National Exams December 2015

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. This is a CLOSED BOOK exam.
3. Any non-communicating calculator is permitted.
4. FIVE (5) questions constitute a complete exam paper.
5. The first five questions as they appear in the answer book will be marked.
6. All questions are of equal value unless otherwise stated and all parts in a multipart question have equal weight.
7. Clarity and organization of your answers are important, clearly explain your logic.
8. Pay close attention to units, some questions involve oilfield units, and these should be answered in the field units. Questions that are set in other units should be answered in the corresponding units.
9. A formula sheet is provided at the end of questions

Question 1 (20 Marks)

Explain (briefly in one or two sentences or may be a simple equation) the following reservoir engineering concepts.

a) Original oil in place
b) Residual oil saturation
c) Oil formation volume factor
d) Water influx
e) Gas cap drive
f) Pseudo-steady-state
g) Skin factor
h) Fractional flow curve
i) Effective permeability
j) Breakthrough time

Question 2 (20 Marks)

A cylindrical core of 10 cm in length and 5 cm^2 cross-sectional flow area with an absolute permeability of 0.5 Darcy has been used to perform a core flood test. Use the following data obtained from a steady-state core flood test to calculate oil and water effective and relative permeabilities when water saturation in the core is 40%. Oil and water viscosities are 3.52 and 1 cp, respectively. Core length = 10 cm, cross-sectional area of the core = 5 cm^2.What is the pressure difference between inlet and outlet of the core when water saturation is 40%?

Water saturation	0	0.2	0.4	0.6	0.8	1
Water rate (mL/sec)	0	0	0.0220	0.0561	0.1100	0.2750
Oil rate (mL/sec)	0.0780	0.0546	0.0260	0.0098	0.0013	0

Question 3 (20 Marks)

An exploration wells has been drilled into a newly discovered oil reservoir. Use the reservoir date given in the following and calculate the bottom-hole pressure after 2 days of production at a flow rate of 250 STBD.

Reservoir external radius, r_e	3000 ft
Total compressibility, c_t	6×10^{-6} psi^{-1},
Oil viscosity, μ	2 cP,
Oil formation volume factor, B_o	1. 25 bbl/STB,
Reservoir permeability, k	100 mD,
Formation thickness, h	100 ft,
Initial reservoir pressure, p_i	3000 psia,
Formation porosity, ϕ	0.20,
Well radius, r_w,	0.33 ft.

Question 4 (20 Marks)
A volumetric dry gas reservoir with a gas specific gravity of 0.65, an initial pressure of 4000 psia and a formation temperature of 200° F has produced 500 MMSCF of gas and the reservoir pressure has dropped to 3000 psia. Determine the initial gas in place and the cumulative gas production when reservoir pressure drops to 2000 psia.

Question 5 (20 Marks)
The daily oil production rate from an oil reservoir is 500 STBD. The drainage area of this well is 200 acres where the average pressure is at 2000 psia. Calculate the flowing wellbore pressure using the following data:

Reservoir permeability, k	200 mD
Oil formation volume factor, B_o	1.252 bbl/STB
Oil viscosity, μ	1 cp
Formation thickness, h	50 ft
Skin factor, s	-1
Wellbore radius, r_w	0.3 ft
Reservoir bubble point pressure, p_b	1000 psia

$$200 \times 43560 = \pi r_e^2 \rightarrow r_e = 1665.267\,ft$$

$$q = \frac{7.08kh(\bar{p} - p_w)}{\mu B_o\left[\ln(r_e / r_w) + \frac{1}{2} + s\right]} \rightarrow 500 = \frac{7.08(0.200)(50)(2000 - p_w)}{(1)(1.252)\left[\ln(1665.267/0.3) + \frac{1}{2} + (-1)\right]} \rightarrow p_w = 1928.2\,psia$$

Question 6 (20 Marks)
Fluid property and reservoir data for an oil reservoir with an initial oil in place of 10 MMSTB are given in the following table. Calculate the cumulative oil production when the reservoir pressure drops to the bubble point pressure.
Porosity = 0.165
Formation compressibility = 2.5×10^{-6} psi^{-1}
Water compressibility = 2.91×10^{-6} psi^{-1}
Reservoir Temperature = 150 °F

