Exam PET100 4 DECEMBER 2020

Censor guide.

1. a) The tension in the dead-line is measured in order to determine the weight of the suspended drill string, or hook load. The weight is given by W in key equation 2.3.1.

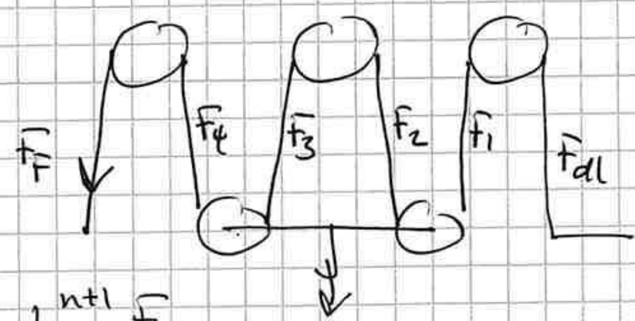
If the weight (or hook load) W changes unexpectedly during a drilling operation, this can suggest problems in the well such as hole stability problems.

1. b) Tension in the fast-line when hoisting is given by key equation 2.3.1,

$$\underline{\underline{F_F = \frac{k-1}{1-k^{-n}} Mg.}} \qquad (*)$$

We find the dead-line tension F_{dl} when hoisting as follows:

Example with $n=4$



$$F_F = kF_4 = k^2F_3 = k^3F_2$$
$$= k^4F_1 = k^5F_{dl}$$

For n lines: $\underline{F_F = k^{n+1} F_{dl}}$

Using (*) we find

$$\underline{\underline{F_{dl}}} = k^{-(n+1)} F_F = \underline{\underline{\frac{1-k^{-1}}{k^n - 1} Mg.}}$$

1.c) The tensile load on the drilling line is given by key equation 2.3.1:

$$\underline{F_F = \frac{k-1}{1-k^{-n}} W.}$$

We find the maximum load W_{max} when $F_F = \frac{F_Y}{SF}$, where F_Y is the tensile strength of the line. See also key equation 3.7.4 for safety factor under tension. We have

$$\underline{W_{max}} = \frac{1-k^{-n}}{k-1} \frac{F_Y}{SF} = \frac{1-1{,}04^{-8}}{1{,}04-1} \frac{931{,}95\,kN}{3{,}5}$$

$$= \underline{\underline{1792{,}74\,kN}} \approx \underline{\underline{182{,}7\,ton}}$$

1.d) The neutral point is defined as the point where the effective axial load is zero, sec. 3.7.2 p.55 in compendium. The drill string is in effective compression below the neutral point. To avoid buckling of drill pipes, the neutral point should always be in the drill collar section, ref. eq. (3.2) in compendium.

With the bit off bottom (and assuming zero nozzle force), the neutral point is at the bottom of the string, see e.g. eq. (3.2) with $F_B = 0$ and $F_D = 0$.

1. e) We use the given equation (1) to determine elongation ΔL:

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

From tabulated values we find the inner diameter to be 0,109 m, and the cross-sectional area of the pipe wall to be $A = \frac{1}{4}\pi(OD^2 - ID^2) \approx 0{,}0034\ m^2$.

Total elongation:

$$\underline{\underline{\Delta L}} = \frac{222{,}7 \cdot 10^4 \cdot 10}{210 \cdot 10^9 \cdot 0{,}0034}\ m \approx \underline{\underline{3{,}12\ cm}}$$

