University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: PET 120 Reservoir Technology

DATE: August 25th 2017

TIME: 09.00-13.00

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

THE EXAM CONSISTS OF 6 pages including 1 attachment

REMARKS: Problem 1 is weighted equal to problem 2

Problem 1

a) Characterize the reservoir fluids dry gas, wet gas and gas condensate by means of:
   1. PT diagrams and GOR values
   2. GOR vs. P_{res} sketches

b) Show with figures and explain the expressions:
   1. Critical point
   2. Isovolume lines
   3. Cricondentherm and Cricondenbar

c) Inside the two phase envelope the gas and oil phases are in equilibrium. The Newton-Raphson method utilizes the flash equations to determine the mole fractions, V and L, of gas and oil, respectively, at given P and T.

   1. Based on 1 mole reservoir fluid at given P and T, which equations are needed to derive the flash equations for n components given below? (Note: The flash equations are not to be derived!)

$$\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} \frac{z_i}{L + K_i V} = 1$$

$$\sum_{i=1}^{n} y_i = \sum_{i=1}^{n} \frac{z_i}{\frac{L}{K_i} + V} = 1$$

2. Show and explain how one can use the flash equations to calculate P_b and P_d at a given T.

d) A gas condensate reservoir with the following data is given:

$T_{res} = 120$ °C
$P_i = 600$ bar
$P_d = 497.45$ bar
$Z_i = 1.426$
$Z_d = 1.259$
$S_{wi} = 0.25$
$\Phi = 0.20$
$B_g = 0.004$ m^3/Sm^3
Bulk reservoir volume (V_b) = $5 \cdot 10^6$ m^3

The reservoir is produced by pressure depletion, and it is assumed that the reservoir is closed during pressure depletion (HCPV = constant). It is also assumed that the reservoir temperature is constant during production.

The fluid is produced through a three-step separator system. Flash calculations have given the following data:

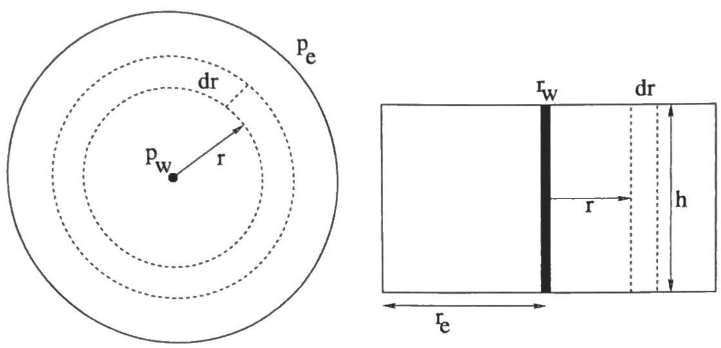
Separator 1 (300 bar, 80 °C)	$V_1 = 0.7674$	$L_1 = 0.2326$
Separator 2 (150 bar, 40 °C)	$V_2 = 0.3652$	$L_2 = 0.6348$
Separator 3 (tank) (1 bar, 15 °C)	$V_3 = 0.6161$	$L_3 = 0.3839$

For the stock tank oil (STO): $M_{STO} = 193.24$ and $\rho_{STO} = 816$ kg/m^3.

1. Calculate GOR (Sm^3/Sm^3) for separator 2.
2. Show that the total GOR is 1661.6 Sm^3/Sm^3.
3. Calculate the production of gas (Sm^3) and oil (Sm^3) from the given bulk reservoir volume, V_b, during pressure depletion from P_i to P_d.
4. Determine the recovery factor of oil (in % of IOIP) and gas (in % of IGIP). Give a comment to the result.
5. Explain by words and equations how gas and oil production can be calculated in the pressure interval from P_d to the abandonment pressure, P_a.

Problem 2:

a) Write Darcy's law for a single phase in one dimension (include the gravitational term). Explain the symbols in the equation and specify the Darcy units.



Figur 1: Cylindrical reservoir with a well in the centre: (left) a view from the top, (right) from the side.

Given the reservoir in Figure 1 and assume horizontal, radial flow from a constant pressure p_e at the outer boundary r_e towards the well with a constant pressure p_w in the well with radius r_w. The reservoir has a constant thickness h.

