

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: MPE 690 - PVT analysis and Reservoir modeling

DATE: May 14, 2012

TIME: 4 hours

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

THE EXAM CONSISTS OF 3 PROBLEMS ON 5 PAGES AND 4 ADDITIVES (page 6-9).

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

Problem 1

Based on the compositional data of a reservoir crude oil, a constant mass expansion, CME, and a separator test can be modelled. See Table 1 and 2, respectively.

Table 1. CME data at T_{res} .

Pressure Bar	Rel Vol. V/V_b	Compress. 1/Bar	Y Factor
500.0	0.9634	1.134E-04	
450.0	0.9693	1.240E-04	
400.0	0.9759	1.364E-04	
350.0	0.9832	1.510E-04	
300.0	0.9914	1.686E-04	
253.3	1.0000	1.884E-04	
250.0	1.0033		4.02
200.0	1.0725		3.68
150.0	1.2087		3.30
100.0	1.5271		2.91
50.0	2.6158		2.52

Table 2. Separator test

Pressure Bara	Temp C	GOR Sm ³ /Sm ³	Gravity air=1	Oil Dens g/cm ³	FVF m ³ /Sm ³
253.3	80.0			0.732	1.340
100.0	60.0	73.7	0.682	0.796	1.155
30.0	40.0	31.1	0.710	0.834	1.070
1.0	15.0	21.3	1.048	0.865	1.000

FVF = Formation volume factor.

The following reservoir data are given:

Initial pressure: $P_i=450$ bar
 Reservoir temperature: $T_{res}=80$ °C
 Bulk reservoir volume: 10^6 m³
 Porosity: $\Phi=0.25$
 Residual water saturation: $S_{wr}=0.2$.

a.

What is the value of P_b at T_{res} ? Verify that the value of P_b is determined correctly.

b.

Determine:

1. Initial oil formation factor, $(B_o)_i$
2. Initial oil and initial gas in place, IOIP and IGIP as Sm³.

c.

Calculate the recovery of STO (Sm³) and gas (Sm³) during a pressure depletion from P_i to P_b . It is supposed that the HCPV is constant during the production.

d.

Show that the average molecular weight of produced gas is given by: $M_g=21.7$.

e.

According to the simulated separator test, it is seen that $(\rho_o)_b=0.732$ g/cm³ = 732 kg/m³. Calculate $(\rho_o)_b$ by using the added empirical correlations and actual values from the separator test. Compare the values and give comments.

f.

Suppose that the reservoir fluid is produced by a pressure depletion from P_i to $P_a=100$ bar.

Illustrate the following relations:

1. $GOR = f(P_{res})$
2. $B_o = f(P_{res})$
3. $\rho_o = f(P_{res})$
4. $\mu_o = f(P_{res})$
5. $\mu_g = f(P_{res})$

Problem 2

The Buckley-Leverett (B-L) equation for water-oil transport (horizontal flow) is given by

$$(A) \quad \frac{\partial}{\partial t} S + \frac{\partial}{\partial x} f(S) = 0, \quad x \in [0,1]$$

where S is the water saturation and x and t are dimensionless variables.

- a) Formulate the two mass balance equations (where Darcy's law has been used), respectively, for water and oil that are used to derive (A). State the main assumptions used to derive (A). Demonstrate why the total velocity (sum of water and oil velocity) becomes constant and express the pressure gradient term in terms of total velocity and mobility functions.
- b) Identify the expression of the function $f(S)$ in terms of mobility functions and give a sketch of a typical fractional flow function $f(S)$. Explain how to calculate the water-front solution after a time T when water is injected at $x=0$. Draw figures and describe the different steps.
- c) A mathematical (but unphysical) solution of the water-flooding problem in point b) can be constructed by using the equation $X_s = f'(S)T$ where $S \in [0,1]$ and X_s represents travelled distance of saturation S . Illustrate this solution and explain mathematically why we obtain the equation $f(S^*) = f'(S^*)S^*$ as a characterization of the front height S^* of the physical solution.
- d) Given the two fractional flow functions 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). Compute oil recovery for $f(S)$ with $M=2.25$ at time T_b corresponding to the time when water breakthrough takes place.
- e) Consider now the fractional flow function with $M=0.5$. What is oil recovery at time T_b for this case, where T_b is the time given in point d)?