2. a) We use the mass balance on p. 85 in the compendium:

$$\rho_w V_w + \rho_{ben} V_{ben} + \rho_{bar} V_{bar} = \rho_{mud} V_{mud}$$

Solve for ρ_{mud}:

$$\underline{\underline{\rho_{mud}}} = \rho_w \underbrace{\frac{V_w}{V_{mud}}}_{=f_w} + \rho_{ben} \overbrace{\frac{V_{ben}}{V_{mud}}}^{=f_{ben}} + \rho_{bar} \overbrace{\frac{V_{bar}}{V_{mud}}}^{=f_{bar}}$$

$$= 1000 \frac{kg}{m^3} \cdot 0{,}84 + 2350 \frac{kg}{m^3} \cdot 0{,}06 + 4480 \frac{kg}{m^3} \cdot 0{,}$$

$$= \underline{\underline{1429 \frac{kg}{m^3}}}$$

2. b) We require $\rho_{mud} = 1500 \frac{kg}{m^3}$ and

$$\frac{V_{ben}}{V_{mud}} = 0{,}04. \equiv f_{ben}$$

From volume balance on p. 85 in compendium we have $f_w + f_{ben} + f_{bar} = 1$.

2.b) Cont: From mass balance, we have

$$\rho_{bar} f_{bar} = \rho_{mud} - \rho_w \underbrace{f_w}_{= 1 - f_{bar} - f_{ben}} - \rho_{ben} f_{ben}.$$

$$(\rho_{bar} - \rho_w) f_{bar} = \rho_{mud} - \rho_w + f_{ben}(\rho_w - \rho_{ben})$$

$$\underline{\underline{f_{bar}}} = \frac{\rho_{mud} - \rho_w + f_{ben}(\rho_w - \rho_{ben})}{\rho_{bar} - \rho_w}$$

$$= \frac{1500 - 1000 + 0{,}04(1000 - 2350)}{4480 - 1000} \approx \underline{\underline{12{,}8\%}}$$

2. c) In the original mud, there is 6% volume bentonite. In $40\,m^3$ of mud, this corresponds to $\underline{V_{ben,0}} = 0{,}06 \cdot 40\,m^3 = \underline{2{,}4\,m^3}$

In the new mud, we require 4% volume fraction bentonite, or $\underline{V_{ben,1}} = 0{,}04 \cdot 40\,m^3 = \underline{1{,}6\,m^3}$

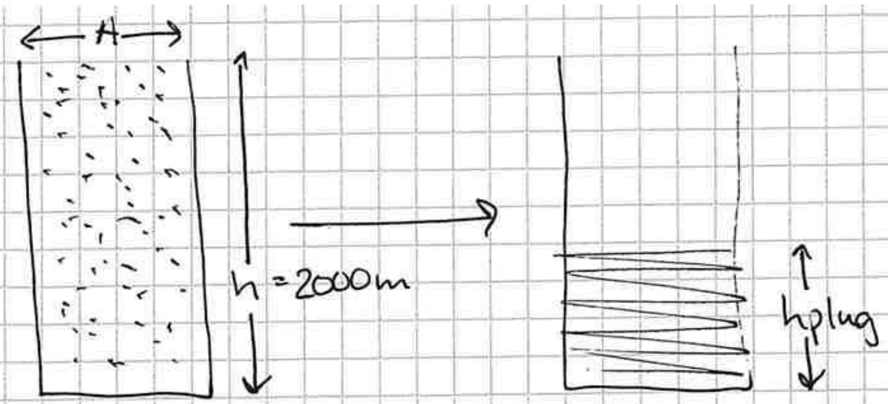
To get the correct amount bentonite, we keep $\frac{1{,}6}{2{,}4} = \underline{\underline{\frac{2}{3}}}$ of the original mud and discard $\underline{\underline{\frac{1}{3}}}$, or $\underline{\underline{13{,}3\,m^3}}$.

The total baryte content in the new mud should be $0{,}128 \cdot 40\,m^3 \approx \underline{5{,}1\,m^3}$.

The baryte content in the mud we keep is $\frac{2}{3} \cdot 0{,}1 \cdot 40\,m^3 \approx \underline{2{,}7\,m^3}$.

Consequently, we need to add $\underline{2{,}4\,m^3}$ or $\underline{\underline{10752\ kg}}$ baryte.

