University of Stavanger

# FACULTY OF SCIENCE AND TECHNOLOGY

**SUBJECT:** Directional Drilling and Flowing Well Engineering - PET 505 **DATE:** 07.12.17

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

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

**THE EXAM CONSISTS OF 10 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 $g = 9.8\ m/s^2$.

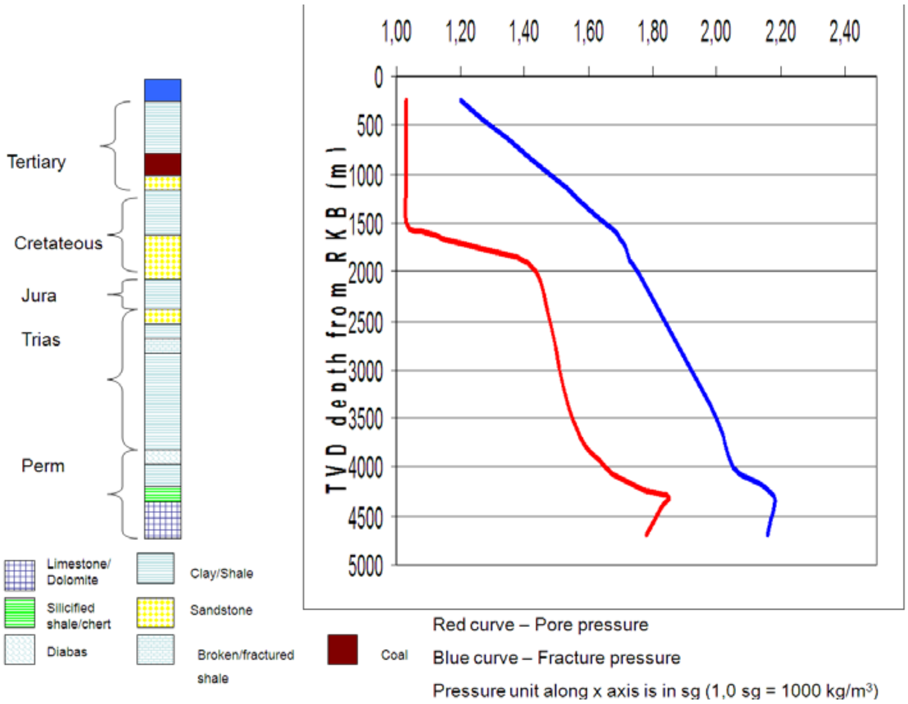
**COURSE RESPONSIBLE:** Rune Time, Kjell Kåre Fjelde

**TELEPHONE NUMBER:** 97035299 (Time), 47860601 (Fjelde)

## PART I - Directional Drilling

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

1) The following figure shows the pore and fracture pressure for a given stratigraphic column.




Give a proposal for where you want to set the different casing shoes and also proposed appropriate mudweights for the different sections! The reservoir is in the dolomite/limestone.

| Hole section | Casing size | Setting depth from RKB (m) | Mudweight (sg) |
|---|---|---|---|
| 36” | 30” | ? | ? |
| 26” | 18 5/8” | ? | ? |
| 17 ½” | 13 3/8” | ? | ? |
| 12 ¼” | 9 5/8” | ? | ? |
| 8 ½” | 7” liner | ? | ? |

2) A production well is 3000 meters deep. The reservoir pressure at this depth is 1.6 sg. The average density of the gas condensate in the well is 0.3 sg. What will the shut in wellhead pressure be in bar and psi ? (This is the pressure seen at the closed XMT)

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

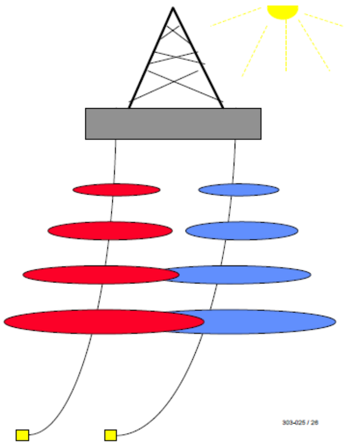
4) How do we communicate measurements taken downhole to surface? (what is the most common way of transferring information)

5) Explain how a rotary steerable drilling system works and mention some benefits these systems have!

6) When drilling with a steerable liner, they have installed a flowdiverter just above the liner such that some of the mud flowing in the drillstring are lead directly into the annulus just above the liner! What was the benefit of doing that?

7)

a) Why do we have to express the wellbore position as an ellipse of uncertainty? Why is it an ellipse and why do they become bigger as you drill ahead?



b) We are drilling in the Eastern Barents Sea. The magnetic pole is to the right of the geographic north pole and the deviation is 11 degrees (i.e. declination is + 11 degrees). The UTM system has a convergence of – 4 degrees (minus 4 degrees). Our magnetometer indicates that the wellbore azimuth is 110 degrees.

