University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: PET 600 Well Completions

DATE: 14 February 2014

TIME: 0900-1300

AID: Calculator

Some formulas and unit conversion factors can be found in Appendix

Separate Attachment: NORSOK D010 rev 3

THE EXAM CONSISTS OF 16 PAGES INCLUDING APPENDIX

NB: DO NOT WRITE YOUR ANSWERS ON THE EXAM SHEET. YOU MUST USE ORDINARY ANSWER SHEETS SO THAT WE HAVE TWO COPIES OF YOUR ANSWERS.

PART I

Five short questions with three alternative answers (multiple choice). Please indicate the answer that you think is most correct.

The estimated time consumption is 0.25 hrs. The correct answer gives 2 points. Maximum score is 10 points.

Question I-1:

Consider an unconsolidated sandstone reservoir. Consider that the overburden stress is larger than the maximum horizontal stress component. There is a defined direction for the maximum horizontal stress, which also is greater than the minimum horizontal stress. Successful implementation of a cased and perforated lower completion concept, i.e. mechanically stable perforations, would require …

Options:

A. … a vertical well path and oriented perforations shot into the direction of the maximum horizontal stress.

B. … a horizontal well path and oriented perforations shot horizontally to both sides of the well path.

C. … a horizontal well path and oriented perforation shot into the direction of the overburden stress component, i.e. upwards.

Question I-2:

In general, perforation penetration depth decreases with …

Options:

A. … increasing rock strength and increasing effective stress.

B. … increasing gun-to-casing clearance, i.e. increasing distance of the perforation gun to the casing wall.

C. Both A. and B. are correct.

Question I-3:

After the upper completion with tubing hanger and Christmas tree has been run, a well is planned to be perforated in underbalance. Which brine would you choose to achieve highest possible underbalance (i.e. highest possible drawdown)?

Options:

A. Saturated sodium formate

B. Saturated sodium bromide

C. Undersaturated (1.03 SG) sodium chloride packer fluid.

Question I-4:

"Selective perforations" is a sand control practice where …

Options:

A. … the phasing of the perforation guns is selected in a specific manner (180° or 360° phasing)

B. … a perforation gun design with a low internal pressure relative to the wellbore pressure is selected.

C. … a sand layer with low mechanical strength is produced through a nearby well section that is perforated in a mechanically strong sand layer and under the assumption that there is good communication (permeability) between both sand layers.

Question I-5:

As a "potential source of inflow", NORSOK D-010, rev. 3 defines …

Answer options:

A. … only permeable reservoir formations.

B. … any formation in the subsurface.

C. … any formation with permeability, but not necessarily a reservoir.

PART II

Four short questions. Provide <u>short</u> answers on your answer sheet.
The estimated time consumption is 0.25 hrs. You can obtain 0-3 points for each answer. Maximum score is 12 points.

Question II-1: Well washing

Please name three typical components in a wash string?

Question II-2: Lower Completion

<u>Swell packers</u>: Please explain briefly

- Their function (why would you use them?)
- The setting mechanism
- The main advantage compared to mechanical openhole packers.

Question II-3: Multi-laterals

The TAML system defines requirements to the integrity of a multi-lateral junction. Please explain the characteristics of TAML level 1, 3 and 5!

Question II-4: Rules and regulations

According to NORSOK D-010, rev. 3, which specifications and qualification criteria shall be established for perforation charges planned to be used in an HPHT well.

PART III Lower Completion

The estimated time consumption is 0.5 hrs. The maximum score for this part is 14 points.

Introduction

Consider drilling and completing wells from an integrated drilling rig installed on a wellhead platform with jacket substructure. The water depth is 120 metre. All depth below are with reference to mean sea level (MSL).

Consider the following operations as basis for further work

- Drill 36 inch section to ~200 mTVDMSL, no inclination, run and cement 30 inch conductor to seabed
- Drill 24 inch section to ~1000 mTVDMSL, 20 deg inclinaton, run and cement 20 inch casing to seabed
- Drill 17½ inch section to ~1500 mTVDMSL, 20 – 60 deg inclination, run and cement 14 inch casing
- Drill 12¼ inch section to ~1900 mTVDMSL, 60 deg inclination, run and cement 9⅝ inch tieback liner
- Drill reservoir section with 8 ½ inch to well TD. Consider underreaming to 9 ½ inch when necessary. The horizontal section length of the reservoir section is about 500 meter.
- Run lower completion
- Run tieback casing and upper completion, incl. tubing hanger and X-mas tree.