2 d)



Initial condition, uniform baryte distribution

Final condition, baryte plug

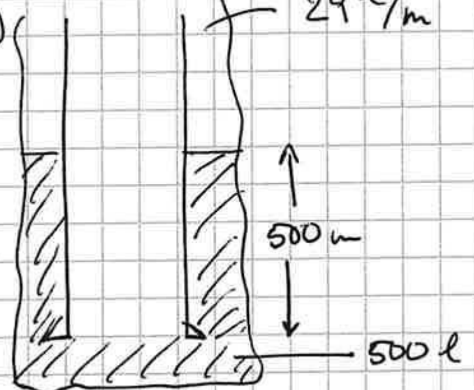
We ~~use~~ use volume balance of baryte to estimate baryte plug height.

Initial condition: $V_{bar} = f_{bar} \cdot A \cdot h$ (*)

Final condition: $V_{bar} = f_{plug} \cdot A \cdot h_{plug}$ (**)

$$\rightarrow \quad \underline{\underline{h_{plug}}} = \frac{f_{bar}}{f_{plug}} \cdot h = \frac{0{,}128}{0{,}6} \cdot 2000\,\text{m} \approx \underline{\underline{427\,\text{m}}}$$

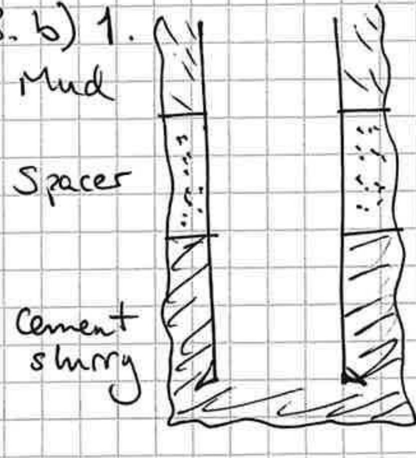
3. a)



Total cement slurry volume that must be mixed:

$$\underline{\underline{V_{cmt}}} = 500\,\ell + 500\,\text{m} \cdot 29\,\frac{\ell}{\text{m}}$$
$$= 15000\,\ell = \underline{\underline{15\,\text{m}^3}}$$

3. b) 1.



Height of spacer: $\underline{h_{spacer}} = \frac{5000}{29}\,\text{m}$
$\approx \underline{172{,}4\,\text{m}}$

Height of mud: $h_{mud} = (2000 - 500 - 172{,}4)\,\text{m}$
$\approx \underline{1327{,}6\,\text{m}}$

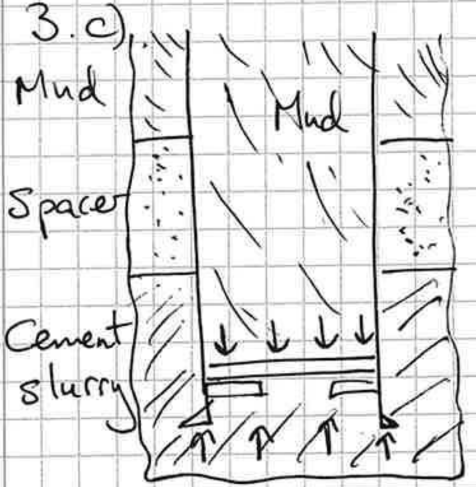
Hydrostatic pressure:

$$P_{hyd} = (\rho_{cmt} \cdot h_{cmt} + \rho_{spacer} h_{spacer} + \rho_{mud} h_{mud})\, g$$

3.b) 1. Cont. $\underline{P_{hyd} \approx 317{,}4 \text{ bar}}$

2. If the formation fractures due to high wellbore pressure, we may loose fluid to the formation and not achieve sufficient height of cement behind casing.

3.c)



We use eq. (8.1) from the compendium to determine the axial stress in the casing.

We have $A_i \approx 0{,}037 \text{ m}^2$, $A_o \approx 0{,}047 \text{ m}^2$.

