National Exams May 2018

17-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. One of two calculators is permitted - any Casio or Sharp approved model.
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)

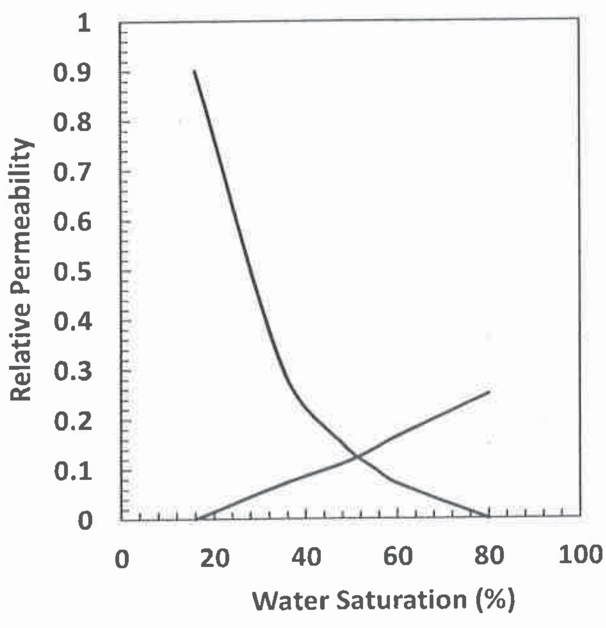
Explain (briefly in one or two sentences) the following reservoir engineering concepts.

a) Reservoir rock
b) Trap
c) Secondary oil migration
d) Wettability
e) Secondary porosity
f) Tortuosity
g) Contact angle
h) Residual oil saturation
i) Overburden pressure
j) Effective permeability

Question 2 (20 Marks)

a) A rock sample of 20 cm long and 4 cm^2 in cross section flows 0.01 cm^3/sec of a 1 cP water under a 2 atm pressure drop. If the core sample is fully saturated by water (S_w=1), what is the absolute permeability?

b) The core sample described in part (a) is flooded with oil with viscosity of 2 cP and a uniform water saturation of 40% was stablished in the core. The pressure drop along the core was measured to be 3 atm. Use the relative permeability data shown in the following to calculate the water and oil rate at 40% water saturation.



c) Use the data provided in part (b) to calculate water effective permeability at the residual oil saturation and oil effective permeability at the connate water saturation.

d) Explain why at any water saturation the sum of the two effective permeabilitis to oil and water is less than the absolute permeability.

Question 3 (20 Marks)

An oil well has been drilled close to an observation well. The distance between the drilled well and the observation well is estimated to be 1000 ft. A downhole pressure gauge is installed in the observation well to monitor the reservoir pressure. The drilled well is put on production at a rate of 100 STBD. Use the reservoir data given in the following and calculate the time required to record a pressure drop of 2.5 psi in the observation well. Note that the observation well acts like a point and the flow rate for this well is zero.

Reservoir external radius, r_e	5000 ft,
Total compressibility, c_t	3×10^{-6} psi^{-1},
Oil viscosity, μ	1 cP,
Oil formation volume factor, B_o	1. 3 bbl/STB,
Reservoir permeability, k	400 mD,
Formation thickness, h	20 ft,
Initial reservoir pressure, p_i	2500 psia,
Formation porosity, ϕ	0.15,
Well radius, r_w,	0.3 ft.
Skin factor, S,	-2

Question 4 (20 Marks)

Production data from a gas reservoir, produced under volumetric condition, are as follows:

$T_i = 200^\circ F$, $T_c = 388R$, $p_c = 735\ psia.$

P (psia)	G_p(MMMSCF)
3800	270
3200	390

a) Estimate the initial gas in place of the reservoir.

b) What will be the recovery factor for this volumetric reservoir at a pressure of 2000 psia?