Torque and drag simulations as well as cement hydraulics simulations have shown that the production casing has to be designed as a tieback solution with two parts, tieback liner and tieback casing, respectively. The upper completion will be designed around a 7” tubing string to allow for high production rates.

Question III.1

Formation evaluation shows that the reservoir sands are highly unconsolidated and require sand control. Based on a risk assessment you will have to choose a lower completion concept. Assume that you can choose between a cased and perforated liner completion and an openhole gravel pack (OHGP). Please list risks (minimum 2 aspects) and opportunities (minimum 2 aspects) of the OHGP method compared to the perforated liner completion!

Question III.2

In water injection wells, the preferred concept is a cased and perforated liner completion. Injections into two separate zones are planned for.

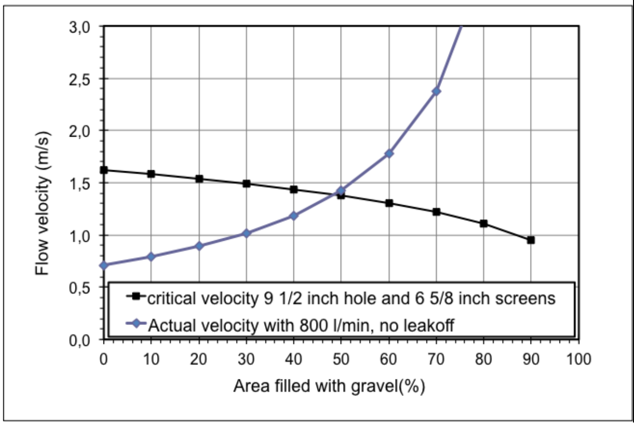
Based on the information presented in the introduction, please draw a functional lower completion that allows injections into two zones that are isolated from each other. Start with the injection tubing and production packer set into the tieback casing and continue to the bottom of the well. Explain your drawing by labeling key completion elements.

Question III-3: Open hole horizontal gravel pack (OHHGP)

For the lower completion 6 5/8" screens will be used to minimize friction losses and drawdown effects along the reservoir section.

To perform a successful OHHGP, the required amount of gravel filled by the alpha wave is by several references given to 50 to 70% of the annular area. At a lower fill percentage, the Beta-wave pack will easily become incomplete leaving voids. At a higher fill percentage, the Beta-wave can be initiated prematurely leaving the lower part of the reservoir section free of gravel.

Based on a set of fluid and gravel characteristics, specialists calculated a relationship of critical velocities and percentage of the annular area fill as presented in the figure and table below.



	Critical Velocity
	9 1/2 inch
% - Area filled with gravel	(m/s)
0	1,62
10	1,58
20	1,54
30	1,49
40	1,44
50	1,38
60	1,31
70	1,22
80	1,11
90	0,95

Key parameters for this base case are:

Density carrier fluid (brine)	1300	kg/m^3
Density gravel	2700	kg/m^3
6 5/8 inch screen outer diameter OD	7,3	Inch
Effective maximum pump rate	800	l/min

Based on this information, please calculate the maximum fluid loss that can be tolerated without compromising the requirement for 70% area fill during alpha wave deposition!

PART IV Upper Completion and Well Barriers

The estimated time consumption is 0.5 hrs. The maximum score for this part is 14 points.

Please consider information given in the introduction to Part III.

Question IV-1:

The platform oil producers will be designed with gas lift due to low reservoir pressure and due to the water injection drainage strategy, that will cause water to break through to producers at some point during the life of the field.

The following operational steps present the completion program (i.e. the last two steps in the Introduction).

