University of
Stavanger

# FACULTY OF SCIENCE AND TECHNOLOGY

**SUBJECT:** Directional Drilling and Flowing Well Engineering - PET 505 **DATE:** 07.12.16

**TIME:** 09.00 – 13.00 **( 4 hours )**

**AID:** Basic definite calculator which means: HP30S, All Casio FX82, Texas Instruments TI-30, Citizen SR-270X, Texas BA II Plus and HP17bII+. No written or handwritten personal notes are allowed.

**THE EXAM CONSISTS OF 7 PAGES, including the front page**

**REMARKS:**

**General information about the problems:**

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

- Give short and concise answers.
- The problems must be answered in the same sequence as given in these exam papers. If answers are given in another sequence, this must be clearly explained.
- Use of informative figures and sketches will generally improve the answers.
- Numerical answers must be supplied with explanation and necessary calculations.
- Acceleration of gravity is $g = 9.8\ m/s^2$.

**COURSE RESPONSIBLE:** Rune Time, Kjell Kåre Fjelde

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## PART I - Directional Drilling

This part constitutes 50 % of the exam. Formulas can be found in the Appendix just after Part I.

1) Which hole sizes and casings are typically used when constructing a well and when do we run BOP and riser for a subsea well ?

2) Explain the functionality and purpose of the DHSW (downhole safety valve) in a production well.

3) What are the different types of vibrations that can occur in the bottomhole assembly ? Make a figure to illustrate these! Also indicate what kind of vibrations the Roller cone and the PDC bit can typically experience!

4) What are the two main type of tools we use for measuring azimuth ? What can cause inaccuracy in the measurements for the two different tools ?

5) What kind of tools are helping us in the geosteering process and why is there a challenge when we cross a fault zone ?

6) If we have a 30 meter vertical sandpackage with shale above. How will you place your horizontal well in case of:
   a) Water driven reservoir
   b) Gas driven reservoir
   c) Heavy oil (gravity driven reservoir)

7) Describe the main principle behind the steerable liner drilling technology and give two examples on advantages this technology can have!

8 )

An oilfield has been discovered just outside a coastal area. The plan is to drill an extended reach well from shore to reach the reservoir. These type of wells will typically be drilled with a build and hold profile.

The target reservoir is located at 3500 meter TVD. The target coordinates are (5916 m West, 1000 m South). The build up rate shall be $\frac{\Delta i}{\Delta l} = \frac{1.5^\circ}{30m}$. After the build up section, the inclination shall be 70 degrees until reaching the target.

a) Find the horizontal displacement and azimuth of the target!

b) Calculate the depth of the kick off point (KOP)!

c) Calculate measured depth of the well!

d) Show by calculation, an alternative way of finding the vertical displacement of the build up section!

e) Assume the horizontal displacement was increased to 7000 meter. How will that affect the KOP if we still want to keep 70 degrees inclination and use the same build up rate? If we want to keep the same KOP as initially or deeper, what has to be done with the inclination ? For this exercise, you can explain with words how these changes will affect the results. You are of course also allowed to use calculations to exemplify.

# Appendix – Formulas

**Formula for dogleg (DL):**

$$\beta = Cos^{-1}(CosI_1 CosI_2 + SinI_1 SinI_2 Cos(A_2 - A_1))$$

**Conversion between radians and degrees:**

$$\beta(rad) = \frac{\pi}{180}\beta(\deg)$$

**Balanced Tangential Method:**

$$\Delta N = 0.5 \cdot \Delta MD(SinI_1 \cdot CosA_1 + SinI_2 \cdot CosA_2)$$
$$\Delta E = 0.5 \cdot \Delta MD(SinI_1 \cdot SinA_1 + SinI_2 \cdot SinA_2)$$
$$\Delta V = 0.5 \cdot \Delta MD \cdot (CosI_1 + CosI_2)$$

**Minimum Curvature Method:**

$$\Delta N = 0.5 \cdot \Delta MD(SinI_1 \cdot CosA_1 + SinI_2 \cdot CosA_2) \cdot RF$$
$$\Delta E = 0.5 \cdot \Delta MD(SinI_1 \cdot SinA_1 + SinI_2 \cdot SinA_2) \cdot RF$$
$$\Delta V = 0.5 \cdot \Delta MD \cdot (CosI_1 + CosI_2) \cdot RF$$
$$RF = \tan(\beta / 2)/(\beta / 2)$$

NB the angle in the denominator must be in radians.