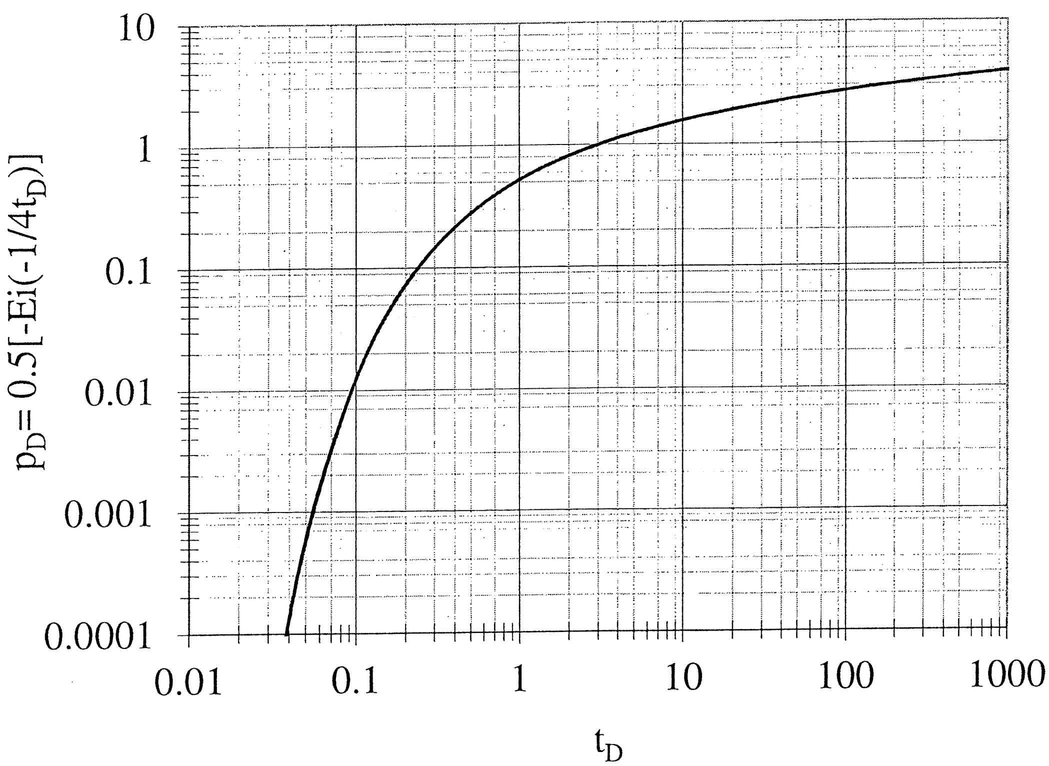
Pressure (psia)	Bo (bbl/STB)	Rs (SCF/STB)
3000	1.315	650
2500	1.325	650
2300	1.311	618

Question 7 (20 Marks)
Log data for an oil well reveals a water oil contact (WOC) depth of 7000 ft. Core analysis data for the reservoir shows a capillary pressure of 10 psi at 40% water saturation. The reservoir oil and water densities are 50 and 62 lb_m/ft^3, respectively. Use the given data and

a) Draw a simple schematic plot of depth (y-axis) and pressure (x-axis) and show:

> **a1)** Threshold (or entry) pressure,
> **a2)** Oil pressure,
> **a3)** Water pressure,
> **a4)** Water oil contact and free water level

b) Calculate depth of 40% water saturation



Plot of dimensionless pressure versus dimensionless time

Formula Sheet

Real gas law

$pV = ZnRT$

where p in psia, T in °R, V in ft^3, R=10.732 psi-ft^3/(lb_{mol}-°R)

Gas formation volume factor, $B_g = 0.02827\frac{ZT}{p}$ in $\frac{ft^3}{SCF}$, where p in psia, T in °R.

