CSD Petroleum Industry Course

Material Balance Problem 1

The time-production-pressure data listed below are actual values obtained during the evaluation of an exploration prospect offshore from Trinidad. The discovery well, to which the data apply, was produced for short intervals between May 10,1963 and February 15, 1965. The question that you are to answer is :

" What is the maximum amount of stocktank oil initially in place in the reservoir unit connected to this well ?"

Note the word maximum. In order for a material balance calculation to yield a maximum value of oil with these date one assumes the following reservoir conditions to exist :

1. there is no initial gas cap present
2. there is no water influx into the oil reservoir
3. the reservoir oil is initially saturated at the initial reservoir pressure of 2840 psig. This is assumed because the producing gas-oil ratio, R_p, of the first time period is larger than the solution gas-oil ratio at 2840 psig. In other words, some free gas was produced almost immediately.

	Cumulative Production		
Date	Tank oil Barrels	Gas MCF	Avg, pressure psig
5/10/63	0	0	2840
7/23/63	36933	37851	2660
5/7/64	65465	74137	2364*
6/11/64	75629	91910	2338*
7/02/64	85544	115256	2375*
2/15/65	96100	148200	2305

PVT dat taken from general correlations are as follows :

Pressure psig	R_s cfb	B_t bbl/bbl	B_g vol/vol
2840	827	1.528	
2660	772	1.563	0.00618
2364	680	1.636	0.00680
2338	675	1.648	0.00691
2375	685	1.634	0.00674
2305	665	1.655	0.00702

* These pressures may be in error as the amount of time given for buildup was limited. The other pressures are believed to be good.

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Material Balance Problem 2

(This is a problem that illustrates the use of the straight line material balance method for a dry gas field. The problem has two parts: the first to determine the initial gas in place, the gas in place at the present time, and the character of the water influx from the aquifer. The second part of the problem is to predict average pressure and cumulative water that will have entered the field four years in the future.)

Gas withdrawals from the XYZ Field have been relatively constant at 24 Mmcf/d. for the first 10 years of production. This has resulted in the following time-pressure-production data:

Date	Datum Pressure psia	Cum.Gas Prod. 10^9 SCF	p/Z	B_g
1967.0	3300	0	4000	0.00431
1969.0	3025	17.52	3738	0.00462
1971.0	2830	35.04	3520	0.00490
1973.0	2670	52.56	3330	0.00519
1975.0	2525	70.08	3160	0.00546
1977.0	2390	87.60	2990	0.00577

Gas contained in the XYZ field is of 0.7 gravity. Average reservoir temperature is 150° F. (at datum) and the California pressure base applies. These conditions were used to develop the p/Z and B_g values listed above.

PART 1. (Past performance)

With the above history data determine the initial gas in place, G, at 1967.0 date, the gas remaining at 1977.0 (report as surface cubic feet), and the Schilthuis steady state efflux constant, k.(ft^3/psi-years)

PART 2. (Future performance)

As a result of market demand it is proposed to increase the off-take rate 25% to 30 Mmcf/d. The question to be answered are :

1. What will the average field pressure be after four years (1981.0) of production at this sustained rate?
2. What will be the total water (cu.ft.) that will have entered the reservoir as of 1981.0 ?

Following are values of gas properties should you need them:

Pressure psia	Z	p/Z	B_g
1800	0.816	2206	0.00782
1900	0.810	2346	0.00735
2000	0.807	2480	0.00696
2100	0.804	2615	0.00660
2200	0.800	2750	0.00627
2300	0.800	2875	0.00600

Material Balance Problem 3

(This problem is an application of the straight line material balance method to a reservoir having an initial gas cap, some water production, and gas injection during later life. The object is to test whether an assumption of no water influx is justified and to determine the best values of the initial oil and gas in place.)

The data below came from an actual field in Southern California. The value of m was estimated from electric log data. Note that two datum levels are used for reporting pressures - one in the oil band and one in the gas cap. (See Column 6 & 7 pressure values) The equation for Y is a means of getting additional significant figures for the B_t values in Column 8.

ASSIGNMENT

In the columns provided below the data set up a computational scheme to provide parameters needed for a straight line material balance for a reservoir having no water influx. Determine the best value of the initial oil in place (STB) and the initial total gas in place (Mmcf).

