University of Stavanger

Faculty of Science and Technology

Department of Petroleum Engineering

SUBJECT: **PET 605**
Well intervention and Plug & Abandonment

DATE: **3 December 2016**

TIME: **09:00 – 13:00**

AID: **Simple calculator**

THE EXAM CONSISTS OF 12 PAGES (including this front page and 1 appendix)

REMARKS: **The exam is divided into two parts**
Part A: Well intervention
Part B: Plug and abandonment
Each part counts 50% of the final grade

EXAM PART A - WELL INTERVENTION

Acronyms, equations and other information at the end of Part A

SECTION I

Five short questions with three alternative answers (multiple choice). Please indicate on your answer sheet the answer that you think is most correct.
Maximum score is 20 points.

Question I-1: Lost well control during live well intervention
You are running CT when suddenly there is a leak in the connection between the Christmas tree and the safety head. What do you do?
Options:

A. Install the BPV.
B. Close the safety head to cut the work string and seal off the wellbore.
C. Bullhead kill-weight mud.

Question I-2: Leaking stripper rubber
You are POOH with your snubbing work string when the stripper rubber fails. The combination of work string weight and pressure-area force is such that the pipe would be ejected from the well if unconstrained. What do you do?
Options:

A. Continue POOH using the stripper rams.
B. Close two pipe rams and change the stripper rubber.
C. Regulate the hydraulic pressure on the snubbing jack, pump dart and POOH.

Question I-3: Wireline lubricator
The WL lubricator …
Options:

A. … is used lubricate the WL with grease to reduce the stripper friction.
B. … is used to lubricate the tool string into a live well.
C. … is not required when running braided line since a grease-injection head is used.

Question I-4: Coiled tubing fatigue
Coiled tubing fatigue is caused by …
Options:

A. … plastic strain as the CT leaves the reel.
B. … plastic strain between injector head and stripper.
C. … both reasons described above.

Question I-5: Norsok D-010 live well barriers
Well barrier elements during WL operation on a platform well include …
Options:

A. … Christmas tree (primary) and production packer (secondary).
B. … Christmas tree (primary) and Christmas tree (secondary).
C. … safety head (primary) and Christmas tree (secondary).

SECTION II

Six short questions. Provide short answers on your answer sheet.
Maximum score is 30 points.

Question II-1: Coiled tubing well intervention BOP stack
What is a slip ram and what is it used for?

Question II-2: Primary barrier element sealing on the outside of snubbing work string
What are three different primary well barrier BOP stack components that are used during live well RAS operations and what are common pressure limitations for these while stripping?

Question II-3: Pressure-testing of well intervention BOP stack
What is the purpose of mixing glycol with water?

Question II-4: Cable type used in WL well intervention
What are the two main cable systems in use and what is the primary well control barrier for these two systems?

Question II-5: Maximum snub force
Given: TVD = 5000 ft, BHP = 2200 psi, hydrostatic gradient of well fluid = 0.30 psi/ft, stripper rubber friction = 1000 lbs, work string OD = 2⅞"
Find: What is the maximum snub force?

Question II-6: Water and oil columns in the well after long shut-in time
Given: TVD = 5000 ft, BHP = 1350 psi, water hydrostatic gradient = 0.45 psi/ft,
oil hydrostatic gradient = 0.30 psi/ft, water cut = 25%, same well diameter from top to bottom
Find: What is the total height of the liquid column in the well after long shut-in time?

SECTION III

Three questions. Provide answers on your answer sheet.
Maximum score is 30 points.

