FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: Directional Drilling and Flowing Well Engineering - PET 505 **DATE:** 17.02.17

TIME: 09.00 – 13.00 **(4 hours)**

AID: Basic 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) What will be done if shallow gas is expected and explain why !

2) The upper sections are usually drilled with water or a waterbased mud system (WBM). It is common to switch to an oil based mud (OBM) in the lower sections. Discuss some advantages/disadvantages with using OBM in an HPHT well.

3) What is meant by “upper completion” and “lower completion” ?

4) What is the purpose of the IADC Bit Dull grading system ?

5) Explain the UTM system!

6) How do we specify the target of a well and explain why?

7) How does a rotary steerable system work ?

8)

We are drilling in North direction. The present inclination is 9 degrees. We have a motor that can change angle with 1˚/10 meter. We will turn the well to the West. Draw a Ragland diagram and perform necessary calculations to answer the following two questions:

a) What is the maximum azimuth change that can be achieved after drilling 30 meters with the motor ?

b) What will the toolface (TF) have to be and what will be the final inclination?

9)

A blowout is taking place in an HPHT well. We will try to intersect the blowing well at the last set casing shoe at 5000 meters TVD using an S shaped relief well. We will intersect at the shoe with an inclination of 10˚. This will be the target of the well. After the build section, there shall be a hold section that has an inclination of 35˚. The well will then drop and the intention is that the well shall hit the target when inclination has been reduced to 10˚. The build up and drop off rates are both 3˚/30 meters.

The coordinates of the last set shoe are 1500 m West, 1800 m South.

NB, remember to make a well sketch, use help figures when solving the exercise.

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

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

c) What will be the measured depth (MD) of the well when reaching the target?

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)

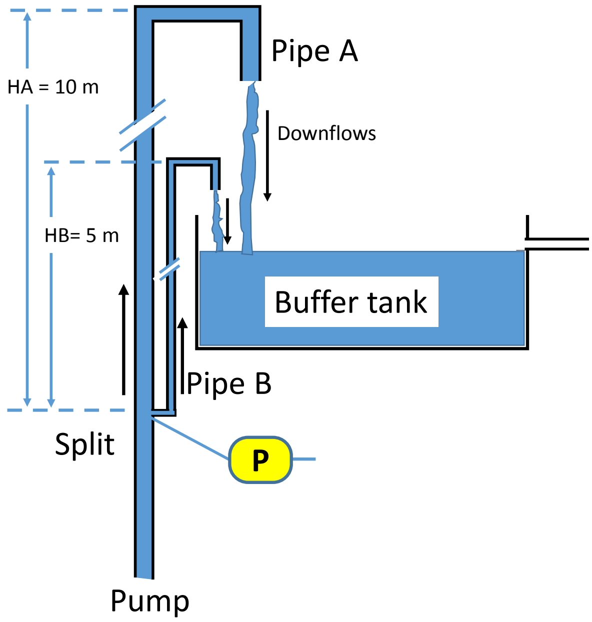
PART II - MULTIPHASE FLOW

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. It is up to you to decide if you need any of them.

Problem 1

a) Describe the various flow regimes that occur in vertical 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 the picture to the right is shown two vertical pipes A and B, with single phase liquid flowing upwards and returning into a tank. The pipe heights are HA=10 m and HB=5 m. Neglect the length and height of the return bends in to the tank (they are small). The pipe inner diameters are DA= 10 cm, and DB = 0.5 cm. Both pipes are smooth. The liquid has density ρ_L = 1100 kg/m3, and viscosity μ_L = 10 cP. The pressure outside the pipes is P0 = 1 bar.



   i. Assume that **initially** the **liquid level** stands **below the split** between A and B. Then pumping starts in order to give a **very low flowrate**. How will the liquid move in the two pipes from the start position start, until finally stabilized? What is the pressure P at the split just when liquid starts to flow out of pipe B?

   ii. What is the pressure P when the flow in pipe A start to flow out?

c) A little later the pumping rate is increased so that the flow speed in pipe A is UA = 2.0 m/s.

   i. Calculate the frictional pressure gradient in A? How are friction calculations done for "smooth pipes"? How much does friction change the measured pressure P?

   ii. Calculate the flow speed UB through pipe B? Is the flow laminar of turbulent?