What will the azimuth be when using the UTM system as reference? and what will the azimuth be when using the geographic north as reference ?

8)

We are drilling slightly downwards with an inclination close to being horizontal. We are using azimuthal resistivity and the sensors are placed 10 meter behind the bit. When the bit is at 5000 meter the 18 ft sensor reacts upon the oil water contact below. When the bit is at 5060 meters the 10 ft sensor reacts. How many meters more can we drill before we enter the water zone if we do not make any well path corrections?

9)

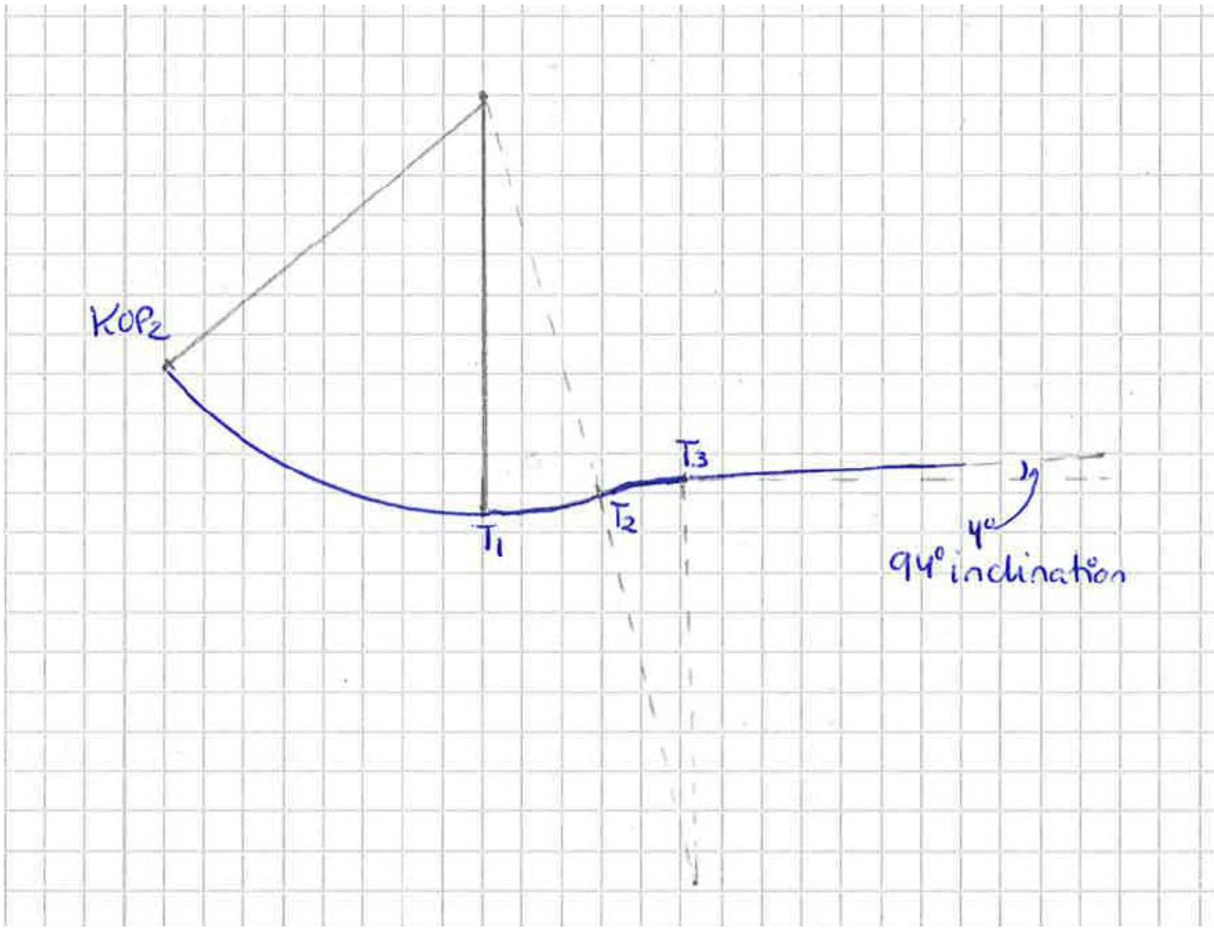
We will here perform calculations for a near horizontal well. There will first be two build sections, i.e. two kick off points (KOP1 & KOP2) before the well becomes horizontal. The inclination after the first build up shall be 40 degrees.

