University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: Directional Drilling and Flowing Well Engineering - PET 505 **DATE:** 13.02.18

TIME: 09.00 – 13.00 **(4 hours)**

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

THE EXAM CONSISTS OF 8 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.

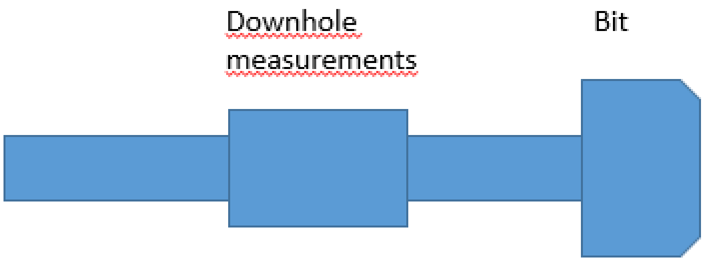
1) Which hole sizes and casings are typically involved when constructing a well ?

2) Make a sketch of a completed well where you include production casing (9 5/8), packer, production tubing, gas lift valve, annular safety valve, downhole safety valve and XMT

3) Describe the three ways you can place the stabilisators in the BHA (bottomhole assembly) to change the directional behaviour of the drillstring (build, hold, drop). (you can illustrate this by drawings)

4) Explain how a mud motor works and how it is used in operation!

5) We measure different parameters downhole. Name 7 parameters that we typically measure



6) Give a description of the UTM system coordinate system

7)

We are drilling in the direction N45W. The present inclination is 9 degrees and the hole shall be turned 45 degrees to the right (azimuth shall increase 45 degrees). The toolface angle will be 90 degrees. The directional drilling tool has a maximum dogleg severity of 3° per 30 meter. Start by drawing a Ragland diagram

a) What will be the expected length of the correction run ?

b) What will the final inclination be (solved graphically or by calculation)?

8)

We will here perform calculations for a near horizontal well. There will first be two build sections, i.e. two kick off points (KOP1 & KOP2) before the well becomes near horizontal (88 degrees). The slot coordinates are (N_s,E_s)=(4.7 m north , 1.5 m east). The target of KOP2 is given by the coordinates: (N_T,E_T)=(550 m north, 1500 m east). Both build up sections have the same build up rate. Otherwise:

- KOP2: 3900 m TVD
- KOP1: 1500 m TVD/1500 m MD.
- Build up rate: $\frac{\Delta i}{\Delta l} = \frac{1.5°}{30m}$

a) Find the horizontal displacement and azimuth of KOP2!

b) Show by calculation that the maximum inclination after the first build up is 38.6 degrees!

c) What is the measured depth when reaching KOP2?

After the second build up, we will enter the reservoir with an inclination of 88 degrees. This inclination will then be kept fixed. Then we will drill a 1200 meter long wellpath where the dogleg severity is 2.0° per 30 meter. A plane, circular arc is assumed for the wellpath in the reservoir section. The well will be turned towards the north.

d) Here one shall calculate the final azimuth of the well! This can be done in several ways. Try to show two different calculation approaches for finding the final azimuth.

e) What are the final coordinates of the well (North, East and Vertical) ?

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

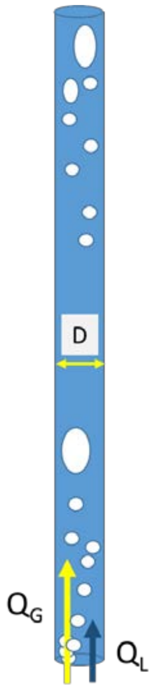
1 feet = 0.3048 m

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

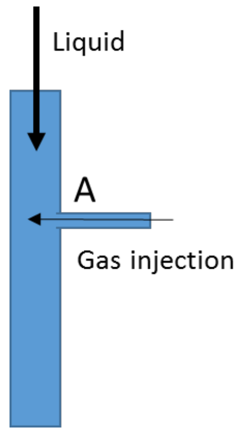
a) Describe briefly the various flow regimes that occur in vertical co-current upwards gas-liquid pipeline flows. Sketch also a flow regime map with superficial gas and liquid flow velocities on the axes. Give values on the axes.

Assume gas liquid flow in a vertical pipe with inner diameter D = 0.1m. The volumetric gas and liquid flow rates are Q_G = 8 L/s and Q_L = 20 L/s (L= litre).

