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Chevron

Chevron Standard Limited

1980-09-08

To: Mr. R. A. Park
From: Mr. D. A. Zeeuwen

WEST BUTLER UNIT #1
PILOT FLOOD PERFORMANCE

Summary

The purpose of this report was to investigate the feasibility of continuing the pilot water flood in the West Butler Field which to date has shown no response.

Conclusions

a) From pressure fall-off tests and BHP measurements on 3 out of 4 WIWs it appears that there is no pressure communication to the central producing well whose static BHP = 44 psi.

b) We may be injecting into several various sized reservoirs as evidenced by reservoir boundaries observed and different BHP obtained in the WIWs.

c) WIW 16-30-9-29 is inoperative because of communication to the aquifer which has a slim chance of being rectified. WIW 14-29-9-29 does not contribute substantially to the scheme as it takes a limited volume of water.

d) The central producer 13-29-9-29 has shown neither production response nor a BHP increase following an extended shut-in period.

e) Reserves for 13-29-9-29 are calculated to be in order of 300000 STB.

f) Material balance calculations show that in the absence of communication to the aquifer the BHP should have increased to between 1500 & 2250 psi.

Recommendations

a) Have Calgary production engineering staff review this report's technical content and recommend on the validity of the author's conclusions.

b) Development Geology should review the West Butler Field following engineering's concurrance with particular emphasis on determining whether or not the field could consist of discreet pools and their potential orientation.

c) In view of the failure to date of the existing pilot flood consider the economics of further infill drilling within the 80 acre pilot and evaluate same.

d) If the subsequent pilot flood is successful review economics of expansion on a close spacing.

e) If economics of further expansion cannot be justified at the onset terminate the pilot flood and surrender our leases.

WEST BUTLER UNIT #1

Pilot Flood Performance

Discussion

Since inception of the pilot water flood in West Butler Unit #1 concern has been expressed over its performance to date. The three water injection wells offsetting the 13-29 producer have been on continuous injection since the fall of 1978 but have been ineffective in producing any response so far. In order to gain some insight into the pilot flood's failure it was decided to conduct pressure fall-off tests on several wells to determine if a plausible reason could be found. Three wells, 12-29, 14-29, & 4-32 were alternately shut in and their surface pressures (which never dropped below zero) were continuously monitored on a chart recorder. From these tests values for permeability, estimated static BHP, skin damage, and distances to nearest boundary were calculated. Based on the above information calculations were also made to estimate connected pore volumes of the individual wells where possible. It should be noted at this time that the "permeability barriers" or "boundaries" referred to in sections C of the fall-off test analyses are approximations only and are distances to the closest heterogeneity. As pointed out in the literature "Advances in Well Test Analysis, monograph volume 5, chapter 10, one cannot say with any degree of precision that the change in a buildup slope constitutes a linear fault as it could be the result of the well's location within a particular reservoir shape or a change in mobility. Whatever the case it is apparent that the permeability restrictions are responsible for the nonexistent communication to the producing well.

In addition to the fall-off tests BHP surveys were run on WIW 16-30 and the producing well 13-29 showing 1080 psi and 44 psi respectively. The former well has been used more for disposal than injection as it takes water on vacuum. It is believed to be communicating directly to the aquifer as a result of the acid job performed during its conversion to an injection well and consequently this well is a poor candidate for further reworks.

In summary the tests indicate that the water is being injected radially, that skin damage has been effectively removed and that if there was an oil well in close proximity to the injectors it would probably produce oil.

Using the PVT data from Daly 6-32, material balance calculations were made using conservative assumptions. For the 80 acre pattern containing an initial OlP volume of 1694000 STB it would take 255600 STB of oil production for the BHP to be reduced to a value of 124 psi which corresponds to an arbitrarily chosen value of 10% for the critical gas saturation. It was further shown that if the oil volume connected to 13-29 equalled 1694000 STB, that for actual production totalling 47198 STB, the BHP should currently be 200 psi, i.e. without the benefit of injection. With injection it should be in the order of 2500 psi. Actual reservoir performance does not match the above figures. Furthermore material balance points to an original OlP volume of 284000 STB, based on a critical gas saturation of 10%, which yields a current recovery factor of 13.8%. The accuracy of the calculation depends of course on the confidence which we may put on the PVT data used and the approximation of $S_g = 0.1$ which is felt to be conservative. Although the PVT data used were from Daly the formation volume factors would not be much different since both fields exhibit low GOR. Moreover the limited amount of OlP associated with 13-29 and its lack of response is supported by the conclusions drawn from the fall-off tests.

Further drilling to develop the field on a close spacing will likely not be economic even at today's prices. To further evaluate the pilot flood it may be worthwhile to drill a well close to 13-29 and determine if it is connected to 13-29 by measurement of its BHP. The optimum location would be approximately midway between 13-29 producer and WIW 4-32 whose BHP is 1300 psi. Then if pressure communication is established to 13-29 the well could serve as an injection well. If however its BHP was in the order of 1300 psi it could serve as a producer for WIW 4-32. It is recommended that the economics of one more infill well and expansion on a closer spacing be reviewed. If the economics do not warrant further drilling the pilot flood should be terminated.

Chevron Butler Prov. WIW 12-29-9-29 WI

Pertinent Details:

GL	1766.85
KB-GL	8.15
KB Elevation	1775.00

Casing: surface - 12 1/4" hole, 10 jts. (367') of 8 5/8", 24#, K55 Algoma smls casing @ 379' cemented w/ 325 sx Portland cement & 2% $CaCl_2$

production - 7 7/8" hole, 63 jts. (2695) of 5 1/2", 14#, K55 Algoma smls casing @ 2680' cemented w/ 125 sx Portland & 6% gel, tailed in w/100 sx Portland cement & .75% TIC, slurries @ 13.7 & 15.4 ppg.res

TD 2749

Open Hole 2680 - 2749

Cores #1 2678 - 2738 recovered 60'
#2 2739 - 2749 recovered 10'

net pay 37.3' (16.9' dense, 1' drilled)
Weighted average porosity - 9.3 %
Weighted average permeability - 3.3 md

Logs SOC/DILL - BHCS - GR

Completion Details 78-04-28

Drilled out cement & cleaned to TD 2749
Acidized w/7000 gals of 15% acid
Washed 12 bbls by open hole in 2bbl washes

Squeezed	42	bbls	15% acid	@ 4	BPM	@ 600	psi
"	22	"	WF 100	@ 5	"	@ 1400	"
"	36	"	acid	@ 3	"	@ 1350	"
"	48	"	WF 100	@ 5	"	@ 1400	"
"	36	"	acid	@ 3	"	@ 1500	"

Completion Details 78-04-28 (cont'd)

Flushed w/54 bbls Devonian water @ 5 BPM @ 1350 psi
Swabbed back 140 bbls liquid
Ran 85 jts. 5 3/8" NUE - CML tubing and landed @ 2673.3 KB on 78-06-02.

History

78-07-07 Pulled tbg for BHP survey
78-07-27 Reran tubing w/Johnson 101S tension packer

packer	3.90
85 jts. 2 3/8" NUE-CML	2668.81
KB - TC	8.3
Landed Depth	2681.01 KB

BHP survey 1978-07-19 - datum depth BHP = 1063.5 psi

FALL-OFF TEST

WIW 12-29-9-29 WI

Pertinent Data

Cumulative injection		18390 m^3 - 115710 bbls
Daily injection rate	q	62.0 m^3 - 390 bbls
Height of pay zone	h	37.3' ($k > 1$ md)
Porosity	ϕ	10.2%
Compressibility	C_t	12.4×10^{-6} psi^{-1}
Viscosity of water	μ_w	0.9 cp
" " oil	μ_o	3.48 cp
Production time	t	7118 hrs
Shut-in time		1980-03-06-1520
Initial shut-in pressure		1170 psi
BHP		Psurface & 1245
Formation volume factor	B	1.0 for water
Initial water saturation	S_w	0.35
Residual oil saturation	S_{or}	0.28

WIW 12-29-9-29 WI WEST BUTLER

A. Permeability Determination

- Change of slope @ Δt = 16 hrs. ($\frac{t \,\&\, \Delta t}{\Delta t}$ = 450)

$$m_1 = 166 \text{ psi/cycle}$$

- If this represents change in effective k from water filled to oil filled reservoir we obtain the following

$$k_1 = 162.6 \frac{q\,\mu\,B}{m_1\,h} = 162.6 \frac{(62)}{.15891} \times \frac{0.9\,(1)}{166\,(37.3)}$$

$$= 9.22 \text{ md} \qquad (\text{i.e.} (\frac{k}{\mu})_w = 10.2)$$

- This effective k extends for 16 hrs, this corresponds to a radius of investigation =

$$r = 2\sqrt{\frac{2.64 \times 10^{-4} (k) t}{\phi\, c_t \quad (\mu)}} = 2\sqrt{\frac{2.64 \times 10^{-4}\ (10.2)(16)}{.093\ (12.4 \times 10^{-6})}} = 386 \text{ ft.}$$

- Assuming radial & even distribution of injection water we may also calculate a fill-up radius as follows

Pore Volume(PV) $= \pi r^2 h \phi\ (1 - S_w - S_{or})$

where $S_w = 0.35$, $S_{or} = 0.28$, and V injected = 115,713 bbls

then $r = V\ inj(5.615)/(\pi h\ \phi\ (1 - S_w - S_{or}))$

$= 383$ ft.

This appears to be more than a reasonable correlation and thus we may assume that reservoir is water filled to a distance 380 ft. from well.

A second straight line portion is encountered after $\Delta t = 16$ hrs. Its slope is 258 psi/cycle. Calculating k again we obtain where we use 3.48 cp for μ_o (Must use $(\frac{k}{\mu})_o$ instead of previous $(\frac{k}{\mu})_w$

$$k_2 = 162.6 \frac{q\mu B}{m_2 h}$$

$$= 162.6 \left(\frac{62}{.15891}\right) \frac{(3.48)\ (1.00)}{258\ (37.3)}$$

$$= 22.9 \text{ md and } \left(\frac{k}{\mu}\right)_o = 6.6 \text{ md . cp}^{-1}$$

WEST BUTLER WIW 12-29

B. Skin Damage Calculation

m_1 = 166 psi/cycle
m_2 = 258 psi/cycle
m_3 = 530 psi/cycle

$(\frac{k}{\mu})_w = 10.2$ md . cp^{-1}

Skin Calculations:

P_{1hr} = 2195 psi

P_{inj} = 1170 & 1245 = 2415 psi

$$S = 1.151 \left[(P_i - P_{1hr})/m - \log \frac{(k)}{(\mu)\phi\ c_t\ r_w{}^2} \ \&\ 3.23 \right]$$

$$= 1.151 \left[\left(\frac{2415 - 2195}{166} \right) - \log \frac{10.2}{0.093\ (12.4 \times 10^{-6})\ (.11)} \ \&\ 3.23 \right]$$

$$= 1.151\ (1.33 - 7.9\ \&\ 3.23)$$

$$= -3.3$$

And ΔPskin = 0.87 m.s = 0.87 (166)(-3.3)
= -476 psi

Conclusion: damage has been removed

WIW 12-29-9-29 WI
WEST BUTLER

C. Calculation of Distance to Permeability Barrier

From p vs $\frac{t \& \Delta t}{\Delta t}$ we see that slope changes from m_2 = 258 psi/cycle to m_3 = 530 psi/cycle.