- Install sand screens
- Run 10¾" tie-back string
- Isolate reservoir section with a middle completion including a preset, deep set plug
- Install X-mas tree
- Displace well to brine
- Rig down BOP and risers
- Retrieve deep-set plug
- Perform open hole gravel pack
- Scrape production packer and tie-back anchor setting area and ensure well clean
- Change out dummy valve to gas lift valve.
- Run upper completion.

TASK: Please sort the steps in correct sequence!

Question IV-2

In oil producers, gas lift designs are challenging because of the production tieback casing that is utilized. Figure IV-1 presents a method without barrier qualified polished bore receptacle (PBR) yet with a mid-string packer between gas lift valves and production packer. Gas lift valves are not qualified as well barrier elements!

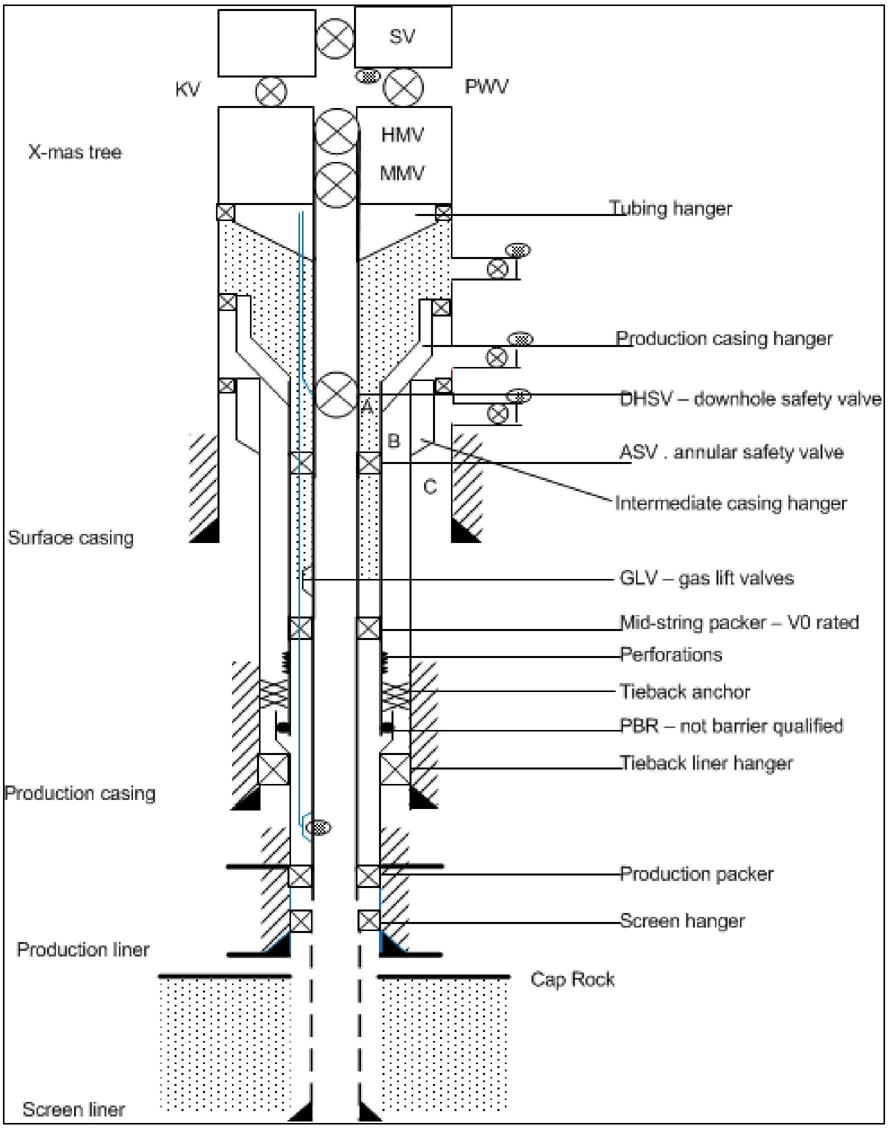


Figure IV-1 – Oil producer with gas lift and tieback production casing. PBR not barrier qualified.

a) Please set up well barrier tables and explain the primary and secondary barrier for the gas lift completion in Figure IV-1

b) What is in your opinion the function of the perforations below the mid-string packer? (Hint: NORSOK D-010, rev. 3, Chapter 15.7).

