University of
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FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: MPE 690 - PVT analysis and Reservoir modeling   DATE: May 6, 2011

TIME: 4 hours

AID: No printed or written means allowed. Definite basic calculator allowed.

THE EXAM CONSISTS OF 3 PROBLEMS ON 5 PAGES AND 1 ADDITIVE.

REMARKS: You may answer in English or Norwegian. Problem 1 is given equal weight as Problem 2 and 3.

Problem 1

A bottom hole sample (BHS) is taken from a reservoir and brought to a PVT-lab.
Given reservoir data:

Temperature: $T_{res} = 130\ ^oC$
Pressure: $P_i = 450$ bara
              $P_b = 332.5$ bara
Porosity: $\Phi = 0.25$
Initial water: $S_{wi} = 0.25$
Bulk res. volume: $10^6\ m^3$

The BHS undergoes a single flash to standard conditions (15 ^oC and 1.01 bara), and the following data are given:

$GOR = 382\ Sm^3/Sm^3$
$(B_o)_b = 2.29\ m^3/Sm^3$
$M_{STO} = 187$
$\rho_{STO} = 839{,}4\ kg/m^3$

$\gamma_g = 0.837$

$(M_o)_{res} = 59.5$

Comp. of STO as mole fractions: x_i $(i = C_1 - C_{10+})$

Comp. of gas as mole fractions: y_i $(i = C_1 - C_{10+})$

Mole% gas: 78.38 and Mole% STO: 21.62

The mole fraction of Methane in the gas and STO is: $y_{C1}=0.7079$ and $x_{C1}=0.343$, respectively.

1. Characterize the reservoir fluid by means of a PT-diagram.
2. M_{STO} is determined experimentally. Describe <u>shortly the principles</u> of the analysis. Use formula.
3. The weight % of each of the components in STO is experimentally determined by gas chromatography. Give a <u>short description of the principles</u> of the analysis. Use formula: $(wt\%)_i=?$ and $(wt\%)C_{10+}=?$).
4. Derive a formula to calculate M_{C10+} for STO; $M_{C10+} = f((wt\%)_i, M_i)$ where $i=C_1 - C_{10+}$ for $(wt\%)_i$ and $i=C_1 - C_9$ for M_i.
5. Calculate the mole fraction of Methane in the reservoir fluid.

A Constant Mass Expansion (CME) was performed, and the data from the analysis are presented below.

Constant Mass Expansion at 130 °C

Pressure Bara	Rel VolV/Vb	Compress 1/bara	Y Factor	Density cm³
500.00	0.9261	3.563E-04		0.5808
450.00	0.9439	4.073E-04		0.5635
425.00	0.9539	4.379E-04		0.5638
400.00	0.9648	4.728E-04		0.5575
375.00	0.9768	5.130E-04		0.5506
350.00	0.9899	5.598E-04		0.5433
332.51	1.0000	5.973E-04		0.5375
325.00	1.0091		2.53	
300.00	1.0443		2.45	
250.00	1.1455		2.27	
200.00	1.3174		2.09	
150.0	1.6378		1.91	

6. Based on the given reservoir bulk volume and supposing the reservoir fluid is produced to the surface by a single flash to standard conditions, calculate IOIP (Sm³) and IGIP (Sm³).
7. Suppose that the fluid production in the pressure interval P_i to P_b is only related to the expansion of reservoir fluid, i. e. a closed reservoir. Calculate the recovery of STO (Sm³) and gas (Sm³) from the reservoir for this pressure decline when processed through a single flash. .
   What is the oil recovery factor (% of IOIP) at P_b ?

Below the saturation point, a differential gas liberation analysis is performed, and the data are shown below.

Differential Gas Depletion at 130 °C

Pressure Bara	Oil FVF Bod	Rsd Sm³/Sm³	Gas FVF Bg	Oil Dens g/cm³	Z FactorGas
332.51	3.081	566.7		0.5378	
300.00	2.634	436.1	4.470E-03	0.5662	0.939
250.00	2.249	317.7	5.151E-03	0.6025	0.903
200.00	1.997	237.5	6.318E-03	0.6354	0.887
150.00	1.809	176.8	8.413E-03	0.6668	0.886
100.00	1.655	127.7	1.279E-02	0.6978	0.898
50.00	1.516	84.9	2.632E-02	0.7301	0.923
1.01	1.069	0.0	1.437E+00	0.8102	0.986
1.01	1.000			0.8663	

8. Give a <u>short description</u> of the analysis.
9. Define the parameters: B_{od}, R_{sd} and B_g.
10. Suppose the reservoir is produced by just a pressure depletion process from P_i to an abandon pressure of 100 bara. Make a schematic drawing of:
    a. GOR vs. P
    b. μ_o vs. P.
    c. μ_g vs. P.
    Give <u>short comments</u> to the figures.

Problem 2

1. Relative permeability curves can be generated from *normalized* relative permeability curves. Describe how this is done, respectively, for a water-oil flow system which involves k_{rw} and k_{row} and for a gas-oil flow system which involves k_{rg} and k_{rog}. Use figures to illustrate curves as well as various critical saturations (residual saturations) involved in the procedure.

2. Define capillary pressure, respectively, for a water-oil system and a gas-oil system. Include figures of typical capillary pressure curves as a function of saturation. Also, describe how the Leverett J-function can be used to represent a capillary pressure function.

3. The mass balance equations for water and oil for a standard Black Oil model can be written as

   (*) $$\nabla \cdot (\overline{\rho_l \vec{v}_l}) = -\frac{\partial}{\partial t}(\varphi \overline{\rho_l} S_l) + q_l, \quad l = o, w.$$

   Write the corresponding equation for gas.