P_b = 4290 psia B_{ob} = 1.6330 R_{sb} = 975 cfb B_{ti} = 1.6291 m = 0.075 B_w = 1.055 $Y = 1.75 + 0.435\,(10^{-3})\,p$

1980

DATE (1)	N_p Bbl. (2)	W_p Bbl. (3)	G_p MCF (4)	G_i MCF (5)	$\overline{P_o}$ psia (6)	$\overline{P_g}$ psia (7)	B_t @ $\overline{P_o}$ (8)	B_g @ $\overline{P_g}$ (9)	B_{ig} @ $\overline{P_g}$ (10)
A 5/1/60	-	-			4,415	4,245	1.6291	0.00431	
B 1/1/62	492,500	7,960	751,300		3,875	4,025	1.6839	0.00445	
C 1/1/63	1,015,700	25,380	2,409,700		3,315	3,505	1.7835	0.00490	
D 1/1/64	1,322,500	42,540	3,901,600	0	2,845	2,985	1.9110	0.00556	
E 7/1/64	1,444,600	51,080	4,437,300	607,200	2,895	3,052	1.8945	0.00545	0.00600
F 1/1/65	1,586,200	62,340	4,987,700	1,389,400	2,975	3,140	1.8700	0.00533	0.00585

Solution Material Balance Problem 1

Assumptions:

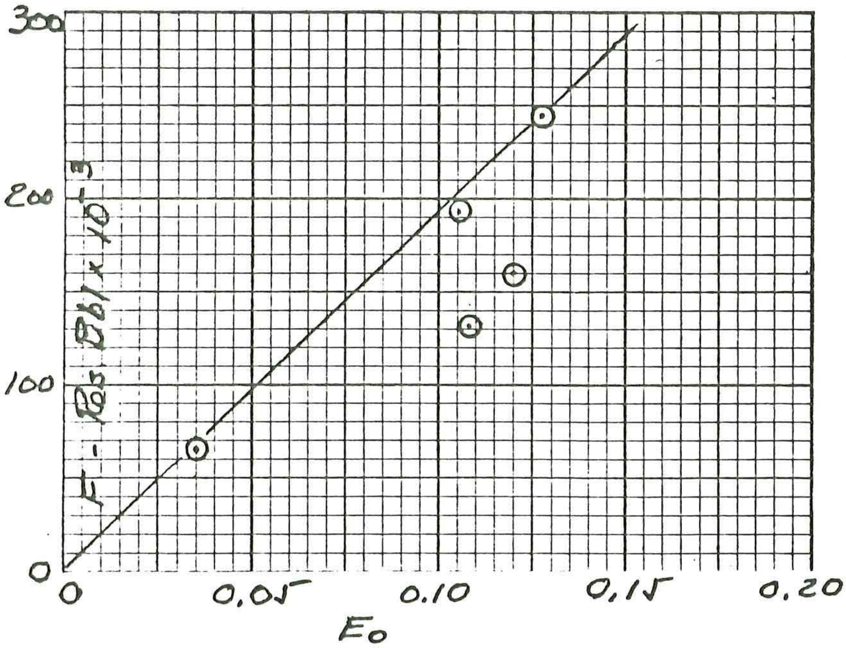
$m = 0$; $W_e = 0$; $p_i = p_b$; ; c_w, c_f neglected.

Voidage = Expansion

$$\underbrace{N_p B_t + (G_p - N_p R_{si}) \frac{B_g}{5.615}}_{\text{Voidage - } F} = \underbrace{N \underbrace{(B_t - B_{ti})}_{E_o}}_{\text{Expansion}}$$

$R_{si} = 875$ ft³/STB $B_{ti} = 1.528$

Avg Press. psig	2-ph FVF B_t	E_o = $(B_t - 1.528)$	$N_p B_t$	$(G_p - N_p R_{si}) \frac{B_g}{5.615}$	F bbl
2660	1.563	0.035	57726	8043	65769
2364	1.636	0.108	107 106	24 218	131 318
2338	1.648	0.120	124 636	36 137	160 774
2375	1.634	0.106	139 779	53 429	193 208
2305	1.655	0.127	159 045	85 922	244 967



Maximum slope $= \frac{290000}{0.15} = 1.93(10^6)$

∴ Maximum initial stocktank oil in place ≅ 1.9 (10⁶) bbl

M.B. Standing

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Solution Material Balance Problem 2

For water influx of Schilthuis SS type we plot $\frac{G_p B_g}{(B_g - B_{gi})}$ vs $\frac{\int (p_i - p)dt}{(B_g - B_{gi})}$

