National Exam May 2002

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 two calculators, the Casio or Sharp approved models. This is a Closed Book exam.

3. Any four questions constitute a complete paper. Only the first four questions as they appear in your answer book will be marked.

4. All questions are of equal value.

1. (25 Marks) A well is located 764 ft away from a sealing fault, in an otherwise infinite reservoir. The reservoir and well data are given below.

Production rate	700 STB/Day	Oil FVF	1.2 bbl/STB
Reservoir thickness	25 ft	Oil Viscosity	0.8 cp
Total compressibility	15×10^{-6} psi^{-1}	Porosity	0.18
Formation permeability	40 md	Connate water saturation	0.23
Wellbore radius	0.3 ft	Initial reservoir pressure	4000 psia
Skin	0		

(a) Calculate pressure in the wellbore 5 days after production began.
(b) Explain why it is possible to use the infinite acting solution to find the solution to part (a), although there is a no-flow boundary, i.e. the fault, in the vicinity of the wellbore.

2. (25 Marks) Consider a well drilled in the center of an undersaturated cylindrical reservoir that is put to production at a constant rate for 15 days and a fluid sample is then taken. It is anticipated that the bottom-hole flowing pressure might have dropped below the bubblepoint pressure at the end of 15 days of production.

r_w	0.5 ft	μ_o	0.8 cp
B_o	1.2 bbl/STB	h	30 ft
ϕ	0.15	A	60 acres
S (Skin)	0	q	20 STB/day
P_i	4000 psia	P_b	3000 psia
k	2 md	c_t	15×10^{-6} psia^{-1}

a) What is the flow regime at the end of 15 days of production?
b) Use the reservoir and well data given above, and by calculating the bottom-hole pressure, check if the bottom-hole pressure has dropped below the bubblepoint pressure.

3. Answer the following two questions:

(a) (12.5 Marks) A live oil sample (oil and its dissolved gas) is filled into a laboratory cell. The bubblepoint pressure of the mixture is 1000 psia. The volume of the live oil was measured at 100°F between 1200 psia and 2000 psia and was found to follow the following equation: $V_O = 10 - 25\times10^{-5}p + 1\times10^{-8}p^2$, where oil volume ($V_O$) is in cm^3 and pressure is in psia. Calculate the isothermal compressibility of the oil at 1500 psia.

(b) (12.5 Marks) Explain why the slope of the plot of oil formation volume factor vs. pressure is positive below the bubblepoint pressure and negative above the bubblepoint pressure.

4. (25 Marks) A single well with a wellbore radius of 0.3 ft is located in the centre of a cylindrical reservoir. The well has produced a total of 11,125 STB at a nearly constant production rate of 600 STB/day, when a build-up test is performed on the well. The shut-in pressure data are plotted on the two attached graphs. Choose the appropriate graphs and calculate reservoir permeability and wellbore skin.

The well and reservoir properties are:

$p_{w(\Delta t=0)} = 1314\ psia \qquad h = 40\ ft$

$B_o = 1.2\ bbl/STB \qquad c_t = 20.1 \times 10^{-6}\ psi^{-1}$

$\mu_o = 0.8\ cp \qquad \phi = 0.14$

$A = 10\ Acres$

5. (25 Marks) It is estimated that the area around a vertical well is damaged to a depth of 1 ft into the formation, beyond the casing. Permeability of the damaged zone is estimated to be 1 md, while the original reservoir permeability is 15 md. The well is producing at constant bottom-hole pressure of 200 psia (under steady-state conditions) from the centre of a cylindrical reservoir. The outer boundary condition is r_e = 1500 ft, p_e = 2000 psia. Other wellbore and reservoir data are:

r_w	0.5 ft		μ_o	1.5 cp
B_o	1.1 bbl/STB		h	20 ft
ϕ	0.15		S_{wi}	0.25

(a) Calculate the oil production rate in STB/day. Make sure you derive the equation needed for your calculations from the appropriate equations given in the attached sheets.

