University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: PET 505 Directional Drilling and Well Flow Engineering

DATE: 10.12.2021

TIME: 09.00 – 13.00 (4 hours) + 15 minutes for uploading files

AID: All aids are permitted

THE EXAM CONSISTS OF 13 PAGES, including the front page

REMARKS:
General information about the problems:

- 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: A.H. Rabenjafimanantsoa, Kjell Kåre Fjelde

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Exam

PET505

Directional Drilling and Flowing Well Engineering

2021 Autumn

Time

The exam starts at: 10.12.2021, 09:00

The exam ends at: 10.12.2021, 13:00

Exams that contains file uploads will have an additional 15 minutes for uploading files.

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Important contacts

If you need help during the exam, you can call one of the phone numbers below. This applies if you need clarifications from the course responsible or administrative support.

Course responsible: Benja, a.h.rabenja@uis.no, telefon numbers: 51 83 21 47 and 51 83 22 15 (Kjell Kåre Fjelde).

Administrative support: 51 83 31 26

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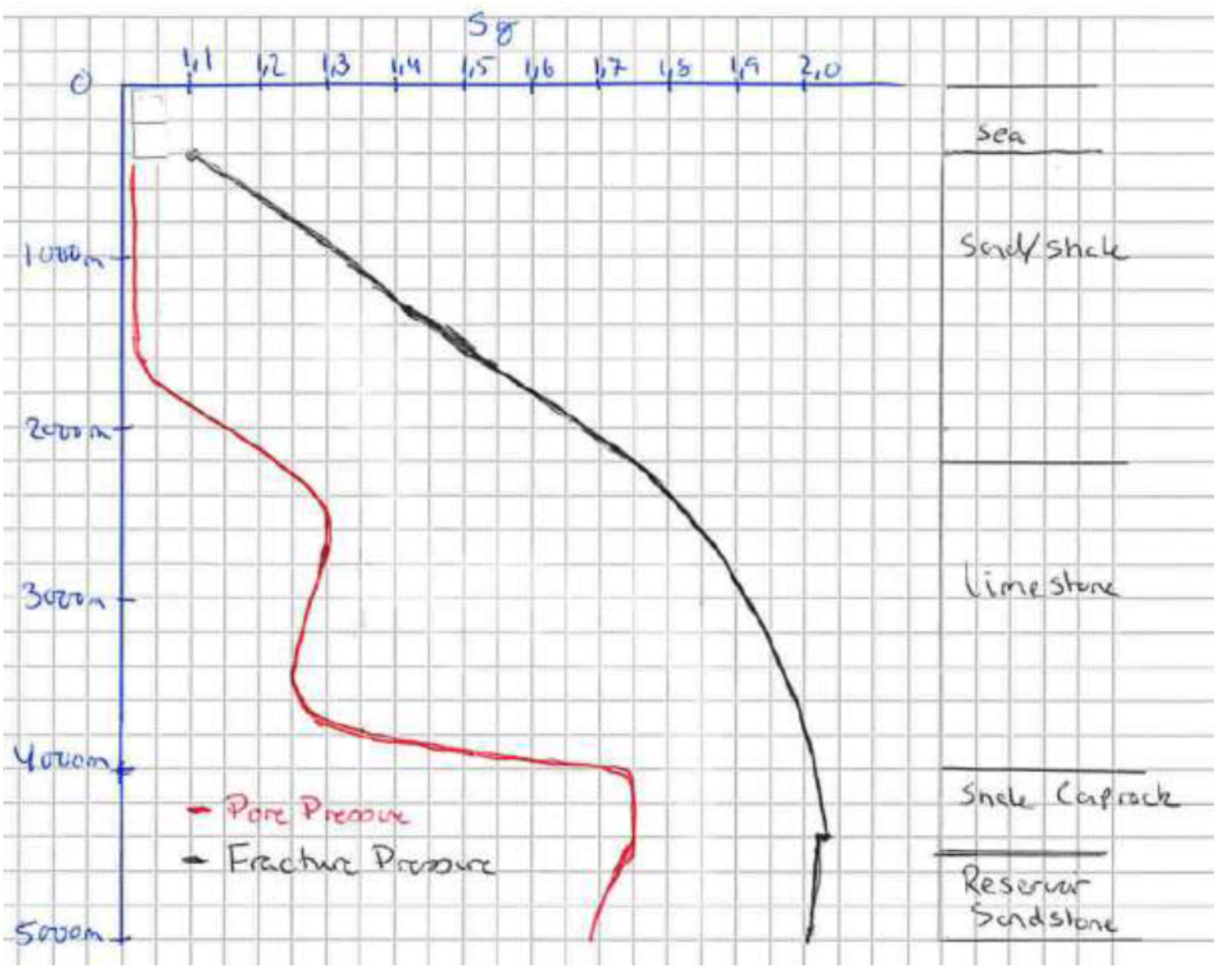
Good luck!