Date	$\int(p_i-p)dt$ psi-years.	F/Eg. $\frac{G_p B_g}{(B_g - B_{gi})}$	$\frac{\int(p_i-p)}{(B_g - B_{gi})}$
1967.0	0	0	0
1969.0	305	261 (10^9)	0.9839 (10^6)
1971.0	1060	291 (10^9)	1.797 (10^6)
1973.0	2167	310 (10^9)	2.462 (10^6)
1975.0	3575	333 (10^9)	3.109 (10^6)
1977.0	5263	346 (10^9)	3.604 (10^6)

From Fig 1

From Fig 2. $G = 232 (10^9)$ SCF

Part 1

$k = 32.29 (10^3)$ ft^3/psi year.) Ans

$W_e)_{10} = 32.29(10^3) \cdot 5263 = 169.92 (10^6)$ ft^3

Part 2.

Gas Remaining $= 232(10^9) - 87.6(10^9) = 144.4 (10^9)$ SCF

As of 1981.0 $G_p = 87.60(10^9) + 4.365 \cdot 30(10^6) = 131.4 (10^9)$ SCF

will use curve to extend $(p_i - p)$ vs t curve.

$$\int_0^{14}(p_i-p)dt = \int_0^{10}(p_i-p)dt + \int_{10}^{14}(p_i-p)dt$$

$$= 5263 + \int_{10}^{14}(p_i-p)dt.$$

p_{14} psia	$\int_{10}^{14}(p_i-p)dt$	B_g	F/E_g	$\frac{\int_0^{14}(p_i-p)dt}{E_g}$
1800	4830	0.00782	293 (10^9)	2.87 (10^6)
1900	4613	0.00735	318	3.25
2000	4427	0.00696	345	3.66
2100	4227	0.00660	379	4.14

Plot F/E_g vs $\int_0^{14}(p_i-p)dt$

From intersection $\bar{p})_{14\,year} = 2034$ psia ans.

" " $\frac{\int_0^{14}(p_i-p)dt}{E_g} = 3.8 (10^6)$

$W_e)_{14} = 32.29 (10^3) \cdot \frac{\int_0^{14}(p_i-p)dt}{E_g} \cdot E_g = 32.29(10^3) \cdot 3.8(10^6) \cdot (0.00684 - 0.00431)$