Part V Material and grading

The estimated time consumption is 0.5 hrs. The maximum score for this part is 15 points.

Question V.1

A. What are the three indentation hardness measurement techniques? Which of them measures surface area and which of them measures depth of indentation?

B. Please write the five categories of stainless steels?

C. What is the term PREN stands for? According to NORSOK or NACE, what is the typical minimum PREN requirement value?

D. Please draw typical steel and alloy steel stress –strain curve. Please show how you determine the yield stress of from the two figures.

E. For a given project an engineer is going to select tubing which has a higher resilience. Assume that the Young's modulus of X-80 and Y-85 tubing material are 125 ksi and 120 ksi respectively. The materials show a typical steel stress-stain behavior. During tensile loading, which these materials absorb more energy before yielding (i.e higher resilience)? Show your work please!

F. What is the difference between API and Non-API grading?

G. A manufacturer produced steel having a grade XT-125 at 75 deg F. When this tubing exposed to a 275 deg F, and the yield stress reduced to 100 ksi. What is the yield strength reduction rate of the tubing?

Part VI Completion and Tubing Design

The estimated time consumption is 0.5 hrs. The maximum score for this part is 15 points.

Question VI.1:

A company X has discovered three reservoirs (Sandstone, Carbonate and Sandstone), which are a certain distance apart in a vertical drilling formation. Using a single, dual and triple packer, the company is planning to produce separately using single tubing from each reservoir.

Your tasks

A. Please sketch the completion design based on the company's desire.

B. Remember also to place blast joint on tubing and tell the reason why?

Question VI.2

Figure VI.1 is an internally pressurized cylinder with inner and outer radius of *a* and *b* respectively and (t>1/10r), where r is the inner radius of the cylinder.

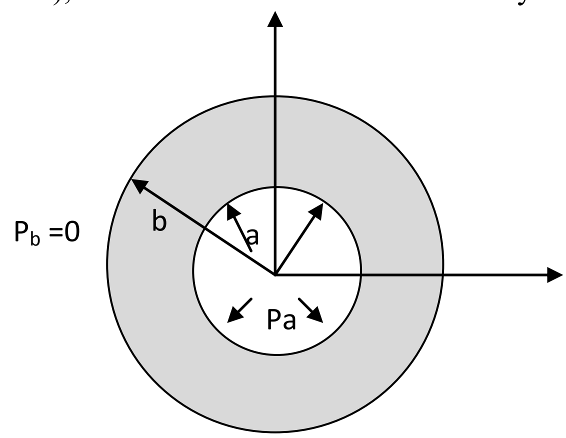


Figure VI.1

Your tasks:

A. What kind of cylinder it is? Give your reason!

B. In order to derive the Lame's stresses in the wall thickness of the cylinder, the solution methods consists of four conditions. What are these?

C. Using Tresca failure criteria and assume that the outer pressure $P_b = 0$, &$\sigma_a = 0$ ie. Open end), show that the pressure that caused yielding, P_y:

$$P_y = 0.5\sigma_y\left(1 - \frac{a^2}{b^2}\right)$$

D If ratio b/a = $\sqrt{2}$, what is the pressure required to cause the inner wall yielding?

Question VI.3:

Assume that a drilling engineer is going to design a production tubing string for sour gas service. The maximum anticipated surface pressure at the inner wall for the 5.5 inch OD pipe of C-90 tubing is 21500 psi. This pressure is the one that causes the inner tube yielding. The API tolerance to be used for the design is 87.5 %. And assume that the outer pressure is zero.

Your task:

What is the wall thickness requirement for the pipe?

Question VI.4:

From home exercise, you were asked to compute the production and injection induced tubing length. Assume that the entire tubing length experiences the change in temperature during production ($\Delta T = 200^{o}F$). Assume that the coefficient of linear thermal expansion of the tubing is $10^{-5}/^{o}F$. The original length of the tubing was 1000ft.

Your task:

What would be the final length of the tubing after being elongated due to the temperature?