PART I - Directional Drilling

This part constitutes 50 % of the exam. Formulas can be found in the Appendix just after Part I. All sub questions are given the score of 2 points.

1] The following figure shows the pore and fracture pressure for a given well prospect



Give a proposal for how to fill in the table below! The size of the casings, casing shoe depths and proposed mudweights are lacking. The reservoir top is at 4500 meters. The water depth is 375 meters. The airgap is 25 meters. Hence, the well starts at 400 meters from RKB.

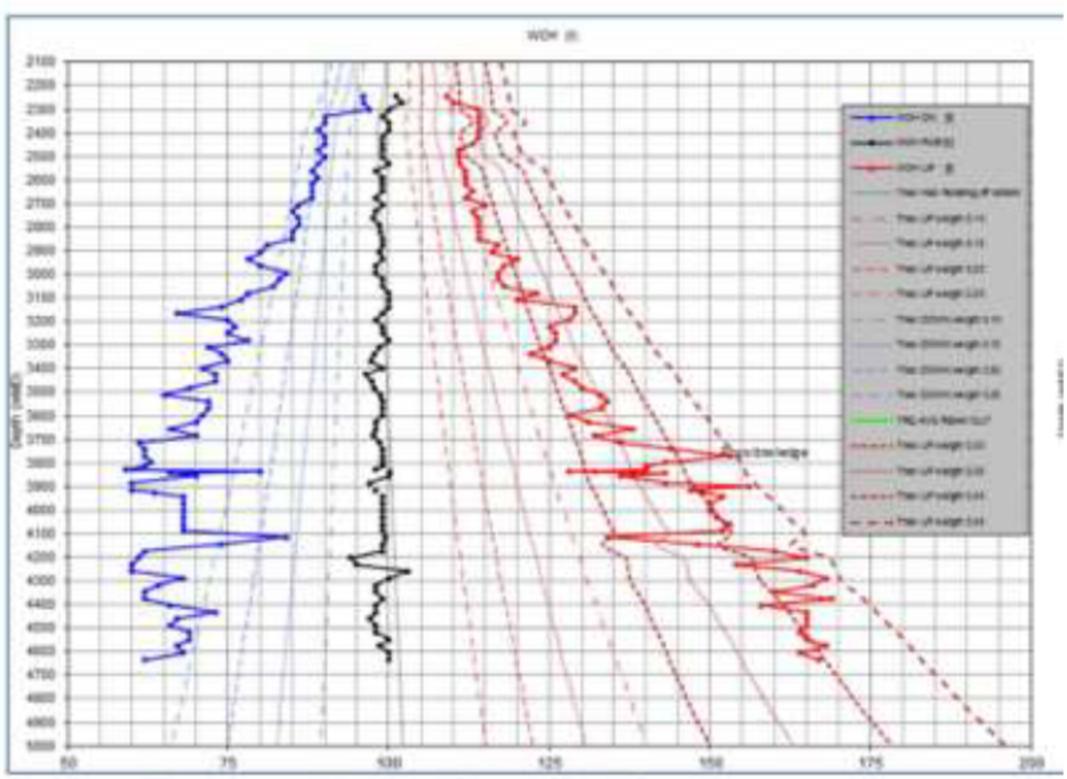
Hole size	Casing size	Setting depth from RKB (m)	Mudweight (sg)
36”			
26”			
17 ½”			
12 ¼”			

2] The reservoir will be drilled with an 8 ½ inch hole size. After this one will complete the well with a so-called cased hole completion. Explain how one proceeds to obtain a cased hole completion.

