University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: Directional Drilling and Flowing Well Engineering - PET 505 **DATE:** 25.01.2020

TIME: 09.00 – 13.00 (4 hours)

AID: Basic calculator is allowed. No written or handwritten personal notes are allowed.

THE EXAM CONSISTS OF 9 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 W. Time, Kjell Kåre Fjelde

PART I - Directional Drilling

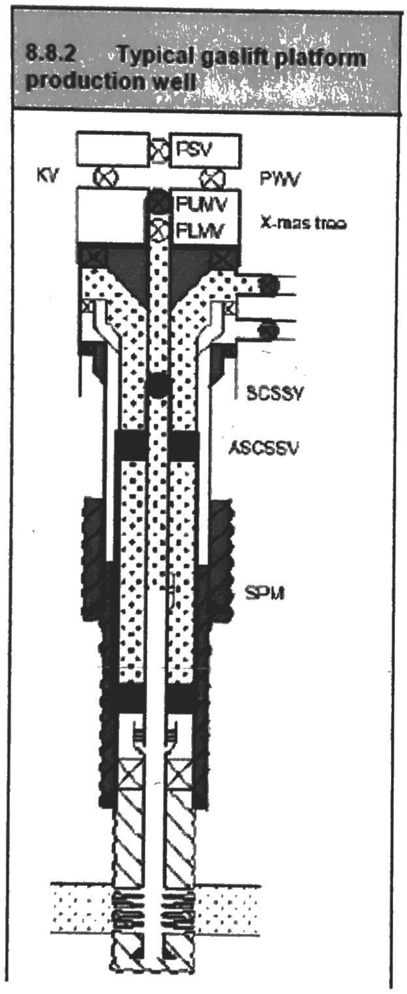
This part constitutes 50 % of the exam. Formulas can be found in the Appendix just after Part I.

1]

What precautions will be taken if shallow gas is expected when drilling the top hole sections? (also explain why)

2]

What will be the primary barrier elements in a production well with gas lift?



3]

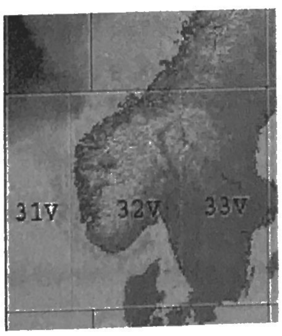
Below, we have a PDC bit and a roller cone. Discuss briefly advantages and disadvantages with each!

4]

What are the advantages of using a rotary steerable system compared to using a mud motor for directional drilling?

5]

The following figure shows a UTM zone. Explain how the East and North coordinates in a UTM zone are defined.



6]

In the Statoil (Equinor) drilling program, we saw that they placed the horizontal well (producer) in the upper part of the sand package near the shale roof. Why do you think they placed the well like this?

7]

Three methods for calculating the vertical, eastern and northern displacement based on survey measurements are: The tangential method, the balanced tangential method and the minimum curvature method.

What are the assumption behind each of these methods regarding the wellpath and which method do you recommend?

8]

During drilling, it was seen necessary to adjust the well path. A correction run with a positive displacement motor and a bent sub had to be carried out. This tool is able to change angle with $\frac{3^\circ}{30m}$

The present inclination is 6 degrees and the azimuth is 180 degrees. The toolface is set at 60 degrees to the right of high side.

We want to find the new inclination and the new azimuth after drilling two stands (60 meters) using the correction tool.

a) Draw a Ragland Diagram

b) What is the new azimuth and 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. Some useful formulas can *eventually* be found in the Appendix of Part II.