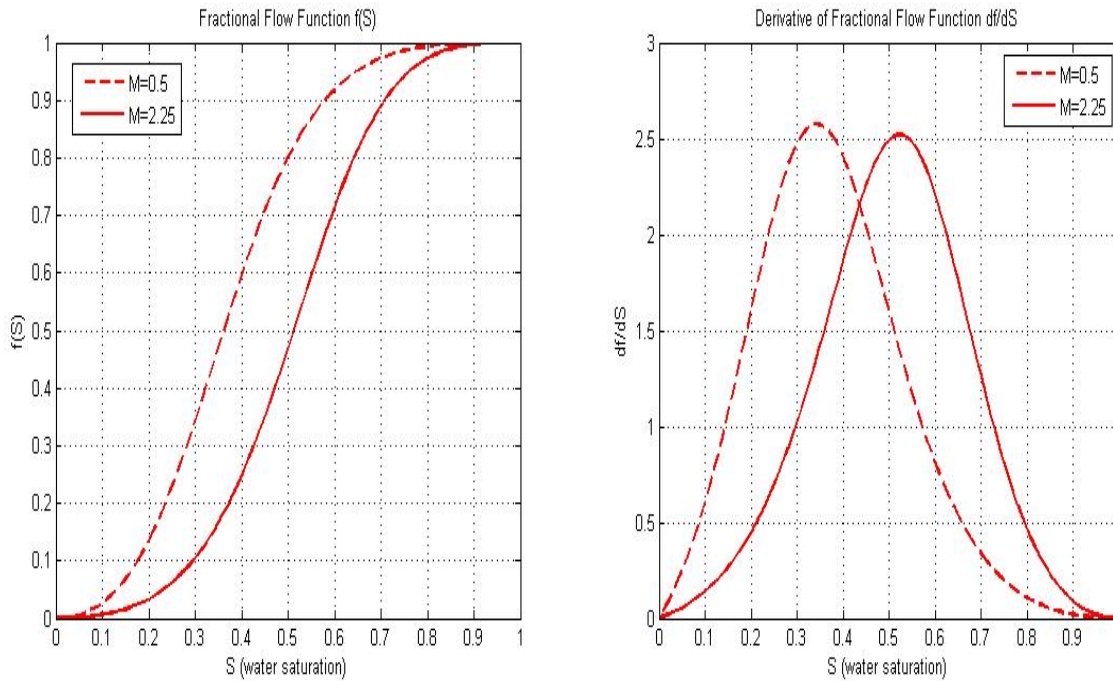


Fig. 1: **Left:** plot of $f(S)$. **Right:** Plot of $f'(S)$.

Problem 3

- a) Consider the single phase mass balance equation in 1D. Explain how to obtain the following form:

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

with $\varphi(p) = \varphi_0[1 + c(p - p_0)]$. Describe various assumptions and equations that have been used to derive (B) from the general single-phase mass balance equation in 1D.

- b) The equation (B) can be written in the form

$$(C) \quad \frac{\partial p}{\partial t} = \kappa \frac{\partial^2 p}{\partial x^2}$$

for a suitable choice of κ when μ, k are assumed to be constant.

Describe a discrete scheme for this equation based on explicit time discretization. Consider the spatial domain $x \in [0,1]$ with no flux conditions at the boundaries, i.e., the pressure gradient is zero. Assume that the spatial domain is divided into N cells where $p_j, j = 1, \dots, N$ are associated with the cell centers.