-therefore we may infer presence of k barrier because of the doubling of the slope value, from eqn. 10.7 Davis & Hawkins*

$$d = \sqrt{1.48 \times 10^{-4} \frac{(k)\,\Delta t}{(\mu)\,\phi\, c_t}} \qquad \text{where } \left(\frac{k}{\mu}\right)_o = 6.6$$

$$= \sqrt{1.48 \times 10^{-4} \frac{(6.6)(380)}{(0.093)(12.4 \times 10^{-6})}} = 567$$

This eqn. is only valid for $\frac{t \& \Delta t}{\Delta t} \gtrsim 30$.

C_c

WEST BUTLER WIW 12-29-9-29 WI

D. Bottom Hole Pressure & Material Balance Calculations

From the fall-off test plot the BHP extrapolated to $(t+\Delta t)/\Delta t=1$ is equivalent to 960 psi, approximately 100 psi lower than that obtained on the 78-07 survey.

If we assume that no injection water has been lost to the aquifer and that the reservoir is limited, say 600 ft. in radius (calculated in section C) from the material balance calculations the BHP should have increased to many times its original value. Using the material balance equation to predict pressure change we obtain:

$$P_i - P_f = \frac{N_p B_o - W_e + W_p B_w}{N B_{oi}\ c_e}$$

$$\Delta p = \frac{\Delta V}{V_o c}$$

where N_p = oil produced = 0
W_p = water produced = 0
W_e = water encroached = water injected = 89960 bbls.
$B_o = B_{oi}$ = formation volume factor = 1.03 assumed constant because of lack of gas
N = original OIP = $\pi r^2 h\phi(1-S_w)/5.61$
= $.445 \times 10^6$ bbls.
$c_e = 19.1 \times 10^{-6}\ \text{psi}^{-1}$

Therefore Δp should = $89960/.445 \times 10^6(1.03)19.1 \times 10^{-6}$
= 10275 psi ?

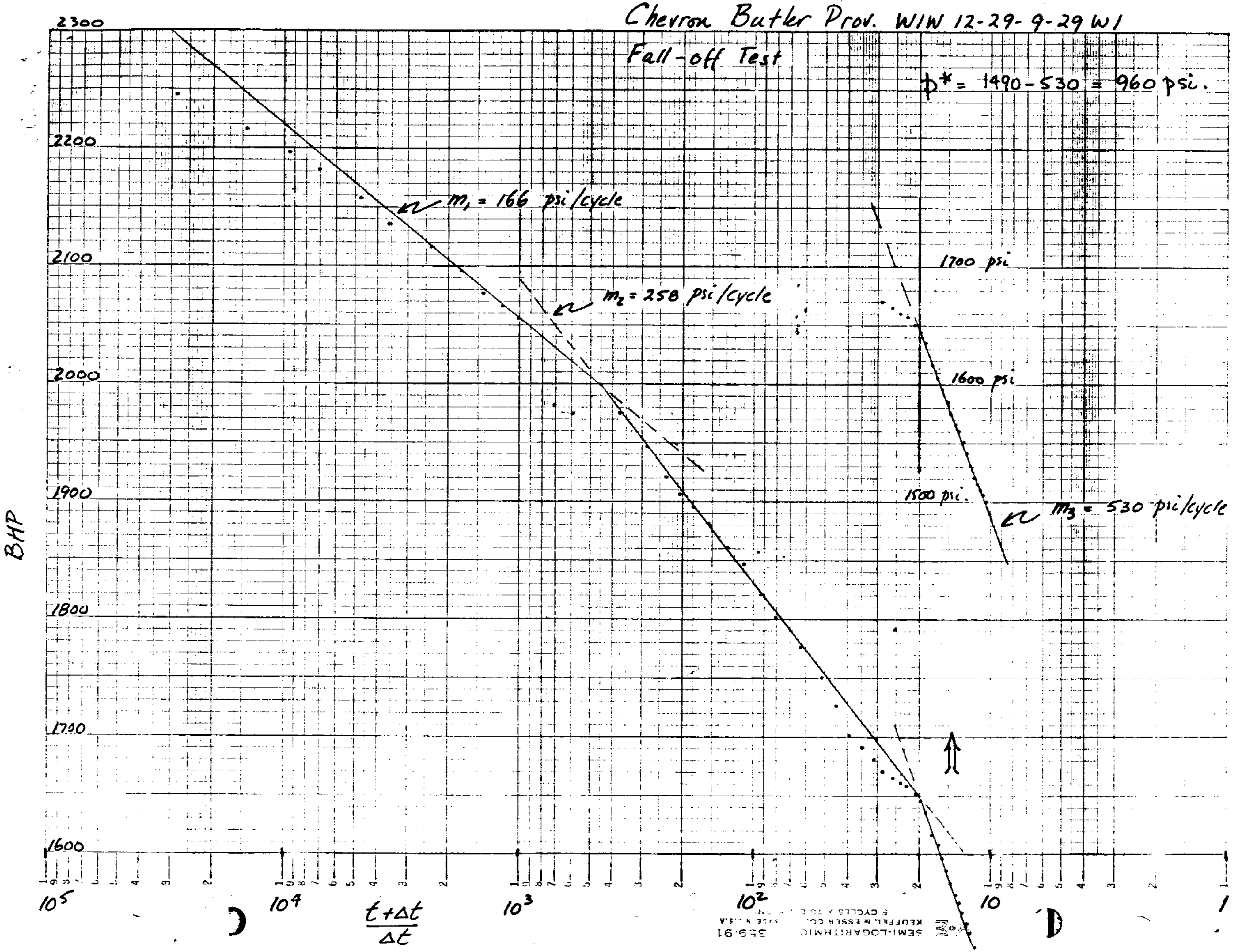
This of course is impossible judging by the lack of BHP increaseand leads us to conclude that the volume connected to the wellbore is either much larger than the radius to the boundary indicates or that communication to the aquifer by way of a natural or hydraulically induced fracture system exists.

TEST DATA WIW 12-29-9-29 WI

Δt	$\frac{t \& \Delta t}{\Delta t}$	BHP
0	∞	2415
0.25	28473	2245
0.50	14237	2215
0.75	9492	2195
1.0	7119	2180
1.5	4746	2157
2	3560	2135
3	2374	2115
4	1781	2095
5	1425	2075
6	1187	2065
7	1018	2055
10	713	1980
12	594	1975
19	376	1975
25	285	1945
30	238	1920
35	204	1905
40	179	1895
45	159	1890
55	130	1860
65	110	1845
77	93	1820
89	81	1800
115	63	1773
140	52	1750
164	44.4	1725
188	39	1700
212	34.6	1690
236	31	1680
200	28.4	1670

TEST DATA WIW 12-29-9-29 WI

Δt	$\frac{t \& \Delta t}{\Delta t}$	BHP
284	26	1665
308	24	1660
332	22.4	1657
356	21	1650
380	19.7	1645
404	18.6	1635
428	17.6	1615
452	16.7	1605
475	16	1595
499	15.26	1585
523	14.6	1575
547	14.0	1565
571	13.47	1560
595	13.0	1550
619	12.5	1540
643	12.1	1530
667	11.67	1520
691	11.3	1515
715	10.95	1510
739	10.6	1505
763	10.3	1500


Chevron Butler Prov. WIW 12-29-9-29 W1
Fall-off Test
$p^* = 1490 - 530 = 960$ psi.
$m_1 = 166$ psi/cycle
$m_2 = 258$ psi/cycle
$m_3 = 530$ psi/cycle
1700 psi
1600 psi
1500 psi
BHP
2300
2200
2100
2000
1900
1800
1700
1600
$\frac{t+\Delta t}{\Delta t}$
10^5
10^4
10^3
10^2
10
1
SEMI-LOGARITHMIC 359-91
KEUFFEL & ESSER CO.
5 CYCLES

CORE LABORATORIES – CANADA, LTD.

Petroleum Reservoir Engineering

WELL: CHEVRON BUTLER 12-29-9-29

FORMATION: MISSISSIPPIAN

SUMMARY INTERVAL: 2678.0 - 2749.0

FILE: 7004-8213

TOTAL FOOTAGE: 71.0

FOOTAGE ANALYZED 53.1

FOOTAGE NOT ANALYZED: TOTAL: 17.9 DENSE 16.9 LOST 0.0 DRILLED 1.0 *NABR 0.0 RUBBLE 0.0

SUMMARY OF ANALYZED CORE:	FOOTAGE	% OF ANALYZED CORE	WEIGHTED AVERAGE POROS. %	POROSITY FEET	WEIGHTED AVERAGE PERM. MD.	PERM. FEET	WEIGHTED AVERAGE RESID. OIL %	WEIGHTED AVERAGE TOT. WATER %
TOTAL	53.1	100.0	9.3	492.39	3.342	177.473	0.0	0.0
BY PERM RANGES:								
LESS THAN 0.01 Md.	0.0	0.0	0.0	0.00	0.000	0.000	0.0	0.0
0.01 0.09 Md.	1.6	3.0	4.3	6.88	0.050	0.080	0.0	0.0
0.10 0.49 Md.	9.5	17.9	7.4	69.86	0.301	2.857	0.0	0.0
0.50 0.99 Md.	4.7	8.9	7.7	36.07	0.643	3.020	0.0	0.0
1.0 9.99 Md.	33.1	62.3	9.9	329.05	3.181	105.276	0.0	0.0
GREATER THAN 9.99 Md.	4.2	7.9	12.0	50.53	15.771	66.240	0.0	0.0

*NOT ANALYZED BY REQUEST

Chevron Butler Prov. WIW 14-29-9-29 WI

Pertinent Details:

GL	1774.5
KB-GL	8.5
KB	1783.0

Casing - surface - 12 1/4" hole, 10 jts. (370.51') of 8 5/8", 24#, K-55 Algoma csg @ 382' KB. Cemented w/350 sx normal Portland & 2% $CaCl_2$.

