separator with an effective length of 5 m and an inner diameter of 1.7 m. consider the required residence time for gas is 20 s, and the required retention time for oil is of 60 s. During normal operating conditions, half of the separator is filled with liquid.

Task 1 (5 points). Calculate what are the maximum volumetric rates of oil and gas (at local pressure and temperature, q_o and q_g), in m^3/d, than can flow through the separator.

Task 2 (5 points). From the values calculated in task 1, compute the maximum allowed standard conditions rates of oil and gas (in Sm^3/d). Use the following expressions:

$$q_{\bar{g}} = \frac{q_g}{B_g} + \frac{R_s}{B_o} q_o$$

$$q_{\bar{o}} = \frac{q_o}{B_o}$$

Use the following values for the black oil properties:

B_g = 0.01 [m^3/Sm^3]

R_s = 50 [Sm^3/Sm^3]

B_o = 1.2 [m^3/Sm^3]

Task 3 (5 points). Consider that a field starts producing in plateau mode with a producing gas-oil ratio (GOR or R_p) equal to 150 Sm^3/Sm^3. What is the maximum oil production (in standard conditions, in Sm^3/d) that can be processed by the horizontal separator.

Task 4 (5 points). The value of producing gas-oil ratio used in Task 3 was calculated using a reservoir model assuming that vertical permeability is low and there is no coning from the gas cap. There is high uncertainty in this assumption. If a higher value of vertical permeability is used, the producing gas-oil ratio reaches 400 Sm^3/Sm^3 during the plateau period. For this situation, estimate what is the maximum oil production (in standard conditions, in Sm^3/d) that can be processed by the horizontal separator.

Additional information:

- You can use the Excel sheet provided to perform your calculations.
- Add text explaining your procedure

Solution:

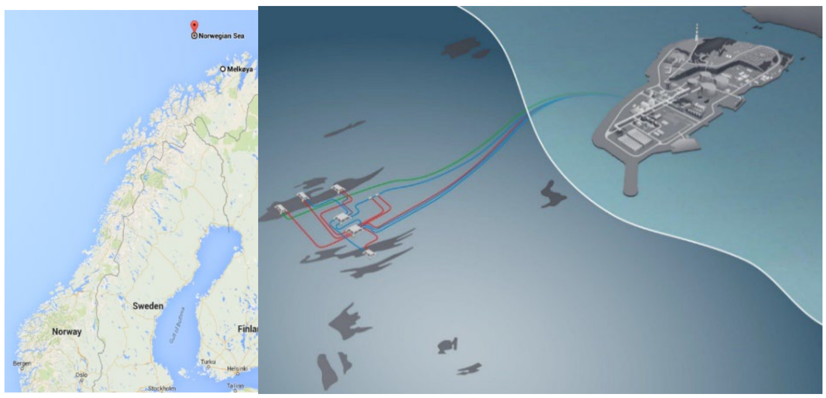
There was an error in the Exam text. The oil residence time in the document is 60 s, but in the excel file it was 30 s. It doesn't matter if you used 30 s or 60 s, if you did it correctly you will still get full marks. Solutions are presented below for both 30 s and 60 s

Horizontal Separator data			
L_{eff}	[m]	5	
ID	[m]	1.7	
$t_{res,g}$	[s]	20	
$t_{res,o}$	[s]	30	
Effective Sep volume (G+O)	[m3]	11.3	
Task 1			
$q_{g,max}$	[m3/d]	24513.8	We clear qg from the expression tres,g = Vg/qg
$q_{o,max}$	[m3/d]	16342.6	We clear qo from the expression tres,o = Vo/qo
Task 2			
B_g	[m3/Sm3]	0.01	
B_o	[m3/Sm3]	1.2	
R_s	[Sm3/Sm3]	50	
$q_{g\_sc,max}$	[Sm3/d]	3.13E+06	We use the formulas provided to compute sc rates
$q_{o\_sc,max}$	[Sm3/d]	13619	
Task 3			
R_p (GOR)	[Sm3/Sm3]	150	We test two options,
Option 1, sep operating at maximum oil sc rate			
q_{o_sc}	[Sm3/d]	13619	
q_{g_sc}	[Sm3/d]	2.04E+06	<--OK, no problem to process the gas
Option 2, separator operating at maximum gas sc rate			
q_{g_sc}	[Sm3/d]	3.13E+06	
q_{o_sc}	[Sm3/d]	20882	<-- This option is not possible, the oil rate is above capacity
Task 4			
R_p (GOR)	[Sm3/Sm3]	400	
Option 1, sep operating at maximum oil sc rate			
q_{o_sc}	[Sm3/d]	13619	
q_{g_sc}	[Sm3/d]	5.45E+06	<-- This option is not possible, the gas rate is above capacity
Option 2, separator operating at maximum gas sc rate			
q_{g_sc}	[Sm3/d]	3.13E+06	
q_{o_sc}	[Sm3/d]	7831	<--OK

