FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: PET 120 Reservoir Technology

DATE: June 9th 2016

TIME: 09.00-13.00

AID: No printed or handwritten papers allowed. Specific simple calculator allowed.

THE EXAM CONSISTS OF 7 pages including 1 attachment

REMARKS: Problem 1 + 2 have equal weight as problem 3

Problem 1

A horizontal and circular gas reservoir is given. The gas is to be produced by pressure depletion, and related data is given below. The reservoir bulk volume to be used in this task is (V_b) = $2{,}5 \cdot 10^6$ ft^3. Assume a closed reservoir, i.e. constant HCPV, and a constant reservoir temperature during pressure depletion.

T_{res} = 250 °F
P_i = 8000 psia
Z_i = 1.347
P_d = 7217 psia
Z_d = 1.259
Φ = 0.25
S_{wr} = 0.10
ρ_{STO} = 51.25 lb/ft^3
M_{STO} = 203.22

Data from a CVD (constant volume depletion) – analysis and a separator test are given below:

Constant volume depletion analysis at 250 °F:

Pressure psia	Liq Vol % of Vd	%Prod Mole	Z Factor Gas	Viscosity lb/ft hr
7217	0	0	1.259	0.16
7000	3.08	1.25	1.228	0.151
6000	15.22	8.08	1.102	0.115
5000	22.24	17.08	1.007	0.087
4000	24.35	28.64	0.944	0.068
3000	23.85	42.87	0.912	0.054
2000	22.12	59.36	0.909	0.044
1000	19.73	77.09	0.935	0.038

Separator test:

Pressure psia	Temp °F	GOR SCF/SBL	Gravity air = 1	Oil Dens lb/ft³	FVF sep bbl/SBL	Bg sep bbl/SBL
7217.1	250					0.004
5000	200	9371.1	0.896	36.0768	1.979	
2500	150	1080.7	0.71	42.516	1.432	
14.7	59	818.8	0.861	51.2481	1	

a) Which fluid type exists in the reservoir? Characterize the fluid by means of a PT-diagram.

b) Draw GOR vs. Pres for dry gas, wet gas and gas condensate.

c) Show that HCPV = 562500 ft^3

d) Show that the total GOR for the complete separation process is approximately 11271 SCF/SBL. Use GORtot = 11271 SCF/SBL in the following tasks of problem 1.

e) What is the production of gas (SCF) and oil (SBL) by pressure depletion from Pi to Pd?

f) Calculate IOIP (SBL) and IGIP (SCF).

g) Describe a typical CVD-analysis.

h) How much well stream fluid as gas (SCF) is produced by pressure depletion from Pd to 5000 psia?

i) How large a recovery degree is the answer in h) out of Gi (% of Gi), if GE_{STO} = 133000 γ_{STO}/M_{STO} with unit (SCF/SBL) is given?

Problem 2

The Buckley-Leverett equation can be applied when water is injected into an oil reservoir. The equation is given by:

$$v_{Sw} = \frac{q_t}{\phi A}\left(\frac{df_w}{dS_w}\right)_{Sw}$$

a) Explain the symbols in the equation, and list the assumptions that the derivation of the equation is based on.

b) Derive the expression for the shock front’s tangent to the fractional flow curve. Make a sketch to be used in the derivation.

c) Show with a sketch how the water saturation and the fractional flow of water in the shock front can be determined graphically.

Problem 3

a) Darcy law given by

$$q_x = -\frac{k \cdot A}{\mu} \cdot \frac{dp}{dx} \qquad (1)$$

1. Explain the symbols in the equation and specify Darcy units in parentheses.

2. Define 1D (1 Darcy)

3. Suppose gas flows through a core sample. Use Darcy law and show that the average rate is given by:

$$\bar{q} = \frac{k \cdot A}{\mu} \cdot \frac{\Delta p}{\Delta L} \qquad (2)$$

Hint: Use ideal gas law and that the mass rate ($q \cdot \rho$)is constant.

4. Suppose we wish to apply SI units in the expression under paragraph a3).
Calculate the conversion factor.

$\mathrm{SI}: [k] = \mathrm{m}^2 \quad [A] = \mathrm{m}^2 \quad [\mu] = \mathrm{Pa} \cdot \mathrm{s} \quad [p] = \mathrm{Pa} \quad [L] = \mathrm{m} \quad [q] = \mathrm{m}^3 / \mathrm{s}$

Given that: 1 atm = $1{,}0132 \times 10^5$ Pa; 1 D = $0{,}987 \times 10^{-12}$ m^2; 1 cP = 10^{-3}Pa.s

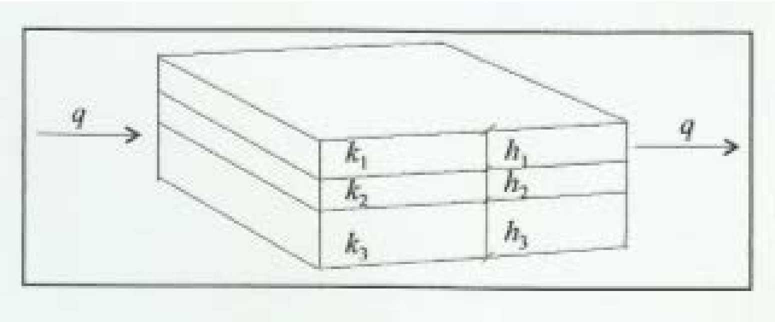
5. Suppose that we wish to use gas for permeability measurement of a core sample in the laboratory. Give a short explanation (few lines) which two effects we have to correct for.

6. What is the advantage of using gas rather than water in the measurement of the permeability of a core sample?

7. Suppose we have a homogenous reservoir with a permeability of k = 1 D. Is this an indication of a reservoir of good or bad production qualities?