- production - 7 7/8" hole, 64 jts. (2684.06) of 5 1/2", 14#, K-55 Algoma smls casing @ 2679 , cemented w/150 sx & 6% gel tailed in w/100 sx cement & .75 TIC.

TD 2759

Open Hole 2679 - 2759, 6 1/8"

Cores #1 2679 - 2739, rec'd 49.0'
#2 2740 - 2759, rec'd 19.0'

net pay - 33.6
weighted average porosity - 10 %
weighted average permeability - 7.22 md

Logs Schlumberger

dual induction SFL
BHC - soniclog GR

Formation Markers

Red Beds - 777
Top Miss. - 895
TD, driller & logger - 975

Completion -

Acidized well bore with 8000 gals of 15% MSR acid diverted with 500 gals WF 100 & 2500 gals WF 80 at pressures up to 1300 psi & 4.25 BPM.

Tubing 2 3/8" NUE - CML & 5 1/2" 101S Johnson packer

packer	3.92 (in 9000# tension)
85 jts. 2 3/8" NUE-CML	2676.64
KB - TC	5.06
	2685.62

BHP survey 1978-07-19 - datum depth BHP = 1004 psi

FALL-OFF TEST

WIW 14-29-9-29 WI

Pertinent Data

Cumulative injection		1200 m^3 - 7560 bbls
Daily injection rate	q	20 BWPD
Height of pay zone	h	33.6' (pay > 1 md)
Porosity	ϕ	10%
Compressibility	C_t	12.4 x 10^{-6} psi^{-1}
Viscosity of water	μ_w	0.9 cp
" " Oil	μ_o	3.48 cp
Production time	t	10000 hrs.
Shut-in time		80-04-12-1030
Initial shut-in pressure		1365 psi
BHP		Psurface & 1250 psi
Formation volume factor	B	1.0 for water
Initial water saturation	S_w	0.35
Residual oil saturation	S_{or}	0.28

WIW 14-29-9-29 WI

A. Permeability Determination

- from plot 3 slopes are evident

  M_1 = 29 psi/cycle

  M_2 = 108 psi/cycle

  M_3 = 372 psi/cycle

- from $\frac{k}{\mu} = \frac{162.6\ q\ B}{M_1\ h}$

$$\frac{k}{\mu} = \frac{162.6\ (20)\ (1)}{29\ (33.6)} = 3.34 \text{ md} \cdot \text{cp}^{-1}$$

- determine nature of fluid in pores

  - fill up radius of water injected

    Volume Injected $= \pi r^2 h\ \phi\ (1 - S_w - S_{or})$

$$r = \sqrt{\frac{V\ (5.615)}{\pi\ h\ \phi\ (1 - S_w - S_{or})}}$$

$$= 104 \text{ ft.}$$

  - time required to "see" beyond fill up radius

$$t = \frac{r^2\ \phi\ C_t}{4 \times 2.64 \times 10^{-4}}\ \frac{\mu}{k}$$

$$= \frac{104^2\ (.10)\ 12.4 \times 10^{-6}}{10.56 \times 10^{-4}}\ \left(\frac{1}{3.34}\right)$$

$$= 3.8 \text{ hrs.}$$

- this corresponds to a value of 2632 for $(t + \Delta t)/\Delta t$ and matches the intersection point on the plot very closely
- therefore the first value of $\frac{k}{\mu}$ obtained from the first slope is the mobility of water $(\frac{k}{\mu})_w = 3.34$ and $k_w = 3.34\ (0.9) = 3$ md
- the second slope $m_2 = 108$ psi/cycle
- the $\frac{k}{\mu}$ value obtained from it will be for the oil

$$(\frac{k}{\mu})_o = \frac{162.6\ qB}{m_1\ h} = 0.9 \text{ md} \cdot \text{cp}^{-1}$$

$$\text{and } k_o = 0.9\ (3.48) = 3.12 \text{ md}$$

- note C_t is total compressibility

$$C_t = C_w\ S_w + C_o\ S_o + C_g\ S_g + C_f$$

- from fig. 8 "Effect of Wellbore Storage on Transient Pressure Analysis" M.B. Standing

$$C_t = 3(0.35) + 9(0.65) + 1100(0) + 5.5\ 10^{-6}$$
$$= 12.4 \times 10^{-6} \text{ psi}^{-1}$$

B. Calculation of Distance to Apparent Permeability Barrier

- from plot we see change in slope from 108 to 372 psi/cycle at t = 432 hrs, non linearity is first observed @ $(t \& \Delta t)/\Delta t = 60$ or $\Delta t = 168$ hrs.

- the slope is more than double indicating not just the presence of a single barrier (i.e. fault) but the presence of multiple reservoir boundaries (p 94, monograph volume 1, pressure buildup & flow tests in wells).

$$d = \sqrt{0.00105 \frac{k \Delta t}{\phi \mu c_t}} = \sqrt{\frac{0.00105\ (0.9)\ 168}{0.1\ (12.4 \times 10^{-6})}}$$

$$= 357 \text{ ft.}$$

West Butler WIW 14-29-9-29

C. Skin Damage Calculation

$$S = 1.151 \left[(P_i - P_{1hr})/m - \log \frac{k}{\mu \phi C_t r_w^2} + 3.23 \right]$$

where $P_i = 2612$ & $P_{1hr} = 2605$; $\left(\frac{k}{u}\right)_w = 3.34$ md . cp^{-1}

$r_w^2 = (7\ 7/8"/2)^2 = 0.11$ ft.^{2}

$M_1 = 29$ psi/cycle

$$S = 1.151 \left[(2612 - 2605)/29 - \log \frac{3.34}{(.11)\ 0.10\ (12.4 \times 10^{-6})} \ \&\ 3.23 \right]$$

$= 1.151\ (.243 - 7.38\ \&\ 3.23)$

$= -4.51$

- and Δpskin $= 0.87\ M_1\ S$

$= 0.87\ (29)\ (-4.51)$

$= -114$ psi

Conclusion - completion removed damage

WEST BUTLER WIW 14-29-9-29

D. BHP & Material Balance Calculations

From the fall-off test plot the BHP extrapolated to $(t+\Delta t)/\Delta t=1$ is equal to 1853 psi which is much greater than original BHP of 1004 psi. Using material balance to predict maximum pressure increase based on radius of nearest boundary we obtain the following. (r = 357')

$$N = \pi r^2 h\phi\ (1 - S_w)/5.61 = 0.156 \times 10^6 \text{ bbls.}$$

$$P_i - P_f = \frac{-W_e}{NB_{oi} \cdot c_e} = \frac{-6947}{0.156 \times 10^6 (1.05) 19.1 \times 10^{-6}}$$

$$= -2264 \text{ psi}$$

and $P_f = 2264 + 1004 = 3268$ psi

Recalculating to find N & thus r using actual pressure increase

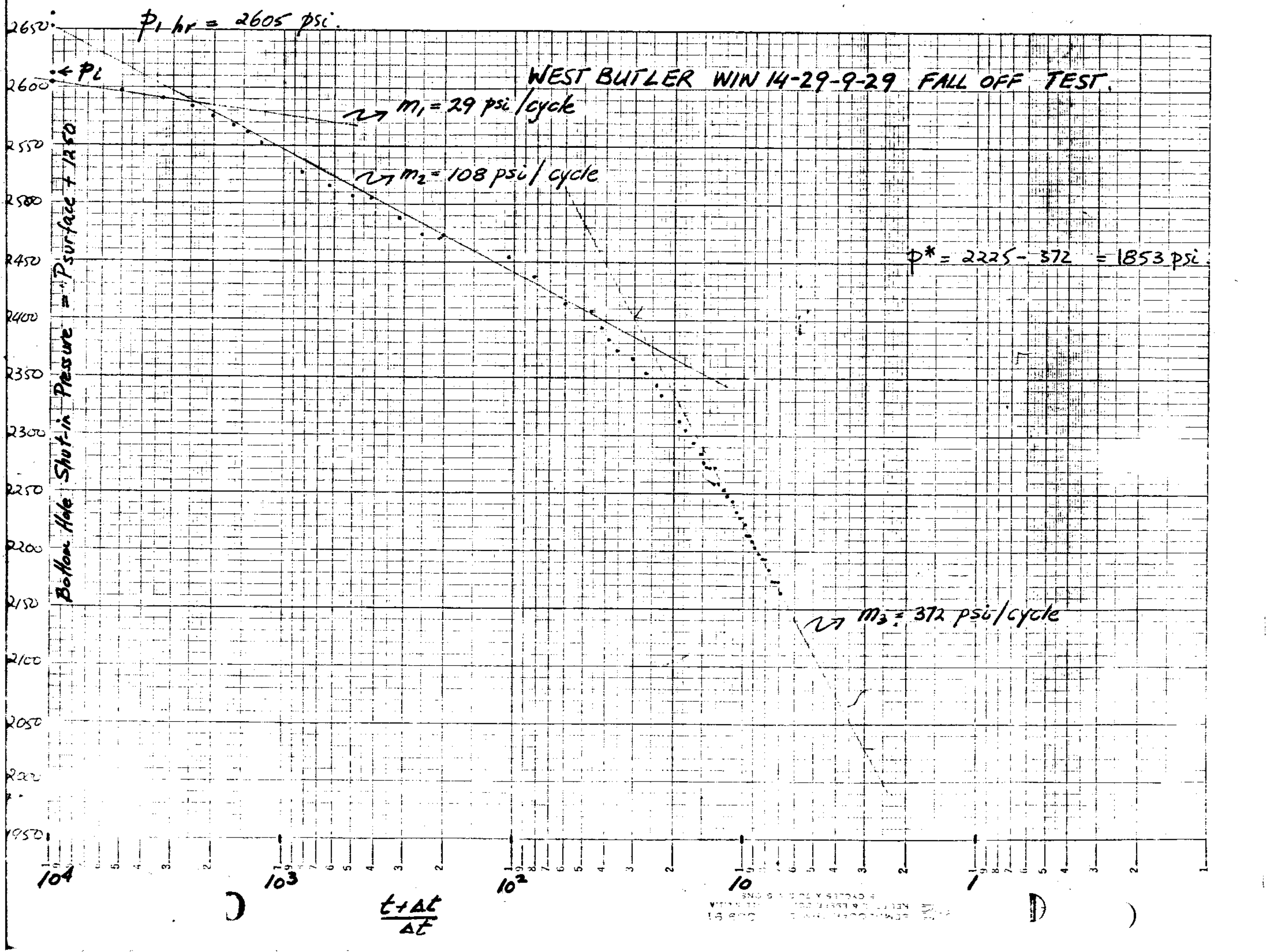
$\Delta p = 1853 - 1004 = 849$ psi we obtain from material balance N = 450,000 STB and r = 600'

The reasonable match between the radius to the nearest boundary and the one obtained from material balance considerations points to a limited reservoir.