Part VII - 3D Design & API Collapse design

The estimated time consumption is 0.25 hrs. The maximum score for this part is 10 points.

Question VII.1:

Figure VII.1 shows the failure envelop for a given design factor (DF) of the tubing whose loadings are shown in Table **VII.2**. The loading are internal pressure, P_i, outer pressure, P_o and axial stress, σ_a. The yield strength of the tubing is σ_y. The geometrical factor is represented by Greek letter, β

Your task:

A. Calculate the SF or (DF)?

B. Is the material safe? If YES, what is the mode of failure?

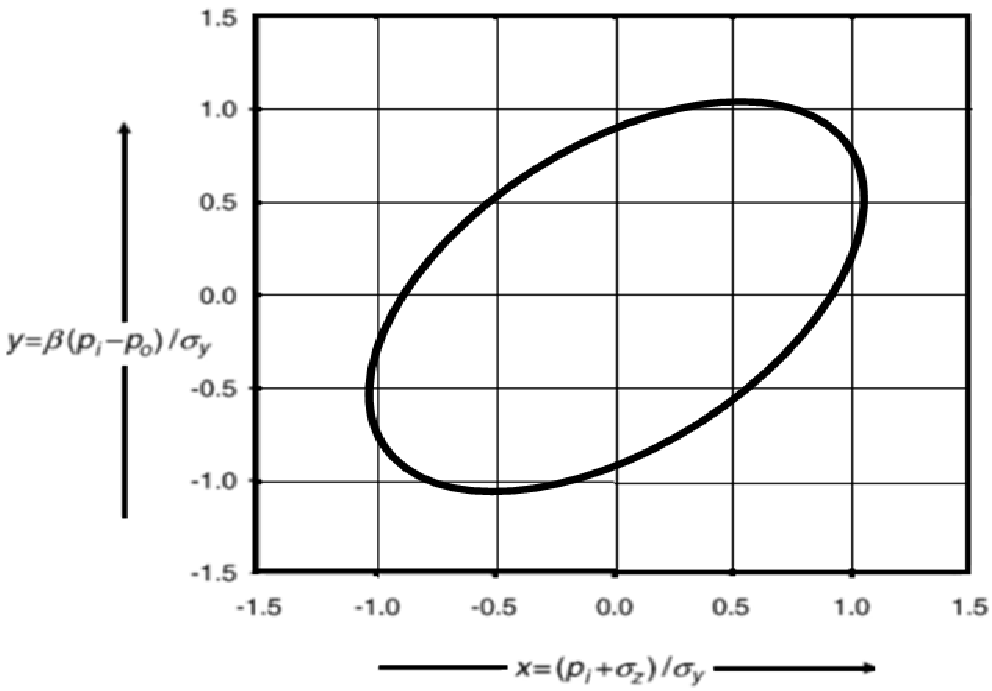


Figure VII.1: Failure envelope for Tubing

β	$\beta.\frac{P_i}{\sigma_y}$	$\beta.\frac{P_o}{\sigma_y}$	$\frac{\sigma_z}{\sigma_y}$
11.36	**0**	**-0.55**	**-0.6**

Table VII.2

Question VII.2:

A. According to API Bulletin 5C3, 1999, how many modes of tubing collapse models exist?

B. In order to select the appropriate model for calculation for a given tubing size, what do you do first?

C. Please mention these modes of collapses?

Question VII.3:

The following is the analytical tri-axial equation for tubing loaded with internal pressure, P_i, outer pressure, Po and axial stress, σ_a. The yield strength of the tubing is σ_y. The geometrical factor is represented by Greek letter, β

$$P_i = \frac{\beta\sigma_a - 2\sigma_a + 2\beta^2 P_o - \beta P_O \pm \sqrt{-3\beta^2\sigma_a^2 - 6\beta^2\sigma_a P_o - 3\beta^2 P_o^2 + 4(\beta^2 - \beta + 1)\sigma_y^2}}{2(\beta^2 - \beta + 1)}$$

A. Is this collapse or burst pressure equation?

B. Please write the bi-axial form of this equation?

Part VIII Corrosion

The estimated time consumption is 0.25 hrs. The maximum score for this part is 5 points.