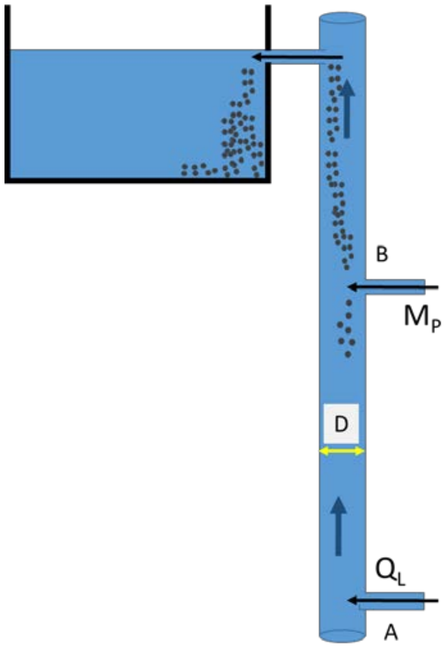
b) Calculate the "no-slip" gas fraction. The true gas fraction in the pipe is 0.25.
   i. Define and calculate the slip ratio S.
   ii. Calculate the superficial gas velocity, and the true gas "phase velocity".

c) In another situation the pipeline in b) transports only liquid. The liquid density is 1000 kg/m^3 and the viscosity is 3 cP (centipoise). The flow velocity is 2.7 m/s. Assume that the pipe is smooth.
   - Calculate friction factor, and the frictional pressure gradient, based on the Dukler formula.
   - Do the same as above, using either the Moody diagram or the Haaland formula. Comment on the results obtained with Dukler, versus Moody (or Haaland).

d) In another situation, gas is injected at low flowrates into the pipe through an injection line at A in the figure. Liquid (water) is now pumped from the top of the pipe as in a). The gas density is 5 kg/m^3 at the injection point. Interfacial tension is 50mN/m. Assume that the gas mostly becomes dispersed into small bubbles, with diameters in the range from 1 mm to 1 cm. The aim is to flow gas downwards in the pipe.
   - What liquid flow speeds are required for this to happen? Explain and do calculations to support your conclusion.
   - What liquid flow speed is needed to "bullhead" Taylor bubbles downwards?



Problem 2



The principle for a hydraulic driven particle separator is shown in the figure to the right. At the bottom point A of a pipe liquid is pumped upwards at a controlled variable flowrate. At point B higher up, particles of various sizes are injected at a certain mass feed rate M_P. The particles are mostly quarts, with a density of 2.65 g/cm^3.

They are assumed to be spherical.

The inner diameter of the pipe is D = 20 cm. The liquid is incompressible with density 1000 kg/m^3, and the viscosity is 1 cP (Newtonian).

a) Particles falling through liquid is exposed to friction forces and settling speed can be calculated from the definition of drag coefficient given by

$$C_d = \frac{F_d}{\frac{1}{2}\rho_f U_{rel}^2 A}$$

Define the different symbols and compare CD with the friction factor concept for pipe flow. What is the unit for the different quantities?

b) Calculate the gravitational force on a particle with diameter d_P =100 μm (micrometer)? Calculate the "effective weight" of the particle in the liquid.

c) Very small particles could in principle be balanced by the upwards liquid speed, thus standing nearly still. For such a situation, find the liquid speed and the particle Reynolds number for a particle diameter d_P= 100 μm (micrometer). Assume that the flow around the particle is laminar ("Stokes flow"). Check that the liquid speed is consistent with laminar flow around the particle.

d) Some particles are transported upwards, while others fall to the bottom. While falling, the average volumetric concentration of particles in the liquid between B and A is 10 %. What is the pressure gradient between A and B, assuming that the liquid flow speed is very low?