Question 5 (20 Marks)

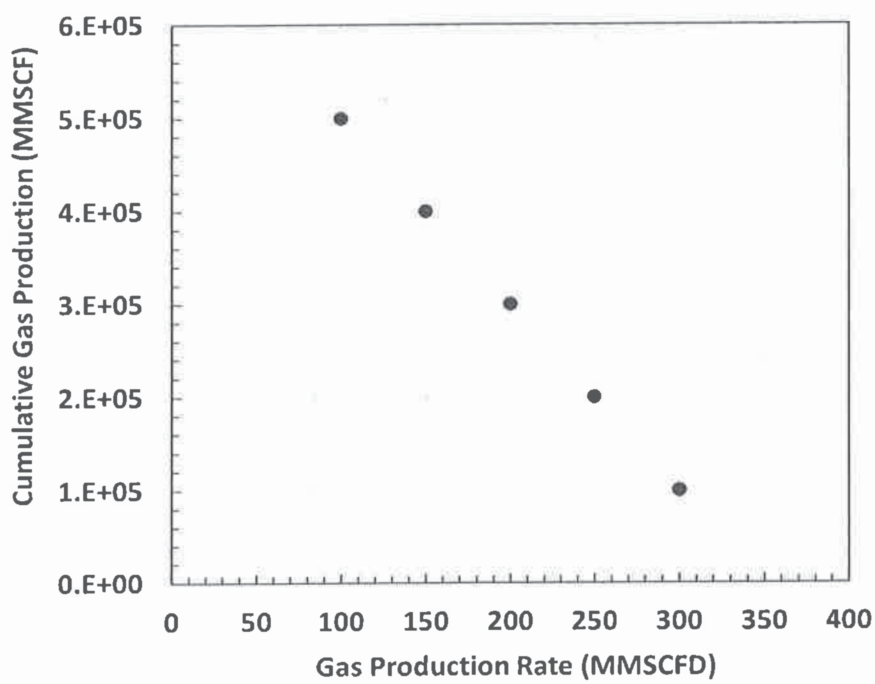
Use the following data for an oil reservoir and determine the depletion drive index, gas cap drive index, and water drive index at 3950 psia. Ignore the effect of water production and water and rock compaction ($c_f = 0$, $c_w = 0$). The original oil in place was 67 MMSTB and the gas cap held 38 MMMSCF of gas at discovery.

p (psia)	N_p (MSTB)	G_p (MMSCF)	B_o (bb//STB)	B_g (bbl/MSCF)	B_w (bb//STB)	R_s (SCF//STB)
4100	0	0	1.41	0.591	1.13	950
3950	1314	1140	1.34	0.602	1.09	800

Question 6 (20 Marks)

The following graph is available from a dry gas field with the boundary-dominated flow condition.