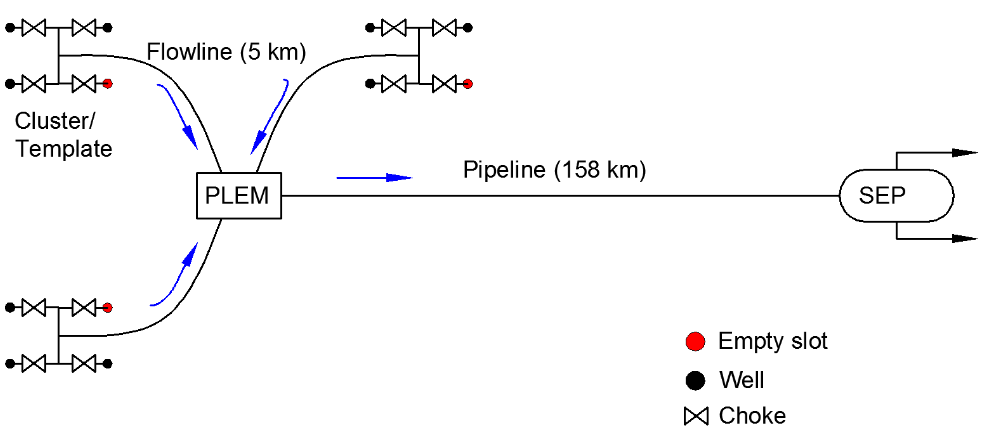
Horizontal Separator data			
L_{eff}	**[m]**	5	
ID	**[m]**	1.7	
$t_{res,g}$	**[s]**	20	
$t_{res,o}$	**[s]**	60	
Effective Sep volume (G+O)	**[m3]**	11.3	
Task 1			
$q_{g,max}$	**[m3/d]**	24513.8	We clear qg from the expression tres,g = Vg/qg
$q_{o,max}$	**[m3/d]**	8171.3	We clear qo from the expression tres,o = Vo/qo
Task 2			
B_g	**[m3/Sm3]**	0.01	
B_o	**[m3/Sm3]**	1.2	
R_s	**[Sm3/Sm3]**	50	
$q_{g\_sc,max}$	**[Sm3/d]**	2.79E+06	We use the formulas provided to compute sc rates
$q_{o\_sc,max}$	**[Sm3/d]**	6809	
Task 3			
R_p **(GOR)**	**[Sm3/Sm3]**	150	We test two options,
Option 1, sep operating at maximum oil sc rate			
q_{o_sc}	[Sm3/d]	6809	
q_{g_sc}	[Sm3/d]	1.02E+06	<--OK, no problem to process the gas
Option 2, separator operating at maximum gas sc rate			
q_{g_sc}	[Sm3/d]	2.79E+06	
q_{o_sc}	[Sm3/d]	18612	<-- This option is not possible, the oil rate is above capacity
Task 4			
R_p **(GOR)**	**[Sm3/Sm3]**	400	
Option 1, sep operating at maximum oil sc rate			
q_{o_sc}	[Sm3/d]	6809	
q_{g_sc}	[Sm3/d]	2.72E+06	<--OK, no problem to process the gas
Option 2, separator operating at maximum gas sc rate			
q_{g_sc}	[Sm3/d]	2.79E+06	
q_{o_sc}	[Sm3/d]	6980	<-- This option is not possible, the oil rate is above capacity

Problem 2 (30 points)

Snøhvit is an offshore gas field located in the Barents Sea 158 km from Hammerfest. The field will be developed with the "subsea to beach" concept. The gas production will be processed in a LNG plant on Melkøya (a nearby island) and transported further in LNG carrier to customers in US and Spain. The field will be produced in plateau mode, with a field rate of 20 E06 Sm3/d.



According to the base case Scenario (BCS) selected for the study, the field is completed subsea with 3 subsea templates, each with 4-well slots. Typically, only three wells are completed in each template (there is one slot is for redundancy). The templates will be symmetrically positioned at 5 km away from the subsea Pipeline Entry Module (PLEM). Each template is connected by flow line to the PLEM where the production streams of all the templates are commingled (combined and mixed). The PLEM is on the seabed approximately 158 km from shore and is connected by the main field export pipeline to the slug catcher (separator) on shore.

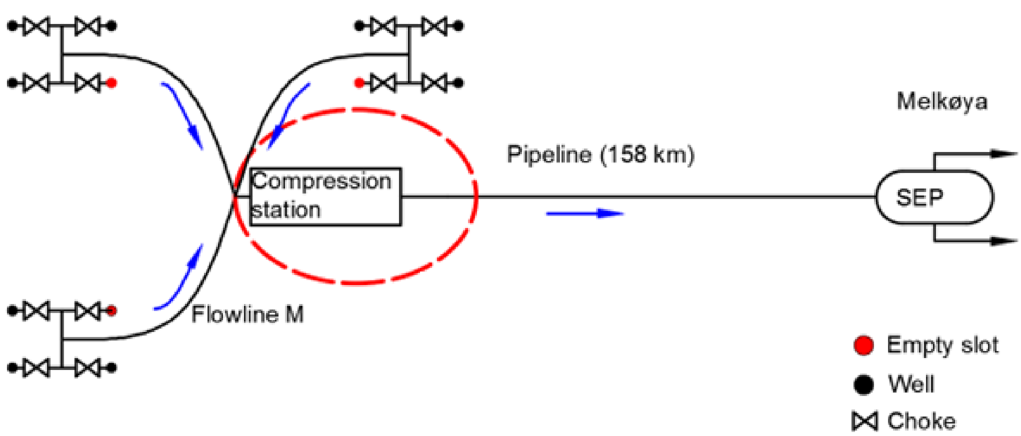


Assume all the wells are identical (in completion, depth and productivity and all other design and operation parameters) and produce from the same reservoir (tank model).