TEST DATA WIW 14-29-9-29 WI

DATE	Δt	$\frac{t \& \Delta t}{\Delta t}$	BHP
04-12	0	∞	2612
	1	10000	2605
	2	5000	2594
	3	3334	2588
	4	2501	2580
	5	2001	2573
	6	1667	2565
	7	1430	2558
	8	1251	2550
	12	843	2525
	16	626	2512
	20	501	2505
04-13	24	418	2503
	32	313	2485
	40	251	2470
04-14	48	209	2470
04-16	96	105	2450
17	120	84	2435
19	168	60	2410
21	216	47.3	2405
22	240	42.6	2390
23	264	39	2380
24	288	36	2370
26	336	30.7	2365
28	384	27	2350
30	432	24.1	2340
05-01	456	22.9	2330
05	548	19.2	2310
07	596	17.8	2300
09	644	16.5	2290
11	692	15.4	2280
12	716	15.0	2275
13	740	14.5	2270
14	764	14.0	2270
16	812	13.6	2270
18	840	12.9	2255

DATE	Δt	$\frac{t \,\&\, \Delta t}{t}$	BHP
05-20	888	12.3	2250
22	936	11.7	2245
24	984	11.2	2240
26	1032	10.7	2230
28	1080	10.3	2225
30	1128	9.9	2220
31	1152	9.7	2210
06-01	1176	9.5	2210
03	1224	9.2	2205
05	1272	8.9	2200
07	1320	8.6	2195
09	1368	8.3	2190
11	1416	8.1	2190
13	1464	7.8	2180
16	1536	7.5	2170
18	1584	7.3	2170
20	1632	7.1	2170
22	1680	6.9	2160



P1 hr = 2605 psi.
Pi
WEST BUTLER WIN 14-29-9-29 FALL OFF TEST.
m1 = 29 psi/cycle
m2 = 108 psi/cycle
P* = 2225 - 372 = 1853 psi.
m3 = 372 psi/cycle
Bottom Hole Shut-in Pressure = Psurface + 1250
t+Δt / Δt
10^4
10^3
10^2
10
1

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WELL: CHEVRON BUTLER 14-29-9-29 INJ

FORMATION:

SUMMARY INTERVAL: 2679.0 – 2759.0

FILE: 7004-8180

TOTAL FOOTAGE: 80.0

FOOTAGE ANALYZED 54.4

FOOTAGE NOT ANALYZED: TOTAL: 25.6 DENSE 13.6 LOST 11.0 DRILLED 1.0 *NABR 0.0 RUBBLE 0.0

SUMMARY OF ANALYZED CORE:	FOOTAGE	% OF ANALYZED CORE	WEIGHTED AVERAGE POROS. %	POROSITY FEET	WEIGHTED AVERAGE PERM. MD.	PERM. FEET	WEIGHTED AVERAGE RESID. OIL %	WEIGHTED AVERAGE TOT. WATER %
TOTAL	54.4	100.0	10.0	544.01	7.220	392.755	0.0	0.0
BY PERM RANGES:								
LESS THAN 0.01 Md.	0.0	0.0	0.0	0.00	0.000	0.000	0.0	0.0
0.01 0.09 Md.	0.6	1.1	5.2	3.12	0.040	0.024	0.0	0.0
0.10 0.49 Md.	16.9	31.1	6.6	111.82	0.298	5.035	0.0	0.0
0.50 0.99 Md.	8.6	15.8	9.2	79.04	0.611	5.251	0.0	0.0
1.0 9.99 Md.	19.3	35.5	10.8	209.11	2.785	53.745	0.0	0.0
GREATER THAN 9.99 Md.	9.0	16.5	15.7	140.92	36.522	328.70[illegible]	0.0	0.0

*NOT ANALYZED BY REQUEST

Chevron Butler Prov. WIW 4-32-9-29 WI

Pertinent Details:

GL	1776.4
KB - GL	8.3
KB	1784.7
Casing	- surface - 12 1/4", 380' of 8 5/8", 24#/ft, K-55 @ 392 KB cemented w/300 sx normal Portland & 2% $CaCl_2$ @ 15.5 ppg.
Production	- 7 7/8" hole, 67 jts. of 5 1/2", 14#/ft, K-55 Algoma smls csg. @ 2683 cemented with 125 sx Portland & 6% gel, tailed in w/100 sx neat cement slurry.
TD	2759
PBTD	2759 - open hole 2683 - 2759
Cores	#1 2685 - 2745 rec'd 60' #2 2746 - 2759 rec'd 11.5'
	Analyzed 50.3 ft out of total of 74 (21.2'dense, 1.5' lost, 1.0' drilled)
	Net pay - 34.8' Weighted average porosity - 12.0% Weighted average permeability - 18.8 md
Logs	SOC - DILL, GR, BHCS
Completion	78-04-24 Drilled out cement from 2643 to 83 and cleaned to bottom. Circulated hole over to fresh water. Landed 2 7/8" tbg. @ 2755.

Acidized as follows - used 15% MSR acid:

- spotted 6 bbls over OH, washed 1 bbl by every 10 mins., back-washed all acid out
- squeezed 60 bbls acid, final rate 2 BPM @ 1000 psi casing pressure
- squeezed 12 bbls WF100, feed rate went from 2 BPM @ 1600 psi to 0.25 BPM @ 1500 psi
- squeezed 30 bbls acid from 1 to 1.75 BPM @ 1500 to 1100 psi
- squeezed 18 bbls WF100 @ 1.75 - 1.5 BPM @ 1400 - 1100 psi
- squeezed 66 bbls acid 1.5 - 4.75 BPM @ 1400 - 1700 psi
- flushed to formation w/24 bbls Devonian water
- swabbed fluid back

Ran 2 3/8" EUE CML tbg. and packer as follows:

5 1/2" Johnson 101S packer	3.15
84 jts. - 2 3/8" EUE CML tbg.	2598.27
KB - TC	5.10
	2606.52

packer set in 10000# tension
annulus full of inhibited fresh water

- BHP survey run on 1978-10-28.
- Datum depth BHP = 1030 psi.

FALL OFF TEST

CHEVRON BUTLER WIW 4-32-9-29 WI

Pertinent Data:

Cumulative injection		20 462 m^3
Daily injection	q	74 m^3, 465 bbls
Height of pay	h	34.8 ft
Porosity	ϕ	12.0%
Compressibility	c_t	12.4 x 10^{-6}
Viscosity of water	μ_w	0.9 cp
Viscosity of oil	μ_o	3.48 cp
Production time	t	7800 hrs
Shut-in time		80-04-07-1030
Initial shut-in pressure		1150 psi
BHP		Psurface & 1250 psi
Formation volume factor	B	1.00
Initial water saturation	S_w	0.35
Residual oil saturation	S_{or}	0.28

WEST BUTLER WIW 4-32-9-29 WI

A. Permeability Determination

- from plot 3 slopes are evident

  $m_1 = 85$ psi/cycle

  $m_2 = 160$ psi/cycle

  $m_3 = 438$ psi/cycle

- from $\frac{k}{\mu} = \frac{162.6\ q\ B}{m_1\ h}$

$$\frac{k}{\mu} = \frac{162.6\ (465)\ 1}{85\ (348)} = 25.6 \text{ md . cp}^{-1}$$

- determine nature of fluid in pores

  - fill up radius of water injected

    Volume injected$(V_i) = \pi r^2 h\ \phi\ (1 - S_w - S_{or})$

$$r = \sqrt{\frac{V_i\ (5.615)}{\pi h\ \phi\ (1 - S_w - S_{or})}}$$

$$= 385 \text{ ft.}$$

- time required to "see" beyond fill up radius

$$t = \frac{r^2\ \phi\ c_t}{4 \times 2.64 \times 10^{-4}}\ \frac{\mu}{k}$$

$$= \frac{385^2\ (.12)\ 12.4 \times 10^{-6}}{4\ (2.64 \times 10^{-4})\ 25.6} = 8.15 \text{ hrs.}$$

- this corresponds to $(t \& \Delta t)/\Delta t = 958$
- from the attached plot there is poor correlation
- the slope change, i.e. change in indicated mobility occurs at $(t \& \Delta t)/\Delta t = 2700$ or $\Delta t = 3$ hrs.
- This corresponds to a radius of 233 ft. or an effective volume of injection = 47500 bbls., the remainder presumably having been lost to the aquifer
- the above presumes that the initial change in slope @$\Delta t = 3$ is indeed a change in mobility and not a change in native permeability which although a possibility is not likely in view of its proximity to the wellbore
- the permeability derived for the first slope is that for water filled rock and thus

$$\left(\frac{k}{\mu}\right)_w = 25.6 \text{ md} \cdot \text{cp}^{-1} \text{ and } k_w = 25.6 \times 0.9 = 23 \text{ md}$$

- the second slope is $m_2 = 160$ psi/cycle and the derived permeability will be for oil

$$\left(\frac{k}{\mu}\right)_o = \frac{162.6\ (465)}{160\ (34.8)} = 13.6 \text{ md} \cdot \text{cp}^{-1}$$

and $k_o = 13.6 \times 3.48 = 47.3$ md

B. Skin Damage Calculation

$$S = 1.151 \left[(P_i - P_{1hr})/m - \log \frac{k}{\mu \phi c_t r_w^2} \;\&\; 3.23 \right]$$

where $P_i = 2400$ $\qquad (\frac{k}{\mu})_w = 25.6$

$P_{1hr} = 2290$

$M_1 = 85$ psi/cycle

$$S = 1.151 \left[(2400 - 2290)/85 - \log \frac{25.6}{.12(12.4 \times 10^{-6})(.11)} \;\&\; 3.23 \right]$$

$$= 1.151 \left(1.29 - 8.19 \;\&\; 3.23 \right)$$

$$= -4.2$$

and ΔPskin $= 0.87$ m . s

$= 0.87\ (85)\ (-4.2)$

$= -310$ psi

Conclusion: damage has been removed

C. Calculation of Distance to Permeability Barrier

- from plot we see that the slope changes from 160 to 325 psi/cycle indicating a barrier & then increases further to 438 psi/cycle

- the point of intersection of the second and third slopes (160 & 325 psi/cycle) occurs at Δt = 168 hrs.

