National Exams December 2017

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)

The following PVT data are available for field "A".

Pressure (psia)	$B_o\ \left(\frac{bbl}{STB}\right)$	$R_{so}\ \left(\frac{SCF}{STB}\right)$	$B_g\ \left(\frac{bbl}{SCF}\right)$
2500	1.40	800	-
2300	1.41	800	0.0014
1500	1.35	600	0.0022

The initial reservoir pressure and temperature were 2500 psia, and 140 °F, respectively and the bubble point pressure was 2300 psia. There was no water drive and no water production from the field.

After production of 600 MMSTB oil and 800 MMMSCF gas, average reservoir pressure dropped from 2500 psia to 1500 psia.

a) Calculate the initial oil in place (STB)
b) Calculate the volume of free gas (SCF) within the reservoir at 1500 psia.
c) Based on connate water saturation of 25% and porosity of 15%, calculate the reservoir bulk volume (bbl).

Question 2 (20 Marks)

A discovery well is located at the centre of an oil reservoir, well above its bubble point pressure. The reservoir and well properties are given below. Production rate from this well was constant at 50 STB/Day for the first 5 days, and was then reduced to 20 STB/Day.

a) Calculate the pressure at the well 2 days after the rate decrease
b) After two days of production at 20 STB/Day, the well was shut in. Estimate the pressure in the wellbore one day after the shut in.

$P_i = 3500\ psia$ $\qquad$ $S_{wi} = 25\%$

$\phi = 0.18$ $\qquad$ $h = 30\ ft$

$C_o = 12\times10^{-6}\ psi^{-1}$ $\qquad$ $\mu = 1\ cp$

$C_w = 4\times10^{-6}\ psi^{-1}$ $\qquad$ $K = 20\ md$

$C_f = 4\times10^{-6}\ psi^{-1}$ $\qquad$ $r_w = 0.3\ ft$

$B_o = 1.2\ bbl/STB$

Assume no damage at the area around the wellbore, and assume the reservoir is large enough such that the effect of pressure disturbance is not felt at the outer boundary of the reservoir.

Question 3 (20 Marks)

The initial reservoir pressure in the vicinity of a new well was 4412 psia. A pressure drawdown test was conducted while the well was flowed at a constant rate of 250 STB/Day. The oil had a viscosity of 0.8 cp and a formation volume factor of 1.136 bbl/STB. Other relevant data follow:

$r_w = 0.198\ ft$

$h = 69\ ft$

$\phi = 3.9\%$

$C_t = 17{\times}10^{-6}\ psi^{-1}$

$S_{wi} = 0.25$

The bottomhole flowing pressure data are plotted on a semilog as well as a linear graph (Figures 1 and 2)

a) Calculate the formation permeability
b) Calculate the value of skin factor
c) Calculate the initial oil in place

Question 4 (20 Marks)

A cylindrical core 1 ft long and 0.1 ft^2 in cross section flows 1.127 STB/Day of a 2.5 cp oil under a pressure drop of 100 psi. Core porosity is 0.15 and formation volume factor of oil is 1.0 bbl/STB.

a) What is the absolute permeability of rock?
b) The same core is maintained at a water saturation of 50% and oil saturation of 50%. Under a pressure drop of 100 psi water and oil flow rates were measured 0.2 and 0.4 STB/Day, respectively. What are the oil and water relative permeability at Sw=0.5? (Viscosity and Formation Volume Factor of water are 1 cp and 1 bb/STB respectively)
c) The method described in part b was used to obtain relative permeability data for the above core. Using this data and viscosity of oil and water fractional flow function of water (f_w) and its derivative were constructed (see Figure 3). Using the data presented in Figure 3, find the water saturation at the front and calculate the distance that the water front has travelled after 10 minutes of water injection at a constant rate of 0.1STB/Day. Consider an intial water saturation of 0.15. (ignore the difference between water and oil pressure, $P_o=P_w$)
d) Explain how the water saturation at the front (S_f) and oil recovery behind the front would have changed if oil viscosity were increased, everything else remaining the same. (Assume Buckly-Leveret solution is valid)

Question 5 (20 Marks)

Draw a set of relative permeability curves for a typical water wet rock. Explain the effect of presence of the non-wetting phase on effective permeability to the wetting phase, and its differences with the effect of presence of the wetting phase on effective permeability to the non-wetting phase. Also, briefly describe the process of imbibition vs. drainage.

Question 6 (20 Marks)

An oil well is producing at a constant rate inside a circular reservoir, which was initially at a constant pressure of $P=P_i$.

