FACULTY OF SCIENCE AND TECHNOLOGY

COURSE:	**PET100 DRILLING**
DATE:	**04 DECEMBER 2020**
DURATION	**09:00 – 13:00 (4 HOURS)**

Universitetet i Stavanger

Exam problems: The exam consists of in total 6 pages including this front page, and five problems, including one multiple choice problem. All five problems count equally, that is 20% per problem.

Exam aids: All aids are permitted. You are **not allowed to get help from other people** when working on your exam assignment. We remind you that when registering for the semester, you confirmed by signature that you have read and understood the rules for cheating and plagiarism in the Exam Rules and Regulations at the University of Stavanger. Plagiarism control will be carried out.

Exam duration: Exams that contains file uploads will have an additional 15 minutes for uploading files. If you have been granted additional extra time, it has been added to your user. You can see how much time you have left on the exam on the top of the screen. Exam answers that are submitted after the time has expired will not be accepted.

Contact persons: If you need help during the exam, you can call one of the phone numbers below. This applies if you need clarifications from the course responsible or administrative support.

Course responsible: Hans Joakim Skadsem, tel: 957 52 843, epost: hans.j.skadsem@uis.no

Administrative support: 51 83 31 26

PS! If something goes wrong in Inspera, and you are not able to hand in your assignment, you need to contact the administrative support as soon as possible.

Withdrawal during the exam: If you wish to withdraw from the exam, you **must** do so by choosing "deliver blank" in the top right menu, and following the instructions.

Uploading files: You will find your candidate number at the top of the page or in Studentweb. You must write your candidate number on all the answer sheets. Also remember to number all the pages and write the total number of pages you deliver on the front page. Remember not to write your name or student number on any of the sheets. Inspera will handle your identity and ensure anonymous assessment. If files are to be uploaded as part of the exam, it will be stated which file type (s) are allowed. PDF is the most used file type.

If you have problems when uploading files in Inspera, you must **immediately** send your file to eksamentn@uis.no. We will not read or answer e-mails that arrive after the submission deadline for the current exam. **This is an emergency solution**, as a general rule all answers must be uploaded to Inspera.

Handing in: The exam will automatically close for uploading when the time is up. Remember that the time given includes the time it will take you to scan and upload your documents.

Good luck!

PROBLEM 1 Rig equipment and drill string

Most drilling rigs use drawworks to trip the drill string in or out of the well.

a) Drawworks typically have a load cell mounted in the dead line that is used for measuring the tension in the cable or drilling line that runs through the drawworks. Why is the tension in the dead line an important measurement in connection with drilling operations?

Assume now that we have n lines between the travelling block and the crown block, and that the total mass of the travelling block, the top-drive and the attached drill string is M. The friction factor in the sheaves of the drawworks is k.

b) What is the tension in the fast line when we lift the travelling block? And what is the corresponding tension in the dead line when we lift the travelling block?

The cable or drilling line that run through the drawworks has a tensile strength of 95 tons, or 931,95 kN. We require a safety factor (SF) of at least 3.5 for the cable during drilling operations.

c) What is the maximum total weight of the travelling block, top-drive and drill string that can be lifted by the drawworks if we have 8 lines between travelling block and crown block, and the friction factor is 1.04?

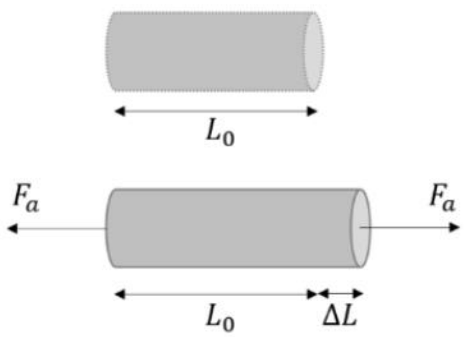
We now turn to the drill string connected to the top-drive. When we dimension the drill string, we normally require the neutral point to be within the drill collar section of the string.

d) What do we mean by neutral point and why should this always be within the drill collar section of the drill string? Where is the neutral point located when the drill bit is off bottom, i.e. when the weight on the bit is zero?

In the continuation of this problem we study 5 inch drill pipes with the following properties:

Outer diameter:	127 mm
Wall thickness:	9,19 mm
Initial length per pipe joint, L_0:	10 m
Young's modulus, E:	$210 \cdot 10^9$ Pa
Yield strength:	$222{,}7 \cdot 10^4$ N
Mass density steel, ρ_s:	7850 kg/m^3

A pipe segment of length L_0 subjected to an axial tensile force F_a will become elongated by a length ΔL in the axial direction, as shown in the figure below. The same holds true also for drill pipes – when they are subject to tensile axial forces, they elongate!