3] The following IADC dull grading characteristics is given for a roller cone bit. What was the condition of the bit and why was it pulled? What must one be careful about when running a new bit into the hole? (Note that some relevant tables from Drilling Data Handbook are given in the Appendix)

Cutting Structure							
Inner	Outer	Dull Char	Location	Bearing Seals	Gauge	Other Dull char	Reasons pulled
7	7	BT		E	4/16		PR

4] The following figure shows the measured Hookload for slack off/tripping in (blue curve) and pick up/tripping out (red curve) for a given well. Explain why the Hookload decreases for slack off while it increases for pick up? The section from 2200 meter to 4600 meter is almost horizontal.



(Figure taken from SPE 185935)

5] What can be done to reduce the uncertainty in wellbore positioning especially when drilling in the Arctic?

6] Explain how a mud motor works and how it is used in operation!

7] 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 4000 meter the 18 ft sensor reacts upon the horizontal oil water contact below. When the bit is at 4100 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?

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 horizontal. The inclination after the first build up shall be 40 degrees.

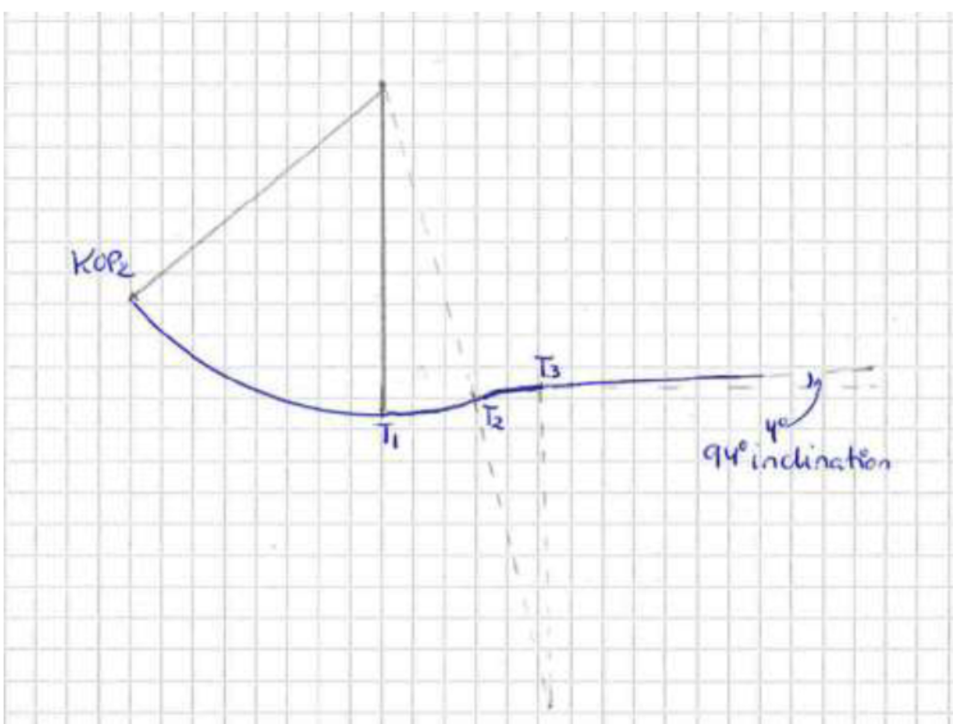
Both build up sections will use a build-up rate $\frac{\Delta i}{\Delta l} = \frac{2^0}{30m}$.

The position of KOP2 is given by the coordinates (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 the 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, one starts 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**, **southern** and **eastern** direction when moving from T1 to T3?

Appendix – Formulas

Formula for dogleg (DL):

$$\beta = Cos^{-1}(CosI_1CosI_2 + SinI_1SinI_2Cos(A_2 - A_1))$$

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)

IADC DULL BIT GRADING
(after IADC/SPE 23938-23939 of 1992)

The dull grading system applies both to roller bits and fixed cutter bits. The system is flexible enough for use in bit reports, daily reports and databases.