$= 310 (10^6)$ ft^3 Ans

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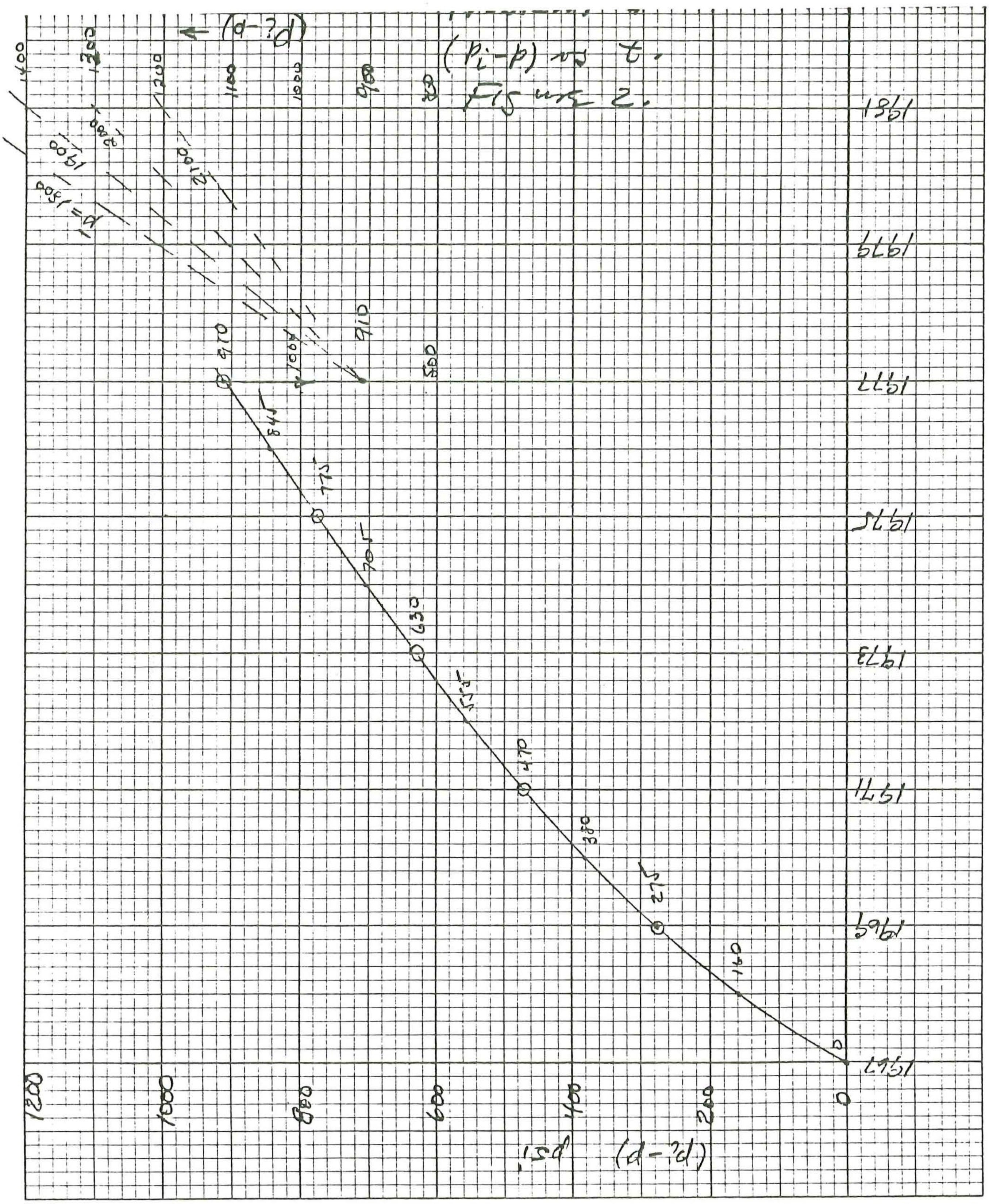
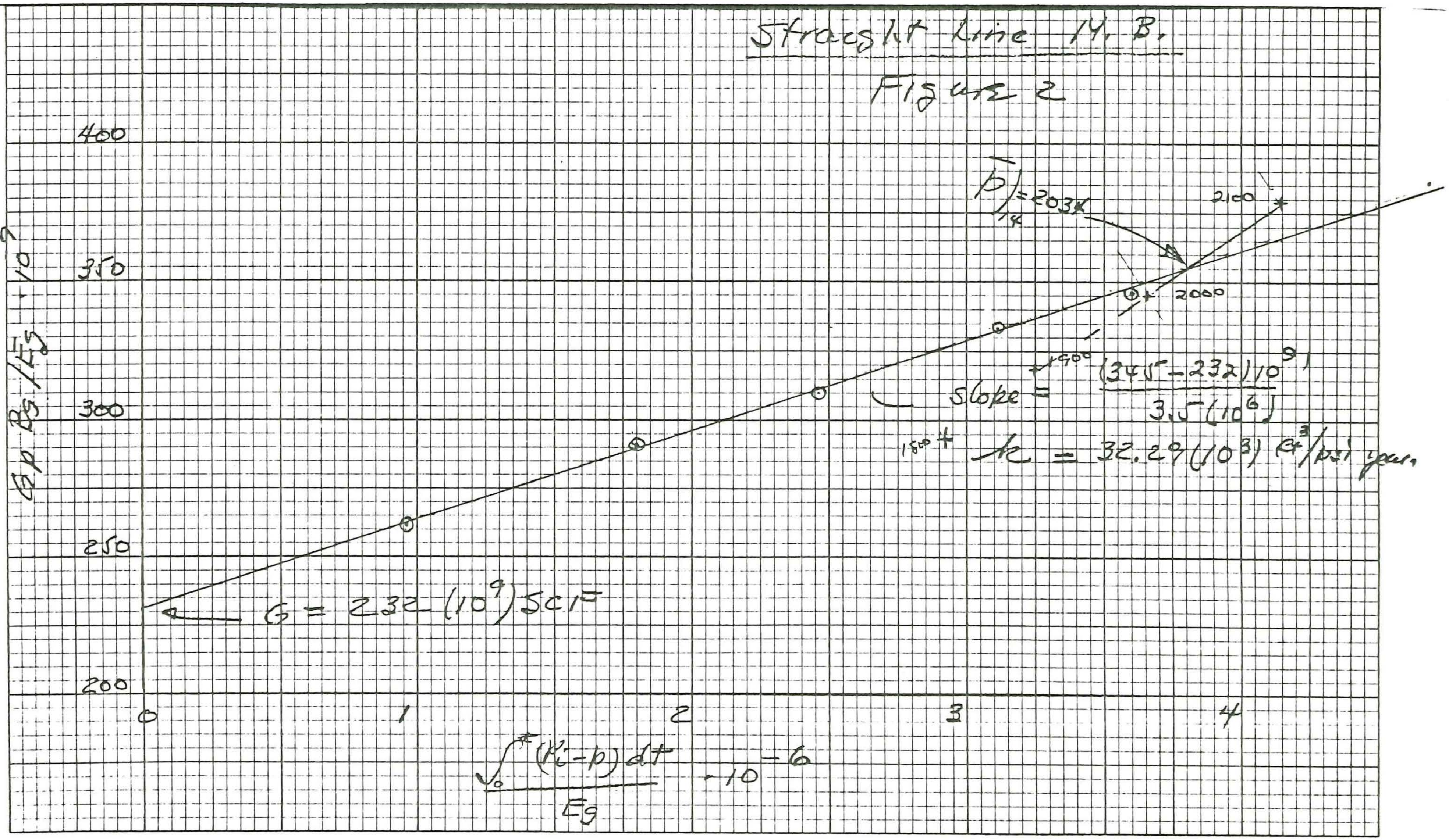
Solution Material Balance Problem 2 Cont.



