National Exams December 2010

98-Pet-A3: Fundamental Reservoir Engineering

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper a clear statement of any assumptions made.
2. Candidates may use one of the two calculators, the Casio or Sharp approved models. This is a closed-book exam.
3. Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.
4. All questions are of equal value. Unless otherwise stated, all parts in a multipart question have equal weight.
5. In answering computational questions, clearly explain your logic.
6. Pay close attention to the units, some questions involve oilfield units, and these should be answered in the field units. Questions that are set in SI units should be answered in SI units.

Question 1 (20 Marks)

Explain (in one or two sentences) what you understand by the following terms.

i. Effective Porosity
ii. Absolute permeability
iii. Oil saturation
iv. Formation volume factor
v. Bubble point pressure
vi. Relative permeability
vii. Capillary pressure
viii. Wettability
ix. Contact angle
x. Solution GOR

Question No. 2 (20 Marks)

Starting from the Darcy's law written in cylindrical geometry, derive an expression for the steady-state in-flow of a slightly compressible fluid into a vertical well. Assume that only one fluid phase is flowing under isothermal conditions and the compressibility of the fluid does not change with pressure. Use the following nomenclature.

q_R = volumetric flow rate measured at a reference pressure,
k = permeability,
h = pay zone thickness,
p_e = pressure at the drainage radius,
p_R = the reference pressure,
p_w = well pressure
c = fluid compressibility
μ = fluid viscosity,
r_e = drainage radius,
r_w = well radius,

Question 3. (20 Marks)

During a PVT experiment a crude oil sample was placed in a variable volume PVT cell and its initial bubble point pressure was determined. The pressure in the PVT cell was then decreased in three steps and the volumes of liquid and gas phases were recorded. After recording the volumes at each pressure the gas was purged out of the cell but all of the liquid was retained. The temperature was kept constant at 15 °C. The following data were recorded.

Pressure (kPa)	Temperature (°C)	Liquid Volume (mL)	Volume of Gas released at cell P and T (mL)	Z-factor for the gas at cell P and T.
30,000	15.0	189.75	0.0	-
20,000	15.0	170.35	24.97	0.886
10,000	15.0	159.85	35.35	0.932
101.325	15.0	147.83	3981.35	1.0

Use 101.325 kPa and 15°C as the standard conditions.

a. Calculate the oil formation factor B_o at 30,000, 20,000 and 10,000 kPa.
b. Calculate the solution gas oil ratio at 30,000, 20,000 and 10,000 kPa.
c. Calculate the two-phase formation volume factors at 20,000 kPa.

Question 4 (20 Marks)

(a) **(8 Marks)** The oil/water capillary pressure curve for a thick reservoir is given in Figure 1. The densities of water and oil at reservoir conditions are 990 kg/m^3 and 875 kg/m^3 respectively. The oil-water interfacial tension is given as 23 mN/m. The reservoir is in direct contact with an underlying aquifer. Given that the water saturation in the reservoir at depth of 2000 m is 55%, what would be the water saturation at depth of 1950 m.

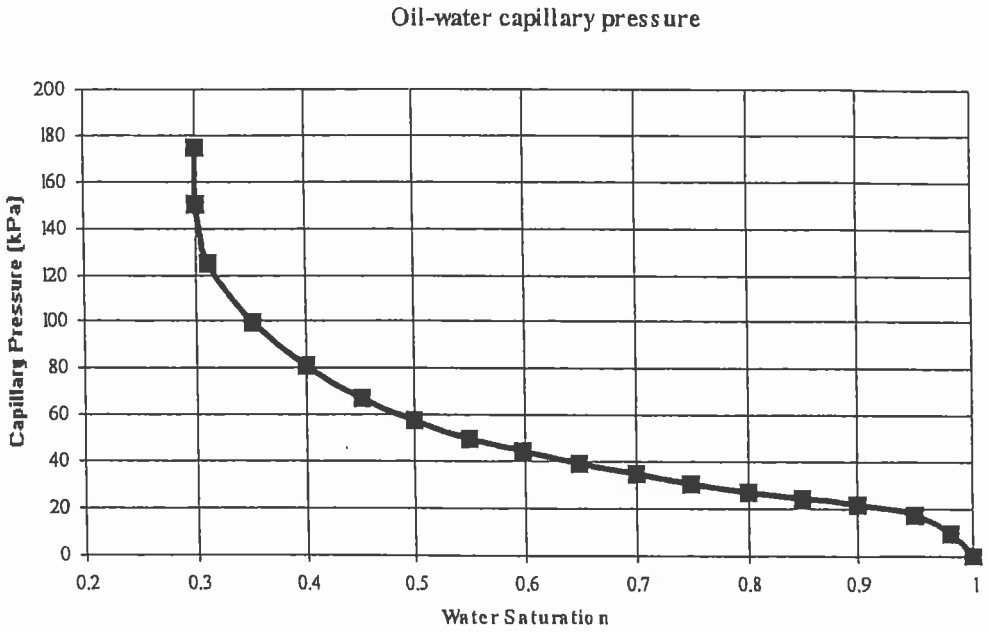

Figure 1: Oil water capillary pressure under static conditions for Question #2(a).