- non linearity on the 160 psi/cycle portion occurs at Δt = 100 hrs.

- therefore distance to barrier

$$d = \sqrt{\frac{1.48 \times 10^{-4}\ k\ \Delta t}{\mu\ \phi\ c_t}}$$

where $\frac{k}{\mu} = 13.6$ md . cp^{-1} and Δt = 168 hrs.

= 476 ft

- using alternate equation to determine distance to nearest boundary

$$d = \sqrt{\frac{0.00105\ k\ \Delta t}{\mu\ \phi\ c_t}}$$

where Δt = 100 hrs.

= 864 ft

- the first number, 476 ft is [redacted] more reliable.

WEST BUTLER WIW 4-32-9-29

D. BHP & Material Balance Calculations

Extrapolation to $(t + \Delta t)/\Delta t$ yields a bottom hole pressure of 1302 psi, approximately 250 psi over original. Assuming no loss to the aquifer a reservoir radius may be calculated from the material balance equation

$$\Delta p = \frac{W_e}{NB_{oi}\ c_e}$$

where $\Delta p = 250$ psi

$W_e = 114416$ bbls.

$c_e = 19.1 \times 10^{-6}\ psi^{-1}$

$B_{oi} = 1.05$

thus $N = 23 \times 10^6$ bbls

and since $N = \pi r^2 h \phi (1-S_w)/5.61$

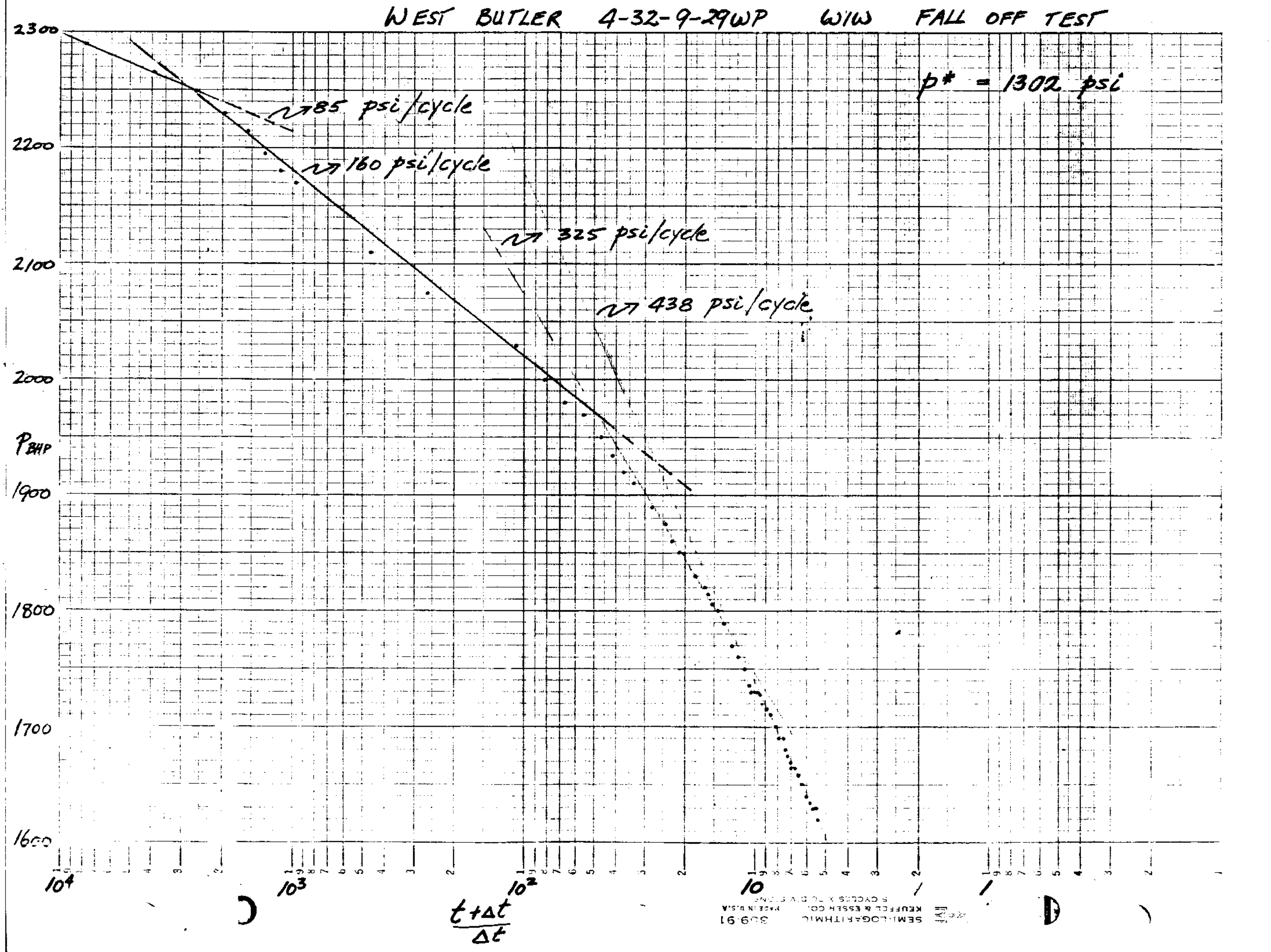
$r = 3900$ ft.

Considering the poor correlation between the theoretical distance at which the mobility to water should change to oil mobility and the distance observed on the plot (see section A) we could recalculate to solve for r using an effective volume of injection equal to 47500 bbls. rather than 114416 bbls. This would yield a value of $N = 9.5 \times 10^6$ bbls and $r = 2500$ ft.

TEST DATA
WIW 4-32-9-29 WI

DATE	Δt	$(t \& \Delta t)/\Delta t$	PBHP
04-07	0	∞	2400
07	1	7800	2290
07	2	3900	2265
07	3	2600	2250
07	4	1950	2230
07	5	1560	2215
07	6	1301	2195
07	7	1115	2180
07	8	976	2170
07	17	460	2110
07	30	261	2075
04-10	72	109	2030
11	96	82	2000
12	120	66	1980
13	144	55	1970
14	168	47	1950
15	192	41.6	1935
16	216	37	1920
17	240	33.5	1910
19	288	28	1890
21	336	24	1875
22	360	22.7	1860
23	384	21.3	1850
24	408	20.1	1850
26	456	18.1	1830
28	504	16.5	1820
29	528	15.8	1815
30	552	15.1	1805
05-01	576	14.5	1800
03	624	13.5	1790
05	672	12.6	1770
07	720	11.8	1760

DATE	Δt	$\left(\frac{t\ \&\ \Delta t}{\Delta t}\right)$	PBHP
05-09	768	11.1	1750
11	816	10.6	1735
12	840	10.3	1730
13	864	10.0	1730
14	888	9.8	1730
16	912	9.5	1728
18	936	9.3	1720
20	984	8.9	1715
22	1032	8.6	1710
24	1080	8.2	1700
26	1128	7.9	1690
28	1176	7.6	1690
30	1224	7.4	1680
31	1248	7.25	1675
06-01	1272	7.1	1670
03	1320	6.9	1665
05	1368	6.7	1665
07	1412	6.5	1660
09	1460	6.3	1650
11	1508	6.2	1650
13	1556	6.0	1640
16	1628	5.8	1635
18	1676	5.65	1630
20	1724	5.5	1630
22	1772	5.4	1620



WEST BUTLER 4-32-9-29WP W/W FALL OFF TEST
p* = 1302 psi
85 psi/cycle
160 psi/cycle
325 psi/cycle
438 psi/cycle
2300
2200
2100
2000
P_{BHP}
1900
1800
1700
1600
10^4
10^3
10^2
10
1
$\frac{t+\Delta t}{\Delta t}$
SEMI-LOGARITHMIC 359-91
KEUFFEL & ESSER CO. MADE IN U.S.A.

CORE LABORATORIES – CANADA, LTD.

Petroleum Reservoir Engineering

WELL: CHEVRON BUTLER 4-32-9-29 INJ

FORMATION:

SUMMARY INTERVAL: 2685.0 - 2759.0 FILE: 7004-8144

TOTAL FOOTAGE: 74.0

FOOTAGE ANALYZED 50.3

FOOTAGE NOT ANALYZED: TOTAL: 23.7 DENSE 21.2 LOST 1.5 *DRILLED 1.0 *NABR 0.0 RUBBLE 0.0

SUMMARY OF ANALYZED CORE:	FOOTAGE	% OF ANALYZED CORE	WEIGHTED AVERAGE POROS. %	POROSITY FEET	WEIGHTED AVERAGE PERM. MD.	PERM. FEET	WEIGHTED AVERAGE RESID. OIL %	WEIGHTED AVERAGE TOT. WATER %
TOTAL	50.3	100.0	10.6	535.68	13.222	665.088	0.0	0.0
BY PERM RANGES:								
LESS THAN 0.01 Md.	0.0	0.0	0.0	0.00	0.000	0.000	0.0	0.0
0.01 0.09 Md.	0.0	0.0	0.0	0.00	0.000	0.000	0.0	0.0
0.10 0.49 Md.	4.7	9.3	5.7	26.86	0.352	1.655	0.0	0.0
0.50 0.99 Md.	10.8	21.5	8.5	91.74	0.724	7.816	0.0	0.0
1.0 9.99 Md.	20.4	40.6	9.1	186.63	2.738	55.847	0.0	0.0
GREATER THAN 9.99 Md.	14.4	28.6	16.0	230.45	41.651	599.770	0.0	0.0

53

*NOT ANALYZED BY REQUEST

WIW WEST BUTLER PROVINCE 16-30-9-29

Pertinent Details:

TD	2795
PBTD	2735
PERFORATIONS	2675-2733
CASINGS	surface - 10 3/4", 32.75#, H-40 @ 408 cemented w/250 sacks & 2% $CaCl_2$ production - 64 joints, 7", 20# J-55 casing @ 2792 cemented w/ 200 sacks neat cement
CORES	#1 2673-2720 recovered 46.4' #2 2720-2770 " 48.4'
LOGS	SOC/Microlaterolog,& ES, SOC - production
KB	1778

Completion: 1956-03-30

- sand frac 2737 - 42 w/ 18000 # 40/60 & 20/40
- established feedrate of 4 BPM @ 3800 psi down 2 3/8" tubing (packer in hol
- ran 2 3/8" EUE tubing, pump and rods

History:

73-05 Pulled tubing, reran 2 3/8" EUE w/7" Johnson 101 tension packer, displaced annulus to oil.