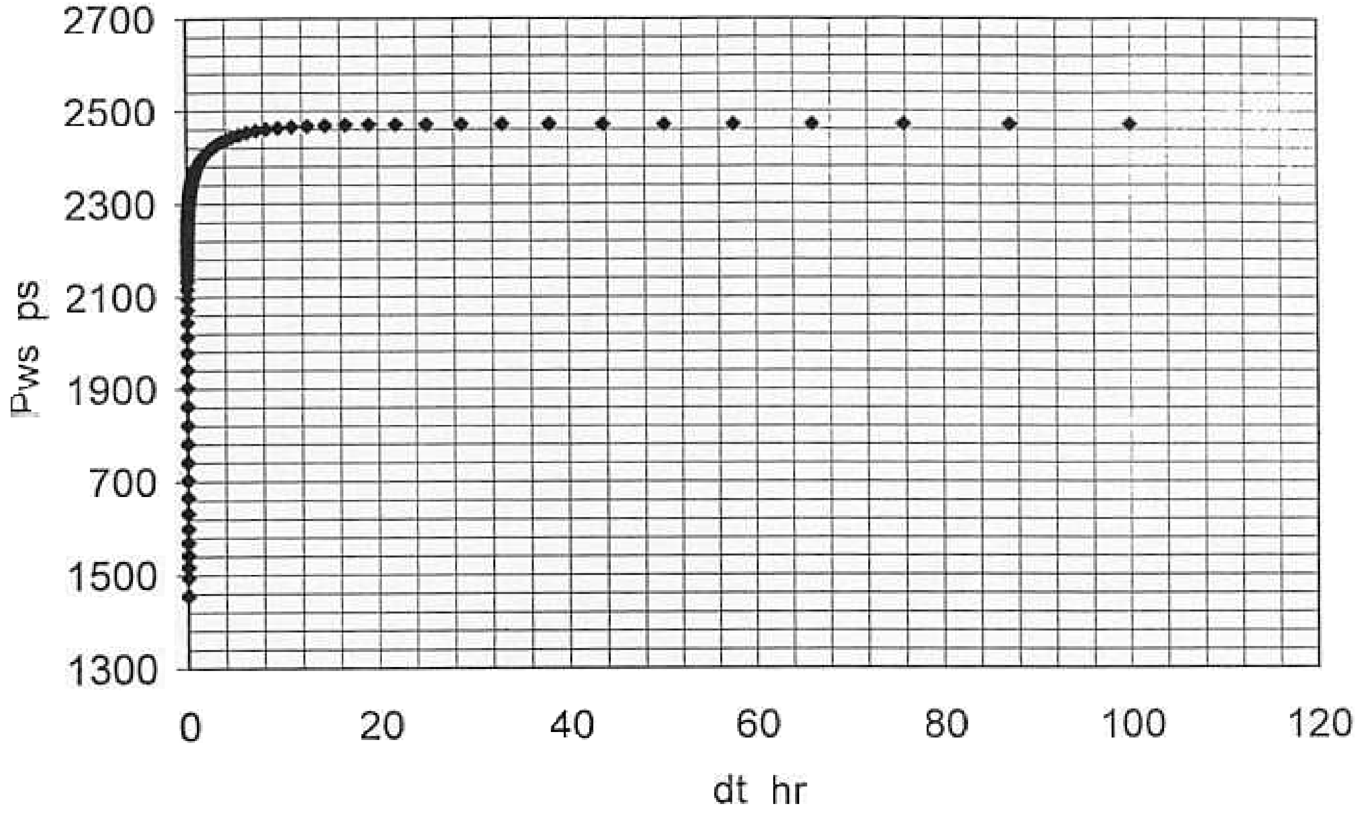
(b) Calculate the skin-factor of the well, if the steady state equation for a damaged well producing under steady state conditions is $q = \frac{0.00708kh}{\mu B} \frac{p_e - p_w}{\ln\left(\frac{r_e}{r_w}\right)}$ where k is the permeability of the formation away from the wellbore, assuming a steady state flow rate of 100 STB/Day.

6. Answer the following two questions:

(a) (12.5 Marks) It can be shown that isothermal compressibility of an ideal gas is equal to $c_v = \frac{1}{p}$

Derive a similar relation for compressibility of a real gas.

(b) (12.5 Marks) Consider two reservoirs at similar conditions (p, T, V_b, ϕ, S_{wi}, etc.). One contains an ideal gas and the other a real gas. Which reservoir contains more SCF of gas? Explain your answer using words or equations.


