University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: Directional Drilling and Flowing Well Engineering - PET 505 **DATE:** 24.02.15

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 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: Kjell Kåre Fjelde, Fionn Iversen

TELEPHONE NUMBER: 47860601 (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 operational problems/challenges can occur during drilling of the upper sections and what can be done to prevent/reduce these (tools and procedures) ?

2) Describe what is the purpose of the following components in a completed well.

   - Wellhead
   - Tubing hanger
   - XMT

3) The following figure shows a hybrid bit. What kind of advantages does this have ?

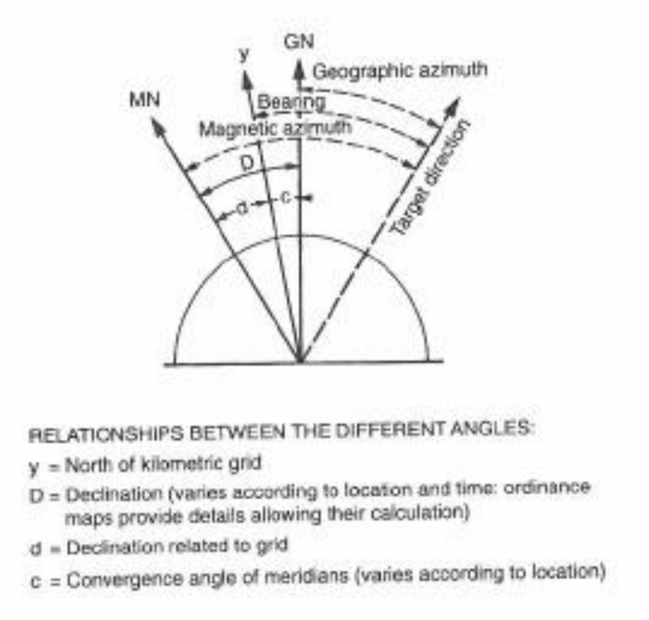
4) Describe the three ways you can place the stabilisators in the BHA (bottomhole assembly) to change the directional behaviour of the drillstring (build, hold, drop). (you can illustrate this by drawings)

5) What do we mean by push the bit vs point the bit steerable tools (what is the main difference in functionality)

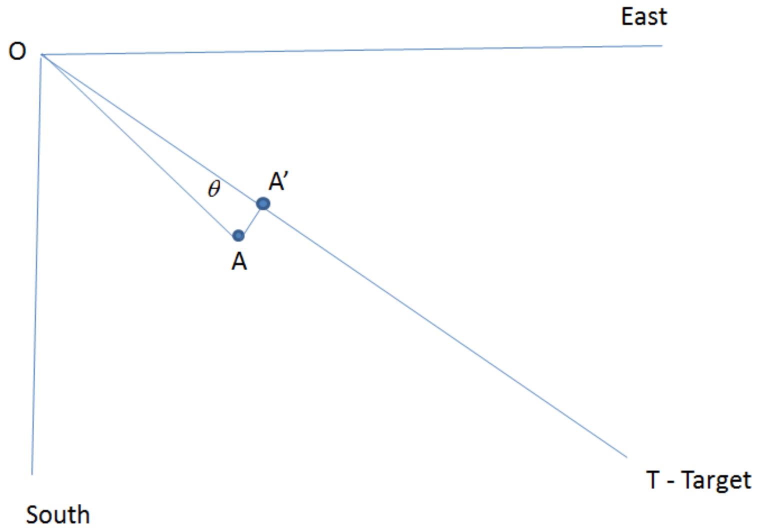
6) When studying the drilling program from Statoil, what kind of uncertainties were intended to be revealed by drilling a pilot hole across a fault ?

7) A well is to be drilled from a fixed installation. The target is 3000 meters to the East and 2000 meter to the South. The depth is 4000 m TVD. The coordinates are given in relation to the geographic north.

a) What is the horizontal displacement of the target and what is the azimuth ?



b) At our location, the magnetic pole is to the left of the magnetic North as indicated in the figure above. In 1990, the difference was 15 degrees. However, every year since then the magnetic pole has moved 0,11 degrees per year to the East (towards Siberia). What will the Azimuth of our target be in 2015 when measured with reference to the magnetic North Pole ?



c) Let the coordinate of A and T be (S_A,E_A) and (S_T,E_T). Show that the angle θ is given by the formula: $\theta = \tan^{-1}(\frac{E_T}{S_T}) - \tan^{-1}(\frac{E_A}{S_A})$ and that $OA' = \sqrt{(S_A^2 + E_A^2)} \cdot Cos\theta$

d) We are given the following survey points:

Point	South (m)	East (m)	TVD (m)
A	100	10	1000
B	1100	1500	2000
C	1500	2500	4000
Target	2000	3000	5000

Perform necessary calculations and make a sketch of the vertical section

8) We are drilling in the direction N45W. The present inclination is 9 degrees and the hole shall be turned 45 degrees to the right. 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) ?