Hooke's law is normally used to relate the axial tensile force to the elongation:

$$F_a = EA\frac{\Delta L}{L_0}. \tag{1}$$

Here E is the Young's modulus for steel and A is the cross-sectional area of the pipe wall.

e) How much longer will a single 5 inch drill pipe become when it is subjected to an axial tensile force equal to the yield strength of the pipe? Assume the pipe is 10 m long in its unstressed condition, and that other properties are as listed in the table above.

PROBLEM 2 Drilling fluid

We will in this problem study a water-based drilling fluid consisting of water, bentonite and baryte. Bentonite is added to obtain required viscosity while baryte is used to obtain desired mass density. Assume mass densities for water, bentonite and baryte as listed in the table below.

Ingredient	**Mass density**
Water	1000 kg/m^3
Bentonite	2350 kg/m^3
Baryte	4480 kg/m^3

Assume now that we have 6% volume fraction bentonite in the drilling fluid, 10% baryte while the rest is water. We have a total of 40 m^3 of the drilling fluid on the rig.

a) What is the mass density of the drilling fluid?

We have found the drilling fluid to be too viscous so we will thin it with water to achieve a bentonite volume fraction of 4%. At the same time we wish to increase the mass density to 1500 kg/m^3 by adding baryte.

b) What is the new volume fraction of baryte in the drilling fluid?

c) The total volume of drilling fluid after is has been thinned with water and weighted to 1500 kg/m^3 with baryte should be the same as the original volume of drilling fluid, i.e. 40 m^3. How much of the original drilling fluid do we have to discard and how many kilograms baryte do we need to add?

The drilling fluid with mass density 1500 kg/m^3 has been used to drill a vertical 12 ¼ inch hole section until 2000 m depth. After tripping the drill string out of the well, the drilling fluid has been left static in the well for an extended period of time. The operation is worried that the dense weighting material (baryte) has fallen out of suspension and generated a baryte plug in the bottom of the well.

d) Assume that baryte particles can achieve a close-packing in the bottom of the well corresponding to a maximum volume fraction 60% baryte within the plug region. Estimate the height of the baryte plug!

   PS: If you have not answered question b) above, you may assume a total volume fraction of 10% baryte in the drilling fluid.

PROBLEM 3 Casing and cementing

The vertical 12 ¼ inch hole section from the previous problem and that was drilled with a water-based drilling fluid of mass density 1500 kg/m^3 will now be completed by running and cementing a 9 5/8 inch casing string with the shoe at 2000 m vertical depth. The volume capacity of the annulus between the casing string and the formation wall is approximately 29 liter per meter.

a) We intend to place cement behind the casing up to a height of 500 m above the bottom of the casing. What volume cement slurry must be mixed and pumped to achieve this? Assume that 500 liter cement slurry is required to fill the bottom of the casing and the short open-hole section below the casing.

The cement slurry density is 1920 kg/m^3. In addition to cement slurry, a total of 5000 liter spacer fluid of mass density 1650 kg/m^3 will be pumped. The spacer fluid will be pumped ahead of the cement slurry. Behind the cement slurry we will pump more of the drilling fluid of mass density 1500 kg/m^3.

b) 1. What is the hydrostatic pressure in the bottom of the well when the cement slurry is pumped in place?
2. What can happen if the pressure in the well exceeds the formation fracturing pressure during cementing?

The outer diameter of the casing is 9 5/8 inches, or 244.5 mm, the inner diameter is 216.8 mm, and the nominal weight per length in air is 79.6 kg/m.

c) What are the axial tensions at the top of the casing string and at the mid-point of 1000 m vertical depth when the cement slurry is pumped in place, and the top plug has landed on the bottom plug within the casing?

Once the cement has cured and is hardened, the cement and a few meters of new formation is drilled out. One will now perform a pressure test of the formation by pulling the drill string up into the casing, shut-in the well by closing the annular preventer, and pumping drilling fluid into the well until a pre-defined pump pressure. This is frequently referred to as a formation integrity test, or FIT.

d) The test results suggest that the casing shoe and formation can withstand at least 345 bar pressure at 2000 m vertical depth. What equivalent mud weight does this correspond to? Can we safely drill ahead with the drilling fluid used to displace the cement?