(b) (12 Marks) Oil/water relative permeability of a reservoir rock/fluid system was characterized and found to fit the following equations:

$$k_{rw} = 0.5(S_w - 0.25)^2$$
$$k_{ro} = 3.6(0.75 - S_w)^2$$

$S_{wi} < S_w < (1\text{-}S_{or})$

The viscosities of oil and water at the reservoir conditions are 1.5 mPa.s and 0.9 mPa.s respectively. Answer the following questions about this rock/fluid system.

(i) What are the irreducible water saturation and residual oil saturation?
(ii) What are the end-point relative permeabilities to oil and water?
(iii) What is the end-point water/oil mobility ratio?
(iv) What is the wettability of the rock-fluid system?

Question 5 (20 Marks)

A volumetric oil reservoir with no original gas cap initially contains 1.250 x 10^6 std. m^3 of oil at its bubble point pressure of 29 MPa with 150 standard m^3 of dissolved gas per standard m^3 of oil. When the reservoir

pressure has dropped to 16 MPa, the gas in solution is 80 standard m^3 per standard m^3 of oil. The initial B_o was 1.35 and at the current pressure of 16 MPa, B_o is 1.22. Other available data are:

Cumulative produced GOR, $R_p = 200$ standard m^3 per standard m^3 of oil (at current res. pressure of 16 MPa), $S_{wi} = 0.25$, and $B_g = 0.0066$ at 16 MPa.

(a) What are the cumulative volumes of oil and gas produced from the reservoir when the reservoir pressure has decreased to 16 MPa.

(b) Calculate the free gas saturation at 16 MPa.

Question 6. (20 Marks)

A producing formation consists of two strata: one 25 ft thick and 100 md in permeability; the other 15 ft thick and 400 md in permeability.

(a) What is the total flow capacity of the formation? **(3 Marks)**

(b) What is the average horizontal permeability of the reservoir? **(3 Marks)**

(c) If during a work-over of a vertical well, the 100 md stratum permeability is reduced to 20 md out to a radius of 6 ft and the 400 md stratum is reduced to 40 md out to a radius of 10 ft, what is the average horizontal permeability of the reservoir after the well work-over, assuming no cross-flow between the beds? Use $r_e = 500$ ft and $r_w = 0.25$ ft. **(10 Marks)**

(d) To what fraction of the original productivity index will the well be reduced to after the damage described in part-c? **(4 Marks)**

Question 7. (20 Marks)

A saturated oil reservoir is in contact with a gas cap and is subject to water influx from an underlying aquifer. The following data are available for this combination drive reservoir.

Volume of bulk oil zone	= 112,000 ac-ft
Volume of bulk gas zone	= 19,600 ac-ft
Initial reservoir pressure	= 2710 psia
Initial formation volume factor	= 1.34 bbl/STB
Initial gas volume factor	= 0.006266 cu ft/SCF
Initial dissolved GOR	= 562 SCF/STB
Cumulative volume of oil produced from the reservoir	= 20 MM STB
Current reservoir pressure	= 2000 psia
Average produced GOR	= 700 SCF/STB
Two-phase formation volume factor at 2000 psia	= 1.4954
Volume of water encroached	= 11.58 MM bbl
Volume of water produced	= 1.05 MM STB
FVF of the water	= 1.028 bbl/STB
Gas volume factor at 2000 psia	= 0.008479

Assuming that the porosity and connate water saturation are same in the gas and oil zones, calculate the stock tank barrels of oil initially in place.

Formula Sheet

Darcy's law: $q = -A\frac{k}{\mu}\frac{\Delta p}{L}$

Darcy's law for radial flow in cylindrical geometry: $q = -2\pi rh \times \frac{k}{\mu}\frac{dp}{dr}$

Mobility ratio: $M = \frac{k_{rw}\mu_o}{k_{ro}\mu w}$

Radial flow equation: $q = \frac{2\pi kh(p_2 - p_1)}{\mu_o \ln(r_2/r_1)}$

Fluid compressibility: $c = -\frac{1}{V}\frac{dV}{dP}$

Gas law: $pV = nZRT$

Two-phase formation volume factor: $B_t = B_o + (R_{soi} - R_{so})B_g$

Material balance equation for a reservoir driven by a gas cap and water influx:

$$N = \frac{N_p[B_t + (R_p - R_{soi})B_g] - W_e + B_w W_p}{B_t - B_{ti} + \frac{mB_{ti}}{B_{gi}}(B_g - B_{gi})}$$

Average permeability for radial flow in series incylindrical geometry: $k_{avg} = \frac{k_a k_b \ln\left(\frac{r_e}{r_w}\right)}{k_a \ln\frac{r_e}{r_a} + k_b \ln\frac{r_a}{r_w}}$

Useful Constants and Conversion Factors:

R = 0.8205 m^3 atm/(kmol K) = 8.315 J/mol K

Standard atmosphere = 101.325 kPa

Temperature in K = 273.15 + °C

1 bbl = 5.615 ft^3

1 Acre = 43560 ft^2

1 acre-ft = 7758 bbl

1 hectare = 10,000 m^2

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