Problem 1

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

*****

Assume steady gas-liquid flow in a horizontal pipe with inner diameter D = 0.1m. The volumetric gas and liquid flow rates are Q_G = 5 L/s and Q_L = 7 L/s (L= litre). The liquid density is 1000 kg/m^3 and the (dynamic) viscosity is 5 cP (centipoise). The pressure is 10 bar. The gas can be assumed ideal, and at reference pressure 1 bar the gas density is 1.2 kg/m^3. The ***kinematic viscosity*** of the gas is $1.3 \cdot 10^{-5}$ m^2/s. Neglect temperature effects.

b) Calculate the superficial velocities. Find the most likely flow regime according to "your own" flow regime map. Calculate also the

   i) gas density and viscosity

   ii) average true gas fraction assuming the slip ratio is 5.

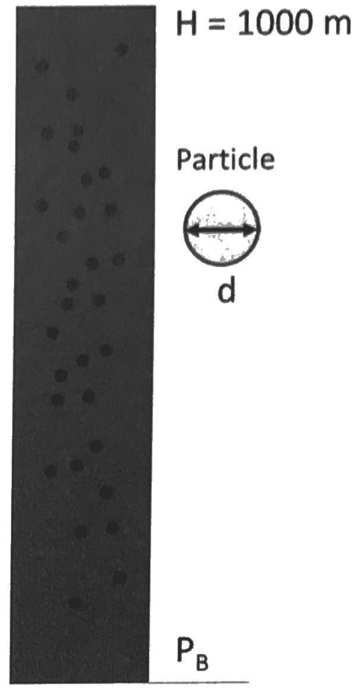
c) Assume for simplicity that the flow regime is slug flow. Make a sketch of the situation if the liquid plugs are gas free. The flow rates of gas and liquid in the pipe are constant, as in a)

   i) What is the mixture velocity in the pipe, and in the liquid plugs? Explain.

   ii) Assume the plugs are L= 6 meters long. Calculate the pressure gradient in the liquid plug, and the total pressure difference between the two ends. Use the Dukler friction factor for simplicity.

d) Assume the flow regime was homogeneous instead of slug, using the same data as in a). What would now be the total pressure gradient in the pipe. Use the Haaland friction factor for this case? Why is this pressure gradient lower than in the liquid plug as will be the result in c)?

Problem 2



This problem concerns cuttings particles suspended in drilling mud in a H = 1000 m high well. The following questions concern settling speed and eventual impact of particles on "bottomhole" pressure P_B. The drilling is stopped, so there is no net mud flow in the well.

The liquid mud itself has density 1100 kg/m^3, and the viscosity is 10 cP. The particle density is ρ_P = 1600 kg/m^3.

a) Consider one single particle with diameter d, and density ρ_P.
   i. Make a sketch showing the forces acting on the particle
   ii. Explain the equation and the symbols

$$F_D = A_P \cdot C_D \cdot \frac{1}{2}\rho U^2$$

b) Calculate the drag force on particles with diameter 0.1 mm. Just assume that the particle fall speed through the mud at some instant was 0.02 m/s. Is the "particle fall regime" laminar or turbulent? Compare the drag force with the effective gravity force (i.e. including buoyancy). Would the fall speed change after this instant? Assume "laminar fall" to find the steady state fall ("settling") speed for the particle.

c) Another particle has diameter 5 mm? Assume that also this particle has an initial fall speed of 0.02 m/s. What will happen to the fall speed of this particle afterwards? Show by calculations.

d) Is the bottomhole pressure P_B influenced by the falling particles? If so - why, and how? If the mud contained 100,000 of only the smallest particles (d = 0.1 mm) per cm^3, what would be the volumetric particle concentration, and from that the "effective" mixture density? Find the bottomhole pressure PB. (The pressure at the top is Ptop = 1 bar).