You are rigged up with RAS to mill a hydrate plug using a mud motor. Below the plug there is pressurized gas. The plug is located 1000' below the surface and the well is vertical above this depth. The hydrate plug isolates the pressure from below and the well is dead above the hydrate plug. The work string is 3½" 15.5 lbs/ft drill pipe with inside diameter of 2.602". The milling fluid density is 9.625 lbs/gal. The annulus space outside the drill pipe is closed using the stripper rams and there is no rotation from the surface. Weight on bit during milling is 10000 lbs. The drill pipe inside pressure is 800 psi greater than the outside pressure during the milling operation regardless of depth. Tensile force is positive and compressive force is negative. The length coordinate z = 0' at the top of the plug and z = 1000' on the surface. Neglect the hydraulic impact force. Given calculations: A_o = 9.6211 in^2 and A_i = 5.3175 in^2. During milling at plug depth (z = 0'), p_i = 1300 psi and p_o = 500 psi.

Question III-1: Real axial force while milling
Develop equation $F_R(z)$ for real axial force as a function of vertical coordinate. Relevant parameters include self-weight, pressure, area and WOB. Calculate F_R(0') and F_R(1000'). What is the weight of the drill pipe hanging in the slips?

Question III-2: Effective force while milling
Write equation $F_E(z)$ for effective axial force as a function of vertical coordinate. Calculate F_E(0') and F_E(1000').

Question III-3: Buckled length while milling
What is length of the buckled portion of the drill pipe? Show calculation and explain your reasoning.

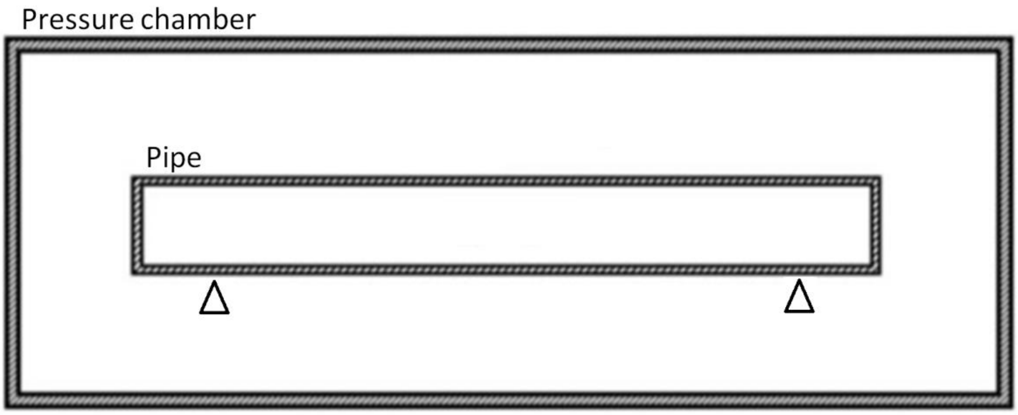
SECTION IV

Two questions. Provide answers on your answer sheet.
Maximum score is 20 points.

Question IV-1: Limiting the pressure input to snubbing jack
Consider a Hydra Rig 225k four-legged snubbing jack with 5" cylinder bore and 3½" piston rods. You have already calculated that the critical buckling load for unsupported pipe buckling is 75000 lbs. What is the maximum pressure output from the hydraulic power pack to ensure that unsupported buckling will not occur?

Question IV-2: Calculate the collapse pressure using the yield circle
Consider a free closed-ended pipe located inside a pressure chamber. The pressure inside the pipe is p_i and the pressure outside the pipe is p_o. The cross-sectional area based on the inside diameter is A_i and the cross-sectional area based on the outside diameter is A_o. The cross-sectional area of steel $A_s = A_o – A_i$.

Use the yield circle and express the collapse pressure for the special case of $F_R = 0$. The desired expression does not contain p_i even if the inside pressure is different from zero.