**Ragland formulas**

$$\Delta A = \tan^{-1}\left(\frac{\tan DL \cdot \sin TF}{\sin I_1 + \tan DL \cdot \cos I_1 \cdot \cos TF}\right)$$

$$I_2 = \cos^{-1}(\cos I_1 \cdot \cos DL - \sin I_1 \cdot \sin DL \cdot \cos TF)$$

$$TF = \cos^{-1}\left(\frac{\cos I_1 \cdot \cos DL - \cos I_2}{\sin I_1 \cdot \sin DL}\right)$$

DL – Dogleg, TF – Toolface, A –Azimuth, I-Inclination

**Units**

1 inch =2.54 cm = 0.0254 m

1 feet = 0.3048 m

1 bar = 100000 Pa = 14.5 psi

1 sg = 1 kg/l (sg - specific gravity)

## PART II - MULTIPHASE FLOW

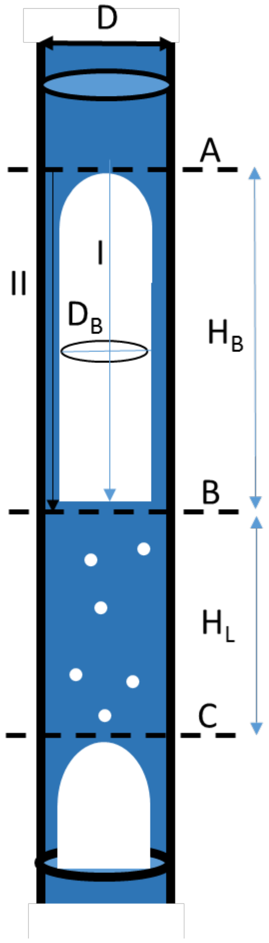
This part constitutes 50 % of the exam. Parameter values are stated in problem text. Some useful formulas can be found in the Appendix of Part II.

### Problem 1

a) Describe the various flow regimes that occur in horizontal gas-liquid pipeline flows. Sketch also a flow regime map with superficial gas and liquid flow velocities on the axes. Give approximate values on the axes.

b) In a given situation in ***vertical pipe*** gas and liquid flows upwards as slug flow. A simple sketch of a ***slug unit*** is shown in the figure to the right. Make a *similar sketch* yourself, pointing out the Taylor bubble, the liquid film and the liquid plug. Can the Taylor bubble move if there is no net liquid flow (e.g. in well flow if the production is stopped) - ***explain***?

In the figure to the right HB=2 m, while HL = 1 m. The pipe inner diameter is 10 cm. The pressure at A is 5 bar, and the temperature is 80 deg C. The gas can be assumed to be ideal, with a density of 1.2 kg/m^3 at Pref=1 bar, Tref=25 degC. The surface tension $\sigma$ = 72 mN/m. The liquid density is 1000kg/m^3.



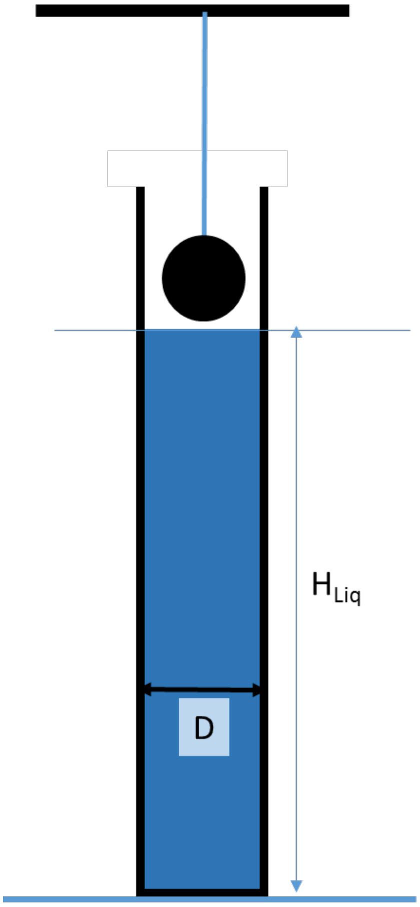
c) What is the ***gas density*** inside the bubbles? Why can we neglect the impact of surface tension in this problem? How small must the bubbles be before we get any significant pressure effect from $\sigma$, e.g. more than 100 mbar?