What is the standard stability condition?

c) Assume that initial data is given by $(p^0)_j, j = 1, \dots, 4$ where

$$(p^0)_1 = 1, (p^0)_2 = 2, (p^0)_3 = 4, (p^0)_4 = 1.$$

Set the quantity $\kappa \frac{\Delta t}{\Delta x^2} = \frac{1}{4}$ and calculate the approximate solution after two time steps, that

is, $(p^2)_j, j = 1, \dots, 4$. Sketch the initial data and approximate solution (p^2) .

d) The mass balance equations for the water and oil component for a standard Black Oil model can be written as

$$(D) \quad \nabla \cdot (\bar{\rho}_l \bar{v}_l) = -\frac{\partial}{\partial t} (\phi \bar{\rho}_l S_l) + q_l, \quad l = o, w.$$

Define the different quantities and write the corresponding equation for the gas component.

Introduce densities at standard conditions, volume factors, and gas-oil solution ratio and explain how these are related. Express the mass balance equations for water, oil, and gas in terms of these Black Oil model parameters and without introducing Darcy's law.

Consider a gas condensate model where part of the oil component can exist in gas phase and formulate the three mass balance equations using Black Oil model parameters.

Important formula/correlations in PVT-Analysis.

Addition 1.

Temperature:

$$^{\circ}\text{K} = 273.15 + ^{\circ}\text{C}$$

$$^{\circ}\text{F} = 1.8 \times ^{\circ}\text{C} + 32$$

$$^{\circ}\text{R} = ^{\circ}\text{F} + 459.69$$

Pressure:

$$1 \text{ atm} = 1013.250 \text{ mBar} = 1.013250 \text{ bar} = 101.3250 \text{ kPa} = 0.1013250 \text{ MPa}$$

$$= 14.69595 \text{ psia}$$

$$\text{psia} = 14.69595 + \text{psig}$$

$$1 \text{ atm} = 760.002 \text{ mmHg at } 0^{\circ}\text{C}$$

Density:

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

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

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

$$\rho_w = 0.9991 \text{ g/cm}^3 \quad (15^{\circ}\text{C}, 1 \text{ atm})$$

Specific density:

For liquids: Determined relative to water at sc.

For gases: Determined relative to air at sc.

$$\gamma_o = \frac{\rho_o}{\rho_w} = \frac{141.5}{131.5 + ^{\circ}\text{API}}$$

$$^{\circ}\text{API} = \frac{141.5}{\gamma_o} - 131.5$$

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

$$M_o = \frac{6084}{^{\circ}\text{API} - 5.9}$$

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

Volume:

$$1 \text{ bbl} = 5.615 \text{ ft}^3 = 0.15898 \text{ m}^3$$

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

$$1 \text{ US Gallon} = 3.785 \text{ litre}$$

$$1 \text{ Imp. Gallon} = 4.546 \text{ litre}$$

Molar volume of gas at standard conditions:

$$V_m = 379.51 \text{ SCF/lb mole } (60^{\circ}\text{F and } 14.69595 \text{ psia})$$

$$V_m = 23644.7 \text{ cm}^3/\text{g mole} = 23.6447 \text{ m}^3/\text{kg mole } (15^{\circ}\text{C and } 101.3250 \text{ kPa})$$

Air:

$$Z_{air} = 0.9959 \quad (60^{\circ}\text{F}, 14.69595 \text{ psia})$$

$$M_{air} = 28.96$$

Gas constant:

$$R = 10.732 \quad (\text{psia, ft}^3, ^{\circ}\text{R, lb mole})$$

$$R = 0.082054 \quad (\text{atm, litre, } ^{\circ}\text{K, g mole})$$

$$R = 8.3145 \quad (\text{kPa, m}^3, ^{\circ}\text{K, kg mole})$$

Addition 2.