Perform the following tasks:

- **Task 1 (10 points)** Calculate choke delta pressure required for initial time and end of year one (**only two times**). The Excel sheet should still work even if the timestep is changed (e.g. from 1 year to 0.5 year)
- **Task 2 (10 points)** Calculate reservoir pressure at which plateau ends.

- **Task 3 (10 points)** Consider reservoir pressure is now equal to 100 bara. If reservoir pressure is not enough to maintain plateau production of 20E06 Sm3/d, consider that a compression station will be installed at the PLEM. Determine the pressure boost required by the compressor.



Additional information

- Use the Excel sheet provided to solve this problem. The Excel sheet contains VBA functions.
- Add text explaining your procedure.
- Use the trapezoidal rule to calculate yearly gas production.
- The gas deviation factor can be calculated with the VBA function "ZfacStanding()"
- Use the following equations (programmed in VBA):

Material balance: $p_R = p_i\left(\frac{z_R}{z_i}\right)\left(1-\frac{Gp}{G}\right)$	With G = 270 E09 Sm^3 Use 360 operational days per year when calculating G_p P_{Ri}, initial reservoir pressure is 276 bara.
Inflow equation: $q_g = C_R \cdot \left(p_R^2 - p_{wf}^2\right)^n$	C_R Inflow backpressure coefficient, 1000 Sm^3/bar^{2n} n, inflow backpressure exponent, 1
Tubing equation: $q_{gsc} = C_T \cdot \left(\frac{p_{wf}^2}{e^S} - p_{wh}^2\right)^{0.5}$	C_T, tubing coefficient, 40288.2 Sm^3/bar S, tubing elevation coefficient, 0.155
Flowline Template-PLEM: $q_{gsc} = C_{FL} \cdot \left(p_{TEMP}^2 - p_{PLEM}^2\right)^{0.5}$	C_{FL}, flowline coefficient, 2.8 E05 Sm^3/bar
Pipeline equation PLEM-shore: $q_{gsc} = C_{PL} \cdot \left(p_{PLEM}^2 - p_{sep}^2\right)^{0.5}$	C_{PL}, pipeline coefficient, 2.75 E05 Sm^3/bar p_{sep}, separator pressure, 30 bara.

Solution

Task 1

Gp = 0 Sm^3, pR=276 bara

1. With qwell = 20E06 / 9, and using the IPR equation, calculate the pwf available
2. With the tubing equation, qwell and pwf, calculate pwh available .
3. With the pipeline equation, qfield = 20E06 Sm^3/d, and psep = 30 bara, Calculate the pplem required
4. With the flowline equation, qtemplate and pplem calculate ptemplate required.
5. Calculate dp choke by pwh-ptemp

Calculate deltaGp by using the trapezoidal rule (qfield_i + qfield_i-1)*(ti – t_i-1)*uptime*0.5

Calculate Gp by summing the deltaGp of the timestep

Calculate recovery factor (Gp/G)

Calculate Z for initial reservoir pressure using the ZfacStanding() VBA function

Use the material balance equation to find pR at time 1. For ti use Z of the previous step.

Repeat steps 1-5.

time	q_{field}	ΔG_p	G_p	R_f	Z	p_R	q_{well}	p_{wf}	p_{wh}	p_{temp}	p_{plem}	p_{sep}	q_{temp}	Δ_{pchoke}
[years]	[Sm^3/d]	[Sm^3]	[Sm^3]	[-]	[-]	[bara]	[Sm^3/d]	[bara]	[bara]	[bara]	[bara]	[bara]	[Sm^3/d]	[bar]
0	20.0E+6	000.0E+0	000.0E+0	0.000	0.967	276	2.2E+6	271.9	245.5	82.1	78.7	30.0	6.7E+6	163
1	20.0E+6	7.2E+9	7.20E+09	0.027		269	2.2E+6	264.5	238.5	82.1	78.7	30.0	6.7E+6	156

Task 2

Assume pR. (e.g. 117 bara)

Perform steps 1-5.

Use the solver (or goal seek) to drive dp choke to zero by changing pR.

time	q_{field}	ΔG_p	G_p	R_f	Z	p_R	q_{well}	p_{wf}	p_{wh}	p_{temp}	p_{plem}	p_{sep}	q_{temp}	Δ_{pchoke}
[years]	[Sm^3/d]	[Sm^3]	[Sm^3]	[-]	[-]	[bara]	[Sm^3/d]	[bara]	[bara]	[bara]	[bara]	[bara]	[Sm^3/d]	[bar]
	20.0E+6					117	2.2E+6	106.9	82.1	82.1	78.7	30.0	6.7E+6	0

Task 3.

Input pR= 100 bara

Perform steps 1-3.

With the flowline equation, qtemplate and pwh calculate psuc available.