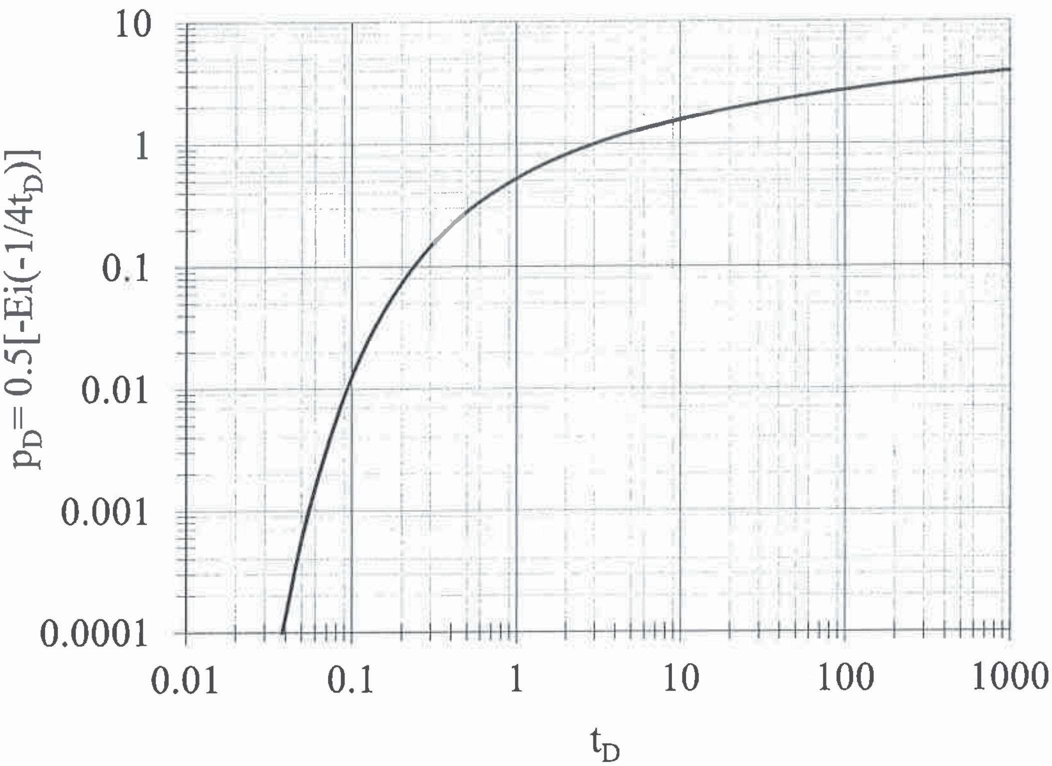
a) Calculate the gas volume (MMSCF) produced during the fifth year of production.
b) Estimate the production life of this reservoir if the economic production rate limit is 10 MMSCFD.



Question 7 (20 Marks)

An undersaturated water-drive radial reservoir with an external radius of 3000 ft has produced for several years without considerable change in the reservoir pressure. After a workover operation on one well with radius of 0.3 in this reservoir the formation around the wellbore is damaged to a radius of 2 ft so that the permeability in the damaged zone has been reduced to 1/10 of the original undamaged permeability. Therefore, well stimulation is planned to improve the well productivity.

a) Calculate the skin factor due to formation damage.
b) Calculate the ratio of oil production rate after the well stimulation to the oil production rate before the well stimulation ($((q_{after} / q_{before})$. Assume that the well flowing bottom hole pressure before and after the well stimulation is kept the same.



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 $\frac{\text{ft}^3}{\text{SCF}}$, 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 q is in STBD, 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,

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

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

$$\underbrace{N(B_t - B_{ti})}_{\text{oil expansion}} + \underbrace{Nm\frac{B_{ti}}{B_{gi}}(B_g - B_{gi})}_{\text{gas expansion}} + \underbrace{(1+m)NB_{ti}\left[\frac{c_w S_{wi} + c_f}{1 - S_{wi}}\right]\Delta p}_{\text{rock and water expansion}} + \underbrace{W_e}_{\text{water influx}}$$

$$= \underbrace{N_p\left[B_t + B_g(R_p - R_{soi})\right]}_{\text{oil and gas production}} + \underbrace{B_w W_p}_{\text{water production}}$$

$$B_t = B_o + B_g(R_{soi} - R_{so})$$

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 ratio of reservoir gas volume to the reservoir oil volume in the primary gas cap and dimensionless, W_p is the cumulative water production in STB, W_e is the cumulative water influx in bbl, B_w is the water formation volume factor. The subscript i denotes the initial condition.