9) A well shall be drilled vertical down to KOP (kick off point at 1100 m MD, 1100 m TVD). Then there will be a build section and a hold section until we reach target T which is located at 4100 m TVD. The horizontal displacement of the target is 1838 m. The build up rate is $\frac{\Delta i}{\Delta l} = \frac{3^0}{30m}$. We have also given: $R = \frac{180}{\pi} \cdot \frac{\Delta l}{\Delta i}$
   a. Calculate the maximum inclination after the build up! (NB make a drawing before starting to solve the problem)

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. Formulas can be found in the Appendix of Part II.

MULTIPHASE PROBLEM 1.

a) f is a stochastic variable. Express the average value of f^2 by the standard deviation and average of f.

b) The cross-sectional velocity field u(r) and phase distribution d(r) has been measured in a flowing pipe with axisymmetric flow, where d(r) = 1 for liquid phase and d(r) = 0 for gas phase. Express as a spatial average
   a. the cross-sectional liquid phase velocity.
   b. the cross-sectional superficial liquid velocity.

MULTIPHASE PROBLEM 2.

a) Derive Laplace's equation for a spherical bubble, giving the pressure difference over the bubble surface as a function of the surface tension and bubble radius.

b) A bubble of CO_2 of diameter 1cm is rising in water close to the water surface. The rise velocity is 0,25 m/s . Express necessary assumptions and estimate
   i. interfacial tension.
   ii. pressure inside the bubble.

c) Assume a CO_2 bubble of equal mass as in b) at 50m water depth. What would be the rise velocity of this bubble? Ideal gas law and constant temperature may be assumed.

$$g = 9{,}81\, m/s^2$$

$$R = 8{,}314\, J/mol\,K$$

At atmospheric conditions:

$$\rho_{Water} = 1{,}0\, kg/l$$

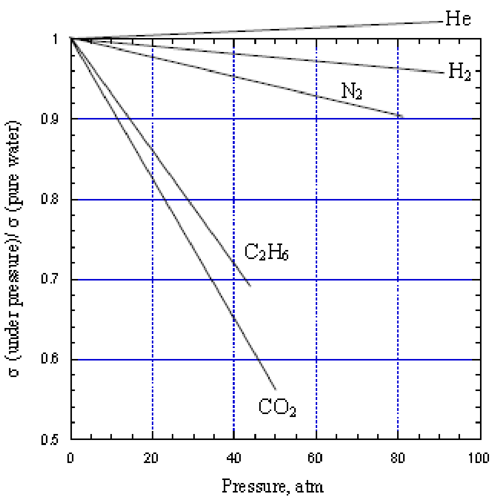
$$\rho_{CO_2} = 1{,}78\, kg/m^3$$

Rise velocity relation:

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

Effect of gas pressure on interfacial tension:

$$\frac{\sigma(P)}{\sigma_0} = 1 - K \cdot P$$



MULTIPHASE PROBLEM 3

Consider upward liquid / gas flow in a vertical pipe, with the following parameters: Pipe diameter D=10cm. Gas volumetric flowrate $q_G = 0{,}15\, m^3/s$. Liquid volumetric flowrate $q_L = 0{,}09\, m^3/s$. Liquid phase velocity $u_L = 20\, m/s$.

a) Determine the slip ratio.
b) Determine gas and fluid fraction.
c) What is the two-phase flow regime?

MULTIPHASE PROBLEM 4

Consider single phase flow of oil in a horizontal pipe with smooth inner surface. Temperature may be assumed constant at 25°C. Pipe diameter 5 cm. Pressure at the pipe inlet is 30 bar. Volumetric flowrate $q_{Oil} = 100\, l/\min$. Liquid density $\rho_{oil} = 900\, kg/m^3$. Liquid viscosity $\mu_{oil} = 2{,}0\, cP$.

a) What is the frictional pressure gradient in the pipe?
b) Consider now a leak in the pipe inlet letting in gas at a mass flowrate of 0,03 kg/s. The gas is ideal with molar weight $M = 25\, g/mol$, and gas viscosity $\mu_{gas} = 0{,}03\, cP$. Ideal gas constant $R = 8{,}314\, J/mol\,K$. What is the effect of the gas leak on the frictional pressure gradient?
c) Consider further an expansion of the pipe from 5 cm to 15 cm diameter. What is the pressure change due to change in velocity over this expansion, neglecting frictional effects?

Appendix – Formulas

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

Small gas fraction corresponds to $\varepsilon_G \leq 0.1$

Turbulent friction factors:

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

Dukler: $C = 0.046, n = 0.2$

Drew, Koo and McAdams: $f = 0.0056 + 0.5C \cdot \mathrm{Re}^{-0,32}$

Nikuradse: $\frac{1}{\sqrt{f}} = 1.74 - 2\log_{10}\left(\frac{2\varepsilon}{D}\right)$