Solution Material Balance Problem 2. Cont



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Solution Material Balance Problem 3

Given: $W_e = 0$ $m = 0.075$

$$F = N_p B_t + (G_p - N_p R_{sb}) \frac{B_g}{5.615} + W_p B_w - \frac{G_i B_{ig}}{5.615}$$

where $R_{sb} = 975$ ft³/STB ; $B_w = 1.055$

$$E_t = (B_t - B_{ti}) + m B_{ti} \left(\frac{B_g}{B_{gi}} - 1 \right)$$

where $B_{ti} = 1.6291$; $B_{gi} = 0.00431$

Date	$N_p B_t$ Res bbl	$(G_p - 975 N_p) \frac{B_g}{5.615}$ bbl	$W_p \cdot 1.055$ bbl	$G_i B_{ig} / 5.615$ bbl	F Res. bbl	E_t Res bbl/STB
B	$8.293(10^5)$	$2.149(10^5)$	8398	—	$1.0526(10^6)$	0.0588
C	$1.812(10^6)$	$1.239(10^6)$	26776	—	$3.0778(10^6)$	0.1711
D	$2.527(10^6)$	$2.587(10^6)$	44880	—	$5.159(10^6)$	0.3173
E	$2.737(10^6)$	$2.940(10^6)$	53889	$6.488(10^5)$	$5.082(10^6)$	0.2977
F	$2.966(10^6)$	$3.266(10^6)$	65769	$1.448(10^6)$	$4.850(10^6)$	0.2698

(1) From slope of "best" straight line of Figure 1, initial oil in place

$$N = \frac{5.3(10^6)}{0.30} = 17.7(10^6) \text{ STB.}$$

(2) Dissolved gas $= N R_{si} = 17.7(10^6) \cdot 975 = 17.26(10^9)$ SCF

Gas cap gas $= N B_{ti} \cdot m \frac{5.615}{B_{gi}}$

$$= \frac{17.7(10^6)\, 1.6291 \cdot 0.075 \cdot 5.615}{0.00431} = 2.817(10^9) \text{ SCF}$$

Total $= 20.07(10^3)$ MMcf.