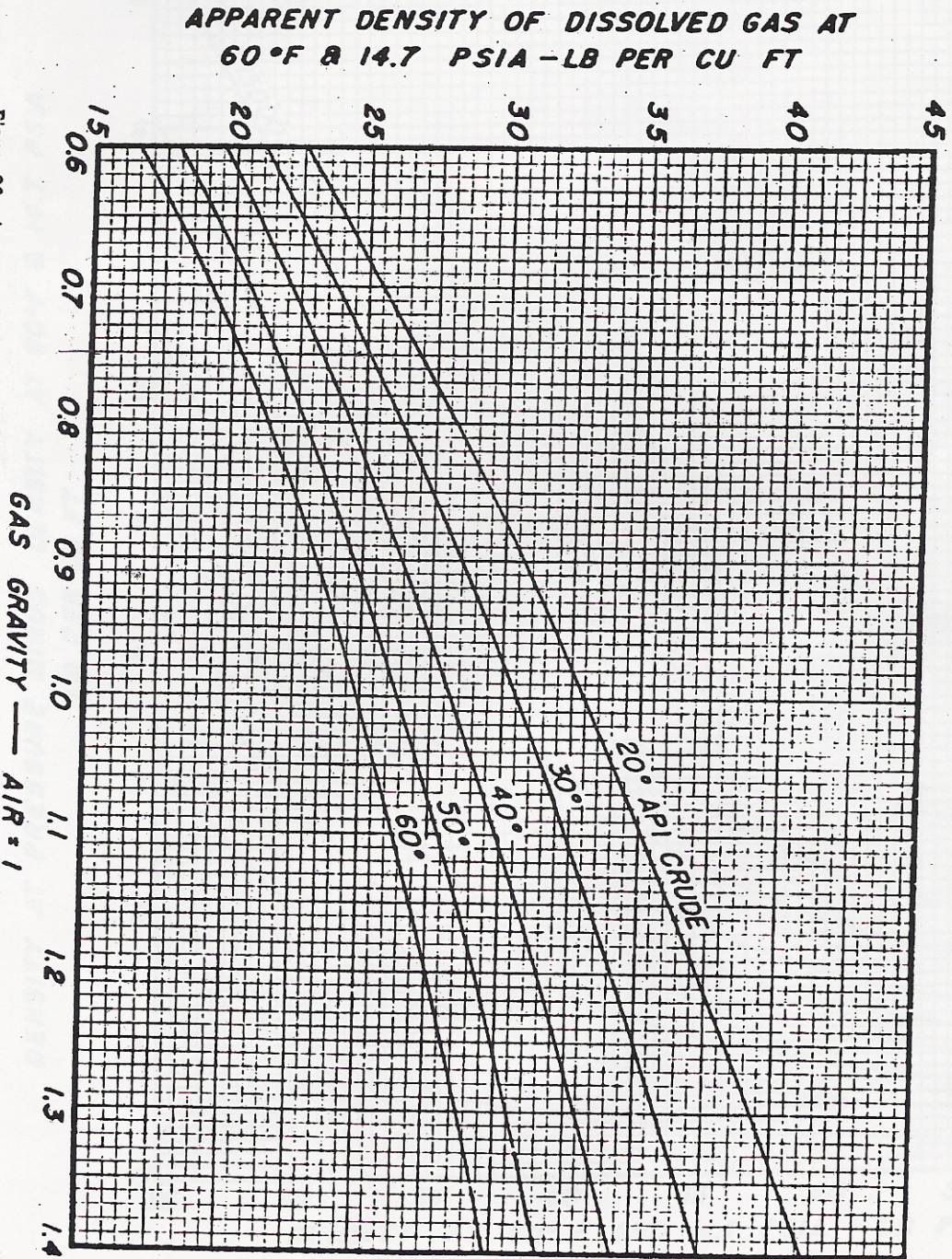


Figure 26—Apparent Liquid Densities of Natural Gases (After Katz, API Drilling and Production Practice, 1942)

Addition 3.