Express the second boundary condition (that at the far boundary) that leads to (a) infinite acting, (b) pseudo steady-state, and (c) steady-state flow regimes.

For each case, qualitatively draw and label a schematic diagram showing pressure profiles in this oil reservoir as a function of time and radius.

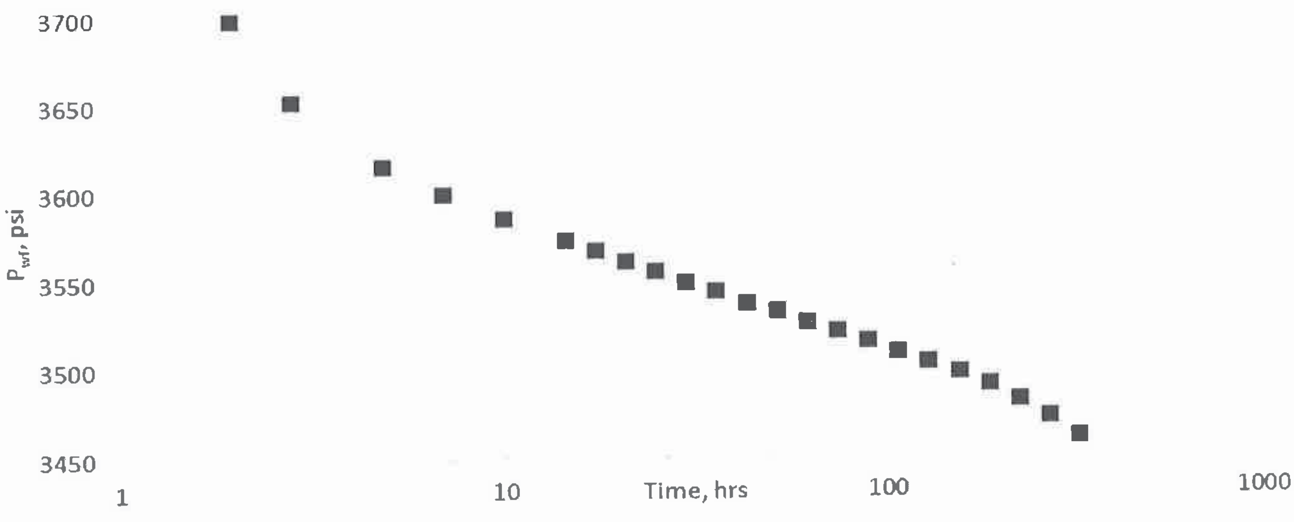

Figure 1

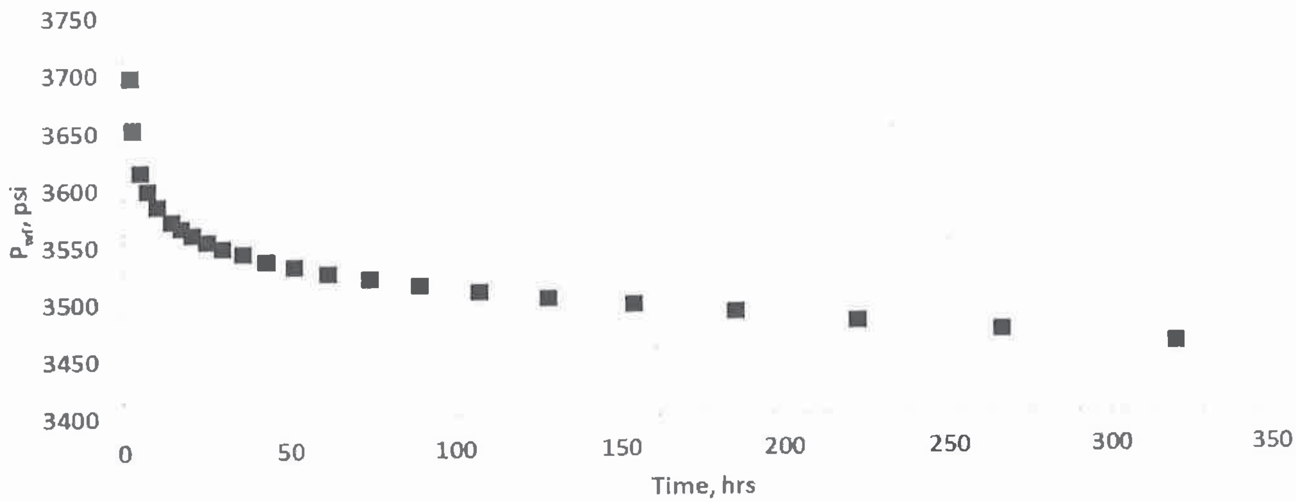

Figure 2

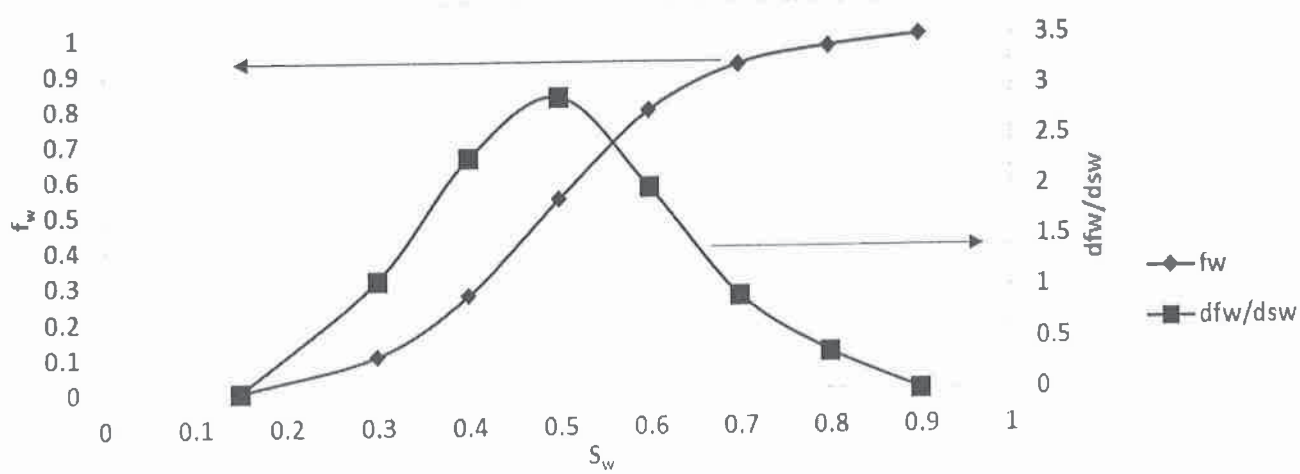

Figure 3

Table 8.1 Values of $-E_i(-x)$ as a Function of x

x	$-E_i(-x)$	x	$-E_i(-x)$	x	$-E_i(-x)$
0.1	1.82292	4.3	0.00263	8.5	0.00002
0.2	1.22265	4.4	0.00234	8.6	0.00002
0.3	0.90568	4.5	0.00207	8.7	0.00002
0.4	0.70238	4.6	0.00184	8.8	0.00002
0.5	0.55977	4.7	0.00164	8.9	0.00001
0.6	0.45438	4.8	0.00145	9.0	0.00001
0.7	0.37377	4.9	0.00129	9.1	0.00001
0.8	0.31060	5.0	0.00115	9.2	0.00001
0.9	0.26018	5.1	0.00102	9.3	0.00001
1.0	0.21938	5.2	0.00091	9.4	0.00001