73-07 Squeezed 250 gals Paran @ .45 BPM @ 1200 psi
" 500 " 15% HCl @ .23 BPM @ 1200 psi

74-08 Shut in well

78-04 Pulled out tubing

78-05 Perforated following w/casing gun @ 4 SPF:
2675-2688, 2688-2694, 2695-2705; 2706-2719, 2720-2733
fluid 2-300 ft F.S.

78-06 Acid job 15% MSR acid
washed 12 bbls acid in 2 bbl washes every 5 minutes
squeezed 42 bbls 15% acid @ 5 BPM @ 1000 psi
" 36 " WF100 @ 3 " @ 1300 "
" 44 " 15% acid @ 5 " @ 1000 "
" 36 " WF100 @ 3 " @ 1500 "
" 42 " 15% acid @ 5 " @ 1500 "

.../2

78-06-03	Swabbed & ran 2 3/8" EUE CML tubing @ 2707
78-08-08	POOH & RIH w/2 3/8" EUE CML w/Johnson 101 packer
78-10-13	Pulled tubing, packed off wellhead
78-10-24	Ran SOC - tracer log
78-12-14	Ran 7" Johnson Packer @ 2736 Sonologged FL @ 600 Pressure tested casing to determine if communication existed between sets of perforations.
79-02-05	Attempt to perforate, some fill in hole Bailed out fill, perforate 837.9 - 838.2 m (2749 - 2750) w/4 SPF. Stuck gun; fish gun out.
79-02-14	Set model K retainer @ 837.5 (2747.7 KB). Could not feed through retainer to perforations below.
79-02-22	Cement squeeze; all perforations above retainer w/75 sacks, no pressure buildup during squeeze
79-02-23	Squeeze again w/100 sacks, no pressure
79-02-24	Squeeze again w/160 sacks, obtained squeeze
79-03-13	Tag cement @ 833.6 (2735)
79-03-14	Acidized w/1.9 m^3 15% acid @ 1.5 MPa @ .03 m^3/min. interval 815.3 - 833.6 (2675 - 2735). Backwash, final salt water feed rate 5.5 MPa @ 0.1 m^3/min.
79-08-31	Ran 51 mm tubing CML @ 788.3 (2586) w/Johnson 101 S.
80-05	Ran BHP survey, BHP = 1080 psi.

WEST BUTLER PROV. 13-29-9-29 WI

Pertinent Details:

GL - 1769.5

KB - GL - 12.5

KB Elevation - 1782

Spud Date - 1956-01-25

Casing - Surface - hole size 13 3/4", 12 jts.(456.43') 10 3/4", 32.75#, 8 rd, smls, H-40 Steward Lloyd landed @ 473.63 cemented w/300 sx Pozmix & 2% $CaCl_2$, 40 sx returns

- production - hole size 9", 73 jts.(2798.28'),7", 20#, 8 rd, smls, J-55 Steward Lloyd @ 2813.4, cemented w/150 sx Pozmix, checked bottom @ 2818

TD - 2825

PBTD - 2773

Perforations - 2673 - 2755

Cores - #1 - 6 1/8", 2665-2720, rec. 52.9'   average k = 18.4 md
#2 - 6 1/8", 2720-2775, rec. 56.1'   average Ø = 12.6%
#3 - 6 1/8", 2775-2785, rec. 10.1'   net pay 56.8 ft.
#4 - 6 1/8", 2785-2825, rec. 40.7'

These values apply to cores #1 & 2. Core shows no water down to 2825 (1043 SS) estimated oil-water line @ -992 SS, 2774 KB.

DST - #1, 2665-2805, WAB, NGTS, rec 90' mud, FP 0, SIP 375 incomplete

Mud - gyp base

Logs - Ran SOC logs - checked bottom @ 2825

ES General	473 - 2825
ES Detail	1781 - 2825
MLL General	2625 - 2825
MLL Detail	2625 - 2825

Completion - 1956-02-09

- perforations: 2704-2710 w/4-16 gram jets & 8 - 5/8" bullets/ft.
- sand frac: 20000# 20/40 @ 0.5/7 ppg @ 7BPM @ 2700-2900 psi through 2 7/8" tubing, landed @ 2707 w/Lane Wells packer
- pulled 2 7/8" & ran 2 3/8" @ 2762 w/2 x 1 1/2" pump

Production History

- several pump changes

78-05
- circulated out 20' of frac sand to 2770
- perforated 2673-2755 w/casing gun @ 4 SPF
- acidized as follows w/7000 gals 15% MSR (mud silt remover)
  - 6 bbls acid wash
  - 48 bbls acid squeeze @ 3 BPM @ 900 psi
  - 24 bbls WF-80 squeeze @ 0.5 BPM @ 1000 psi decreasing to 0.2 BPM @ 1250 psi
  - 88 bbls acid squeeze @ 0.25 - 2 BPM @ 1200 psi
  - 18 bbls WF-80 squeeze, final rate 0.25 BPM @ 1350 psi
  - 20 bbls acid squeeze @ 0.25 - 2 BPM @ 1200 psi
  - flushed w/24 bbls water @ 2-3 BPM @ 1150-1025 psi
  - SI 20 mins., pressure dropped to 800 psi
  - recovered 135 bbls water
  - landed tubing @ 2755 KB & ran 2 x 1 1/2 x 8 pump

BHP Surveys

1969-05 ,	100 psi (270 ft. submergence)
1976-05 ,	112 psi - survey
1980-05-14,	43.6 psi @ 2737.9 ft

WEST BUTLER PROV. 13-29-9-29

Estimation of Original Oil-In-Place by Material Balance

Data required to solve for N is listed below. The PVT date was obtained from California Standard Daly 6-32 oil & gas samples. Subsurface samples were obtained from this well and properties thus obtained were also used in the 71-12 feasibility study by S. N. Borowski.

Given:

original BHP	- 1050 psi
current BHP (from 80-05 survey)	- 43.6 psi
bubble point pressure	- 220 psi
reservoir temperature	- $82^{o}F$
water compressibility	- 2.7×10^{-6} psi^{-1}
oil compressibility @ 1500 - 220 psi	- 6.53×10^{-6} psi^{-1}
formation volume factors @ 1050 psi	- B_{oi} - 1.050
@ 220 psi	- B_{bp} - 1.056
@ 44 psi	- B_o - 1.048
oil gravity	- 34.7^{o} API @ $60^{o}F$
gas produced -G_p	- ft.^{3}
oil produced -N_p	- 39123 bbls.
water produced -W_p	- 4083 bbls.
gas-oil ratios - original - R_{si}	- 104 SCF/bbl.
@ 44 psi - R_s	- 75 SCF/bbl.
produced - R_p	- 90 SCF/bbl.
water formation volume factor - B_w	- 1
gas volume factor B_g @ 44 psi	- $ZnRT/p = 0.249$ ft.^{3}/SCF
	- = 0.044 bbls/SCF
original oil saturation -S_o	- 0.65
original water saturation -S_w	- 0.35
gas saturation -S_g	- fraction
original pore volume -V_{pi}	- bbls.
current pore volume -V_p	- bbls.
formation compressibility -C_f	- 5.5×10^{-6} psi^{-1}
original oil volume -V_{oi}	- reservoir bbls.
final oil volume -V_o	- "
original water volume -V_{wi}	- "
final water volume -V_w	- "

MATERIAL BALANCE CALCULATIONS

Initially the reservoir was undersaturated, thus $S_g = 0$, the original pore volume then was equal to the volume occupied by the oil and connate water.

$$V_{pi} = V_{oi} + V_{wi} \qquad (1)$$

$$\text{where } V_{oi} = NB_{oi}$$

$$\text{and since } S_w = 0.35,\ V_{wi} = \left(\frac{.35}{0.65}\right) NB_{oi}$$

- taking formation compressibility into account we can equate the initial and final pore volumes

$$V_p = V_{pi}\,(1 - C_f\Delta p)$$

$$= 1.54\ NB_{oi}\,(1 - C_f\Delta p) \text{ by substitution} \qquad (2)$$

$$= 1.608\ N$$

In its present state the reservoir contains free gas which has evolved from the oil and of course has expanded, oil which has shrunk because of the change in formation volume factor and production and connate water which has expanded. The water content also has to be reduced to account for the produced water. If we make the initial assumption that no free gas has been produced, except of course for N_pR_p, we may express the above 3 volumes, (i.e. V_p) in reservoir bbls in terms of N and solve for N by substituting them in eqn. (2).

$$V_p = V_g + V_o + V_w \qquad (3)$$

Free Gas $- V_g = G_fB_g$ (4)

G_f—total free gas in reservoir $= NR_{si} - (N - N_p)R_s - N_pR_p$ (5)

$$= 104N - (N - 39123)75 - 39123(90)$$

$$= (29N - 0.59 \times 10^6) \text{ SCF}$$

$$\text{and } V_g = (29N - 0.59 \times 10^6)\ 0.044$$

$$= 1.276N - 2.59 \times 10^4 \quad \text{res. bbls.} \qquad (6)$$

<u>Oil</u>

$$V_o = (N-N_p)\ B_o = (N - 39123)\ 1.048 \qquad (7)$$

$$= 1.048N - 41000 \quad \text{res. bbls.} \qquad (8)$$

<u>Water</u>

-the original water has expanded by an amount equal to $C_w \Delta p$ but has been reduced by water production equal to $W_p B_w$.

$$V_w = 0.53\ NB_{oi}\ (1 + C_w \Delta p) - W_p B_w \qquad (9)$$

$$= 0.5580N - 4083 \quad \text{res. bbls.} \qquad (10)$$

Summing the above volumes we obtain for V_p

$$V_p = 2.882N - 70983 \text{ res. bbls.} \qquad (11)$$

Substituting in eqn. (2) & solving for N

$$2.882N - 70983 = 1.608N$$

$$N = 55721 \quad \text{STB}$$

Now solving for residual gas saturation S_g from (6)

$$V_g = 45200 \text{ res. bbls.}$$

$$\text{and } S_g = \frac{V_g}{V_p} = 0.50$$

From core analysis it can be seen that ϕ & k are 12.6% and 18.4md respectively. It is highly unlikely that such a high residual gas saturation is present in the formation. Moreover fractional recovery for this value of N, 70% is totally unrealistic. Assigning a critical gas saturation of 10% to the rock and recalculating a value of N = 284000 STB is found. This corresponds to a primary recovery of 13.8%, a more realistic approximation.