Cutting structure				Bearing seals	Gauge	Other dull char.	Reason pulled
Inner	Outer	Dull char.	Location				
Table **1**	Table **1**	Table **3**	Table **4**	Table **5**	Table **6**	Table **3**	Table **8**

Table 1

Inner cutting structure (inner = inner 2/3 of the bit)
Outer cutting structure (outer = outer 1/3 of the bit – gauge row only)

In columns 1 and 2 a linear scale from **0** to **8** is used to describe the condition of the cutting structure according to the following:

Steel tooth bits

A measure of lost tooth height due to abrasion and/or damage:

0 = No loss of tooth height
1
⋮
8 = Total loss of tooth height

Insert bits

A measure of total cutting structure reduction due to lost, worn and/or broken inserts:

0 = No lost, worn and/or broken inserts
1
⋮
8 = All inserts lost, worn and/or broken

Fixed cutter bits

A measure of lost, worn and/or broken cutting structure:

0 = No lost, worn and/or broken cutting structure
1
⋮
8 = All of cutting structure lost, worn and/or broken.

IADC DULL BIT GRADING
(after IADC/SPE 23938-23939 of 1992) (continued)

Table 2 – Dull characteristics
(Use only cutting structure related codes)

BC* = Broken Cone
BF = Bond Failure
BT = Broken Teeth/Cutters
BU = Balled Up Bit
CC* = Cracked Cone
CD* = Cone Dragged
CI = Cone Interference
CR = Cored
CT = Chipped Teeth/Cutters
ER = Erosion
FC = Flat Crested Wear
HC = Heat Checking
JD = Junk Damage
LC* = Lost Cone
LN = Lost Nozzle
LT = Lost Teeth/Cutters
OC = Off Center Wear
PB = Pinched Bit
PN = Plugged Nozzle/Flow Passage
RG = Rounded Gage
RO = Ring Out
SD = Shirttail Damage
SS = Self Sharpening Wear
TR = Tracking
WO = Washed Out Bit
WT = Worn Teeth/Cutters
NO = No Dull Characteristics

* Show cone # or #'s under location (table 3).

Table 3 – Location

Roller cone		Fixed cutter
N = nose row	Cone #	C = cone
M = middle row	1	N = nose
G = gage row	2	T = taper
A = all rows	3	S = shoulder
		G = gauge
		A = all rows

Table 4 – Bearings/seals

Non-sealed bearings	Sealed bearings
A linear scale estimating bearing life used: 0 = no life used 8 = all life used	E = seals effective F = seals failed N = not able to grade X = fixed cutter bit

Table 5 – Gauge condition

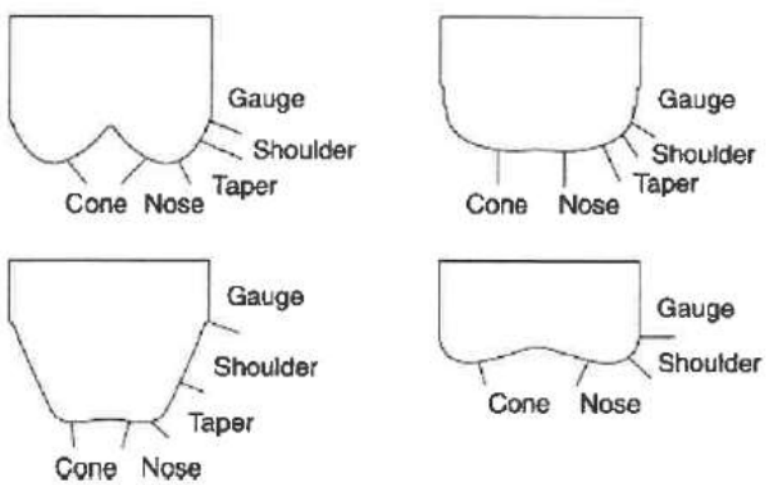
Code	Explanation
I	In Gauge
1/16	Undergauge up to 1/16"
2/16	Undergauge 1/16" to 1/8"
3/16	Undergauge 1/8" to 3/16"
4/16	Undergauge 3/16" to 1/4"

IADC DULL BIT GRADING
(after IADC/SPE 23938-23939 of 1992) (continued)