4. Introduce densities at standard conditions, volume factors, and gas-oil solution ratio and explain how these are related. Reformulate the mass balance equations for water, oil, and gas in terms of these Black Oil model parameters.

5. Give a list of the unknown variables in the Black Oil model, and identify the different equations that can be used to solve for the unknowns. Indicate briefly how to simplify the system of equations.

6. Finally, assume that water is the only phase, i.e., a single phase system is considered. Explain how the Black Oil model then is reduced to a model of the following form:

   (**) $$\frac{\partial}{\partial t}(\varphi(p)) = \frac{\partial}{\partial x}\left(\frac{k}{\mu}\frac{\partial p}{\partial x}\right)$$

   with $\varphi(p) = \varphi_0[1 + c(p - p_0)]$. Describe various assumptions and equations that have been used to derive (**) from the Black Oil model given in 3 and 4.

Problem 3

This problem is about the Buckley-Leverett (B-L) equation for water-oil transport. This equation is given by

$$\frac{\partial}{\partial t_D}S + \frac{\partial}{\partial x_D}f(S) = 0,$$

where S is the water saturation and x_D and t_D are dimensionless variables.

1. Given the two fractional flow functions $f(S)$ shown in Fig. 1 (left figure) corresponding to two different values of the viscosity ratio $M = \mu_w / \mu_o$. The corresponding derivatives $f'(S)$ are also shown in Fig. 1 (right figure). Sketch the solution at time $T = 0.3$ (dimensionless) for the case with $M = 0.5$. In particular, determine (approximately) the front height, position of front, and saturation distribution behind front (at least two points).

2. The parameter M (viscosity ratio) appearing in $f(S)$ is changed to M=2.25. See Fig. 1 for corresponding curves for $f(S)$ and $f'(S)$.
   What is the main difference between solutions computed with M=0.5 and M=2.25?

3. Compute oil recovery for $f(S)$ with M=2.25 at time T_b corresponding to the time when water breakthrough takes place.

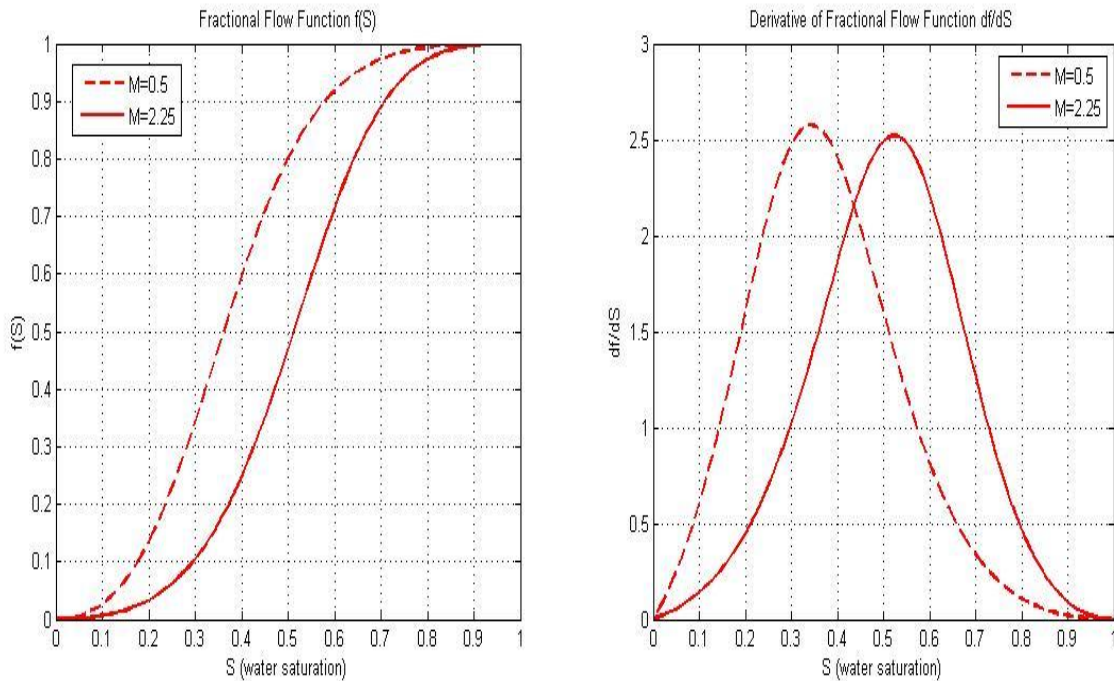4. What is oil recovery at time T_b for the case with M=0.5?

Fig. 1: **Left**: plot of $f(S)$. **Right:** Plot of $f'(S)$.

Additive 1.

Temperature:
$$^oK = 273.15 + {}^oC$$
$$^oF = 1.8 \times {}^oC + 32$$
$$^oR = {}^oF + 459.69$$

Pressure:
1 atm = 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:
$1 \text{ g/cm}^3 = 62.43 \text{ lb/ft}^3 = 350.54 \text{ lb/bbl}$

$1 \text{ lb/ft}^3 = 16.0185 \text{ kg/m}^3$

$\rho_w = 0.999015 \text{ g/cm}^3$ (60 ^oF, 1 atm)

$\rho_w = 0.9991 \text{ g/cm}^3$ (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:
$1 \text{ bbl} = 5.615 \text{ ft}^3 = 0.15898 \text{ m}^3$

$1 \text{ ft}^3 = 0.0283 \text{ m}^3$

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)

$V_m = 23644.7 \text{ cm}^3$/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)