1.1	0.18599	5.3	0.00081	9.5	0.00001
1.2	0.15841	5.4	0.00072	9.6	0.00001
1.3	0.13545	5.5	0.00064	9.7	0.00001
1.4	0.11622	5.6	0.00057	9.8	0.00001
1.5	0.10002	5.7	0.00051	9.9	0.00000
1.6	0.08631	5.8	0.00045	10.0	0.00000
1.7	0.07465	5.9	0.00040		
1.8	0.06471	6.0	0.00036		
1.9	0.05620	6.1	0.00032		
2.0	0.04890	6.2	0.00029		
2.1	0.04261	6.3	0.00026		
2.2	0.03719	6.4	0.00023		
2.3	0.03250	6.5	0.00020		
2.4	0.02844	6.6	0.00018		
2.5	0.02491	6.7	0.00016		
2.6	0.02185	6.8	0.00014		
2.7	0.01918	6.9	0.00013		
2.8	0.01686	7.0	0.00012		
2.9	0.01482	7.1	0.00010		
3.0	0.01305	7.2	0.00009		
3.1	0.01149	7.3	0.00008		
3.2	0.01013	7.4	0.00007		
3.3	0.00894	7.5	0.00007		
3.4	0.00789	7.6	0.00006		
3.5	0.00697	7.7	0.00005		
3.6	0.00616	7.8	0.00005		
3.7	0.00545	7.9	0.00004		
3.8	0.00482	8.0	0.00004		
3.9	0.00427	8.1	0.00003		
4.0	0.00378	8.2	0.00003		
4.1	0.00335	8.3	0.00003		
4.2	0.00297	8.4	0.00002		