Another method which may be used to calculate N is to assume that the initial high production volumes to the point in time where production was relatively constant corresponds to the decline in reservoir pressure from initial to bubble point pressure. Using the relationship between N, N_p and respective FVF's we can say that

$$N = N_p\ B_{bpt}/(B_{oi} - B_{bpt})$$

$$= 6500 \times 1.056/(1.05 - 1.056) = 1.14 \times 10^6 \text{ STB}$$

where N_p is approximately 6500 bbls obtained from decline curves.

The above analysis points to a primary recovery of 3.4%. Based on well parameters listed previously for 13-29 we can calculate the radius of the reservoir which for values of 284000 and 1140000 STB turns out to be 330 and 660 ft. respectively.

WEST BUTLER UNIT #1

Voidage Calculation for Pilot Flood Area

- Calculation of BHP in the 5-spot pattern using material balance
- Assumptions used in the derivation:

  1. All injection is radial, i.e. only 25% of injection into each well contributes to voidage replacement within the pattern.

  2. Only 25% of voidage from 16-30, prior to its conversion, is included, excluding its water production which is considered to have originated from the aquifer.

  3. Oil-in-place is calculated on the basis that the reservoir is homogeneous throughout with a pay thickness of 40.1 ft (k $>$ 0.5 md) and average porosity of 11%.

  4. Using the enclosed area of 80 acres yields a lower theoretical final BHP than had 200 acres and total injection figures been used.

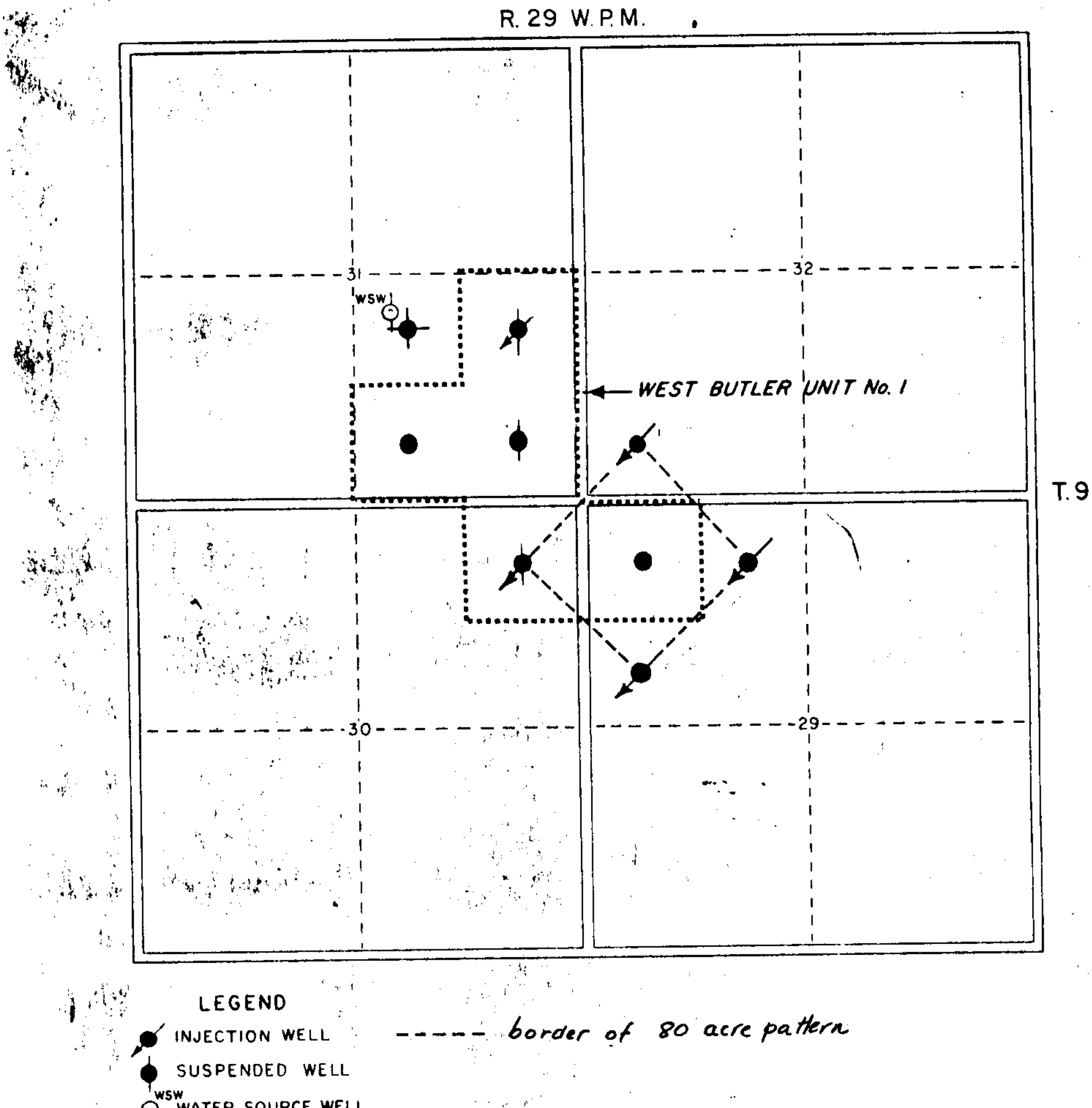


FIGURE 1

WEST BUTLER UNIT No. 1

AS OF 1977 - 12 - 31

SCALE: 3" = 1 MILE

WEST BUTLER UNIT #1

Voidage Calculation

The oil and water production volumes and injection volumes for the 5-spot pattern are detailed below:

WELL	PRODUCTION (bbls) (to 80-07) Oil	Water	CUMULATIVE INJECTION (to 80-07)	REMARKS
16-30	32299	12044	103379	converted '73
13-29	39123	4083	-	producer
12-29	-	-	139626	WIW
14-29	-	-	8675	WIW
4-32	-	-	124813	WIW
2-31	58470	910	-	producer

Therefore N_p - 47198 bbls, from 13-29 - 39123 bbls
16-30 - 8075 bbls

W_p - 4083 bbls, from 13-29

W_e - 94125 bbls, from 16-30 - 103382 bbls
4-32 - 124813 bbls
14-29 - 8675 bbls
12-29 - 139626 bbls

$$\text{Oil-in-place} = \text{area} \times \text{pay} \times \text{porosity} \times (1 - S_w)/B_{oi}$$

$$= 80 \text{ acres} \times \frac{7756 \text{ bbls}}{\text{acre-ft}} \times 40.1 \text{ ft} \times 0.11 \; \frac{(1 - 0.35)}{1.05}$$

$$= 1{,}694{,}000 \text{ STB}$$

Using the material balance equation to solve for Δp where $C_e = 19.1 \times 10^{-6}\ \text{psi}^{-1}$

$$NB_{oi}c_e\Delta p = N_pB_o - W_e + B_wW_p$$

$$\Delta p = -1194 \text{ psi}$$

The final reservoir pressure should be equal to 1050 + 1194 = 2244 psi. Note that W_e includes injection from WIW 16-30 which is believed to be communicating directly to the aquifer. If we assign 0 injectivity to 16-30 & recalculate the BHP should still have increased by 433 psi to 1483 psi. The above does not allow for possible free gas production but it will be shown later that no free gas will be produced and consequently the gas will go back into solution thus allowing us to use the above equation for an undersaturated reservoir.

From surveys and fall-off tests we see that the BHP's are as follows:

13-29	producer	44 psi	-	survey
12-29	WIW	960 psi	-	extrapolation
14-29	WIW	1853 psi	-	"
4-32	WIW	1302 psi	-	"
16-30	WIW	1080 psi	-	survey

Since the BHP of the central producer is currently 44 psig it would be of interest to calculate what the theoretical BHP should be at this point in time without injection. The following analysis assumes that there is indeed 1.694×10^6 STB of OIP and that the PVT data from DALY 6-32 apply. It will be shown that for any OIP volume of 1.694×10^6 STB a gas saturation of 10% will not be reached until N_p = 255,600 STB with a corresponding BHP = 124 psi. Furthermore in view of the fact that only 47198 STB have been produced to date we can calculate that the BHP at this value of N_p should be 200 psi, relatively close to the bubble point value of 220 psi.

When $S_g = 0.1$ the following relationship will apply:

$$\left(\frac{B_t - B_o}{B_t}\right) = \frac{0.1}{1-S_w}$$

$$\text{or} \quad \frac{B_t}{B_o} = 1.1817$$

From the PVT data, column 2, the ratio of volume of oil & gas to volume at the bubble point is given, this is equivalent to B_t/B_{bpt} which is essentially the same as B_t/B_o in the pressure range of interest. At the value of $B_t/B_o = 1.1817$ we see that the BHP = 124 psi and its corresponding FVF = B_o = 1.0549, $p = P_i - P_f$ = 1050 - 124 = 926 psi.

Using the material balance equation to predict N_p @ $S_g = 0.1$ we may write, neglecting formation compressibility,

initial pore volume = final pore volume

oil	water	=	remaining oil	water	gas

$$NB_{oi} + 0.53NB_{oi} = (N-N_p)B_o + (0.53NB_{oi})(1+C_w\Delta p) + S_g(NB_{oi}+0.53NB_{oi})$$

produced water

$$-W_p(1 + C_w \Delta p)$$

and solving obtain N_p = 255,600 STB @ $S_g = 0.1$

Also fractional recovery @ $S_g = 0.10$ is 15%.

Since N_p is only 47198 STB we may conclude that for $N = 1.694 \times 10^6$ all the free gas is still contained in the reservoir. We may also conclude that the BHP @ $N_p = 47198$ STB should lie somewhere between 124 psi and 220 psi, the bubble point presumably having been reached @ $N_p = 9625$ STB from $N_p = N(B_{oi} - B_{bpt})/B_{bpt}$

Taking 200 psi as the probable BHP @ $N_p = 47198$ we can substitute it and its appropriate FVF's and see if the equation balances.

$$\underbrace{NB_{oi}}_{\text{Oil}} + \underbrace{0.53NB_{oi}}_{\text{Water}} = \underbrace{(N - N_p)B_o}_{\text{Oil}} + \underbrace{0.53\ NB_{oi}\ (1 + C_w \Delta p)}_{\text{Water}} + \underbrace{\left[NR_{si} - (N - N_p)R_s - N_pR_p\right]B_g}_{\text{Gas}} - W_p\ (1 + C_w \Delta p)$$

The terms B_o, Δp, R_s, R_p, & B_g are all @ 200 psi

thus $p = +850$ psi , $R_s = 102\ ft^3/bbl$, $B_g = .01145\ \frac{\text{res bbls}}{ft^3}$
$B_o = 1.056$ " , $R_p = 103$ "

L.H.S. = 2.7214×10^6 STB
R.H.S. = 2.718×10^6 STB

The gas saturation at $N_p = 47198$ is equal to 1.4%.