[signature] Stendu's
05/30/80

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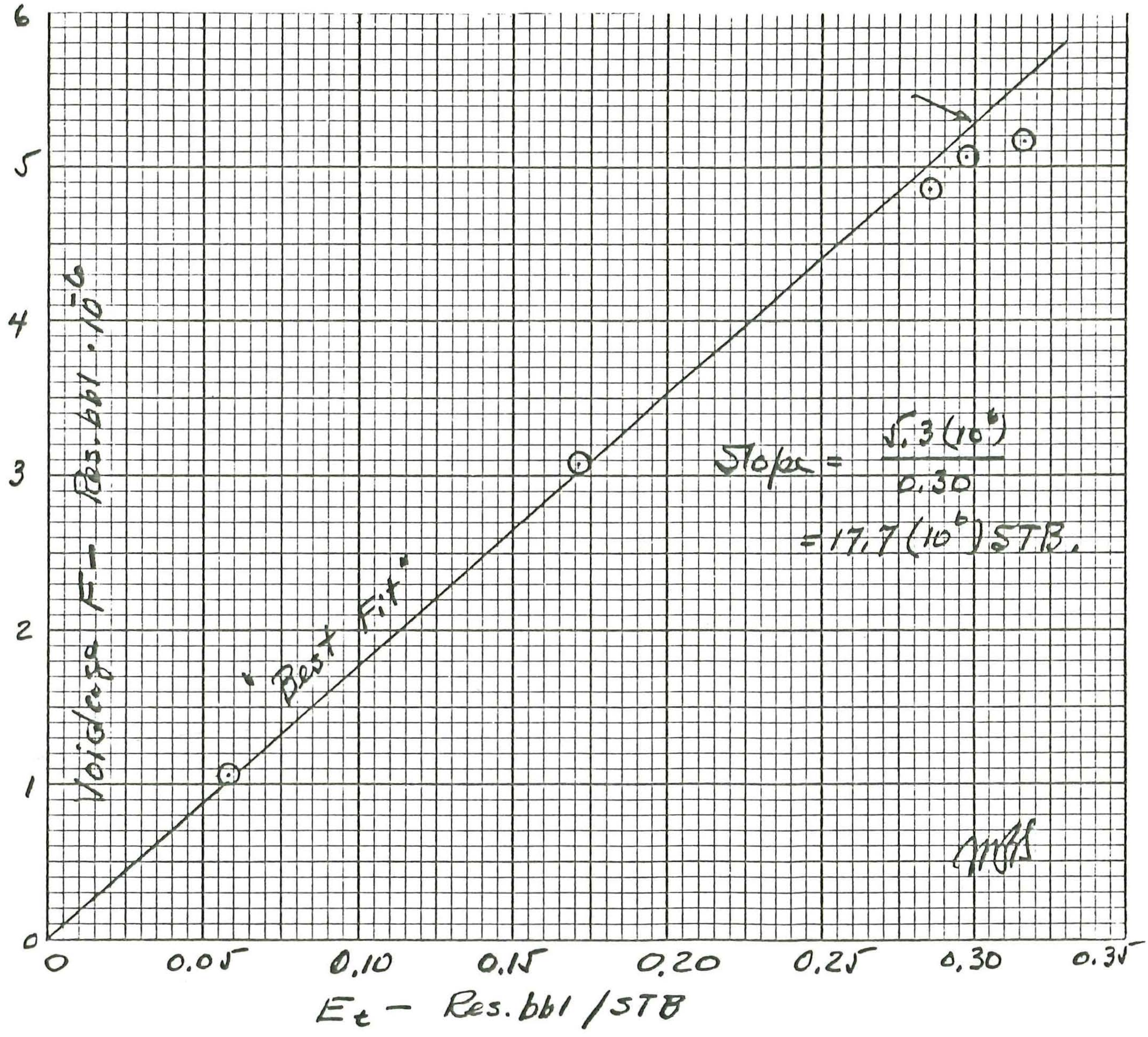
Solution Material Balance Problem 3 Cont.

Figure 1 - Straight Line Material Balance



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Material Balance Problem 4

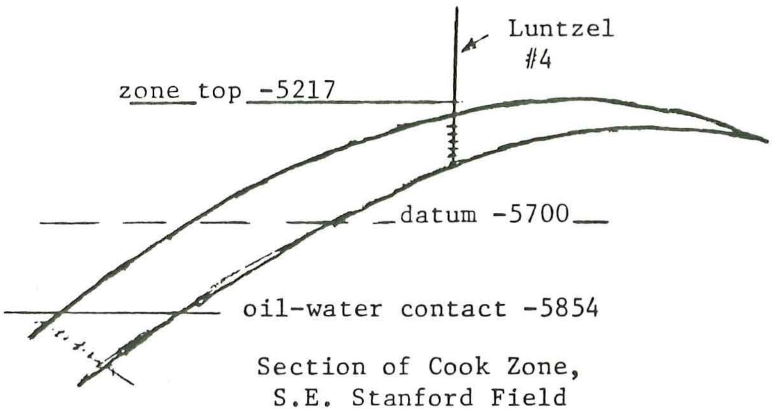
[This problem teaches the calculating procedure used to predict oil and gas recovery factors of reservoirs that produce by solution gas drive (depletion drive) mechanism. The general method is referred to as a Tarner prediction, using the Tracy modification.]

(1) Tarner, J.: "How Different Size Gas Caps and Pressure Maintenance Programs Affect Amount of Recoverable Oil," Oil Weekly (June 12, 1944), p. 32.