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

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

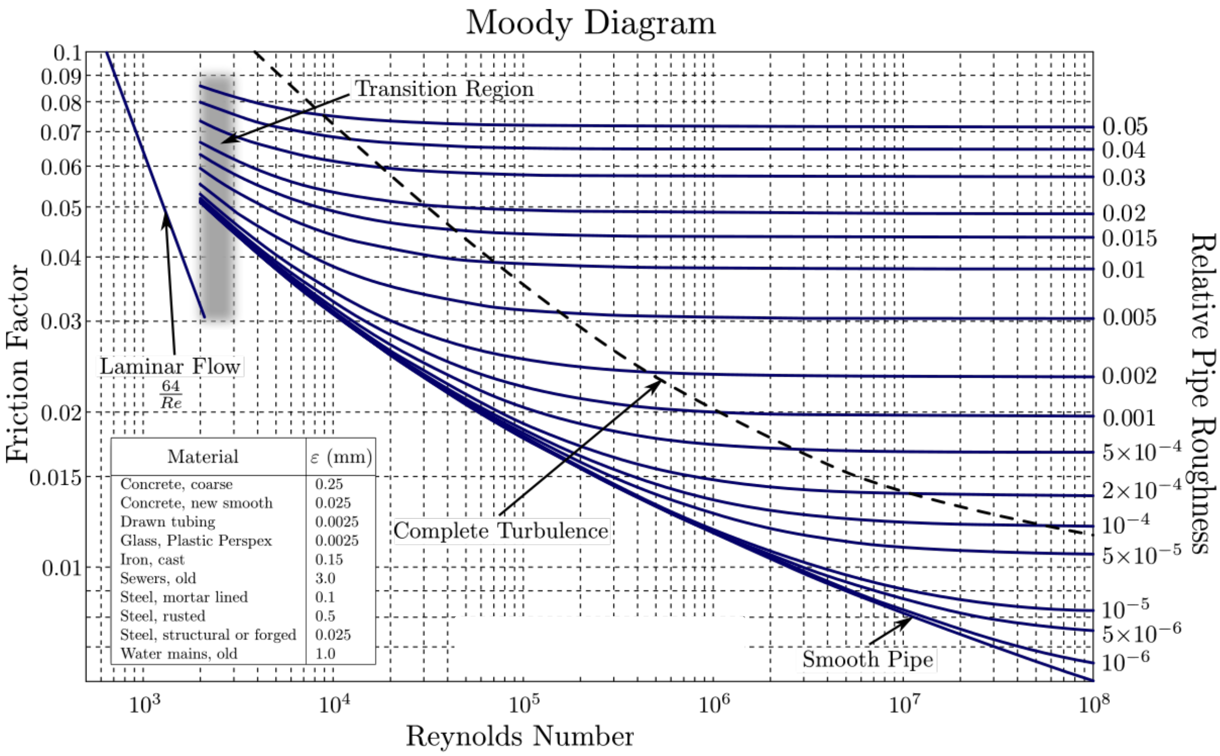
Blasius form: $f = C \cdot \mathrm{Re}^{-n}$

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

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

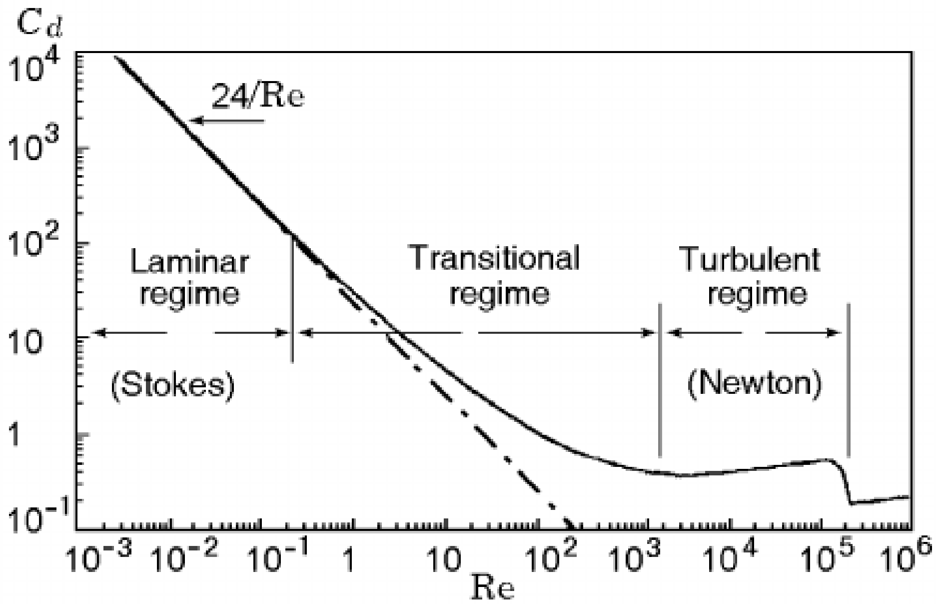
Colebrook & White: $\frac{1}{\sqrt{f}} = 1.74 - 2\log_{10}\left(\frac{2\varepsilon}{D} + \frac{18.7}{\mathrm{Re}\sqrt{f}}\right)$

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



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: $C_d = \dfrac{24}{Re_p}$