Axial load at the top ($d=0$ in eq. (8.1)):

$\underline{F_{a,top}}$ = Weight of casing in air − Uplift due to hydrostatic pressure outside casing + Weight due to mud inside casing

$$= m_s g h - P_{hyd} \cdot A_o + \rho_{mud} g h A_i$$

$$= (79{,}6 \cdot 9{,}81 \cdot 2000 - 317{,}4 \cdot 10^5 A_o + 1500 \cdot 9{,}81 \cdot 2000 \cdot A_i) \text{ N}$$

$$\approx \underline{1158 \text{ kN}} \approx \underline{\underline{118 \text{ ton}}}$$

At the half-way point, $d = 1000$ m in eq. (8.1), and we get

$$\underline{\underline{F_{a,mid}}} = m_s g h - P_{hyd} A_o + \rho_{mud} g h A_i - m_s g d$$

$$\approx \underline{\underline{377 \text{ kN}}} \approx \underline{38 \text{ ton}}$$

3. d) The FIT suggests formation integrity up to at least 345 bar pressure.

This pressure corresponds to a mud weight of: $\rho_{mud,eq}\, g h = 345 \cdot 10^5\,\text{Pa}$.

Solved for $\underline{\underline{\rho_{mud,eq} \approx 1758{,}4 \frac{kg}{m^3}}}$.

The mud used to displace cement has a lower density, so $\underline{\underline{\text{yes}}}$.

4. a) We use key equation 10.4.3 from the compendium:

$$\underline{P_{bh}} = P_{dp} + \rho_{mud}\, g h$$

$$= 15\ \text{bar} + \frac{1500 \cdot 9{,}81 \cdot 2500}{1 \cdot 10^5}\ \text{bar}$$

$$= \underline{\underline{382{,}9\ \text{bar}}}$$

4. b) Regrettably, a piece of information necessary to solve this question was left out of the English exam set, viz. the pit gain of $12{,}8\ m^3$ $(= V_i)$. This was by mistake. The information was only present in the Norwegian exam set.

Candidates that did not answer this question will <u>not</u> have points deducted from their score. The correct answer is provided below, for completeness.

4.b) Cont. We use key equations 10.4.1 and 10.4.2. Total influx/kick volume:

$$\underline{\underline{V_k}} = V_i + Q_m \Delta t = 12{,}8\ m^3 + \frac{2500\frac{l}{min} \cdot 130s}{1000\frac{l}{m^3} \cdot 60\frac{s}{min}} \approx \underline{\underline{18{,}2 m^3}}$$

Total volume outside drill collars:

$$\underline{V_{dc}} = 0{,}0528\ m^2 \cdot 172 m = \underline{9{,}1\ m^3}$$

Since $V_k > V_{dc}$, the kick extends above the collar section. Total height is then:

$$\underline{\underline{h_k}} = h_{dc} + \frac{V_k - V_{dc}}{A_{dp}} = 172 m + \frac{18{,}2 - 9{,}1}{0{,}0673} m$$

$$\approx \underline{\underline{307{,}7\ m}}$$

4.c) 1. We use key equation 10.4.4 to estimate required kill mud weight.

$$\underline{\underline{\rho_{km}}} = \rho_m + \frac{P_{dp} + \Delta P_s}{gh}$$

$$= 1500\frac{kg}{m^3} + \frac{(15+8) \cdot 10^5}{9{,}81 \cdot 2500} \frac{kg}{m^3} \approx \underline{\underline{1593{,}8 \frac{kg}{m^3}}}$$

2. Drill string volume: $V_{dp,in} = 0{,}00785 \cdot 2500\ m^3$

$$\approx 19{,}6\ m^3$$

Drill collar volume: $V_{dc,out} = 9{,}1\ m^3$

Drill pipe volume: $V_{dp,out} = 0{,}0673 \cdot 2328\ m^3$

$$\approx 156{,}7\ m^3$$

Total volume: $V_{tot} \approx 185{,}4 m^3$.