Hydrostatic and capillary pressures

$p = \rho \frac{g}{g_c}\frac{h}{144}$,

$p_c = p_o - p_w$,

where p is pressure in psia, g=32.17 ft/sec^2, g_c=32.17 ($1b_{mass}$-ft)/(lb_f-sec^2), h in ft and ρ is density in lb_{mass}/ft^3, subscripts o and w stand for oil and water, respectively.

Equation for steady-state linear and radial flows in oil field units.

$$q = -\frac{1.127kA}{\mu B_o}\left(\frac{dp}{ds} \pm 0.433\gamma \sin\theta\right),$$ + for upward flow and - for downward flow.

$$q = \frac{7.08kh(p_r - p_w)}{\mu B_o[\ln(r/r_w) + s]}, \quad \bar{p} = \frac{1}{V}\int_V p dV$$

where dV=2πrhdr, A is the cross-sectional area in ft^2, γ is oil specific gravity, θ is slope with horizontal level in degree, k is permeability in Darcy, h is formation thickness in ft, r is radius in ft, p is pressure in psia, $\bar{p}$ is the average pressure in psia, s is skin, B_o is the oil formation volume factor in bbl/STB, and μ is viscosity in cP.

Darcy equation in Darcy's unit- Linear

$q = -\frac{kA}{\mu}\frac{dp}{dx}$, k is permeability in Darcy, A is area in cm^2, μ is viscosity in cp, L is length in cm, and p is pressure in atm.

Transient flow equations in field units:

$$\eta = \frac{6.33k}{\phi\mu c}, \qquad t_D = \frac{\eta t}{r^2}$$

$$p_D = \frac{1}{2}(\ln t_D + 0.809)$$ only if t_D>100,

$$p(r,t) = p_i - \frac{0.141q_o\mu_o B_o}{kh}(p_D + S)$$

where ϕ is porosity, t is time in day, t_D is the dimensionless time, k is permeability in Darcy, h is formation thickness in ft, r is radius in ft, p is pressure in psia, c is the oil compressibility in psi^{-1}, B_o is the oil formation volume factor in bbl/STB, μ is the oil viscosity in cP, S is skin factor, and p_D is the dimensionless pressure. The subscript i denotes the initial condition.

Pseudo critical pressure and temperature

$$T_{pc} = 168 + 325\gamma_g - 12.5\gamma_g^2 \quad \text{in}\ ^oR$$

$$p_{pc} = 677 + 15.0\gamma_g - 37.5\gamma_g^2 \quad \text{in } psia$$

Reduced temperature: $T_r = \dfrac{T}{T_c}$

Reduced pressure: $p_r = \dfrac{p}{p_c}$

where γ_g is the gas specific gravity (Air=1)

Gas reservoirs material balance equation

$$\frac{p}{Z} = \frac{p_i}{Z_i}\left(1 - \frac{G_p}{G}\right)$$

where p is pressure in psia, G_p is the cumulative gas production, and G is the original gas in place. The subscript i denotes the initial condition.

Oil reservoir material balance

$$\frac{N_p}{N} = \frac{(B_t - B_{ti}) + B_{ti}\left[\dfrac{c_w S_{wi} + c_f}{1 - S_{wi}}\right]\Delta p}{B_t + (R_p - R_{soi})B_g} \qquad B_o = B_t - B_g(R_{soi} - R_{so})$$

where c_w is water compressibility in psi^{-1}, c_f is the rock compressibility in psi^{-1}, S_w is the initial water saturation, Δp is pressure drop in psi, N is the initial oil in place in STB, N_p is the cumulative oil production in STB, B_t is the two-phase formation volume factor in bbl/STB, B_g is the gas formation volume factor in bbl/SCF, R is the gas oil ratio in SCF/STB and m is dimensionless. The subscript i denotes the initial condition.