(2) Tracy, G.W.: "Simplified Form of the Material Balance Equation," Trans., AIME (1955), 204, 243.

1980

The Cook Zone of the S.E. Stanford Field produces 35.1°API stock tank oil from depths ranging from -5217' (zone top) to -5854' (O/W contact).



Section of Cook Zone,
S.E. Stanford Field

Datum level in this zone is -5700'. Laboratory tests on bottomhole samples indicate the reservoir oil was saturated in the crest of the structure at discovery. However, the reservoir oil gets progressively more undersaturated as one moves away from the crest.

The PVT data listed below were determined by Marsden Laboratories, Inc., on a bottomhole sample from Well Luntzel No. 4. From early well tests, it appears that fluid in the region of this well had a bubble point pressure of 2500 psia at the regional temperature of 180°F. Calculations based on resistivity logs indicate the interstitial water in the region of this well to average 20%. Average porosity (of 67 cores) is 25.5% (arithmetic).

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Material Balance Problem 4 Cont.

SUMMARY OF RESERVOIR FLUID PROPERTIES, WELL LUNTZEL #4, COOK ZONE

Pressure psia	R_s ft^3/STB	B_o RB/STB	B_g ft^3/ft^3	μ_o cp
2500	650	1.325	0.00447	0.90
2300	618	1.311	0.00473	0.97
2100	586	1.296	0.00509	1.05
1900	553	1.281	0.00562	1.14
1700	520	1.266	0.00638	1.26
1500	486	1.250	0.00750	1.39
1300	450	1.233	0.00907	1.54

Pressure psia	μ_g cp	$5.615 \frac{\mu_o}{\mu_g} \frac{B_o}{B_g}$	ϕ_n	ϕ_g
2500	0.0160	93.62(10^3)	∞	∞
2300	0.0158	95.84	61.00	0.0650
2100	0.0156	96.23	26.36	0.0312
1900	0.0154	94.74	13.70	0.0189
1700	0.0152	92.36	7.61	0.0128
1500	0.0150	86.72	4.17	0.00927
1300	0.0148	79.43	2.19	0.00699