Duration: $V_{tot} / Q_{km} = \frac{185{,}4 m^3}{500/(60 \cdot 1000)} \approx \underline{371 min}$

4. d) In the driller's method, we begin by circulating the kick out of the well with the original mud, ref. fig 11.5 and sec. 11.4 in the compendium.

The standpipe pressure is then $P_{dp} + P_{c1}$,

or $15\text{ bar} + \underbrace{8\text{ bar} + 4\text{ bar}}_{\text{circ. pressures}} + \underbrace{8\text{ bar}}_{\text{safety margin}} = 35\text{ bar}$.

At the end of the first circulation, we start filling the drill string with kill mud.

To calculate the new standpipe pressure, P_{c2}, we use key equations 11.2.1 and 11.2.2

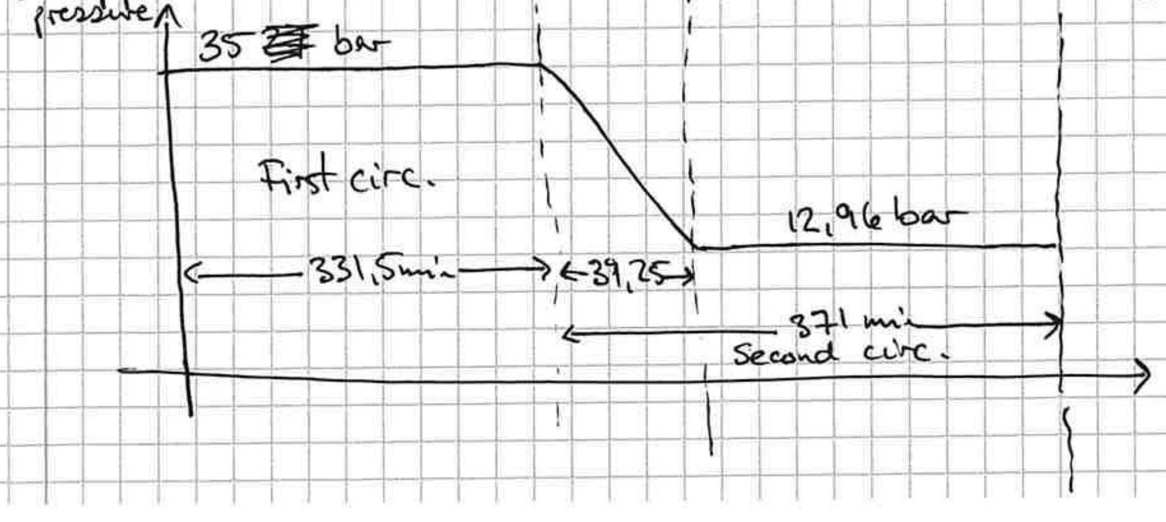
$$\Delta P_{F_{km}} = \frac{\rho_{km}^{0,8}\,\mu_{km}^{0,2}}{\rho_m^{0,8}\,\mu_m^{0,2}}\,\Delta P_{F_m} = 8{,}71\text{ bar}$$

$$\Delta P_{D_{km}} = \frac{\rho_{km}}{\rho_m}\,\Delta P_{D_m} = 4{,}25\text{ bar}$$

Duration of first circulation: $\dfrac{V_{dc,out} + V_{dp,out}}{500\frac{\ell}{min}/1000\frac{\ell}{m^3}} \approx \underline{331{,}5\text{ min}}$

Duration of second circulation: $\underline{371\text{ min}}$ (4. c) 2.)

Duration of phase 3 (fig 11.5): $\dfrac{V_{dp,in}}{500\frac{\ell}{min}/1000\frac{\ell}{m^3}} \approx \underline{39{,}25\text{ min}}$



5.

1 : B	6 : B
2 : A	7 : A
3 : A	8 : D
4 : E	9 : D
5 : B	10 : B