Calculate dp comp by pplem-ptemp

time	q_{field}	ΔG_p	G_p	R_f	Z	p_R	q_{well}	p_{wf}	p_{wh}	p_{suc}	p_{plem}	p_{sep}	q_{temp}	Δ_{pcomp}
[years]	[Sm^3/d]	[Sm^3]	[Sm^3]	[-]	[-]	[bara]	[Sm^3/d]	[bara]	[bara]	[bara]	[bara]	[bara]	[Sm^3/d]	[bar]
	20.0E+6					100	2.2E+6	88.2	60.2	55.4	78.7	30.0	6.7E+6	23

Problem 3 (3 points)

Select from the list below the stages that are part of the field planning phase:

- Feasibility studies
- Appraisal
- Detailed engineering
- Pre-engineering
- Business case identification
- Issue statement of commerciality

Solution:

Points for correct answer: 1.5

Points deducted for wrong answer: 0.75

If you choose an alternative which is wrong, points will be deducted, but only down to zero, it is not possible to get negative points in a question.

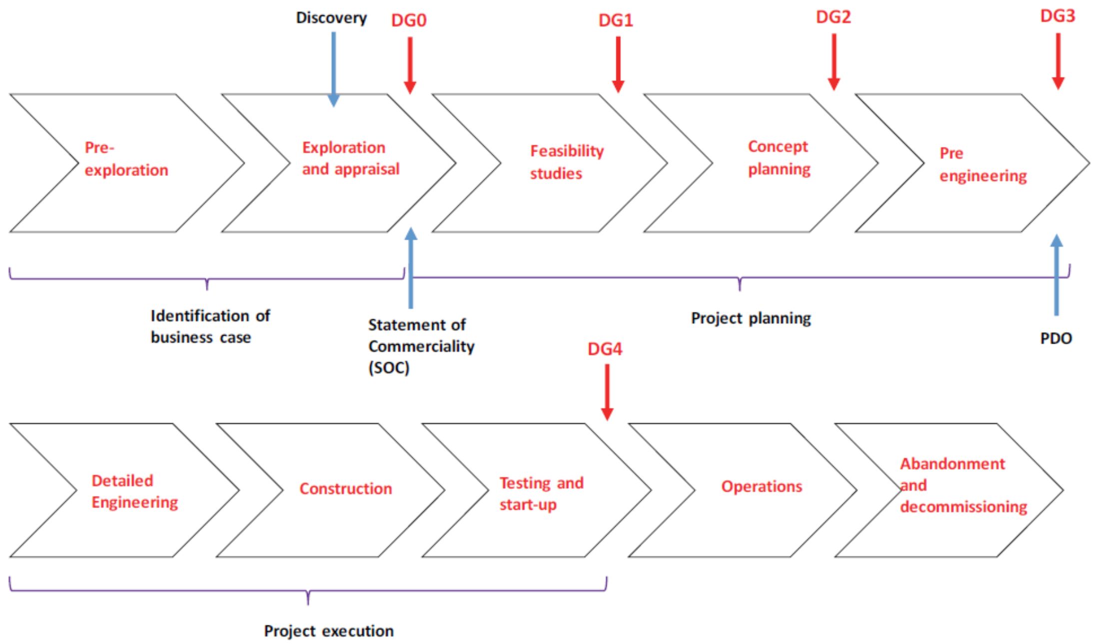


FIGURE 5-3. FIELD DEVELOPMENT PROCESS

Problem 4 (1 point)

How many decision gates do we normally have in a field development process?

- 3
- 5 (3 points)
- 4
- 6

Solution:

Points for correct answer: 1

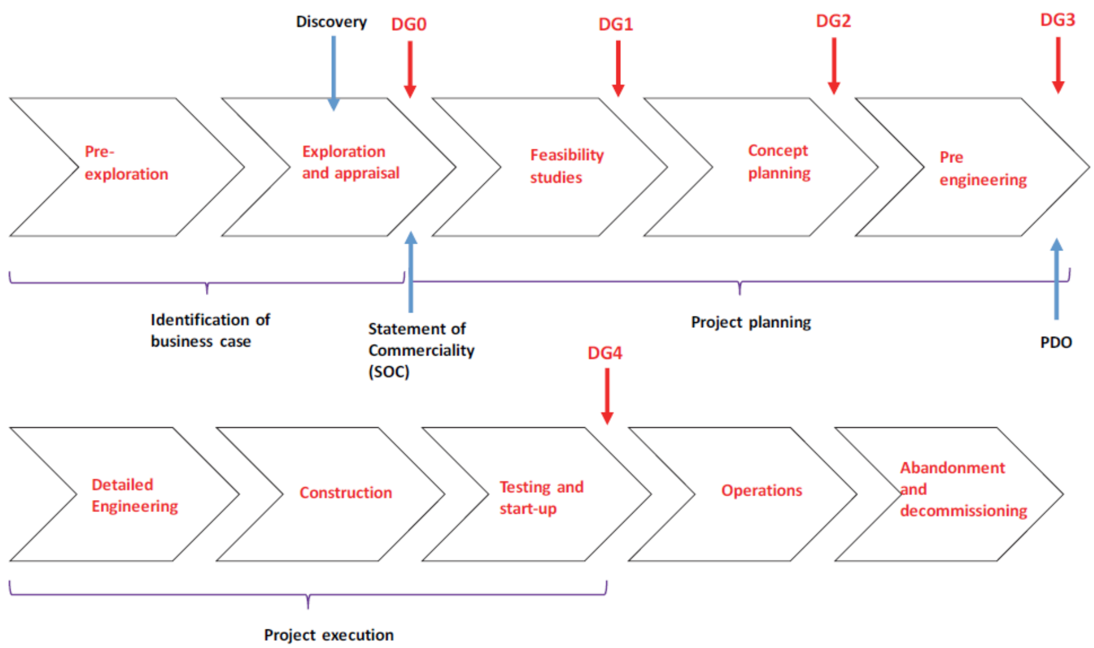
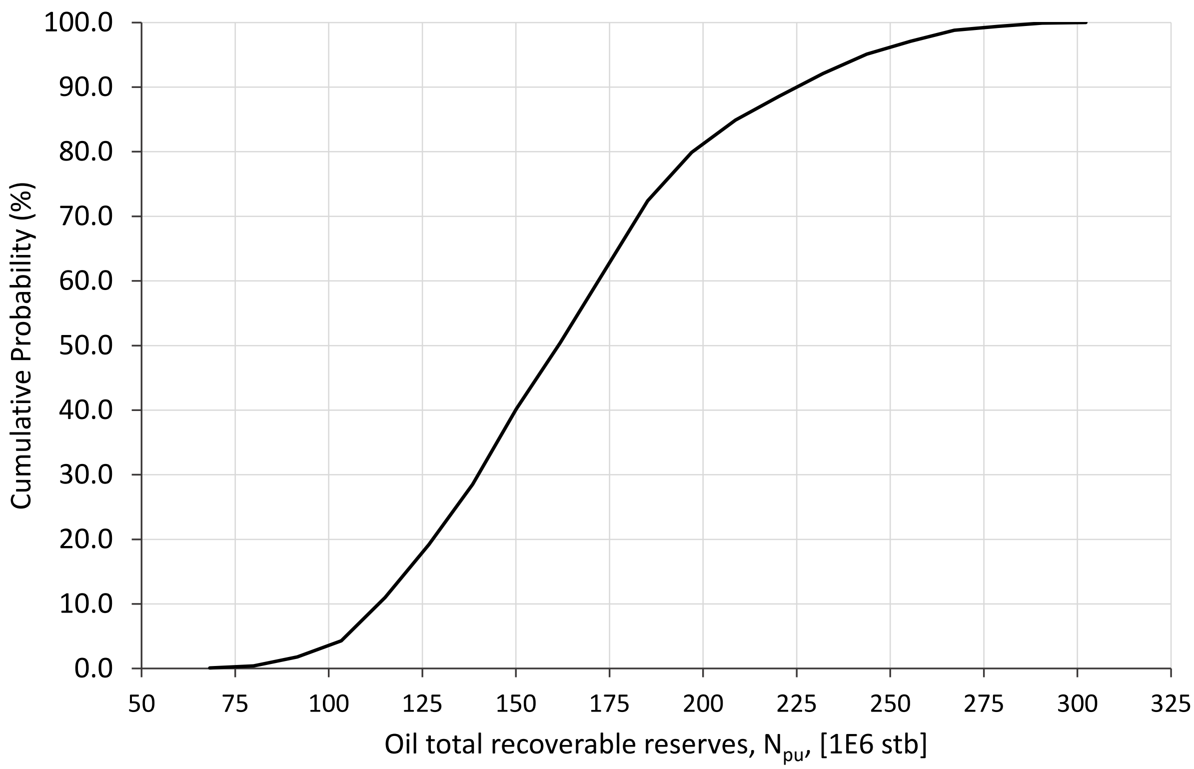


FIGURE 5-3. FIELD DEVELOPMENT PROCESS

Problem 5 (20 points)

Your company is deciding whether to develop or not an oil reservoir in the Norwegian Continental Shelf. They are currently in the business case identification phase. Using information from a few exploration wells, and seismic, they have calculated the following cumulative distribution function for total recoverable reserves of oil:



The NPV of the project (output in million USD) can be estimated using the following formula (only oil is recovered from this field, due to lack of gas transport infrastructure):

$$NPV = P_o \cdot 0.7 \cdot N_{pu} - C$$

Where:

- P_o is the price per barrel of oil [USD/bbl]. Use 60 USD/bbl
- C is the initial cost of the development, mainly representing facilities and wells [in million USD]. Given by the equation:

$$C = N_{pu} \cdot 4.3 + 2002$$

- N_{pu} is total recoverable reserves of oil [in Million stb]. **In both equations, N_{pu} must be input in million stb.**

Address the following tasks:

Task 1 (5 points). Report P10, P90 and P50 for the CDF provided.

Task 2 (10 points). Estimate the value of NPV for which there is a 90% probability that the project value will be equal to it or higher.

Task 3 (5 points). Discretize the distribution provided in three values. The three values should have similar probabilities. Use the method of bracket mean.

Additional information

- Use the provided Excel sheet to solve this problem
- Add text explaining your procedure.
- Clarification about P90, P50 and P10
  - There should be at least a 90% probability (P90) that the quantities actually recovered will equal or exceed the low estimate.
  - There should be at least a 50% probability (P50) that the quantities actually recovered will equal or exceed the best estimate.
  - There should be at least a 10% probability (P10) that the quantities actually recovered will equal or exceed the high estimate.