Used acronyms
BHP – bottomhole pressure (pressure in the well at reservoir depth)
BOP – blowout preventer
BPV – back-pressure valve
CT – coiled tubing
OD – outside diameter
POOH – pulling out of hole
RAS – rig-assist snubbing
TVD – true vertical depth
WL – wireline

Equations and information (useful and not useful)

$F_E(z) = F_R(z) - A_i p_i(z) + A_o p_o(z)$	$w = \frac{12\rho A}{231}$ | w, lbs/ft | ρ, lbs/gal A, in^2
$p = \frac{12\rho TVD}{231}$ | p, lbs/in^2 | ρ, lbs/gal TVD, ft	$w = w_s + w_i - w_o$
Density if steel = 65.5 lbs/gal = 7.85 sg 1 sg = 8.34 lbs/gal g = 9.80665 m/s^2	231 in^3/gal, 12 inch/ft, 0.3048 m/ft, 2.54 cm/inch, 14.50377 psi/bar, 6894.757 Pa/psi, 0.224809 lbs/N
Short-hand for foot is termed '	Short-hand for inch is termed "

Inside wall: $DF_i = \frac{1}{\sqrt{x_i^2 + y_i^2}}$	Outside wall: $DF_o = \frac{1}{\sqrt{x_o^2 + y_o^2}}$	$x^2 + y^2 = \left(\frac{\sigma_{vM}}{\sigma_y}\right)^2$	$DF = \frac{\sigma_y}{\sigma_{vM}}$

	Inside pipe wall (i) $(r = r_i)$	**Outside pipe wall (o)** $(r = r_o)$
Input		
Positive bending stress load case (tension)	$A_s\sigma_z = A_s\sigma_a + F_E \frac{r_o r_i}{2I}$	$A_s\sigma_z = A_s\sigma_a + F_E \frac{r_o^2}{2I}$
Negative bending stress load case (compression)	$A_s\sigma_z = A_s\sigma_a - F_E \frac{r_o r_i}{2I}$	$A_s\sigma_z = A_s\sigma_a - F_E \frac{r_o^2}{2I}$
Output		
General von Mises stress equations	$\sigma_{vM}^2 = \left(\frac{F_E}{A_s} \pm \frac{F_E r_o r_i}{2I}\right)^2 + 3\left(\frac{A_o(P_i - P_o)}{A_s}\right)^2$	$\sigma_{vM}^2 = \left(\frac{F_E}{A_s} \pm \frac{F_E r_o^2}{2I}\right)^2 + 3\left(\frac{A_i(P_i - P_o)}{A_s}\right)^2$
General circle coordinates	$x_i = \frac{F_E}{A_s\sigma_y}\left(1 \pm \frac{2r_o r_i}{r_o^2 + r_i^2}\right)$ $y_i = \frac{\sqrt{3}A_o(P_i - P_o)}{A_s\sigma_y}$	$x_o = \frac{F_E}{A_s\sigma_y}\left(1 \pm \frac{2r_o^2}{r_o^2 + r_i^2}\right)$ $y_o = \frac{\sqrt{3}A_i(P_i - P_o)}{A_s\sigma_y}$

EXAM PART B – PLUG & ABANDONMEMT

1. When downhole activities or production from a well is discontinued, the well status needs to be distinguished. List the three different well statuses and explain them in your own words. (**5p**)

2. List 5 main challenges associated with the plug and abandonment of wells. (**5p**)

3. In the context of permanent P&A, three different well barrier envelopes are distinguished; primary barrier, secondary barrier and environmental barrier. Explain the environmental barrier and its two main objectives. (**5p**)

4. There are different techniques of plug placement. Two main techniques are balanced plug method and two-plug method. Explain them and list the main advantage of the two-plug method. (**5p**)

5. An operator decided to permanently P&A a reservoir in a field. A strong aquifer supports the reservoir. The reservoir pore pressure gradient is 0.563 psi/ft at 12795 ft TVD. Consider a worst-case scenario of the well filled entirely with gas. Assume a gas gradient equal to 0.1 psi/ft. The minimum horizontal stress is 94% of the fracturing stress. The reservoir formation strength data is given in Table 1. Calculate the minimum setting depth of the secondary plug by plotting and the implementation of pressure gradient curve method. (**20p**)

Table 1 – Fracture gradient versus depth.