BEHAVIOR OF OIL FIELD HYDROCARBON SYSTEMS

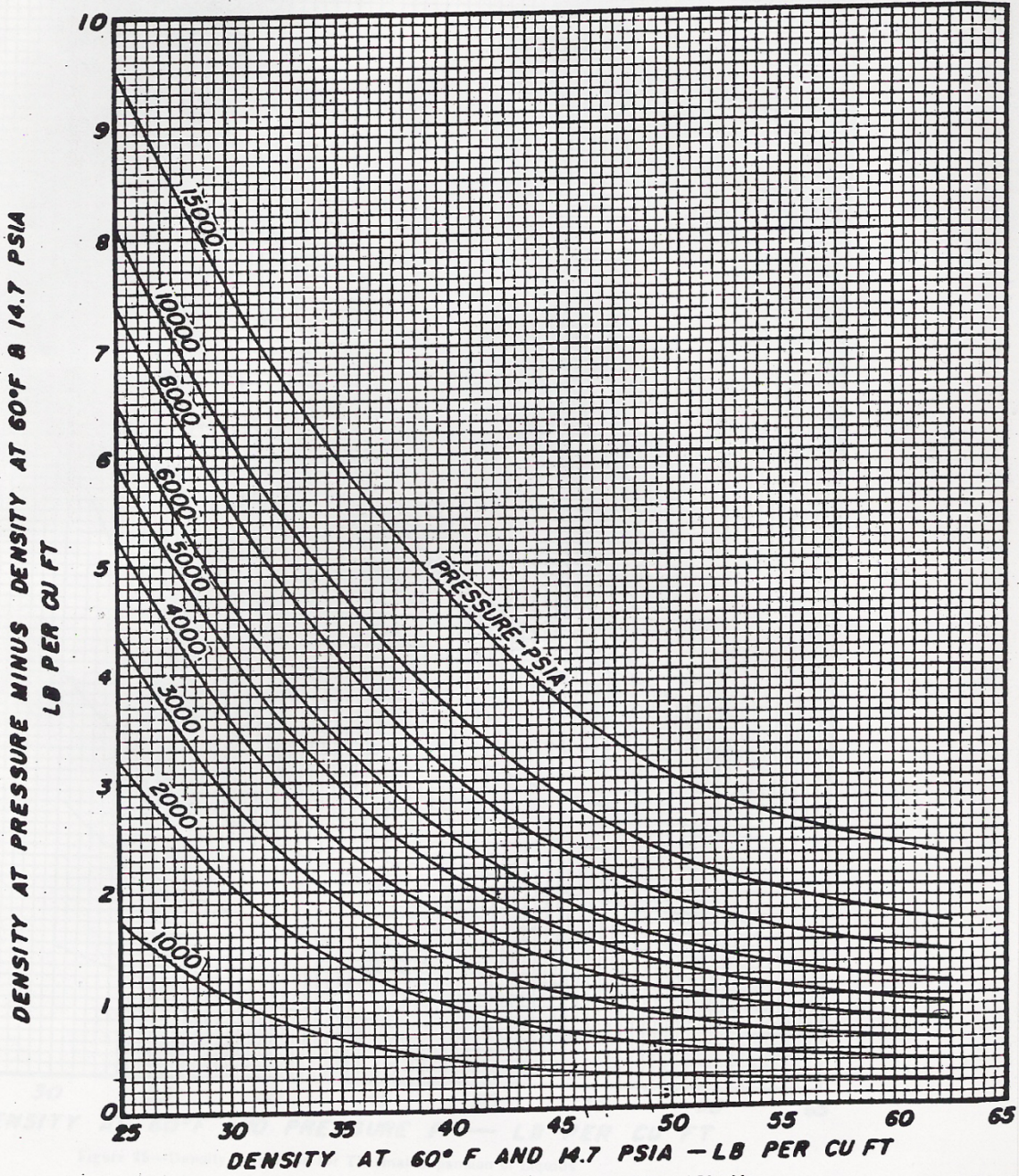


Figure 24—Density Correction for Compressibility of Liquids

Addition 4.