Decline curve analysis

Exponential decline: $q = q_i e^{-Dt}$, Harmonic decline: $q = q_i/(1 + Dt)$

Hyperbolic decline $q = q_i(1 + bDt)^{-1/b}$ Cumulative production $G_p = \int q dt$

where q is rate in SCFD, G_p is the cumulative production in SCF, t is time in day , D is the decline rate in 1/day and subscript i stands for 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

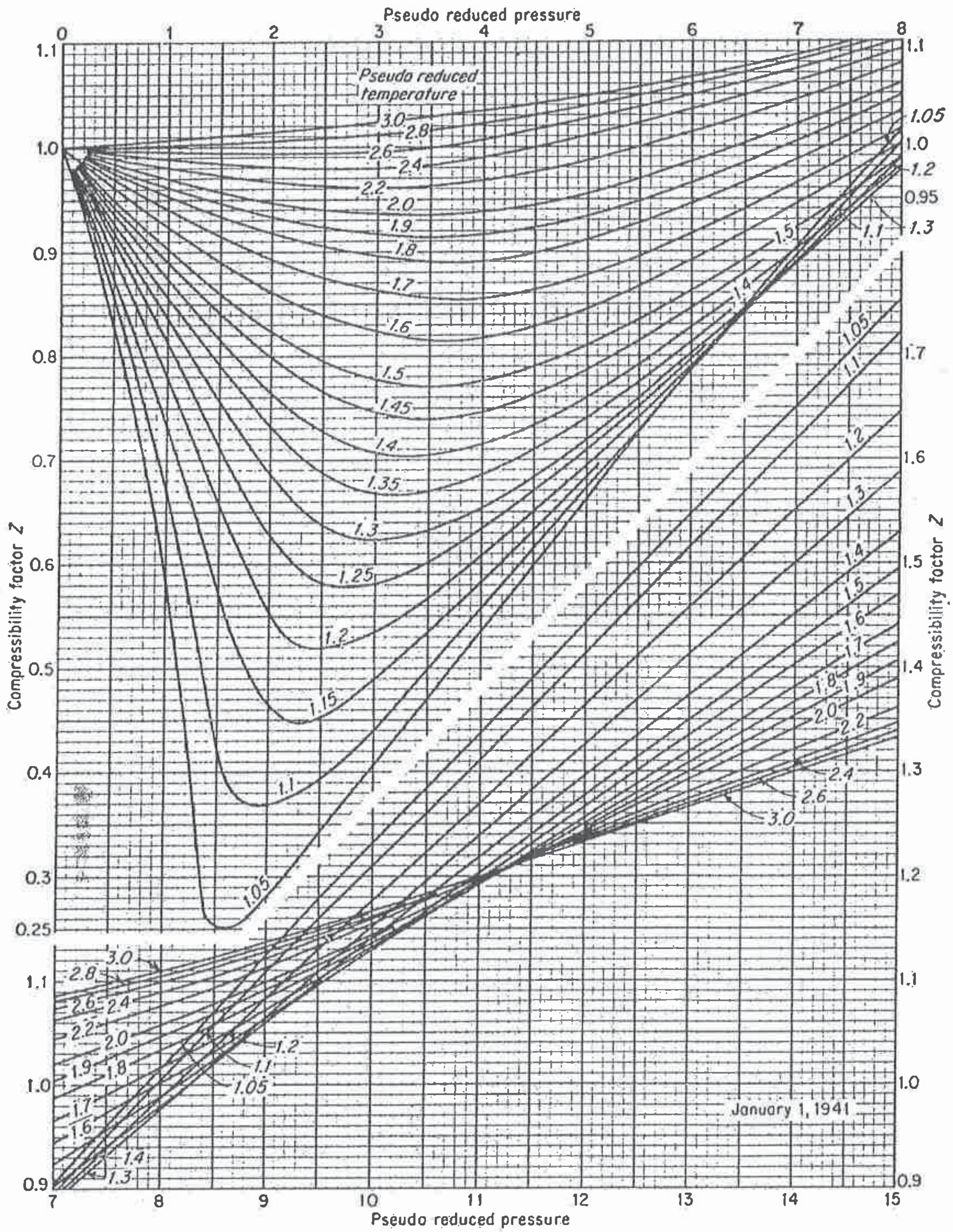


Fig. 4-16. Compressibility factor for natural gases. (*Standing and Katz, 4-87. Courtesy AIME.*)