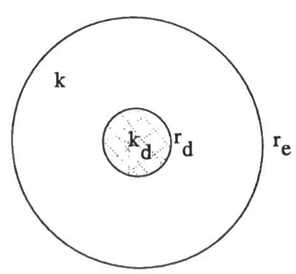
b) Explain what we mean with a stationary flow. Assume that we have a stationary flow, use Darcy law and show that the flow rate, q, in the well is:

$$q = \frac{2\pi\, h\, k}{\mu} \frac{p_e - p_w}{\ln(r_e/r_w)}, \tag{1}$$

for an incompressible fluid.

c) Use equation (1) and determine the pressure at the boundary, p_e, which is needed to produce 100 bbl/day of oil from the reservoir. Assume: $r_w = 0.5$ ft, $k = 200$ mD, $p_w = 2000$ psia, $\mu_o = 5$ cp, $r_e = 330$ ft, $h = 20$ ft. (1 atm = 14.696 psi, 1 bbl = $159 \cdot 10^3$ cm^3 and 1 ft = 30.48 cm)

In the following we will assume that the permeability in the vicinity of the wellbore differs from the original permeability. This zone has an extension of r_d and a permeability of k_d, see the figure below.



d) Show that in this case the flow rate in the well can be written on the same form as in equation (1), with $k \to \bar{k}$, where:

$$\frac{\ln(r_e/r_w)}{\bar{k}} = \frac{\ln(r_d/r_w)}{k_d} + \frac{\ln(r_e/r_d)}{k}. \tag{2}$$

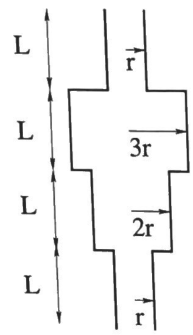
Assume that $r_d = 10$ ft and $k_d = 50$mD. What is the pressure at the outer boundary in this case in order to produce 100 bbl/day of oil?

e) The skin factor, S, is defined (*in Darcy units*):

$$S = \frac{hk}{q\mu}\Delta p_{\text{skin}}\,, \qquad (3)$$

where Δp_{skin} is the additional pressure drop due to the zone in the vicinity of the well. What is the value of the skin factor in this case?

In the following we will investigate a single pore shown in Figure 2. The pore is filled with water.



Figur 2: A cross section of a pore made of four cylindrical elements of equal length.

f) Use the Young Laplace law:

$$p_c = p_o - p_w = \sigma_{ow}\left(\frac{1}{R_1} + \frac{1}{R_2}\right),$$

to show that the pressure in the oil phase has to be larger than:

$$p_o = p_w + \frac{2\,\sigma_{ow}\cos\theta}{r},$$

in order to displace water and enter the pore.

g) The pore is filled with water and assumed to be 100% water wet. Assume r = 1 μm, and σ_{ow}=25 mN/m. Calculate:

1. Entry pressure for the smallest part of the pore.
2. Entry pressure for the widest part of the pore.
3. The oil saturation if only the smallest part of the pore is invaded by oil.

Assume that the oil enters the pore from below. What happens? Will the whole pore or only part of it be filled with oil? Draw the corresponding (drainage) capillary pressure curve for this pore.

h) Assume that the capillary pressure is so high that the whole pore is filled with oil. The pressure in the oil phase is lowered such that water can imbibe from the top, until the whole pore is filled with water. Make a table with one column with the pressure difference between oil and water (capillary pressure), and one column with the corresponding water saturation. Draw the capillary imbibition curve for this process.

In the following we will look closer at an oil reservoir. The following volumes are defined:

Reservoir		Surface
ΔV_g^R	$\longrightarrow$	$\Delta V_{g,g}^S + \Delta V_{o,g}^S$
ΔV_o^R	$\longrightarrow$	$\Delta V_{o,o}^S + \Delta V_{g,o}^S$.

On the left hand side there is a reservoir volume of gas (ΔV_g^R) and oil (ΔV_o^R). When an unit of oil is lifted to surface conditions, a volume of oil is produced ($\Delta V_{o,o}^S$) and a volume of gas that under reservoir conditions was dissolved in the oil ($\Delta V_{g,o}^S$). Similar for the gas phase. We ignore dissolved oil in gas, i.e. $\Delta V_{o,g}^S = 0$.