Conversion Factors

1 m^3 = 6.28981 bbl =35.3147 ft^3
1acre = 43560 ft^2
1ac-ft = 7758 bbl
1Darcy = 9.869233×10^{-13} m^2
1 atm =14.6959488 psi =101.32500 kPa=1.01325 bar
1 cP = 0.001 Pa-sec
1 m = 3.28084 ft = 39.3701 inch

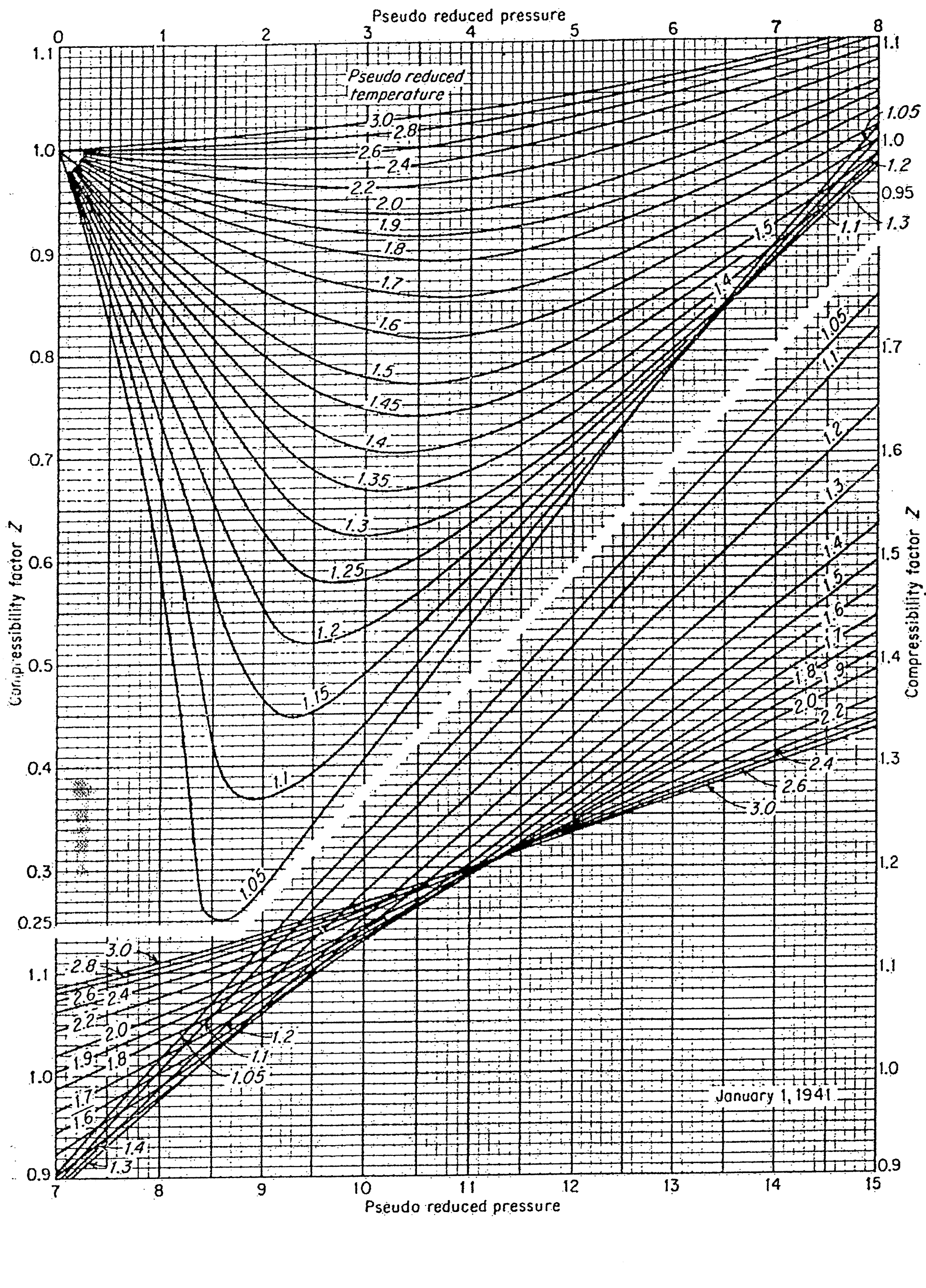


Fig. 4-16. Compressibility factor for natural gases. (*Standing and Katz, 4-87. Courtesy AIME.*)