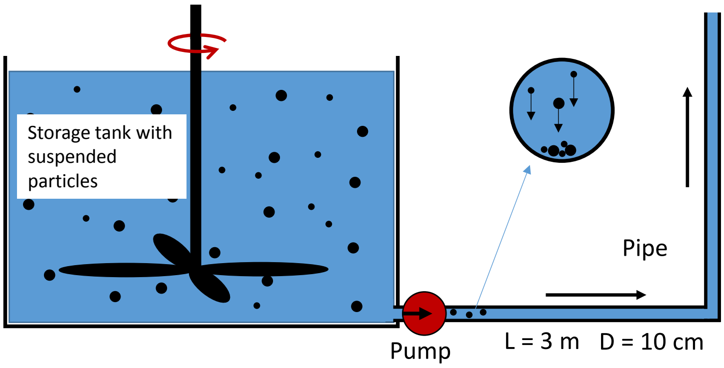
d) Even later, gas is entering into the flow from the bottom. The pipe split unit is made in such a way that gas bubbles ***cannot enter*** into pipe B, only liquid. The gas fraction can for simplicity be assumed constant (ε_G = 0.1). Assume the gas is **ideal** with density ρ_{Gref} = 1.2 kg/m3 at 1 bar and the present temperature.

   i. Calculate the gas density at 2.5 bar. What is meant with ideal gas?

   ii. Calculate the hydrostatic pressure gradient in pipe A? For simplicity use the gas density value you got in i) above.

   iii. Will the flow in B increase or decrease, compared to the gas free cases? Explain.

Problem 2



A large tank as shown in the figure to the right contains liquid with small particles kept in suspension as a mixture using a mixing propeller so that the particle concentration is constant around in the tank (the particle distribution is homogeneous). The liquid has density 1000 kg/m3. The **dynamic** viscosity is 1 cP.

The particle concentration (by volume) in the tank is 5%. The particle diameter d_p ranges from 100 μm (micrometer) to 1500 μm. The particle density is 2.6 g/cm3.

a) The pipe initially contains only liquid, the same liquid as in the tank. The pump starts at t=0 causing a constant volumetric flow. The flow velocity is U = 5 cm/s in the beginning. The particles are evenly distributed in the pipe just after the pump. They move with the liquid while they fall.

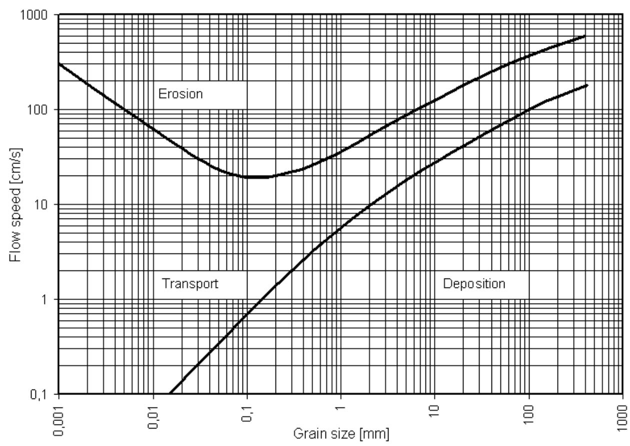
   i. Assume that the smallest particles follow Stokes law. Calculate their fall velocity. Check with the particle Reynolds number if the condition is fulfilled?

   ii. How long time does it take for the smallest particles which enter the pipe to fall down to the bottom? How far have they moved along the pipe in this time interval?

   iii. How long time would it take to fill the horizontal pipe if all particles settled there? Is this realistic? Explain what happens to the liquid flow speed if the particles settle and builds a bed over time. Make a drawing to explain. You may use the so-called "Hjulstrøm diagram" below to support your answer. What is meant with "Erosion", "Transport" and "Deposition"?

b) Particles may eventually reach the vertical pipe section. Can the biggest particles be transported by the liquid up the pipe? Give calculations to support your answer.

Extra information:



- ***Particle fall velocity*** in Stokes fall (laminar) :

$$V = \frac{g d_p^2 (\rho_p - \rho_L)}{18 \mu_L} \quad (\text{ for } Re_p < 10)$$

- ***Particle Reynolds number***: $Re_p = \frac{U_p d_p}{\nu_L}$ where U_p is the *relative velocity* between particles and liquid, and ν_L is the liquid ***kinematic*** viscosity **(!).**
- The so-called "***Hjulstrøm diagram***" to the right shows how particles will move in a **horizontal** flow in rivers (water) – or in pipes, as a function of the flow speed over a "particle bed" which is lying at the bottom.
- For particles falling with $Re_p > 10$, a published **correlation** gives the steady state fall velocity as:

$$V = \frac{16.17 \cdot d_p^2}{1.8 \cdot 10^{-5} + (12.1275 \cdot d_p^3)^{0.5}} \quad (\text{unit is m/s})$$

Appendix – Formulas (- if needed)

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:

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

Bubble rise velocity relations:

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

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

Mixture viscosity relations for gas and liquid:

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

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

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: $f = 0.0056 + 0.5 \cdot \mathrm{Re}^{-0.32}$

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