Fracture gradient (psi/ft)	Depth (ft TVD)
0.78806	7545
0.79672	8595
0.81404	8891
0.76641	8923
0.7794	11122
0.8227	11154
0.82703	12139
0.85734	12762
0.87899	12795

6. A platform well (Figure 1) has been drilled and completed with the vertical tree in 1985. The top of cement (TOC) in the B-annulus is below the permanent packer and the well suffers from sustained casing pressure in the A- and B-annulus. Caliper log shows big holes along the production tubing (shown with triangle on the well schematic). Operator decided to permanently plug and abandon the well. Through the operation, BOP has been necessitated to control the well pressure. Create a decision making flowchart for permanent P&A of reservoir zone only. Include the contingency plans. (**15p**)

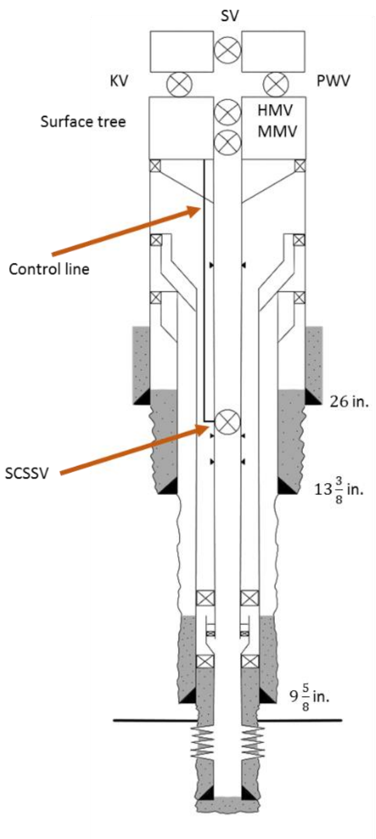


Figure 1 – A platform well completed with the vertical tree.

7. Traditional methods of creating an annulus barrier in uncemented casing require section milling. List 4 challenges that section milling creates during a P&A operation. (**5p**)

8. You have been asked to design a balanced cement plug for an openhole with a size of 8½ in. with a plug length of 800 ft. Assume that 10 bbl of spacer is pumped ahead of cement plug. (**15p**)

   Additional information:

   Hole capacity: 0.3941 ft^3/ft

   Drillpipe: 4-in, 14.0 lbm/ft, Grade X-95

   Wall thickness of the drillpipe: 0.330 in.

   ID of the drillpipe: 3.340 in.

Based on the given information calculate the followings:

   a. Calculate the required volume of cement slurry.

   b. Length of balanced plug with drillpipe in.

   c. Volume of spacer behind the cement.

9. Certain formations are known to move as a result of stress differences. These formations are able to isolate an annulus space where cement is missing. List 2 of the qualification requirements of a formation seal based on the guidelines for qualification of materials for the suspension and abandonment of wells, Oil & Gas UK, Issue 1. (**5p**)

10. Appendix A shows SBT (Segmented Bond Log) of a 10 ¾ in. cemented casing. The interval 2525 – 2544 m is carbonate formation with low source of gamma ray. However, the interval 2550-2575 m is a shale formation with high source of gamma ray. Write your reflection on the cement quality in the interval of 2550 – 2575 m. Support your reflections with reasons and write them. Additional information: ATMN: Minimum Attenuation; ATMX: Maximum Attenuation; ATAV: Average Attenuation; CCL: Casing Collar Locator. (**10p**)