Considering the fact that 255600 STB have to be produced in order to lower the BHP to 124 psi it is readily obvious that the OIP volume of 1.694×10^6 STB is not there since we have produced much less and have only a reservoir pressure of 44 psi left. The conclusion that must be drawn is that the reservoir is limited.

Including the term for water injected into the material balance equation will yield the final theoretical BHP. First we can obtain a rough estimate of BHP so that we may use proper FVF's.

final system compressibility, i.e. $S_g = 0$, will be $C_t = 12.4 \times 10^{-6}$ psi
by definition $C_t = \frac{\Delta V}{V} \frac{1}{\Delta p}$

where ΔV = net water injected − gas to be compressed

$$= W_e - W_p - S_g\left(\frac{NB_{oi}}{1 - S_w}\right) = 51731 \text{ STB}$$

and so $\Delta p = \frac{\Delta V}{V} \times \frac{1}{C_t}$

$= 2345$ psi

If the equation balances, we have chosen the correct Δp. Substituting in equation

$$\text{L.H.S.} = 2.7214 \times 10^6 \text{ STB}$$

$$\text{R.H.S.} = 2.744 \times 10^6 \text{ STB}$$

The final pressure at this point in time should then be approximately 2550 psi.

The estimated OIP associated with 13-29 producer was calculated to be 284,000 STB. The BHP obtained in 1976-05 indicated 112 psi. Since this is relatively close to the theoretical BHP that should exist for a reservoir at $S_g = 0.1$ which we have just calculated to be 124 psi we can also apply the same recovery factor at this gas saturation to the oil recovered at that point and calculate N:

$$N_p(\text{@ BHP} = 112 \text{ psi}) = 0.15\ N$$

$$\text{and } N = \frac{35000}{0.15} = 233{,}000 \text{ STB}$$

Form 54801

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 330

Well California Standard
Daly No. 6-32

VOLUMETRIC DATA OF Reservoir Fluid SAMPLE

1. Saturation pressure (bubble-point pressure) 220 PSI @ 82 °F.
2. Thermal expansion of saturated oil @ 5000 PSI = $\frac{V @ 82\ °F.}{V @ 73\ °F.}$ = 1.00283
3. Compressibility of saturated oil @ reservoir temperature: Vol./Vol./PSI:

   From 5000 PSI to 3000 PSI = 5.00×10^{-6}

   From 3000 PSI to 1500 PSI = 5.60×10^{-6}

   From 1500 PSI to 220 PSI = 6.53×10^{-6}
4. Specific volume at saturation pressure: cu. ft./# 0.01929 @ 82 °F.

Form 50870

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Page 3 of 10

File RFL 330

Well California Standard
Daly No. 6-32

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATIONS @ 82 °F., RELATIVE VOLUME OF OIL AND GAS, V/Vs	VISCOSITY OF OIL @ 82 °F., CENTIPOISES	DIFFERENTIAL VAPORIZATION @ 82 °F. LIBERATED GAS SCF PER BARREL OF RESIDUAL OIL	SOLUTION GAS SCF PER BARREL OF RESIDUAL OIL	RELATIVE OIL VOLUME, V/VR	B_t
5000	0.9735				1.028	
4500	0.9758				1.030	
4000	0.9782				1.033	
3500	0.9807				1.036	
3000	0.9833				1.038	
2575		4.32				
2500	0.9861				1.041	
2035		4.12				
2000	0.9888				1.044	
1510		3.89				
1500	0.9916				1.047	
1035		3.70				
1000	0.9947				1.050	
900	0.9953				1.051	
800	0.9959				1.052	
600	0.9973				1.053	
500	0.9980				1.054	
495		3.55				
330		3.48				
300	0.9995				1.055	
220	1.0000	3.44	0	104	1.056	1.056
212	1.0026					
210		3.44				
200	1.0126					
188	1.0245					
180	1.0353					
176			3	101	1.056	1.1072
171	1.0499					
170		3.46				
156	1.0792					
139	1.1217					
132			8	96	1.055	1.1934
127	1.1676					

V = Volume at given pressure.
V_s = Volume at saturation pressure at the specified temperature.
V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

Form 50870

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 330

Well California Standard
Daly No. 6-32

Reservoir Fluid SAMPLE TABULAR DATA

PRESSURE PSI GAUGE	PRESSURE-VOLUME RELATIONS @ 82 °F. RELATIVE VOLUME OF OIL AND GAS, V/Vs	VISCOSITY OF OIL @ 82 °F. CENTIPOISES	DIFFERENTIAL VAPORIZATION @ 82 °F. LIBERATED GAS SCF PER BARREL OF RESIDUAL OIL	DIFFERENTIAL VAPORIZATION @ 82 °F. SOLUTION GAS SCF PER BARREL OF RESIDUAL OIL	DIFFERENTIAL VAPORIZATION @ 82 °F. RELATIVE OIL VOLUME, V/VR	Bt
103	1.2846					
88			14	90	1.054	1.406
85		3.56				
83	1.4603					
70	1.7065					
60	1.9702					
54			24	80	1.050	1.966
49	2.4026					
40		3.82				
39	2.9881					
35			34	70	1.046	2.837
20		4.11				
0		5.35	104	0	1.009	

@ 60° F. = 1.000

Gravity of Residual Oil =

34.7° API @ 60° F.

V = Volume at given pressure.

V_s = Volume at saturation pressure at the specified temperature.

V_R = Residual oil volume at 14.7 PSI absolute and 60° F.

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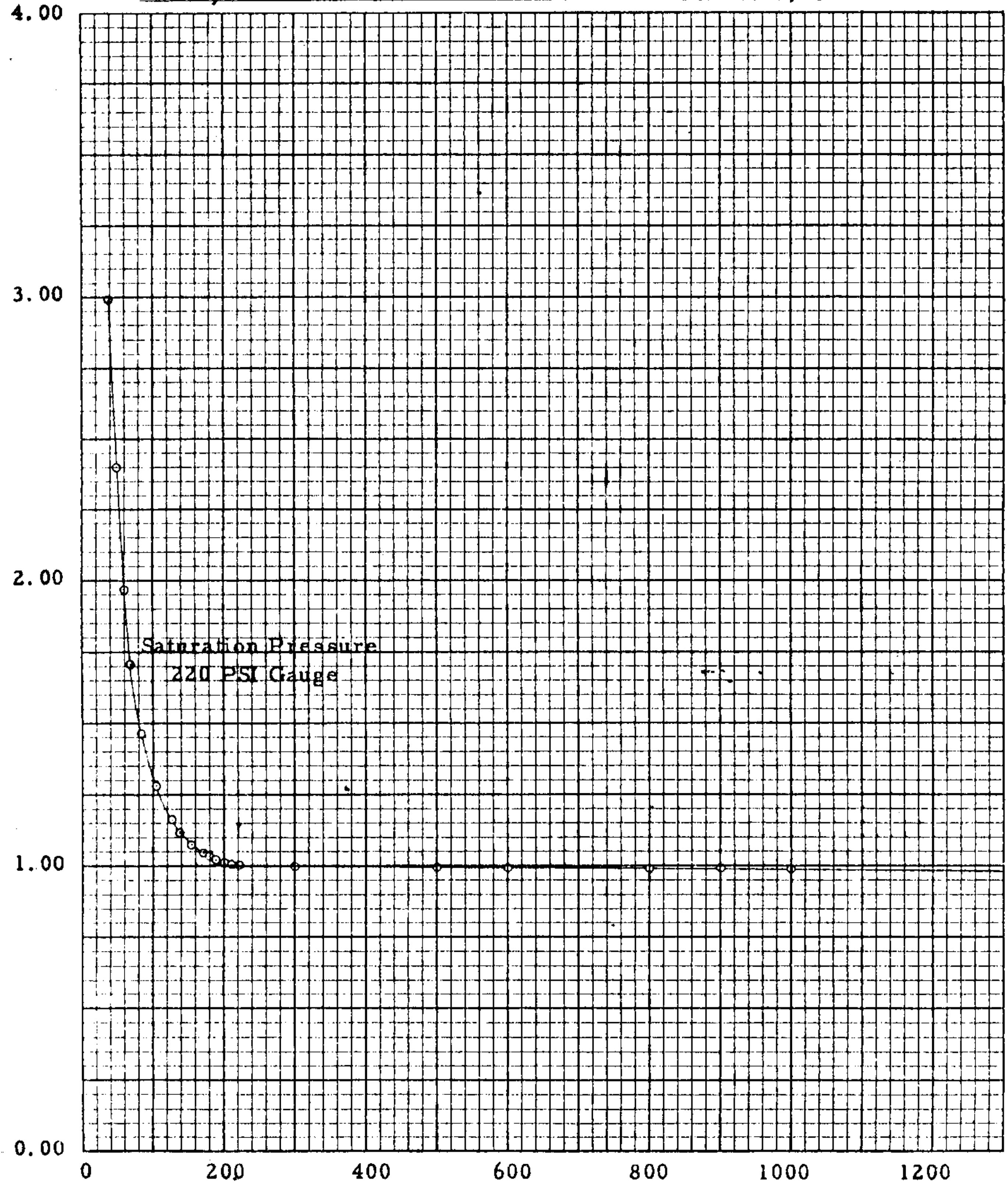
Petroleum Reservoir Engineering
DALLAS, TEXAS

File RFL 330

PRESSURE-VOLUME RELATIONS OF RESERVOIR FLUID

Company The California Standard Company Formation Mississippian, First Crinoidal
Well California Standard Daly No. 6-32 County
Field Daly State Manitoba, Canada



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DALLAS, TEXAS

DIFFERENTIAL VAPORIZATION OF RESERVOIR FLUID

Company The California Standard Company Formation Mississippian, First Crinoidal
Well California Standard Daly No. 6-32 County
Field Daly State Manitoba, Canada