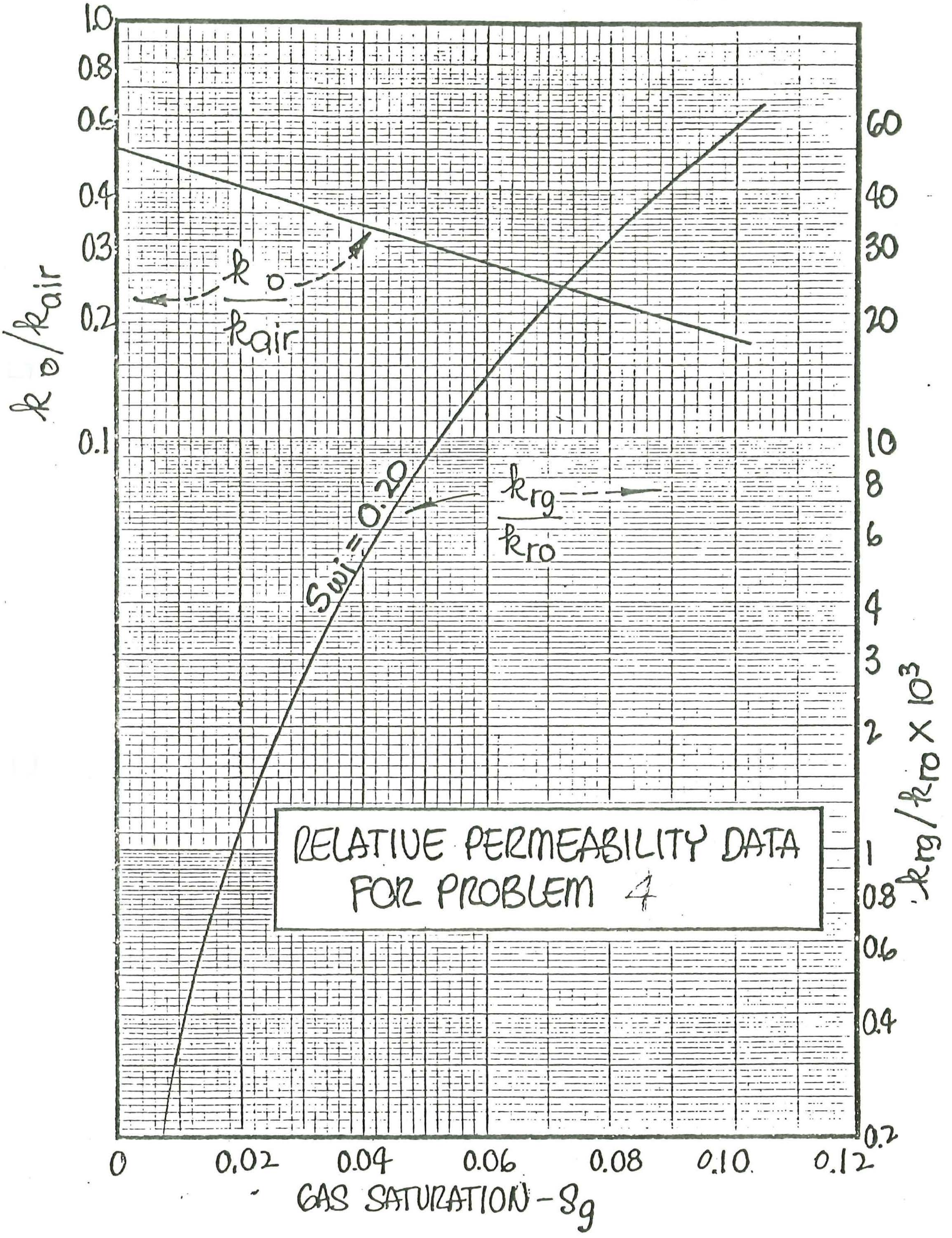
ASSIGNMENT

(1) Using the attached relative permeability data published by C.R. Knoff (*Trans.*, AIME, 1965), calculate the percent of initial gas and oil in the region of the Luntzel No. 4 well that would be produced at reservoir pressures of 2300, 2100, 1900, and 1700 psia.

(2) Calculate the instantaneous producing gas-oil ratio at the above pressures.

GUIDE ANSWERS

$\bar{p}$ psia	N_p % IOIP	G_p % IGIP
2300	0.956	0.985
1700	4.41	7.99



1.0
0.8
0.6
0.4
0.3
0.2
0.1
k_o/k_{air}
k_o / k_{air}
$S_{wi} = 0.20$
k_{rg} / k_{ro}
60
40
30
20
10
8
6
4
3
2
1
0.8
0.6
0.4
0.2
$k_{rg}/k_{ro} \times 10^3$
RELATIVE PERMEABILITY DATA
FOR PROBLEM 4
0
0.02
0.04
0.06
0.08
0.10
0.12
GAS SATURATION - S_g

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Solution Material Balance Problem 4

The following values for solution of Problem 4 were developed by SR-52 program "Sol'n Gas Drive - Tarner" of April 1 1977

B_{oi} (2500 psia) = 1.325 S_w = 0.20

p_j psia	p_k psia	G_{pj} SCF	N_{pj} Bbl	ϕ_{gk}	ϕ_{nk}	R_{sk} ft³/bbl	B_{ok} dim	R_j ft³/bbl	$\left(\frac{5.615\,\mu_o B_o}{\mu_g B_g}\right)_k$
2500	2300	0	0	0.0650	61.00	618	1.311	650	95.84 (10^3)
2300	2100	6.401	0.00956	0.0312	26.36	586	1.296	690	96.23
2100	1900	14.918	0.02025	0.0189	13.70	553	1.281	905	94.74
1900	1700	29.377	0.03246	0.0128	7.61	520	1.266	1462	92.36
1700	1500	51.912	0.04409	0.00927	4.17	486	1.250	2413	86.72
1500	1300	83.402	0.05440	0.00699	2.19	450	1.233	3695	79.43

p_k psia	R_k est	S_g Fr	k_g/k_o	R_k calc	G_{pk} ft³	N_{pk} Bbl	Test.
2300	690	0.0160	.75 (10^{-3})	690	6.401	0.00956	0.99996
2100	908	0.0333	3.3 (10^{-3})	903	14.918	0.02025	0.9992
1900		0.0516	9.6 (10^{-3})	1462	29.377	0.03246	1.0000
1700		0.0693	20.5 (10^{-3})	2413	51.912	0.04409	1.0000
1500		0.0863	37.0 (10^{-3})	3695	83.402	0.05440	1.000
1300		0.1026	61.0 (10^{-3})	5295	123.241	0.06326	1.0000