A. What are the criteria for corrosions to occur? Please draw electro-chemical cell that describe the process of corrosion showing the parts on the figure

B. What is the primary function of cathode protection? What are the two classification of CP? Please write the difference between the two.

Part VIIII: Conoco-Halliburton company-IO course

The estimated time consumption is 0.25 hrs. The maximum score for this part is 5 points.

A. What benefits one can achieve from IO? Please mention at least four elements

B. Please mention four elements used by IO in order to meet the objective

C. What does RTO stands for? What is the purpose of RTO engineer at onshore drilling center?

D. If there should be any meaning of removing people from offshore to town, there are two elements which must be trustable. What are these?

Formula sheet

Resilience

$$R = \frac{\sigma_y}{2E} \qquad 1$$

Tresca Failure Criteria

$$\sigma_y = \sigma_{max} - \sigma_{min} \qquad 2$$

Dimensionless failure envelope analysis

$$x = (p_i + \sigma_z)/\sigma_y \qquad 3$$

$$y = \beta(p_i - p_o)/\sigma_y \qquad 4$$

$$SF = \frac{1}{\left[x^2 - xy + y^2\right]^{0.5}} = \frac{\sigma_y}{\sigma_{VME}} \qquad 5$$

$$y = \frac{x}{2} \pm \sqrt{\frac{1}{SF^2} - \frac{3}{4}x^2} \qquad 6$$

Thin walled cylinder

$\sigma_\theta = P\frac{r}{t}$ $\quad$ $\sigma_z = P\frac{r}{2t}$ (Closed end), σ_a=0 (open end) $\quad$ $\sigma_r \approx 0$ $\quad$ 7

Thick walled cylinder

1 Radial stress

$$\sigma_r = \frac{p_a a^2 - p_b b^2}{b^2 - a^2} - \frac{a^2 b^2}{(b^2 - a^2) r^2}(p_a - p_b) \qquad 8$$

2 Hoop stress

$$\sigma_\theta = \frac{p_a a^2 - p_b b^2}{b^2 - a^2} + \frac{a^2 b^2}{(b^2 - a^2) r^2}(p_a - p_b) \qquad 9$$

3 Axial stress

$$\sigma_a = \frac{F_a}{A} + \frac{p_a a^2 - p_b b^2}{b^2 - a^2} \qquad 10$$

Special cases of Eqs- 8 &9

a) Internal pressure only, (i.e P_b =0). Eq. 8 and 9 reduces to

$$\sigma_r = \frac{P_a a^2}{b^2 - a^2}\left(1 - \frac{b^2}{r^2}\right) \qquad 11$$

$$\sigma_\theta = \frac{P_a a^2}{b^2 - a^2}\left(1 + \frac{b^2}{r^2}\right) \qquad 12$$

$$\begin{cases} \sigma_a = 0 & Open-Ends \\ \sigma_a = 2\upsilon \frac{P_a a^2}{b^2 - a^2} & Closed-Ends \\ \sigma_a = \frac{P_a a^2}{b^2 - a^2} & Closed-and-Open-ends \end{cases} \qquad 13$$

b) External pressure only, (i.e P_a =0). Eq. 8 and 9 reduces to

$$\sigma_r = -\frac{P_b b^2}{b^2 - a^2}\left(1 - \frac{a^2}{r^2}\right) \qquad 14$$

$$\sigma_\theta = -\frac{P_b b^2}{b^2 - a^2}\left(1 + \frac{a^2}{r^2}\right) \qquad 15$$

$$\begin{cases} \sigma_a = 0 & Open-Ends \\ \sigma_a = -2\upsilon \frac{P_b b^2}{b^2 - a^2} & Closed-Ends \\ \sigma_a = -\frac{P_b b^2}{b^2 - a^2} & Closed-and-Open-ends \end{cases} \qquad 16$$

API Bulletin 5C3, 1999 burst design

$$P_y = Tol * 2\sigma_y \frac{t}{D}$$ (Tol= Tolerance, or Safety factor) 17

Thermal effect on elongation

$$\Delta L = \alpha . L_o . \Delta T \qquad 18$$