LIST OF FORMULA

Conversion factors

R: Universal gas constant = 8.3144621 J/(mole.K) = $10.73 \frac{psia.ft^3}{lb-mole.^oR}$

$1\ bbl = 5.615 ft^3$

$^oR = 460 + \ ^oF$

$Acre = 43560\ ft^2$

$M: 10^3$

$MM: 10^6$

$MMM: 10^9$

Complete form of Material Balance Equation

(i) For gas reservoirs:

$$G(B_g - B_{gi}) + GB_{gi}\left(\frac{c_w S_{wi} + c_f}{1 - S_{wi}}\right)\Delta\bar{P} + W_e = G_P B_g + B_w W_P$$

(ii) For oil reservoirs:

$$N_p[B_t + (R_p - R_{soi})B_g] + W_p B_w = W_e + N[B_t - B_{ti}] + \frac{mNB_{ti}}{B_{gi}}(B_g - B_{gi}) + (1+m)NB_{ti}\left(\frac{C_w S_{wi} + C_f}{1 - S_{wi}}\right)\overline{\Delta p}$$

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

Any consistent set of units.

Darcy's Law for Steady State Linear and Radial Flow

$$q_o = 0.001127\frac{kA\Delta P}{\mu_o B_o L}$$

$$q_o = \frac{0.00708kh}{\mu_o B_o}\frac{p_e - p_w}{ln\left(\frac{r_e}{r_w}\right)}$$

Field units (STB/Day, md, ft, cp, psi)

Well Performance Equations

(i) Pressure Buildup Analysis

Horner equation:

$$p_{ws} = p_i + m \log\left[\frac{t_p + \Delta t}{\Delta t}\right]$$

Skin factor:

$$S = 1.151\left[\frac{(p_{w,\Delta t=0} - p_{1hr})}{m} - log\left(\frac{k}{\phi\mu_o c_t r_w^2}\right) + 3.23\right]$$

(ii) Pressure drawdown analysis (or constant terminal rate solution)

Transient period:

(a) Ei from table

$$p(r,t) = p_i + \frac{70.6 q_o \mu_o B_o}{kh} Ei\left(-\frac{\phi\mu_o c_t}{0.001055k}\frac{r^2}{t}\right)$$

(b) Log approximation if $\frac{\phi\mu c_t}{0.001055k}\frac{r^2}{t} < 0.01$:

$$p(r,t) = p_i - \frac{162.6 q_o \mu_o B_o}{kh}\left[log\left(\frac{k}{\phi\mu_o c_t}\frac{t}{r^2}\right) - 3.23\right]$$

$$p(r_w,t) = p_i - \frac{162.6 q_o \mu_o B_o}{kh}\left[log\left(\frac{k}{\phi\mu_o c_t}\frac{t}{r_w^2}\right) - 3.23 + 0.87S\right]$$

$$S = 1.151\left[\frac{(p_{1hr} - p_i)}{m} - log\left(\frac{k}{\phi\mu_o c_t r_w^2}\right) + 3.23\right]$$

Pseudo steady state:

$$p(r_w,t) = p_i - \frac{162.6 q_o \mu_o B_o}{kh}\left[log\left(\frac{4A}{\gamma C_A r_w^2}\right) + 0.87S\right] - \frac{0.2339 q t B_o}{\phi c_t A h}$$

$$\frac{dp}{dt} = -\frac{0.2339qtB_o}{\phi c_t A h}$$

For circular reservoir $C_A = 31.62$

Where

p_{ws} = $wellbore\ pressure\ during\ buildup,\ \ psi$

t_p = $Effectove\ producing\ time,\ \ hrs$

ϕ = $Porosity,\ \ fraction$

μ_o = $oil\ viscosity,\ \ cp$

c_t = $total\ reservoir\ compressibility,\ \ psi^{-1}$

k = $permeability,\ \ md$

h = $reservoir\ thickness,\ \ ft$

r_w = $wellbore\ radius,\ \ ft$

Δt = $shut - in\ time,\ \ hrs$

q_o = $oil\ flow\ rate,\ \ STB/Day$

B_o = $oil\ formation\ volume\ factor,\ \ bbl/STB$

$$m = -\frac{162.6 q_o \mu_o B_o}{kh}, psi/\log cycle.$$

γ = 1.781

A = $Drainage\ area,\ \ ft^2$

C_A = $Dietz\ shape\ factor, dimensionless$

Buckley-Leverett Solution to Two-Phase Flow in Porous Media

$$x(S_w, t) = \frac{5.615 q_t B_w t}{\phi A}\left(\frac{\partial f_w}{\partial S_w}\right)\bigg|_{S_w}$$