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 /fall velocity relations:

$$U_{T\infty}^0 = \frac{g d_e^{\,2} \Delta\rho}{6\mu}\left(\frac{\kappa+1}{3\kappa+2}\right), \text{ where } \kappa = \frac{\mu_d}{\mu}$$; small spherical bubbles, droplets, and particles

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

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

Mixture viscosity relations:

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:

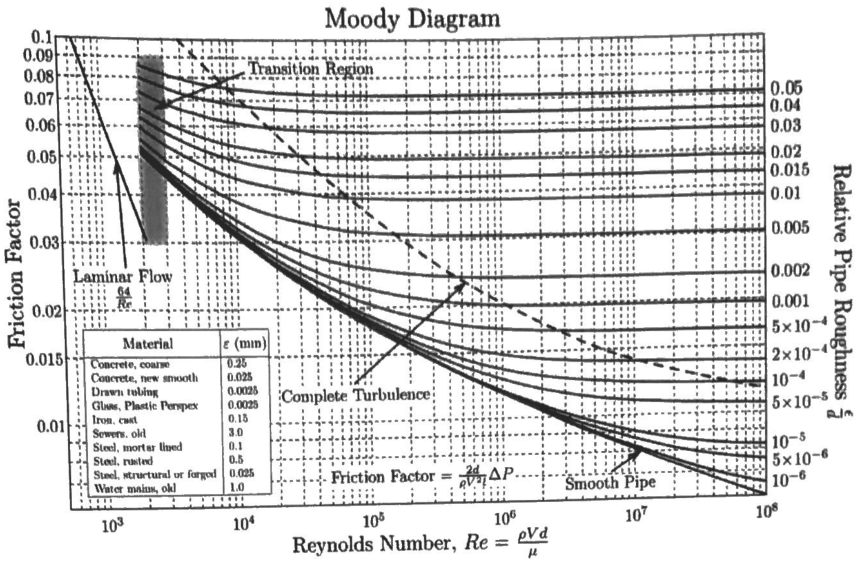
Blasius form: $f = C \cdot \mathrm{Re}^{-n}$

Dukler: $C = 0.046, n = 0.2$

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

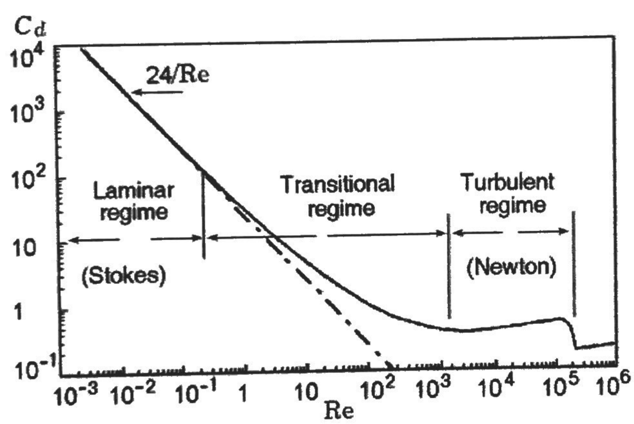
Colebrook & White: $\frac{1}{\sqrt{f}} = 1.74 - 2\log_{10}\left(\frac{2\varepsilon}{D} + \frac{18.7}{\mathrm{Re}\sqrt{f}}\right)$

Haaland: $\frac{1}{\sqrt{f}} \approx -1.8 \cdot \log_{10}\left(\left(\frac{\varepsilon / D}{3.7}\right)^{1.11} + \frac{6.9}{\mathrm{Re}}\right)$



PARTICLE SETTLING

Particle drag coefficient vs particle Reynolds number



Particle Reynolds number: $Re_p = \dfrac{\rho_L U_{rel} d_P}{\mu_L}$

For laminar flow around the particle: $C_d = \dfrac{24}{Re_p}$

And in general:

$$C_D = \frac{24}{\mathrm{Re}} + \frac{2.6\left(\frac{\mathrm{Re}}{5.0}\right)}{1+\left(\frac{\mathrm{Re}}{5.0}\right)^{1.52}} + \frac{0.411\left(\frac{\mathrm{Re}}{2.63\times10^5}\right)^{-7.94}}{1+\left(\frac{\mathrm{Re}}{2.63\times10^5}\right)^{-8.00}} + \frac{0.25\left(\frac{\mathrm{Re}}{10^6}\right)}{1+\left(\frac{\mathrm{Re}}{10^6}\right)}$$