8. Suppose we have a layered reservoir with liquid flow as shown in the figure below. Show that the average permeability can be expressed as:

$$\bar{k} = \frac{\sum_{j=1}^{3} k_j \cdot h_j}{\sum_{j=1}^{3} h_j} \qquad (3)$$



9. Is eqn. (3) valid for gas flow as well? Explain.

10. Suppose that liquid flows through the layered reservoir as shown in the figure above.

Given that: k_1 = 0,2 D; h_1 = 0,60 m; k_2 = 0,15 D; h_2 = 1,80 m; k_3 = 0,40 D; h_3 =

1,20 m; $\mu = 10^{-3}$Pa.s; Width = 2 m; Length = 5 m; Pressure difference = $1{,}013\text{x}10^6$ Pa

Calculate the total flow rate q in m^3/s.

b) Following reservoir data is given

p (bar)	B_o (Rm^3/Sm^3)
308 (p_i)	1,247
239 (p_b)	1,258

$c_w = 4{,}33 \cdot 10^{-5}$ bar^{-1} $\quad c_p = 12{,}4 \cdot 10^{-5}$ bar^{-1} $\quad S_{wc} = 0{,}2$

1. Define with symbols and words the concept of *isothermal compressibility.*

2. The compressibility of unsaturated oil can be expressed as

$$c_o = \frac{1}{V_o}\frac{\Delta V_o}{\Delta P} \qquad (4)$$

What conditions apply?

3. Define the volume factor B_o and show that the compressibility of unsaturated oil also can be expressed as

$$c_o = \frac{1}{B_o}\frac{\Delta B_o}{\Delta P} \qquad (5)$$

4. Calculate the compressibility of unsaturated oil in the reservoir example above.

5. The total compressibility is defined as

$$c_t = S_o c_o + S_w c_w + S_g c_g + c_p \qquad (6)$$

You may assume that $S_w = S_{wc}$ (see paragraph 9 below)

Calculate the total compressibility in the reservoir example above.

6. Suppose that the reservoir is produced by pressure depletion. Which drive mechanisms do we have when $p \geq p_b$?

7. Show that the recovery factor of oil when $p \geq p_b$ is given by

$$\frac{N_p}{N} = \frac{B_{oi}}{B_o}\frac{c_t}{1 - S_{wc}}\Delta p \qquad (7)$$

8. Calculate the recovery factor at $p = p_b$

9. Calculate the water saturation at $p = p_b$ and show by this that the initial (connate) water saturation (S_{wc}) is little affected by a drop in pressure.

10. Which drive mechanisms will normally dominate when $p < p_b$ (given that we initially have an unsaturated oil)? Write down the expression for recovery factor for this case. Which parameter is decisive for the recovery factor? Give an explanation.

11. Most of the oil fields at the Norwegian Continental Shelf are not produced by pressure depletion (primary production) but by use of water injection (secondary production). Give an explanation.

Material Balance Equation

Assumption: $W_e = W_p = 0$

$$F = N\left[E_o + m \cdot E_g + E_{f,w}\right]$$

$$F = N_p \cdot \left[B_o + (R_p - R_s) \cdot B_g\right]$$

$$E_o = (B_o - B_{oi}) + (R_{si} - R_s) \cdot B_g$$

$$E_g = B_{oi} \cdot \left[\frac{B_g}{B_{gi}} - 1\right]$$

$$E_{f,w} = (1 + m) \cdot B_{oi} \cdot \frac{c_f + c_w \cdot S_{wc}}{1 - S_{wc}} \cdot \Delta P$$

Attachment 1
Important formula/correlations in PVT-Analysis.

Temperature:

$^oK = 273.15 + ^oC$
$^oF = 1.8 \times ^oC + 32$
$^oR = ^oF + 459.69$

Pressure:

1atm = 1013.250 mBar = 1.013250 bar = 101.3250 kPa = 0.1013250 MPa = 14.69595 psia
psia = 14.69595 + psig
1 atm = 760.002 mmHg at 0 ^oC

Density:

1 g/cm^3 = 62.43 lb/ft^3 = 350.54 lb/bbl
1 lb/ft^3 = 16.0185 kg/m^3
$\rho_w = 0.999015$ g/cm^3 (60 ^oF, 1 atm)
$\rho_w = 0.9991$ g/cm^3 (15 ^oC, 1 atm)

Specific density:

For liquids: Determined relative to water at sc.
For gases: Determined relative to air at sc.

$$\gamma_o = \frac{\rho_o}{\rho_w} = \frac{141.5}{131.5 + {}^oAPI}$$

$$^oAPI = \frac{141.5}{\gamma_o} - 131.5$$

Cragoe`s formula (empirical formula giving molecular weight of hydrocarbons):

$$M_o = \frac{6084}{^oAPI - 5.9}$$

$$\gamma_g = \frac{M_g}{M_{air}} = \frac{M_g}{28.96}$$

Volume:

1 bbl = 5.615 ft^3 = 0.15898 m^3
1 ft^3 = 0.0283 m^3
1 US Gallon = 3.785 litre
1 Imp. Gallon = 4.546 litre
Molar volume of gas at standard conditions:
V_m = 379.51 SCF/lb mole (60 ^oF and 14.69595 psia)
V_m = 23644.7 cm^3/g mole = 23.6447 m^3/kg mole (15 ^oC and 101.3250 kPa)

Air:

$Z_{air} = 0.9959$ (60 ^oF, 14.69595 psia)
$M_{air} = 28.96$

Gas constant:

R = 10.732 (psia, ft^3, ^oR, lb mole)
R = 0.082054 (atm, litre, ^oK, g mole)
R = 8.3145 (kPa, m^3, ^oK, kg mole)