d) One may calculate the pressure difference $\Delta P_{AB}$ between positions A and B in two ways; either along path I - or along path II (outside the bubble), as indicated in the figure. Use only the hydrostatic pressure gradient and calculate $\Delta P_{AB}$ for these two different cases? Can this be correct? Explain briefly this apparent "paradox".

e) The gas fraction in the liquid plug is 0.1 consisting of small bubbles. The Taylor bubble has an average diameter 0.9D (D is the pipe diameter). Calculate the:

  i. average ***gas fraction*** over the Taylor bubble section from A to B
  ii. hydrostatic ***pressure difference*** between A and B, if we simply use the homogeneous no-slip model.
  iii. average hydrostatic ***pressure gradient*** over the whole slug unit between A and C (using the homogeneous no-slip model).

**Problem 2**



A vertical well can be modelled in a very simplified way as a pipe as shown in the figure to the right. In this problem the task is to study the impact of particles in a liquid (e.g. mud) on the effective density and pressures. The ***original*** liquid height $H_{liq}$ = 10 m and the pipe diameter is D = 10 cm.

***NOTE: there is no net liquid flow in this problem***

The action of many small particles can be simplified by a single ball with diameter $d_{ball}$ = 9 cm. The liquid density is as 1000 kg/m^3. The liquid viscosity is 2000 cP (very viscous!). The ball has density 5000 kg/m^3.

a) Calculate the initial bottom pressure ($P_{bottom}$)
   i. with no ball ("particles") in the liquid
   ii. with the ball immersed into the liquid hanging in a thin wire. The liquid ***volume*** is unchanged. Calculate the change in $P_{Bottom}$? Explain the reason for the pressure increase. (Hint: Ball volume = (4/3)*Pi *r^3)

b) The string is now cut. After some time the ball will reach a final velocity. Explain why? What is the condition for constant speed? Show the ***acting forces*** with a figure. Will the bottom pressure now increase compared to in question a)ii ?

c) For single phase liquid flow in pipes many different friction factors can be found. What is the difference between Moody and Fanning friction factors? Write the corresponding formula for frictional pressure gradient for each type?

d) Assume that in an article you find the friction factors listed below. Determine for each case if they are of Moody or Fanning type. (Hint: calculate ***f*** for a few selected Reynolds numbers and compare the values).
   a. $f1 = 0.0056 + 0.5 \cdot Re^{-0.32}$
   b. $f2 = 0.052 \cdot Re^{-0.21}$
   c. $f3 = -1.8 \cdot \log_{10}(6.9 / Re)$
   d. $f4 = 0.36 \cdot Re^{-0.2}$

# Appendix – Formulas

**Velocity profile for laminar Newtonian flow in a pipe:**

$$u(r) = u_{\max}\left(1-\left(\frac{r}{R}\right)^2\right)$$

**Laplace's equation, spherical bubble:**

$$p_i = p_o + \frac{2\sigma}{R}$$

**Rise velocity relations:**

$$U_0 = 1.53\left[\frac{\sigma g(\rho_L - \rho_G)}{\rho_L{}^2}\right]^{1/4}$$ ; 1mm < D < 1cm

$$\mathrm{U_{TB}} = \mathrm{u_L} + 0.35\sqrt{\mathrm{gD}}$$ ; Taylor bubble

**Mixture viscosity relations:**

Cichitti: $\mu_m = x\mu_G + (1-x)\mu_L$

McAdams: $\dfrac{1}{\mu_m} = \dfrac{x}{\mu_G} + \dfrac{1-x}{\mu_L}$

Dukler: $\mu_m = \varepsilon_G\mu_G + (1-\varepsilon_G)\mu_L$

**Turbulent friction factors:**

Blasius form: $f = C\cdot\mathrm{Re}^{-n}$

Dukler: $C = 0.046,\ n = 0.2$

Drew, Koo and McAdams: $\mathrm{f} = 0.0056 + 0.5\cdot\mathrm{Re}^{-0.32}$

Colebrook & White: $\dfrac{1}{\sqrt{f}} = 1.74 - 2\log_{10}\left(\dfrac{2\varepsilon}{D} + \dfrac{18.7}{\mathrm{Re}\sqrt{f}}\right)$