- The one dimensional interpolation VBA function “OneDInterp()” is available in the Excel sheet if you need it.
- Use the following guideline to discretize a continuous cdf:

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

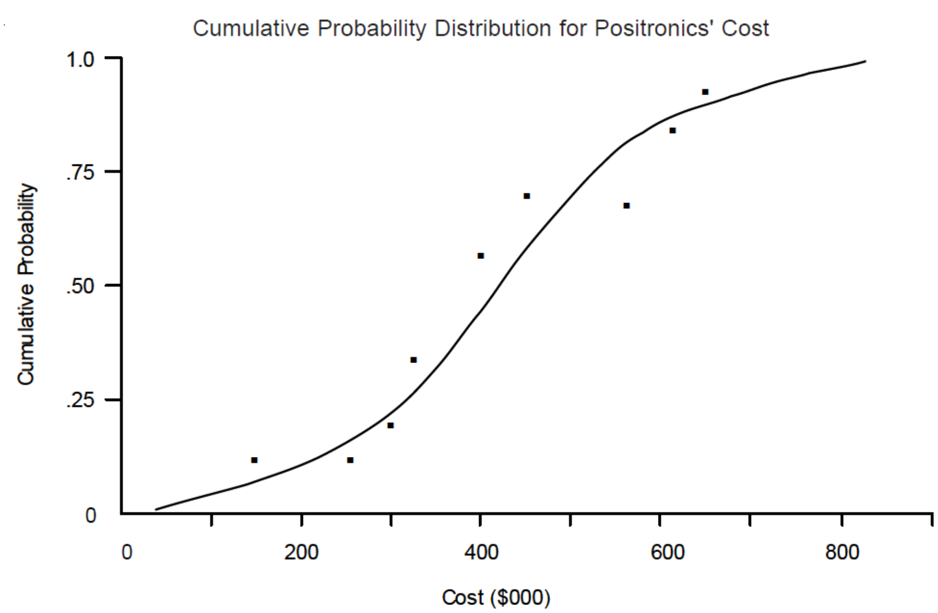
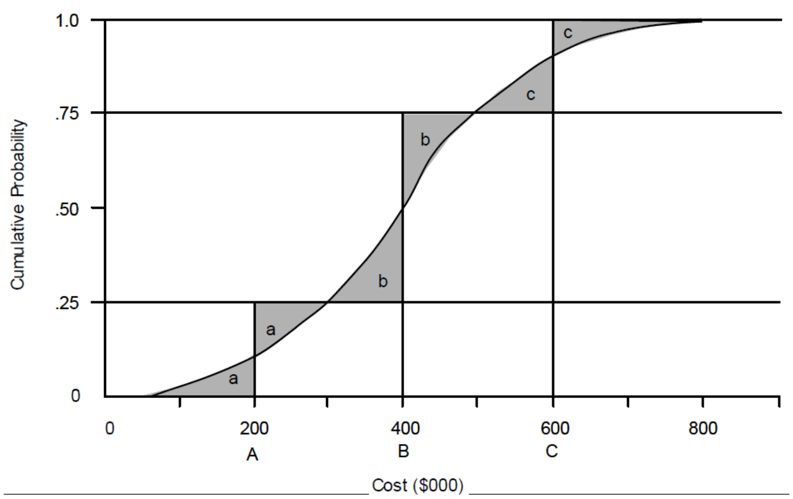


Figure 2–15

Approximation of Discrete Probability Distribution for Positronics' Cost



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.