11. Which option is correct regarding Young's modulus? (**1p**)

    a. Materials with lower Young's moduli are more susceptible to failure when exposed to the common mechanical stresses

    b. It describes tensile elasticity or the tendency of a material to deform along ab axis when opposing forces are applied along that axis

    c. Young's modulus does not characterize the flexibility of a material

    d. None of the above mentioned options are correct

12. Figure 2 shows the axial Stress-Strain curve for a material. Select the correct option. (**1p**)

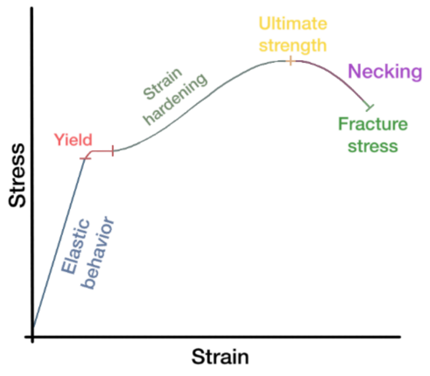


Figure 2 – Axial stress-Strain curve for a material.

    a. The material is brittle

    b. The material is ductile

    c. The material has no tendency to creep

    d. All the options are correct

13. Regarding creep, all the followings are correct EXCEPT: (**1p**)

   a. It is a time-dependent deformation

   b. Material creeps to reduce high shear stresses

   c. Formation creep can lead to collapse of casing

   d. Instantaneous linear deformation under constant load

14. All the following options are correct EXCEPT: (**1p**)

   a. Poisson’s ratio is defined as lateral strain to axial strain in a material loaded uniaxially in the axial direction

   b. Poisson’s ratio is a unitless parameter

   c. Poisson’s ratio allows calculation of shear failure

   d. Poisson’s ratio allows calculation of lateral deformation of barrier under a given pressure and under temperature change

15. In well cementing logging, the elapsed time between the transmitter firing and the arrival of the first part of the wave exceeding a preset amplitude threshold, is called: (**1p**)

   a. Travel time

   b. Transit time

   c. Amplitude

   d. Attenuation

16. In well cementing logging, regarding the transit time, all the following answers are correct EXCEPT: (**1p**)

   a. Shorter transit time is an indication of either poor sonde centralization or a fast formation

   b. Slightly longer transit time is generally an indication of a good bond and should correspond to reasonably low amplitudes

   c. If no transit-time curve is present on the log, no quality control of the logs is possible, and the evaluation will be very limited

   d. Slightly longer transit time is generally an indication of a good bond and should correspond to reasonably high amplitudes

17. Traditional methods of creating an annulus barrier in uncemented casing require section milling. Perforate, wash and Cementing (PWC) has been suggested and utilized as an alternative method to section milling. According to the given preview, select the correct answer. (**1p**)
    a. Currently, there is no method to verify the quality of the cement placed behind the casing by PWC technique
    b. The PWC annulus cleanout and cementing method is not highly dependent on compatibility between all fluids circulated into and out of the annular space
    c. The top perforations are larger to facilitate easier initiation of washing behind the casing without creating pressures exceed the adjacent formation fracture gradient
    d. PWC is not capable to establish a mechanical foundation for the cement plug inside the casing

18. According to NORSOK D-010, Rev. 4, all the following options are correct EXCEPT: (**1p**)
    a. The overburden formation including shallow sources of inflow shall be assessed with regards to abandonment requirements.
    b. Multiple reservoir zones/perforations located within the same pressure regime can be regarded as one reservoir.
    c. Control lines and cables shall not form a part of the permanent barriers.
    d. Requirement for isolation of formations, fluids and pressures for temporary and permanent abandonment are not the same.

19. Absence of SCP (Sustained Casing Pressure) during the life cycle of the well indicates that … (**1p**)
    a. Poor sealing capability of the casing cement.
    b. Milling operations is necessary.
    c. Running leak off test is necessary.
    d. Good sealing capability of the casing cement.

20. Based on the NORSODK D-010, Rev. 4, “the application of technical, operational and organizational solutions to reduce the risk of uncontrolled release of formation fluids throughout the entire life cycle of the well” is called… (**1p**)
    a. Temporary abandonment
    b. Leak testing
    c. Permanent well barrier
    d. Well integrity