2700
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2300
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1900
700
1500
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Pws ps
0
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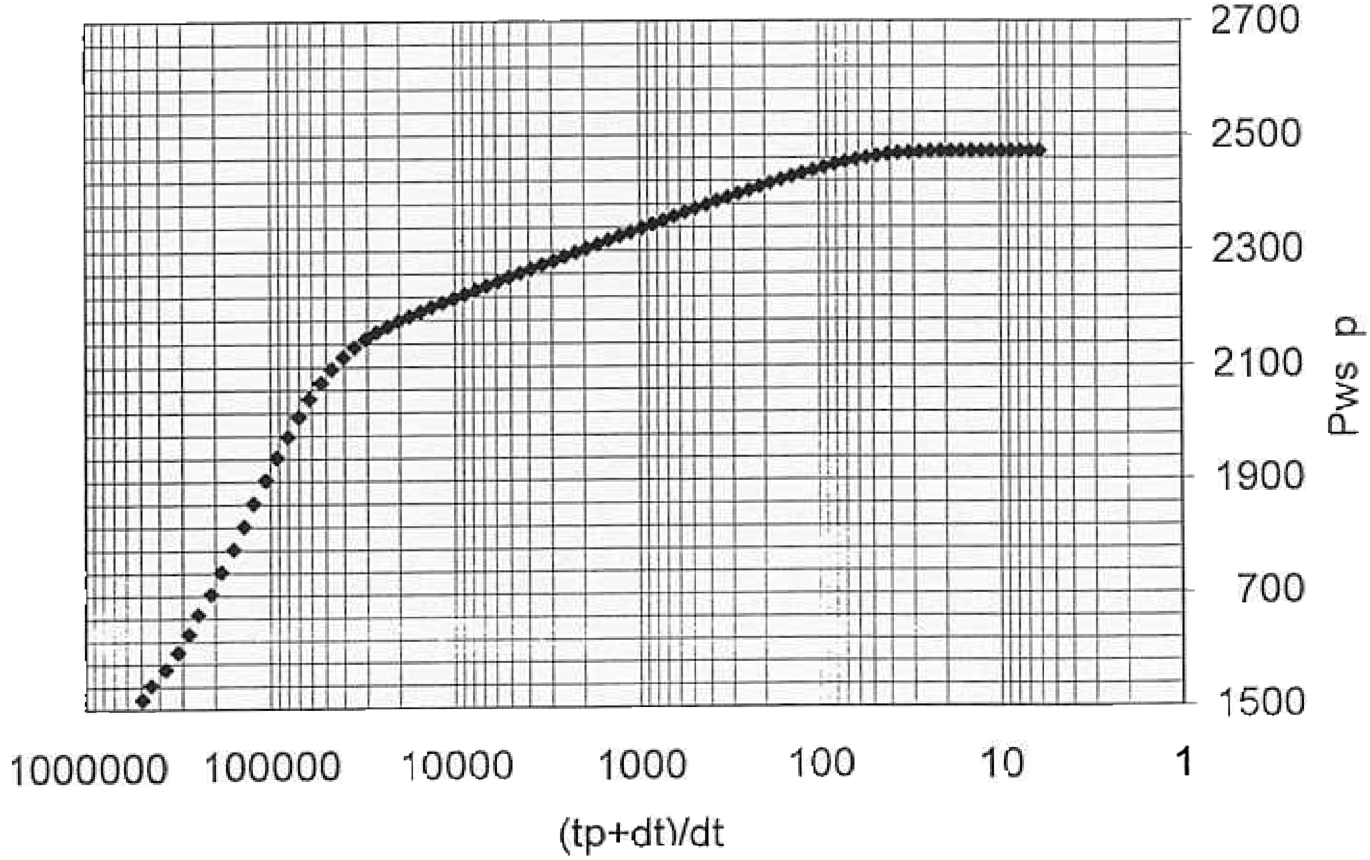
2700
2500
2300
2100
1900
700
1500
Pws p
1000000
100000
10000
1000
100
10
1
(tp+dt)/dt

Useful Formulae

A. Conversion Factors

1 acre = 43560 ft^2
1 bbl = 5.615 ft^3
°R = 460 + °F

B. Darcy's law for steady-state linear and radial flow

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

$$q_o = 0.00708 \frac{kh(p_e - p_w)}{\mu_o B_o [\ln(r_e / r_w) + S]}$$

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

C. Well Performance Equations

(i) Pressure Buildup analysis

Horner equation:

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

Skin factor:

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

(ii) Pressure drawdown analysis (or constant terminal rate solutions).

Transient period:

(a) Ei form (at any *r*)

$$p(r,t) = p_i + \frac{70.6 q_o \mu_o B_o}{kh} Ei\left(-\frac{948 \phi \mu_o c_t r^2}{kt}\right)$$

(b) Log$_{10}$ form valid for $\frac{948 \phi \mu c_t r^2}{kt} < 0.01$

$$p(r,t) = p_i - m\left[\log\left\{\frac{kt}{\phi \mu_o c_t r^2}\right\} - 3.23\right]$$

For pressure in the wellbore there will be an additional 0.87 *S* in the above square bracket, outside the log-term.

Pseudo steady state:

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

For a circular reservoir C_A = 31.62

Where

P_{ws}	=	wellbore pressure during buildup, psi
$P_{w\Delta t=0}$	=	wellbore pressure at instant of shut-in, psi
P_{1hr}	=	horner shut-in pressure, psi, at Δt = 1 hr.
t_p	=	effective producing time, hrs.
ϕ	=	porosity, fraction
μ	=	oil viscosity, cp
c_t	=	total reservoir compressibility, psi^{-1}
k	=	effective 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 volume factor, bbl/STB
m	=	$\frac{162.6 q_o \mu_o B_o}{kh}$, psi/log cycle.
γ	=	Euler's constant 1.781
A	=	drainage area, ft^2.
C_A	=	Dietz shape factor, dimensionless.

D. Material Balance Equation for Gas Reservoirs

$$G(B_g - B_{gi}) + W_e B_w = G_p B_g + W_p B_w$$

$$\frac{p}{z} = \frac{p_i}{z_i}\left(1 - \frac{G_p}{G}\right)$$: For a volumetric reservoir

where the equations are written in any consistent set of units and

- B = Formation volume factor
- G = Original Gas in Place
- G_p = Cumulative volume of gas produced
- P = Pressure
- W = Cumulative water volume
- Z = Gas Compressibility factor

Subscripts

- e = encroached
- g =gas
- i = initial
- p = produced
- w = water

E. Fluid Properties

1. Isothermal Compressibility

$$c = -\frac{1}{V}\left.\frac{\partial V}{\partial p}\right|_T$$