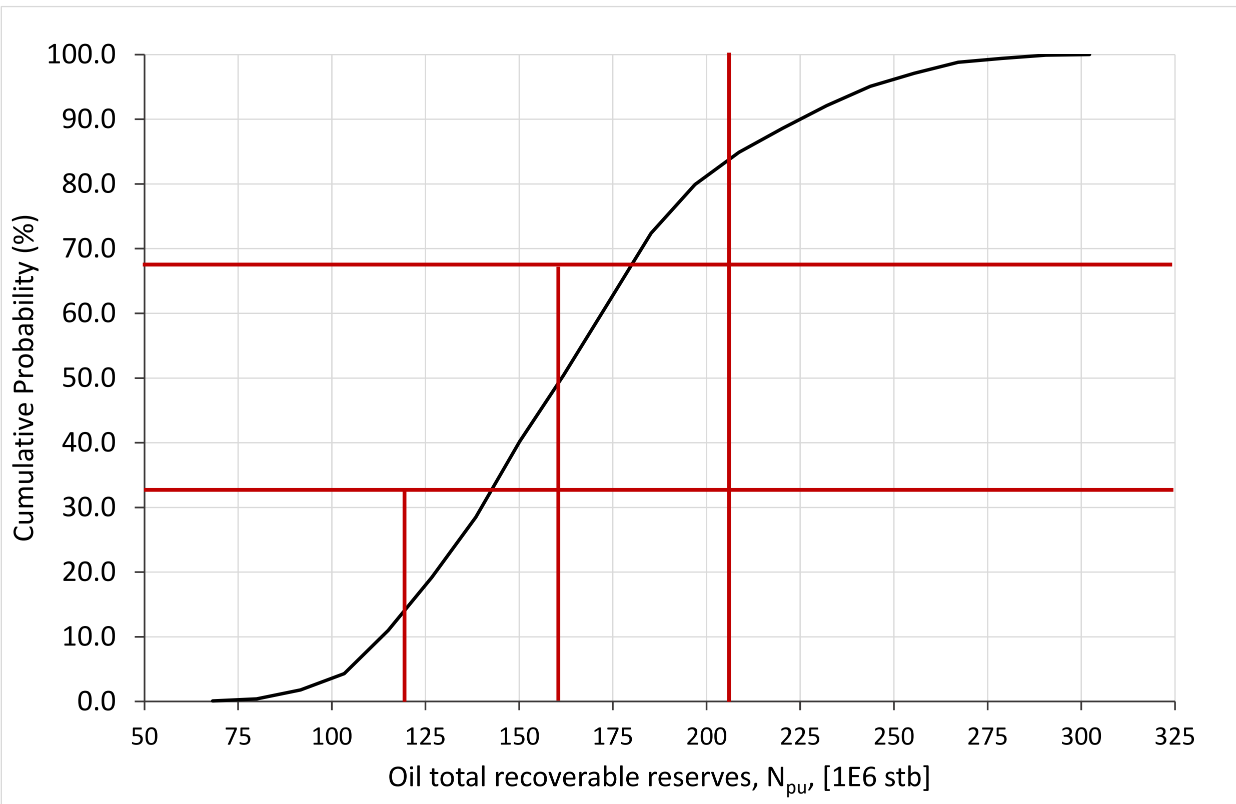
The procedure sounds much more complicated than it is in practice. The result is that we now have approximated the continuous probability distribution; the discrete probability distribution is shown in tree form in Figure 2–16. The actual values are A = 200, B = 400, and C = 600. These values are used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

Solution

Task 1 & task 2

oil TRR [1E06 stb]	Cumulative Probability	oil TRR [1E06 stb]		Task 1			"-Interpolating on the table (columns B and C) "
68.2	0.1	68.2		**P90**	**[1E06 stb]**	113.3	"-P90, there is 90% probability than the values are equal to P90 or higher. This is equivalent to"
79.9	0.4	79.9		**P50**	**[1E06 stb]**	161.4	"the value X for which there is 10% probability that all values are equal or lower than X "
91.6	1.8	91.6		**P10**	**[1E06 stb]**	225.0	"-Repeat for 50% and 90%"
103.3	4.3	103.3					
115.0	11.0	115.0					
126.7	19.2	126.7		**Task 2**			
138.4	28.5	138.4		**Npu**	[1E06 stb]	113.3	"-Following the same logic as in task 1, here we have to use P90, all other variables are deterministic"
150.1	40.2	150.1		**C**	[1E06 USD]	2489.1	"(They have 0 uncertainty)"
161.8	50.4	161.8		**Po**	[USD/bbl]	60	
173.5	61.4	173.5		**NPV**	[1E06 USD]	2268.7	
185.2	72.4	185.2					
196.9	79.9	196.9		**Task 3**	<--See the chart		
208.6	84.9	208.6					
220.3	88.6	220.3					Probability
232.0	92.1	232.0		**Value 1**	[1E06 stb]	120	0.333
243.7	95.1	243.7		**Value 2**	[1E06 stb]	160	0.333
255.4	97.1	255.4		**Value 2**	[1E06 stb]	207	0.333
267.1	98.8	267.1					
278.8	99.4	278.8					
290.5	99.9	290.5					
302.2	100.0	302.2					