PROBLEM 4 Kick

We have now drilled the vertical well from the previous problem down to 2500 m below the drill floor using a drilling fluid flow rate of 2500 l/min. The mass density of the drilling fluid is, as before, 1500 kg/m^3 and its viscosity has been measured to be 15 cP. We use a drill string with a 172 m long drill collar section at the bottom. Inner and outer cross-sectional areas as listed in the table below.

Cross-sectional area	**Value**
Inner area in the drill string, both drill pipe and drill collar	0,00785 m^2
Annular area, outside drill collars	0,0528 m^2

Annular area, outside drill pipes	0,0673 m^2

We suddenly observe that the liquid level in the return tank for drilling fluid rises. After 130 seconds it is obvious that a kick is in process and we have to shut down the mud pump and close the BOP. After the pressure stabilizes, we measure 15 bar pressure on the top of the drill string and 29 bar in the annulus, directly below the closed BOP.

a) What is the pressure at the bottom of the well now, with the BOP closed?

b) What is the height of the kick over the bottom of the well?

We will mix a kill mud with sufficient mass density to provide a safety margin of 8 bar against the formation pressure. As we circulate the kick out, we will use a fixed pump rate of 500 l/min. The viscosity of the kill mud is measured to be 18 cP.

c) 1. What is the required mass density of the kill mud?
2. How long does it take to circulate the entire well once, i.e. to circulate the drill string and the annulus between drill string and formation?

The kick will be circulated out of the well using the driller's method using the stated flow rate of 500 l/min. The friction pressure loss and the nozzle pressure loss at a flow rate of 500 l/min with the original mud are estimated to be approximately 8 bar and 4 bar, respectively.

d) Plot the pump pressure as function of time through the entire circulation procedure. Denote your plot with numbers showing pressures and duration of the various stages of the procedure.

PROBLEM 5 Multiple choice questions

1. Which one of the following components will not be found the bottom-hole assembly (BHA)?
   a. Reamer
   b. Liner
   c. Jar
   d. Stabilizer
2. What is the function of *slips*?
   a. Fixing the drill string in the rotary when making or breaking connections
   b. Guide the drill string down the well while drilling
   c. Transfer torque from the top-drive or the rotary table to the drill string
   d. Centralize casing in the open-hole section
3. Which of the following drill bit types is <u>not</u> a *fixed-cutter* bit?
   a. Roller-cone bit
   b. PDC bit
   c. Diamond bit
   d. Impregnated bit
4. Which of the following parameters influence the rate of penetration while drilling?
   a. Type of drill bit
   b. Formation properties
   c. Weight on bit (*WOB*) and rotational speed (*RPM*)
   d. Type of drilling mud
   e. All of the above

5. What is the continuous phase in water-based drilling muds?
    a. Oil drops
    b. Water
    c. Baryte
    d. Filter cake
    e. None of the above
6. Which of the following compounds is <u>not</u> a common ingredient in drilling muds?
    a. Baryte
    b. Hydrogen sulphide
    c. Bentonite
    d. Water
    e. Polymers
7. Which of the following statements related to primary cementing of casings is <u>not</u> correct?
    a. The entire length of the open-hole section that has been drilled must in any case be cemented, i.e. we need to pump sufficient volume of cement to fill the entire annulus up to the previous casing shoe
    b. Cement shall prevent the flow of fluids from one formation zone to another
    c. Cement shall protect the casing from corrosive formation fluids
    d. Cement shall support the casing string mechanically
8. What type of BOP ram cuts the drill string?
    a. Pipe ram
    b. Blind ram
    c. Cut ram
    d. Shear ram
9. When a kick has been detected and the well is shut in, what can we use the pressure in the drill string and the annulus pressure below the BOP for?
    a. Estimate the formation pressure at the bottom of the well
    b. Required mass density of kill mud
    c. The type of fluid that has entered the well
    d. All the above
10. Which one of the following statements related to kick and well control procedures is correct?
    a. Once a kick is detected and the well is shut in, the drill string pressure and the annulus BOP pressure will be the same
    b. Once a kick is detected and the well is shut in, the annulus BOP pressure will normally be greater than the drill string pressure
    c. Formation fluids can enter the well if the well pressure is higher than the formation pressure
    d. The location of the influx is most likely at the casing shoe of the previous casing
    e. None of the above are correct