National Exams May 2016

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)** Infinite acting
- **b)** Threshold pressure
- **c)** Compaction drive
- **d)** Well stimulation
- **e)** Productivity index
- **f)** Drawdown test
- **g)** Formation volume factor
- **h)** Isothermal compressibility
- **i)** Oil reserve
- **j)** Residual oil saturation

Question 2 (20 Marks)

A 10 cm long and 3 cm diameter core plug is fully saturated with 22 cm^3 of water. Water is injected into the core at a flow rate of 1 cm^3 per min. and a stabilized pressure drop of 20 psi is measured along the core plug. An oil flood is then conducted on this plug. It is found that 15 cm^3 of water was displaced from this plug by the oil. After reaching this value, no further water could be displaced from the core plug. At this condition the oil flow rate was 0.1 cm^3 per min. and a stabilized pressure drop of 30 psi is observed along the core plug. Use the given data to answer the following questions.

Oil viscosity = 12 cp,
Water viscosity = 1 cp,
Oil formation volume factor =1 m^3/m^3,
Water formation volume factor =1 m^3/m^3,
Capillary pressure = 0.

a) What is the core plug porosity?
b) What is the core plug absolute permeability?
c) What is the connate (or irreducible) water saturation of this core plug?
d) What is the oil relative permeability at the connate water saturation?

Question 3 (20 Marks)

An exploration wells has been drilled close to a sealing fault in a newly discovered oil reservoir. The distance between the well and the sealing fault is estimated to be 250 ft. The well is put on production at a rate of 250 STBD. Use the reservoir date given in the following and calculate the bottom-hole pressure after 1 day of production. Assume infinite acting except for the fault limitation.

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 has the following production history.

Time (year)	Pressure (psia)	Gas compressibility factor (Z)	Cumulative production (MMMSCF)
0.5	1680	0.870	0.96
2.0	1335	0.900	3.92

a) Calculate the initial gas in place for this reservoir,

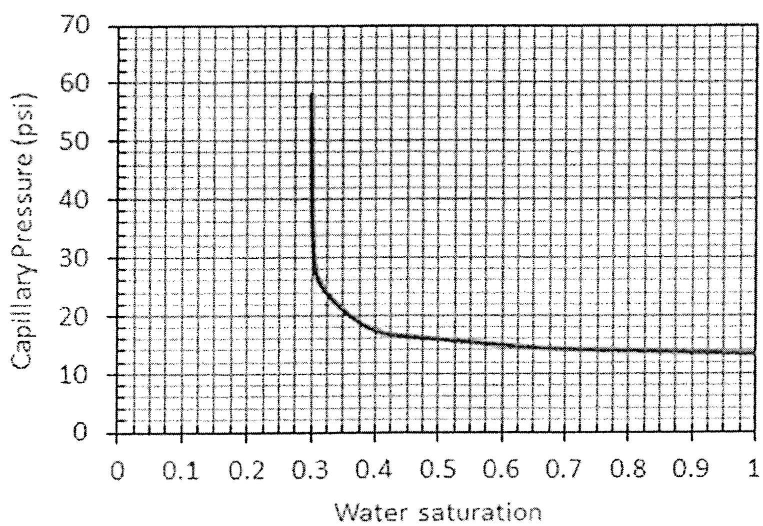
b) Calculate cumulative production when reservoir pressure declines to 1000 psia. The gas compressibility factor is 0.92 at 1000 psia.

Question 5 (20 Marks)

The capillary pressure data for an oil reservoir is shown in the following graph. The depth of free water level for this reservoir is estimated to be 6000 ft and the oil and water densities are 50 and 65 lb_{mass}/ft^3, respectively. Use the given data to answer the following questions.

a) What is the depth of water oil contact?

b) Estimate thickness of the transition zone?

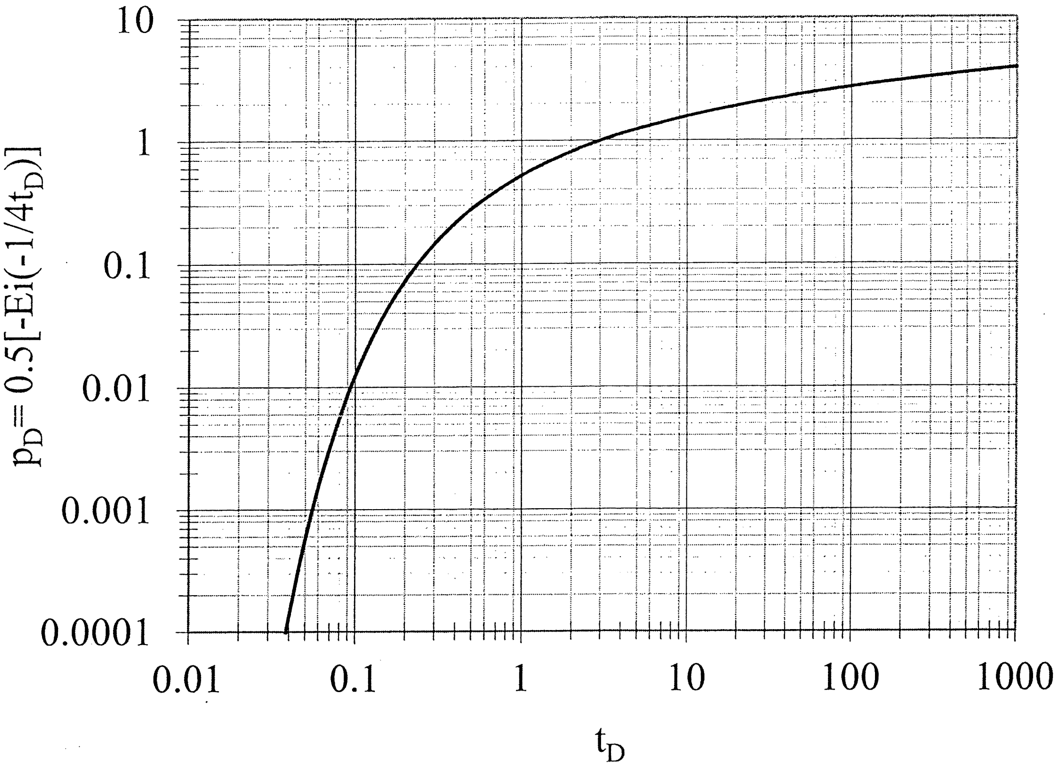


Question 6 (20 Marks)
The following rock and fluid properties data for an oil reservoir are given. Use these data to calculate the cumulative oil production when the reservoir pressure drops to 3900 psia. Ignore rock and water compressibility effect.

Porosity = 0.20,
Reservoir Temperature = 150 °F,
Reservoir Area = 1000 acres,
Formation thickness 70 ft,
Initial water saturation = 0.25,
Initial pressure = 5000 psia,
Bubble point pressure =3500 psia.

Pressure (psia)	Bo (bbl/STB)	Rs (SCF/STB)
5000	1.315	700
3900	1.320	700

Question 7 (20 Marks)
The oil production rate from an oil well is 800 STBD. The well drainage area is estimated to be 200 acres and the reservoir pressure at the external radius of the drainage area is 2000 psia. If the oil viscosity is 2 cp, the oil formation volume factor is 1.2 bbl/STB, the wellbore radius is 0.33 ft, thickness of pay zone 20 ft, and the formation permeability is 200 mD, what is the wellbore flowing pressure? What is the reservoir average pressure?



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

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

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

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