Both build up sections will use a build up rate $\frac{\Delta i}{\Delta l} = \frac{2^0}{30m}$. We have also given: $R = \frac{180}{\pi} \cdot \frac{\Delta l}{\Delta i}$

The position of KOP2 is given by ($N_{Kop2}$,$E_{Kop2}$)=(1100 m south, 1100 m east) and the TVD of KOP2 is 3800 meters.

a) Find the horizontal displacement and azimuth of KOP2!
b) Calculate the depth of KOP1!

c) What will be the **measured depth**, **true vertical depth** and **horizontal displacement** of the well when the well has become horizontal ? (Note this corresponds to T1 in figure below)




Due to some geological issues, one will immediately after reaching horizontal start to build angle with the same rate as before. At T2 the inclination is 106 degrees. Then at T2 on start to drop angle with the same rate as before until one reaches an inclination at T3 that is 94 degrees. This will be kept through the reservoir section.

d) What will the displacement changes be in vertical, northern and eastern direction when moving from T1 to T3 ?

## 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

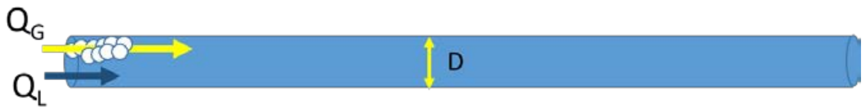
1 sg = 1 kg/l (sg - specific gravity)

# 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 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.




Assume stratified smooth gas liquid flow in a horizontal pipe with inner diameter D = 0.1m. The volumetric gas and liquid flow rates are  $Q_G$ = 8 L/s and $Q_L$ = 1 L/s (L= litre).

b) Calculate the "no-slip" liquid fraction. The true gas fraction in the pipe is 0.4.
   i. Define and calculate the slip ratio S.
   ii. Calculate the superficial gas velocity, and also the gas flow velocity ("phase velocity") in the case of no slip.

c) In another situation the pipeline in b) transports only liquid. The density is 1000 kg/m^3 and the viscosity is 1 cP (centipoise). The flow velocity is 1 m/s.
   - Assuming the pipe is smooth, calculate the friction factor, and the frictional pressure gradient, based on the Dukler formula.

d) During time, deposits build up in the pipe to make it rough. With the same flow rate as in c) it is observed that the pressure drop increases to 1500 Pa measured over a length of 10 meter. The pipe diameter is assumed unchanged (for this calculation).
   - Can a relative roughness of 1% ( $10^{-2}$ ) be enough to explain such an increase? Use e.g. the Haaland formula or Moody graph.

**Problem 2**

A vertical well with a static liquid column can be modelled in a very simplified way as shown in the figure to the right. The task is to study the effect of a compact cylinder which is gradually lowered into the liquid by a thin strong wire running over the top pulley.

The cylinder diameter $d_C$ = 19 cm, its height is $h_C$ = 15 meters, and the density is 4000 kg/m^3. The inner diameter of the well is D = 20 cm.

The initial liquid column height $H_{liq}$ = 100 m, then at the origin y=0.

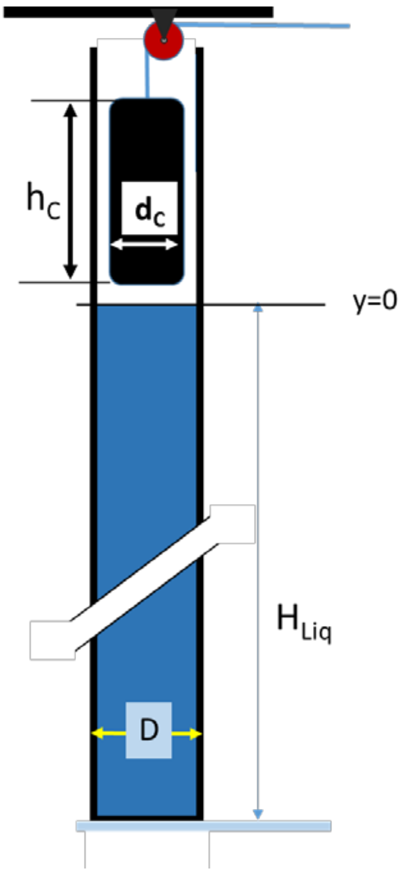
***NOTE: there is no net liquid flow in or out of the well.***

The liquid is incompressible with density 1000 kg/m^3, and the viscosity is 2000 cP (very viscous – but still Newtonian).

a) Calculate the initial bottom pressure in the well ($P_B$) before the cylinder reaches the liquid interface. Calculate also the cylinder volume, mass and weight as felt by the wire.

b) The cylinder is slowly lowered until it reaches the interface, and is further gradually immersed into the liquid. Calculate the liquid height $H_{liq}$ when the cylinder is completely immersed, but still hangs in the wire. For this case;
   i. What is the bottom pressure PB?
   ii. Calculate the apparent weight of the cylinder.