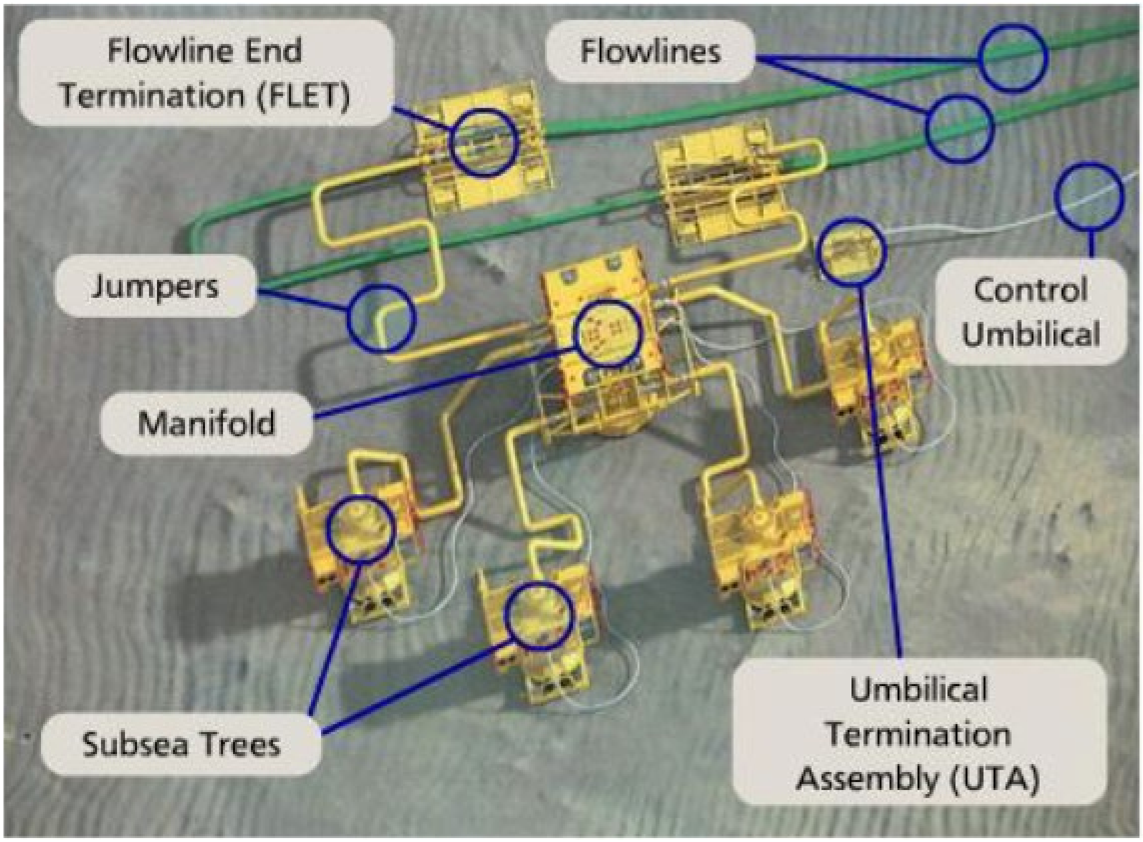
Task 3



			Probability
Value 1	[1E06 stb]	120	0.333
Value 2	[1E06 stb]	160	0.333
Value 2	[1E06 stb]	207	0.333

Problem 6 (9 points)

Consider the figure shown below.



Select the statements that are true.

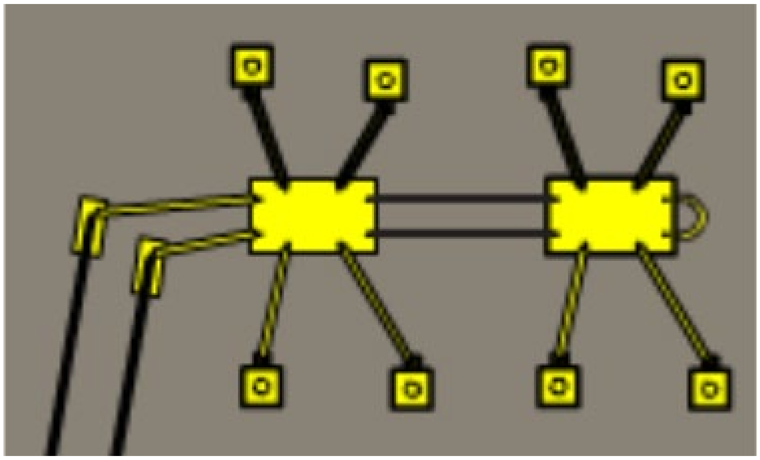
- With this arrangement it would be possible to pig the jumpers from X-mas trees to manifold and from manifold to FLETs by sending a pig from topside through the flowlines
- If there a single multiphase meter in the manifold template, and it is possible to test each well separately without disrupting production, then 3 headers are required in the template.
- In this configuration it is possible to pig the flowlines
- If hydrate formation is of concern, the umbilical carries hydrate inhibitor, and is distributed to the wells (injected upstream the wellhead choke). It can be distributed using a subsea distribution unit, but in this case, it seems it is distributed via the manifold.

Points for correct answer: 3

Points deducted for wrong answer: 9

If you choose an alternative which is wrong, points will be deducted, but only down to zero, it is not possible to get negative points in a question.

Problem 7 (9 points)



When using a daisy chain subsea field layout like the one in the image above, select the statements that are true:

- Wells are satellite
- Wells are part of a 4 well subsea template
- Wells connect to a manifold template via jumpers
- In this configuration is possible to test individual wells with the test separator topside without stopping production from the rest. However, this requires all wells except the one to test should be routed to one flowline.
- In this configuration it is not possible to perform pigging

Points for correct answer: 3

Points deducted for wrong answer: -4.5

If you choose an alternative which is wrong, points will be deducted, but only down to zero, it is not possible to get negative points in a question.

Problem 8 (4 points)

To avoid hydrate formation in a flowline during normal operating conditions, a colleague working on this project has suggested to increase the pressure of the receiving separator located at the end of the pipeline to 120 bara, and having a subsea pump at the inlet of the flowline, such that the fluid in the pipe remains in single phase oil during transportation, there will be no gas liberation and therefore, hydrate formation will no longer be a concern. Is this solution valid?

- Yes
- No

Points for correct answer: 4

Problem 9 (4 points)

Wax deposition occurs in a pipeline (select those applicable)

- If the temperature of the fluid drops below the cloud point
- If the temperature of the wall is lower than the temperature of the core of the fluid
- There are small hydrocarbon molecules like methane
- Presence of water

Points for correct answer: 2

Points deducted for wrong answer: 2

If you choose an alternative which is wrong, points will be deducted, but only down to zero, it is not possible to get negative points in a question.