Table 6 – Reason pulled or run terminated

BHA	= Change Bottom Hole Assembly	LIH	= Left In Hole
DMF	= Downhole Motor Failure	HR	= Hours On Bit
DTF	= Downhole Tool Failure	LOG	= Run Logs
DSF	= Drill String Failure	PP	= Pump Pressure
DST	= Drill Stem Test	PR	= Penetration Rate
DP	= Drill Plug	RIG	= Rig Repair
CM	= Condition Mud	TD	= Total Depth/Casing Depth
CP	= Core Point	TW	= Twist Off
FM	= Formation Change	TQ	= Torque
HP	= Hole Problems	TR	= Weather Conditions

Location designation



PART II - WELL FLOW ENGINEERING

This part constitutes 50 % of the exam. All questions are weighted equally.

Problem 1

1. What is interfacial tension (IFT)? And what is surface tension compared with IFT? Use sketches to illustrate your answer.

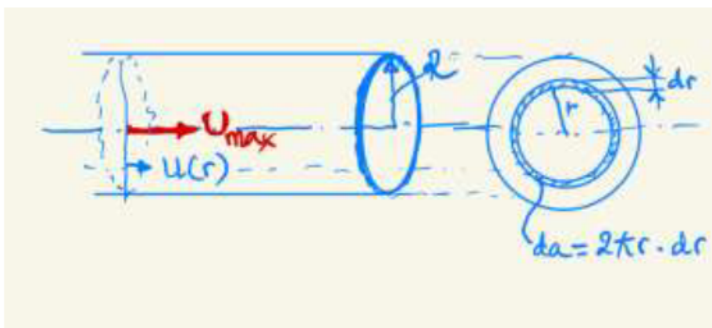
2. Give a description of the flow regimes that occur in horizontal pipes two phase gas-liquid flow? And draw the flow regime map with reasonable values on the axes

3. Show that if the velocity profile in a cylindrical pipe can be expressed as:

$$u(r) = U_{max}(1 - \frac{r}{R})^n$$

then the middle velocity (cross sectional) in the pipe can be written as:

$$U = \frac{2\,U_{max}}{(n+1)(n+2)}$$



Note that the expression (1-(r/R)) in the above equation is in power of n.

4. Consider gas-oil flow in a horizontal pipe where the diameter is 0.15m. The following data are given for the flow regime with constant flowrates.

	Superficial velocities [m/s]	Densities [kg/m³]	Viscosities [mPas*s]
Oil	3	850	2
Gas	0.5	50	0.05

The surface tension is 30mN/m.

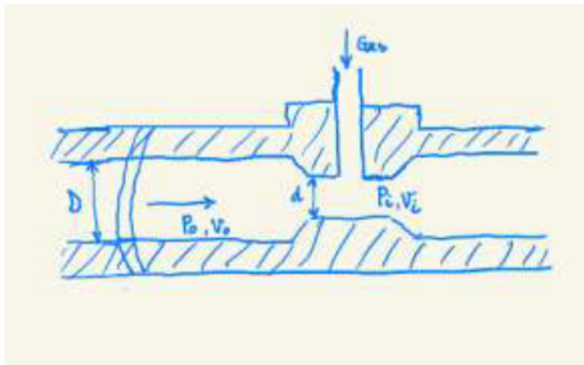
What type of flow regimes do we have in the pipe according to Mandhane's regime map?

Problem 2

1. What is an ensemble average? Give example.

2. What type of instruments can be used to depict flow regimes?

3. Assume the following water-gas situation.



Water is flowing from the left to the right. The gas is sucked in through the hose, as shown in the figure, with a choke (or venturi) and is transported together with water so that they can form a two-phase mixture. The water velocity, V_o is 3m/s. The pressure at the outlet is 1 bar. We assume that the water density and viscosity are 1000 kg/m^3 and 1 cP respectively. The friction in the pipe is neglected.

What should the diameter d be so that gas is dragged into the venturi?

4. Give the expressions for the following pressure gradients in one dimensional single-phase stationary pipe flow in a well:
   i. Hydrostatic pressure gradient
   ii. Frictional pressure gradient
   iii. Acceleration pressure gradient
   iv. Total pressure gradient

In a vertical well, the liquid is flowing downward in a gradually decreasing pipe diameter. Explain qualitatively how these different pressure gradients do behave along the well.