   Later, the wire suddenly breaks when the cylinder is completely immersed, so that the cylinder starts to fall freely through the liquid.




c) Assume that the annulus around the cylinder is concentric. If the cylinder fall velocity at some instant t is V(t), what is then the liquid velocity UL(t) in the annulus?

d) Answer the following questions regarding the bottom pressure PB:
   i. Make a qualitative graph of PB versus time while the cylinder accelerates.
   ii. Show the forces acting on the cylinder with a sketch! How much friction force is needed to obtain constant fall speed?
   iii. Finally, when the cylinder has reached the bottom and stops, what is then the value of PB?

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

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

**Turbulent friction factors:**

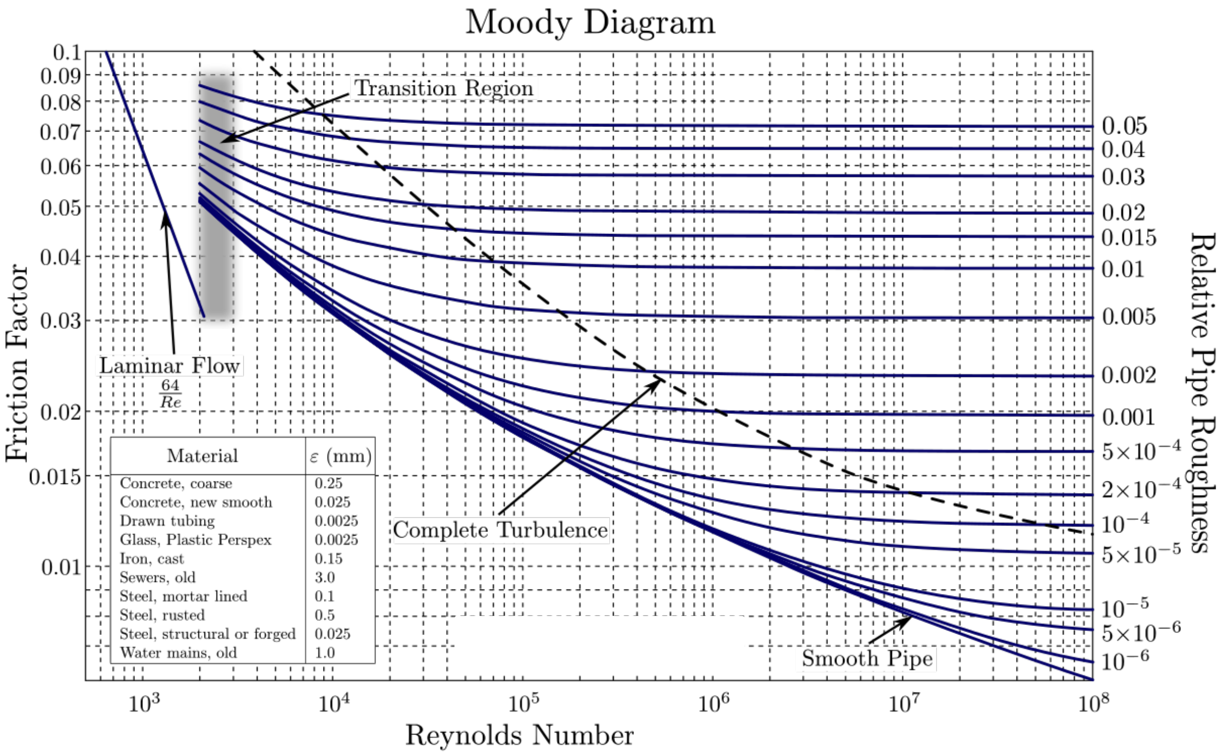
Blasius form: $f = C \cdot \mathrm{Re}^{-n}$

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


Moody Diagram
Transition Region
Laminar Flow
64/Re
Complete Turbulence
Smooth Pipe
Friction Factor
Reynolds Number
Relative Pipe Roughness
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.015
0.01
10^3
10^4
10^5
10^6
10^7
10^8
0.05
0.04
0.03
0.02
0.015
0.01
0.005
0.002
0.001
5×10^-4
2×10^-4
10^-4
5×10^-5
10^-5
5×10^-6
10^-6
Material | ε (mm)
Concrete, coarse | 0.25
Concrete, new smooth | 0.025
Drawn tubing | 0.0025
Glass, Plastic Perspex | 0.0025
Iron, cast | 0.15
Sewers, old | 3.0
Steel, mortar lined | 0.1
Steel, rusted | 0.5
Steel, structural or forged | 0.025
Water mains, old | 1.0